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(54) **DOE-BASED SYSTEMS AND DEVICES FOR PRODUCING LASER BEAMS HAVING MODIFIED BEAM CHARACTERISTICS**

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(21) Appl. No.: **09/859,964**

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**Related U.S. Application Data**

(63) Continuation of application No. 09/302,790, filed on Apr. 30, 1999, now abandoned.

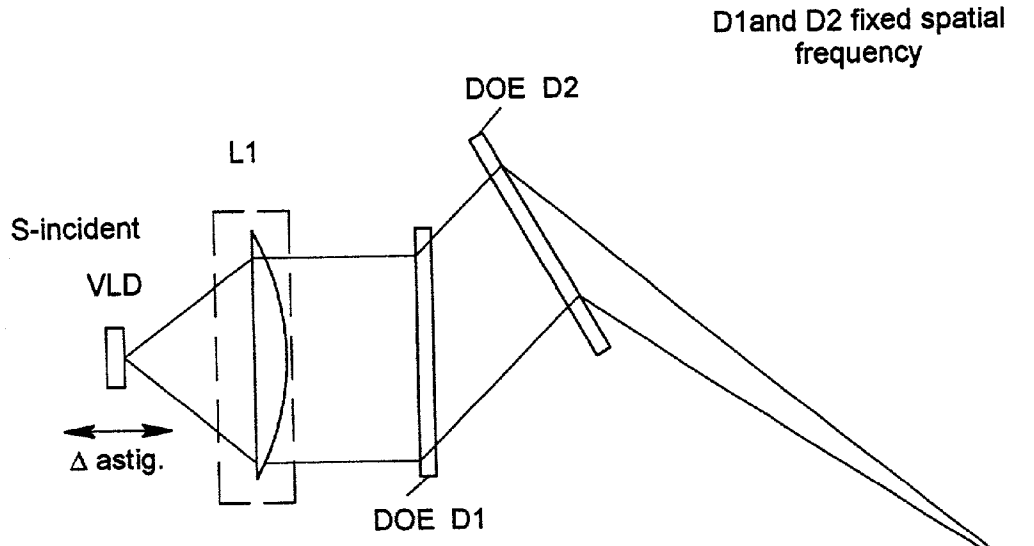
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(52) **U.S. Cl.** ..... **372/102**; 359/563; 359/29

(57) **ABSTRACT**

Novel methods are disclosed for designing and constructing miniature optical systems and devices employing light diffractive optical elements (DOES) for modifying the size and shape of laser beams produced from a commercial-grade laser diodes, over an extended range hitherto unachievable using conventional techniques. The systems and devices of the present invention have uses in a wide range of applications, including laser scanning, optical-based information storage, medical and analytical instrumentation, and the like. In the illustrative embodiments, various techniques are disclosed for implementing the DOEs as holographic optical elements (HOEs), computer-generated holograms (CGHs), as well as other diffractive optical elements.




*Embodiment 1*

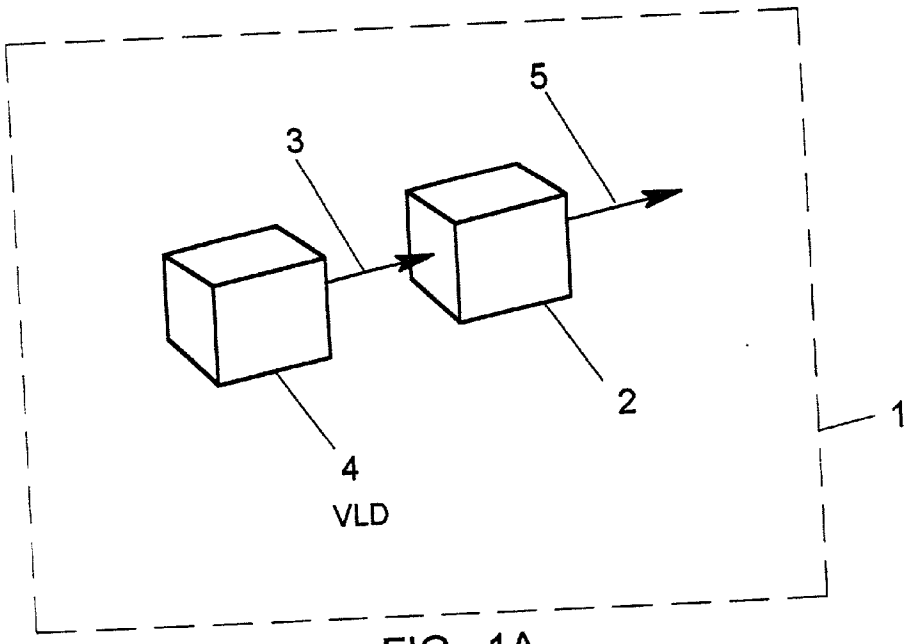



FIG. 1A

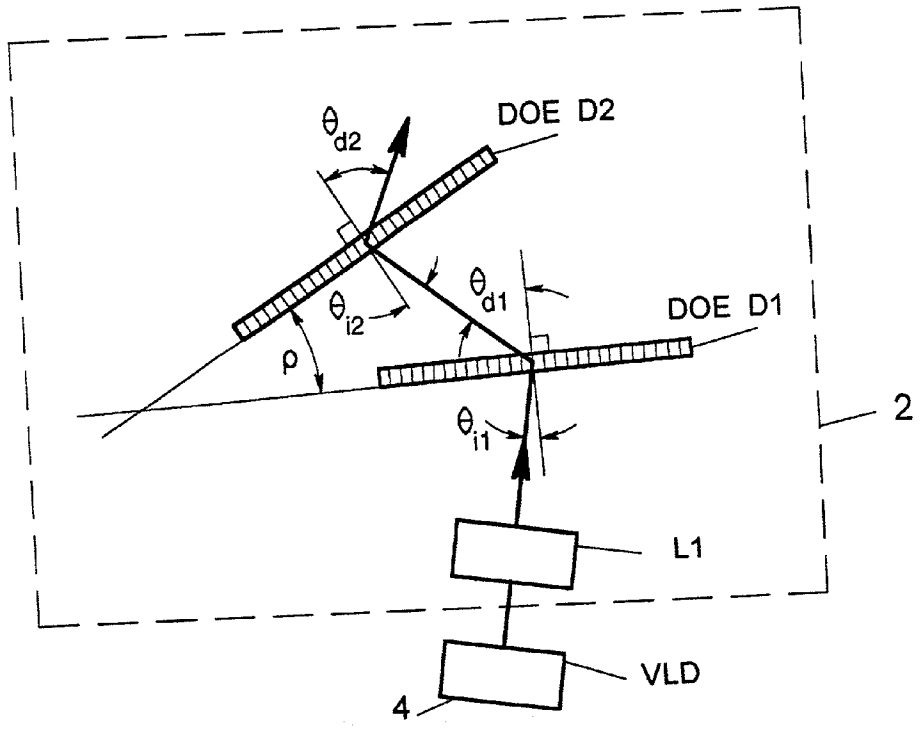



FIG. 1B

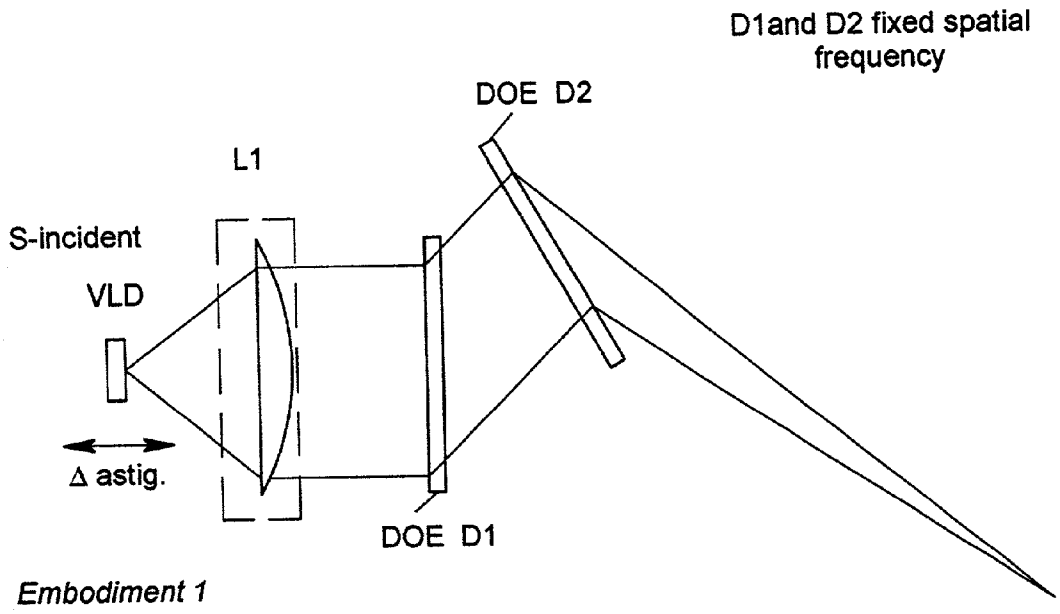

D1and D2 fixed spatial frequency
DOE D2
L1
S-incident
VLD
Δ astig.
DOE D1
Embodiment 1

FIG. 2A

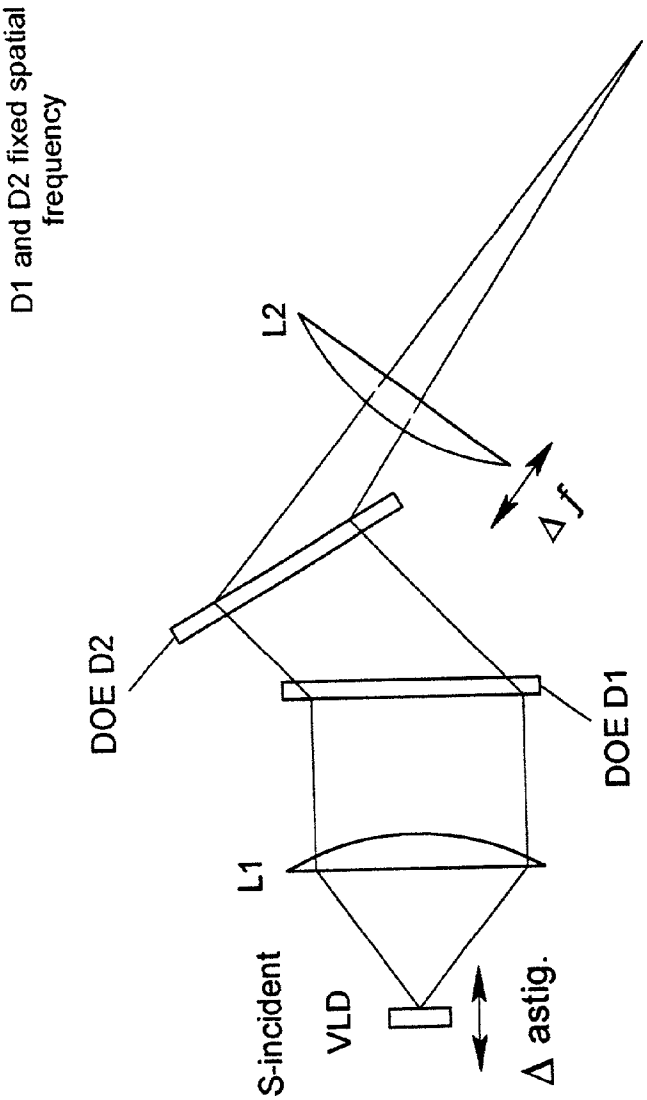



FIG. 2B1

*Embodiment 2*

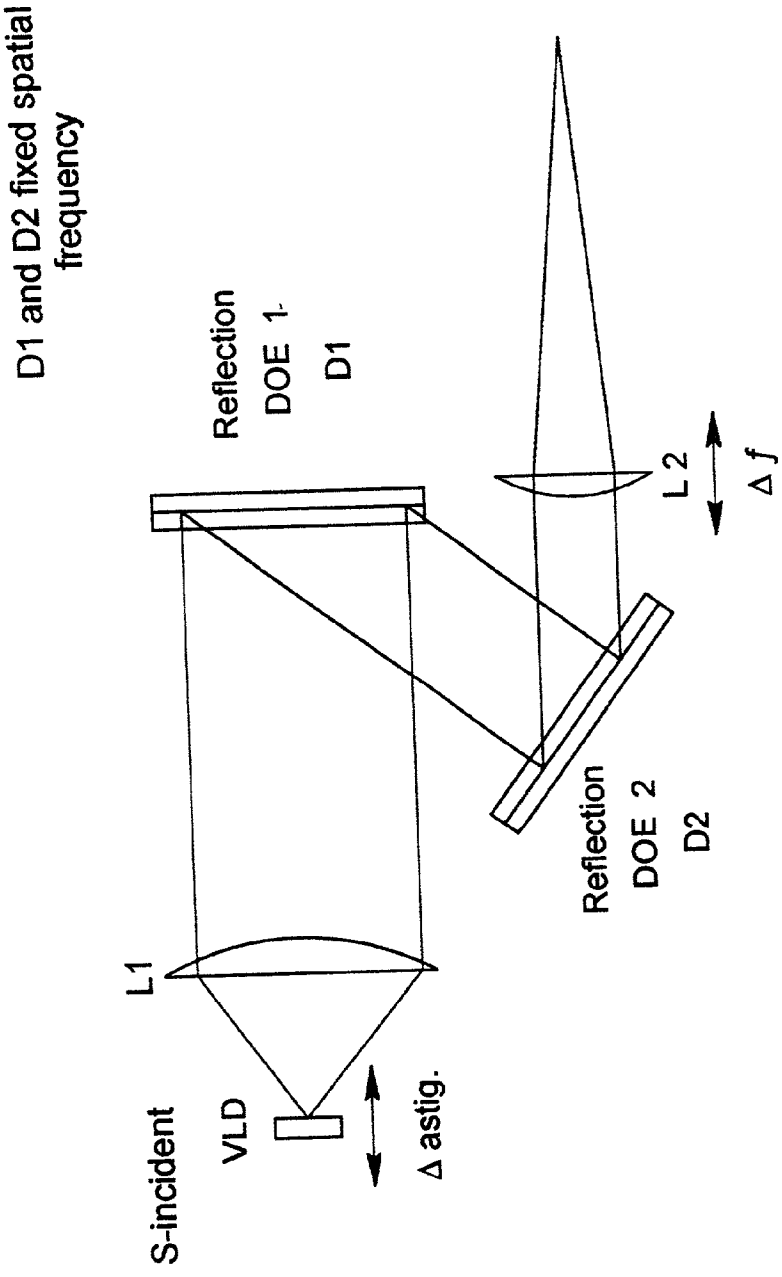

D1 and D2 fixed spatial frequency
Reflection
DOE 1
D1
L2
Δ f
L1
S-incident
VLD
Δ astig.
Reflection
DOE 2
D2
First Alternative Realization of Embodiment 2

FIG. 2B2

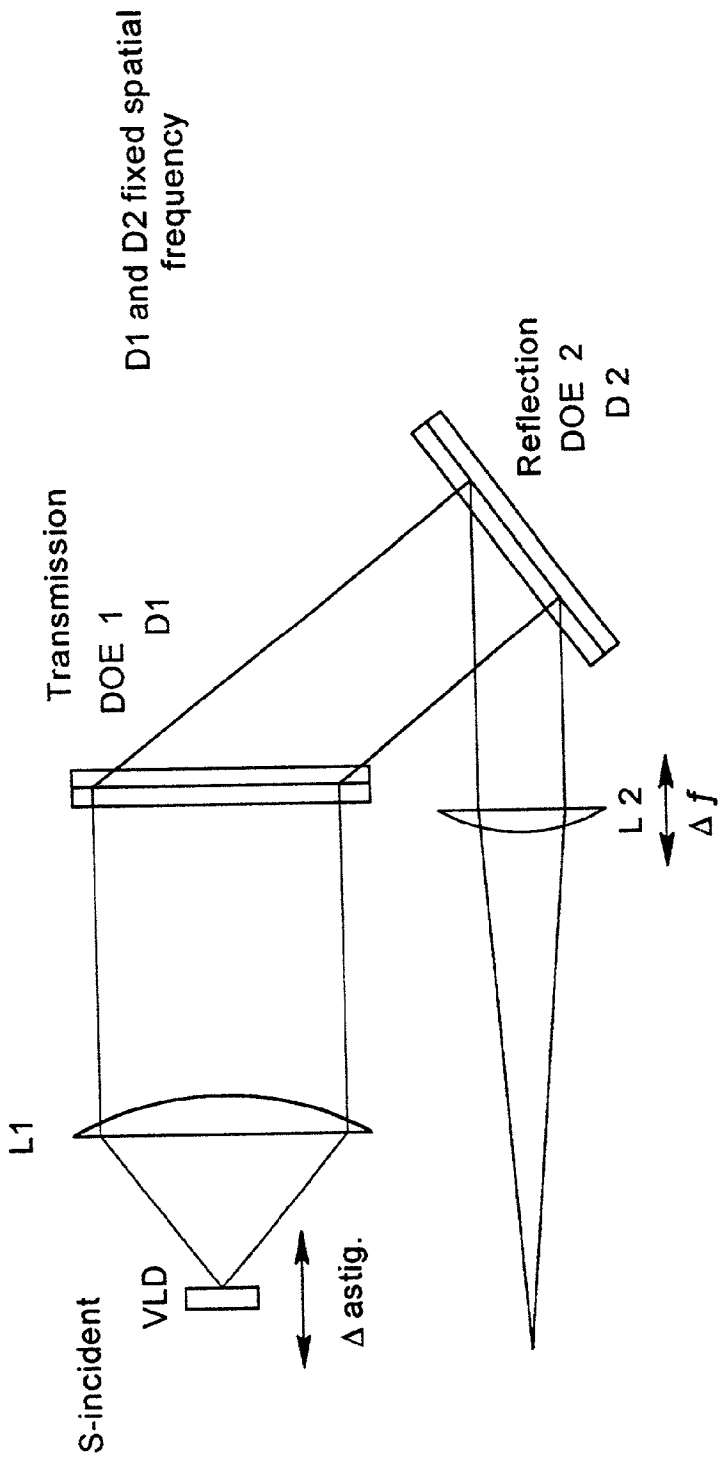



FIG. 2B3

*Second Alternative Realization of Embodiment 2*

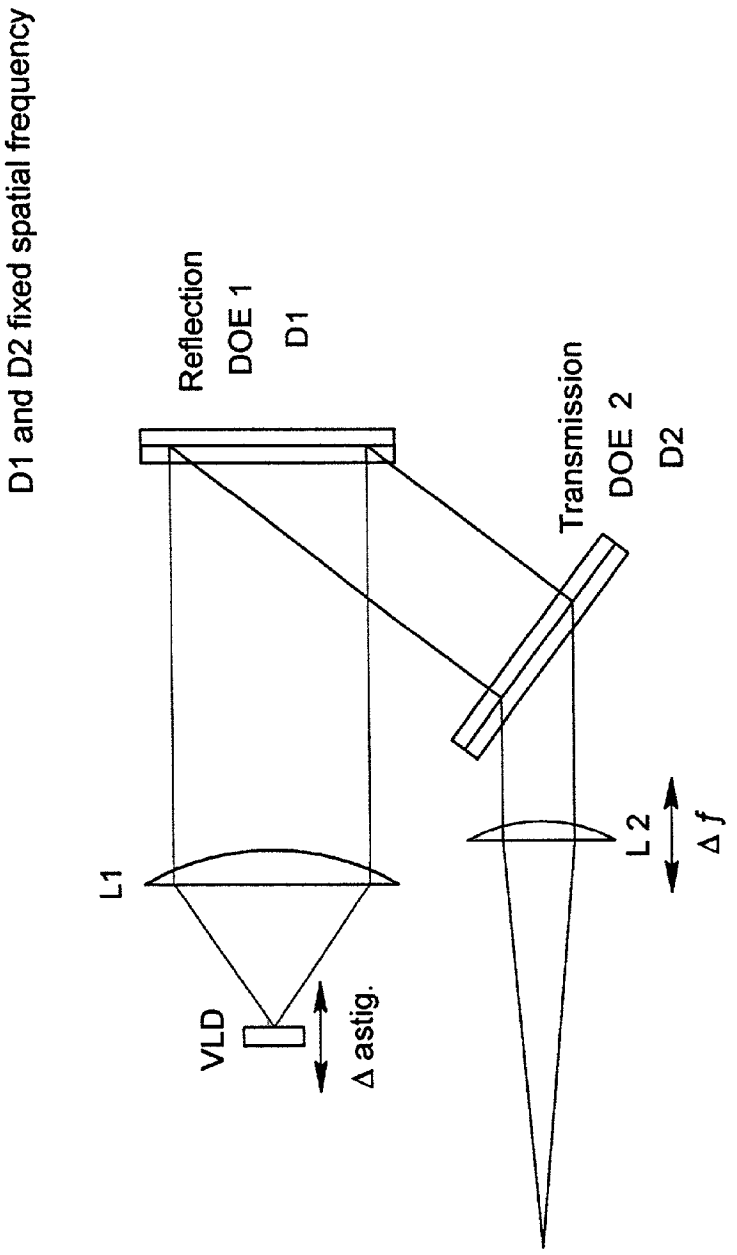



FIG. 2B4

*Third Alternative Realization of Embodiment 2*

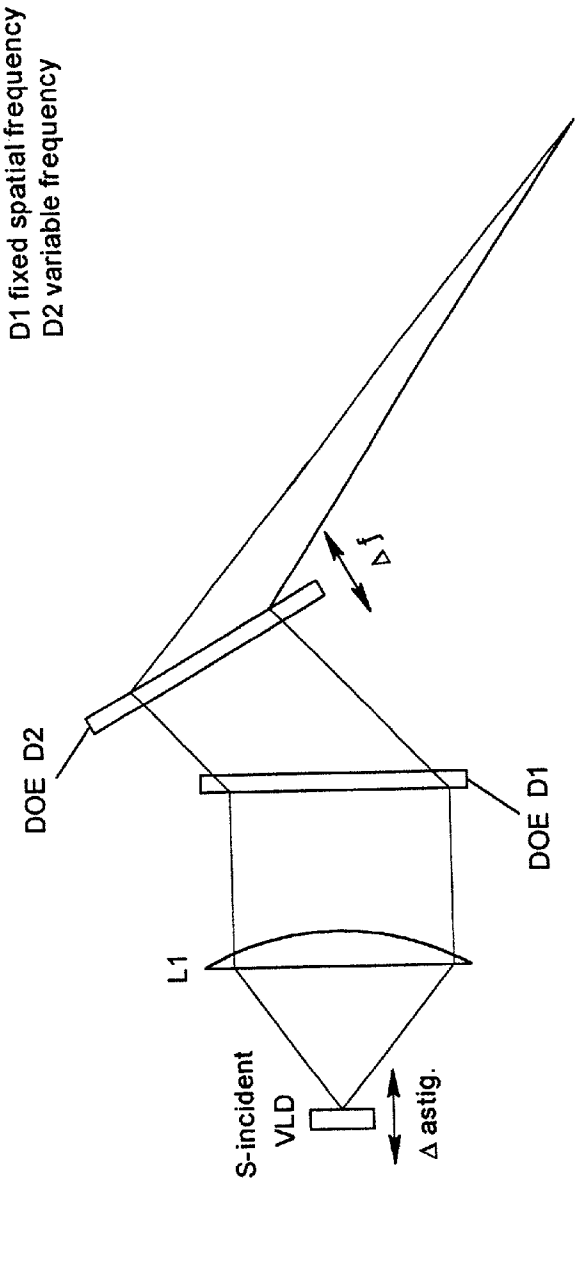



FIG. 2C

*Embodiment 3*

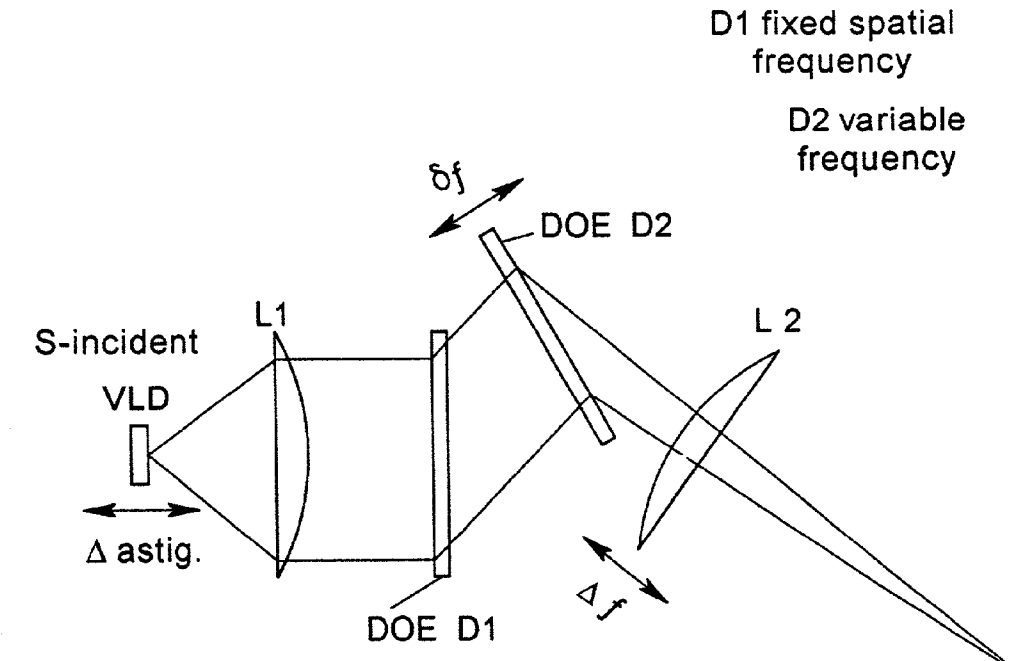

D1 fixed spatial frequency
D2 variable frequency
δf
DOE D2
L1
L 2
S-incident
VLD
Δ astig.
DOE D1
Δf
Embodiment 4

FIG. 2D

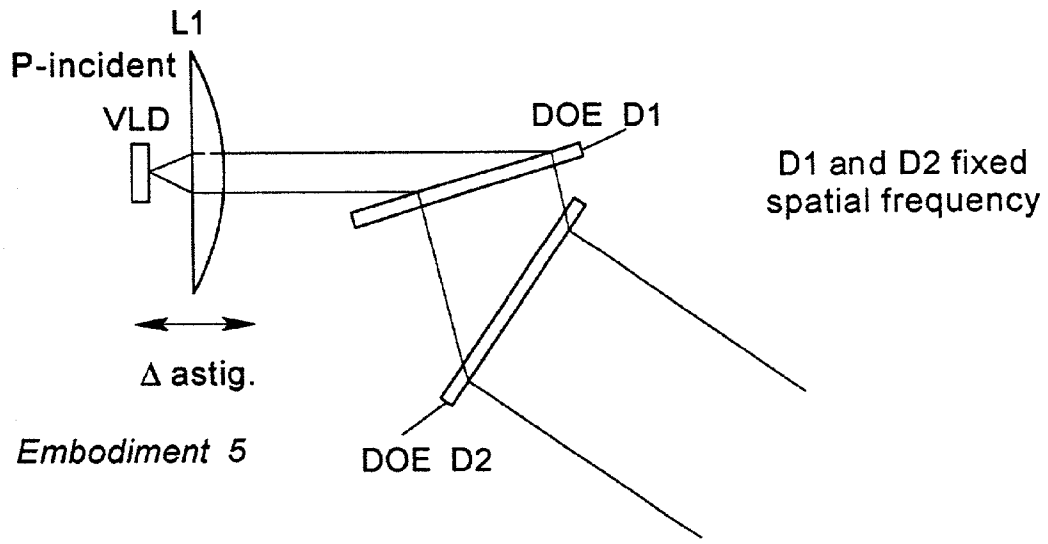

L1
P-incident
VLD
DOE D1
D1 and D2 fixed spatial frequency
Δ astig.
Embodiment 5
DOE D2

FIG. 2E

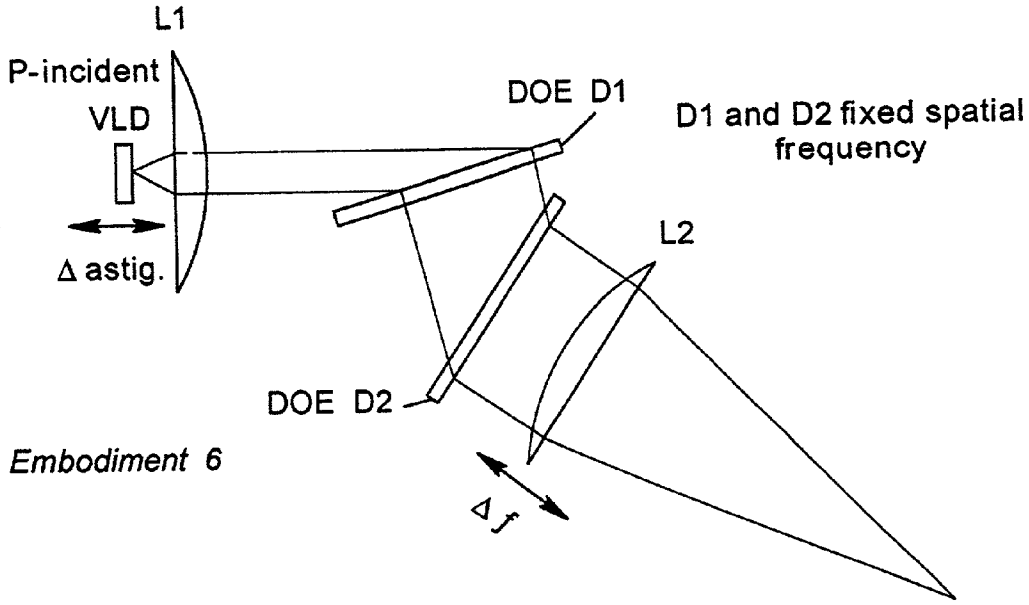

L1
P-incident
VLD
Δ astig.
DOE D1
D1 and D2 fixed spatial frequency
L2
DOE D2
Embodiment 6
Δf

FIG. 2F

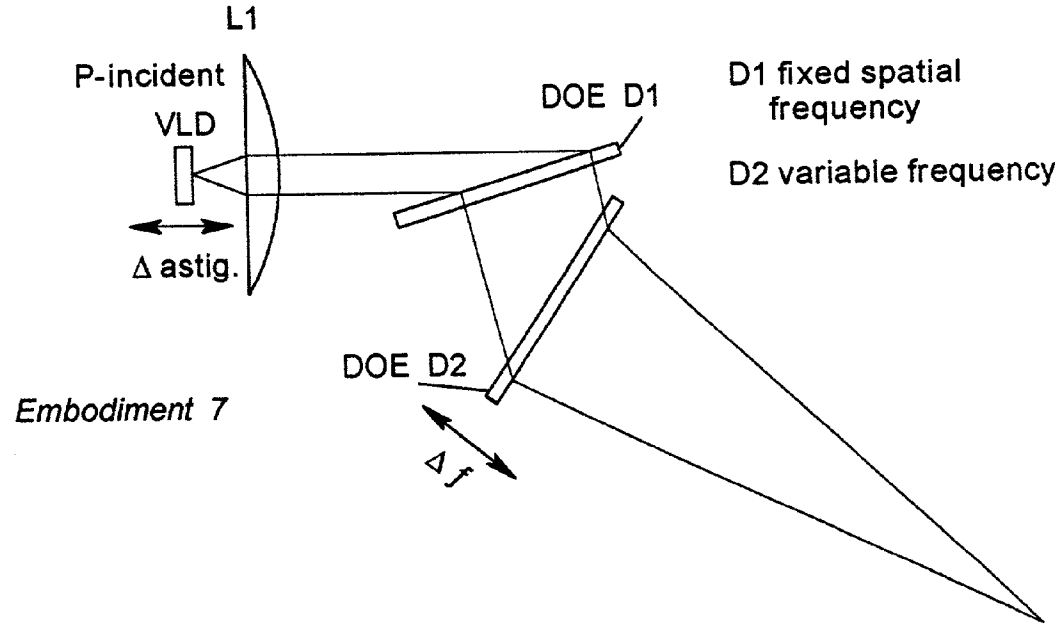

L1
P-incident
VLD
Δ astig.
DOE D1
D1 fixed spatial frequency
D2 variable frequency
DOE D2
Embodiment 7
Δf

FIG. 2G

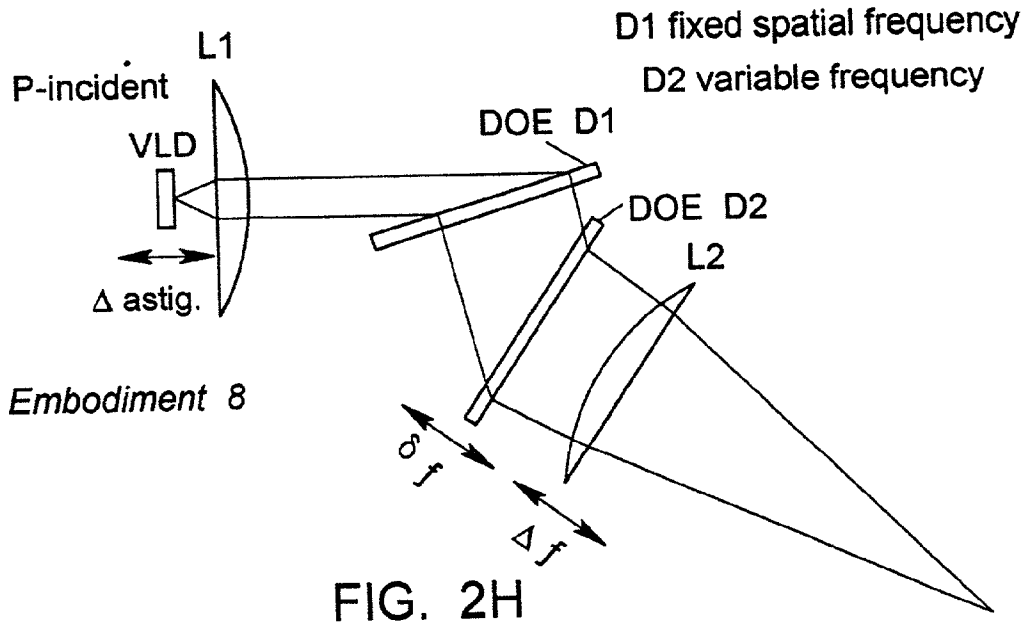

L1
P-incident
VLD
Δ astig.
Embodiment 8
D1 fixed spatial frequency
D2 variable frequency
DOE D1
DOE D2
L2
δ f
Δ f

FIG. 2H

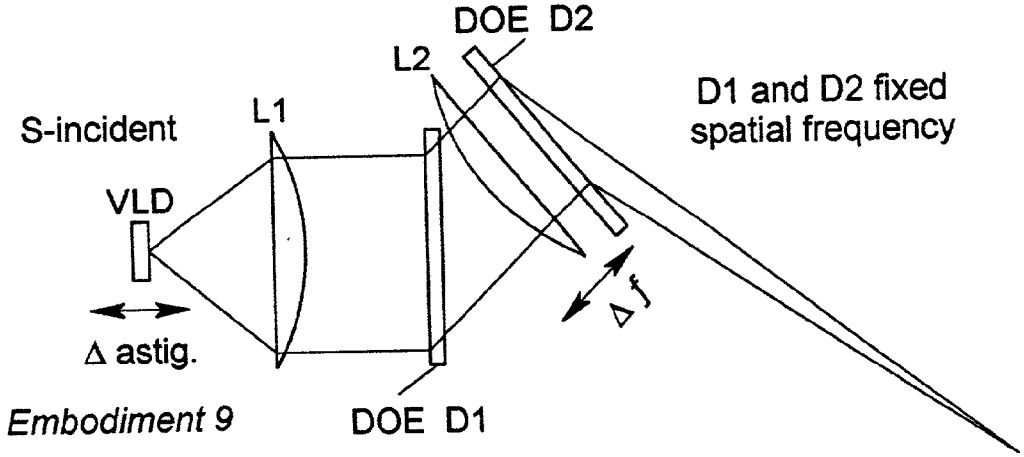
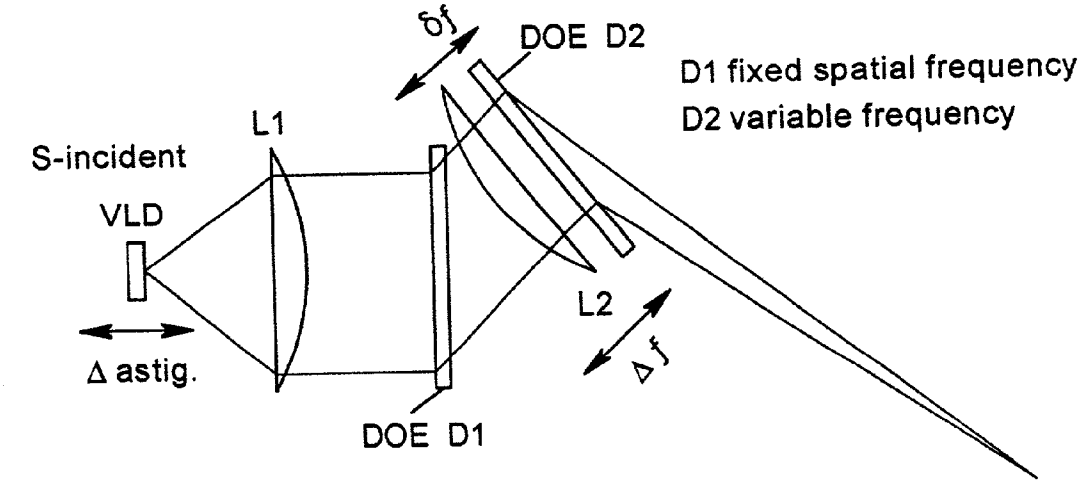
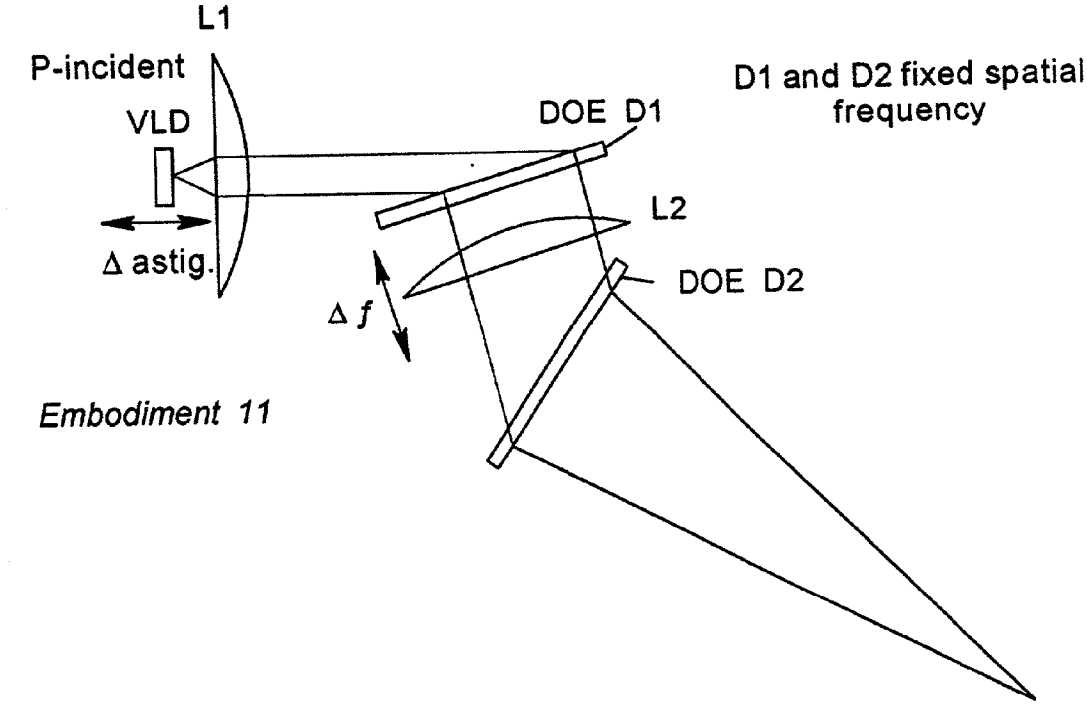

DOE D2
L2
D1 and D2 fixed
spatial frequency
S-incident
L1
VLD
Δ astig.
Embodiment 9
DOE D1
Δ f

FIG. 2I




*Embodiment 10*

FIG. 2J




*Embodiment 11*

FIG. 2K

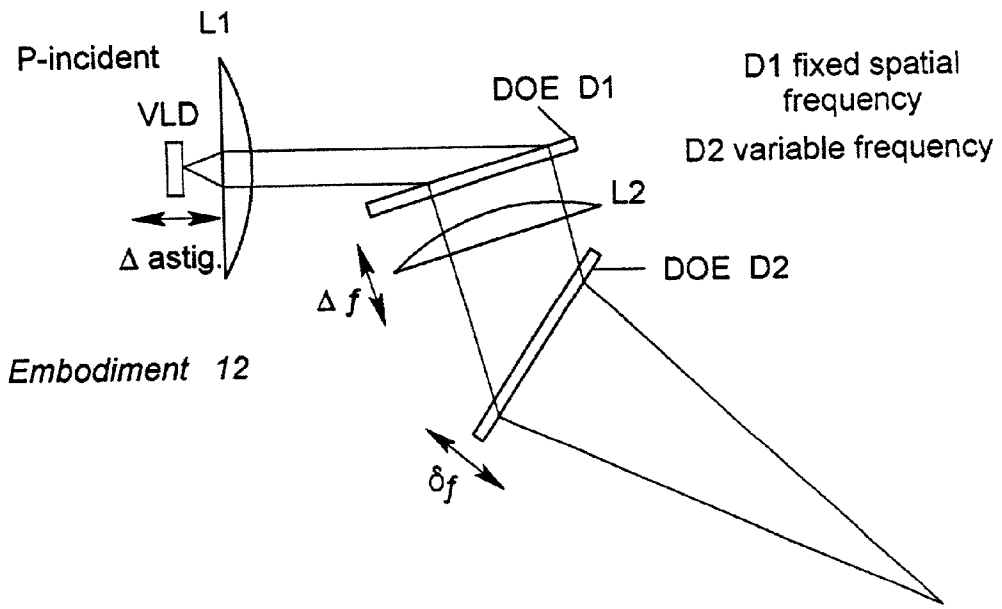

L1
P-incident
VLD
Δ astig.
DOE D1
D1 fixed spatial frequency
D2 variable frequency
L2
DOE D2
Δ f
δf
Embodiment 12

FIG. 2L

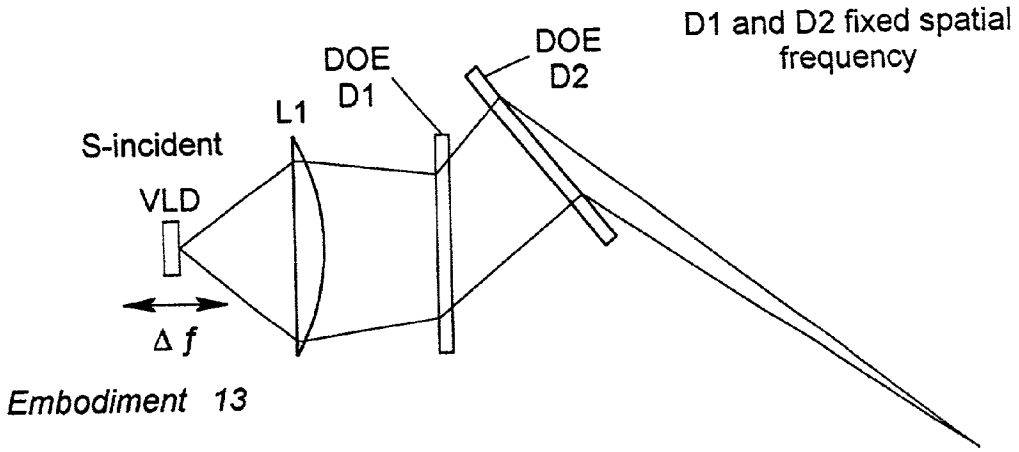

D1 and D2 fixed spatial frequency
DOE D1
DOE D2
L1
S-incident
VLD
Δ f
Embodiment 13

FIG. 2M

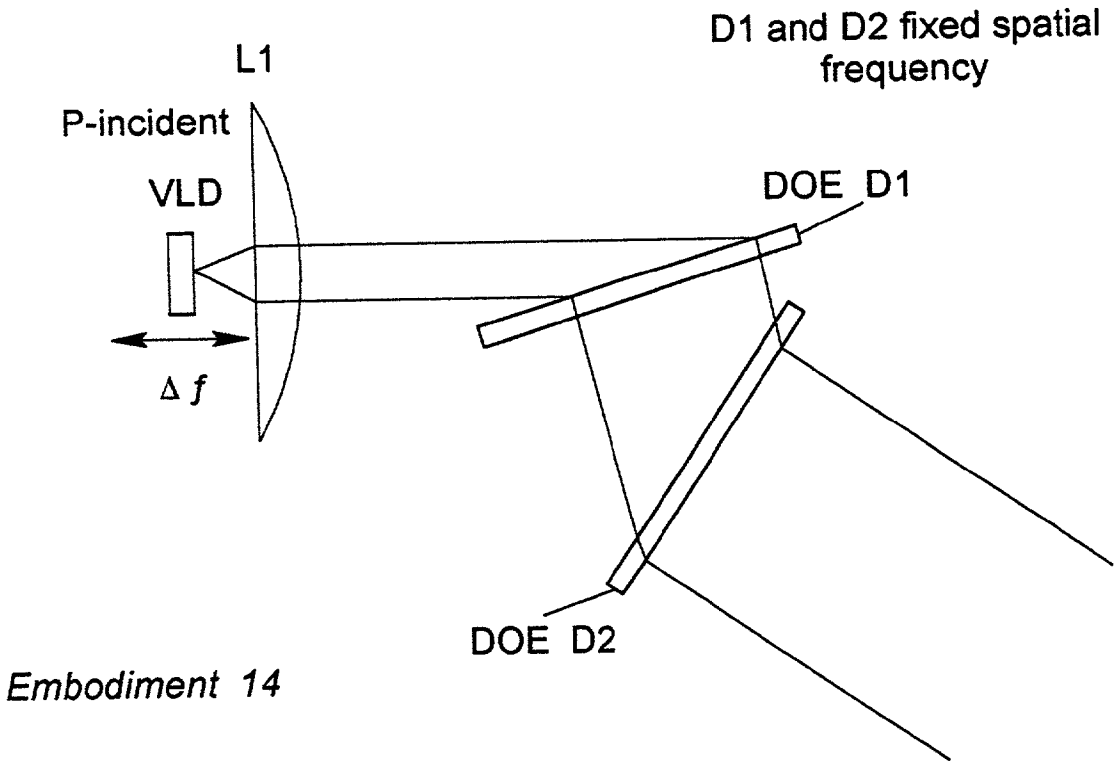

D1 and D2 fixed spatial frequency
L1
P-incident
VLD
DOE D1
Δ f
DOE D2
Embodiment 14

FIG. 2N

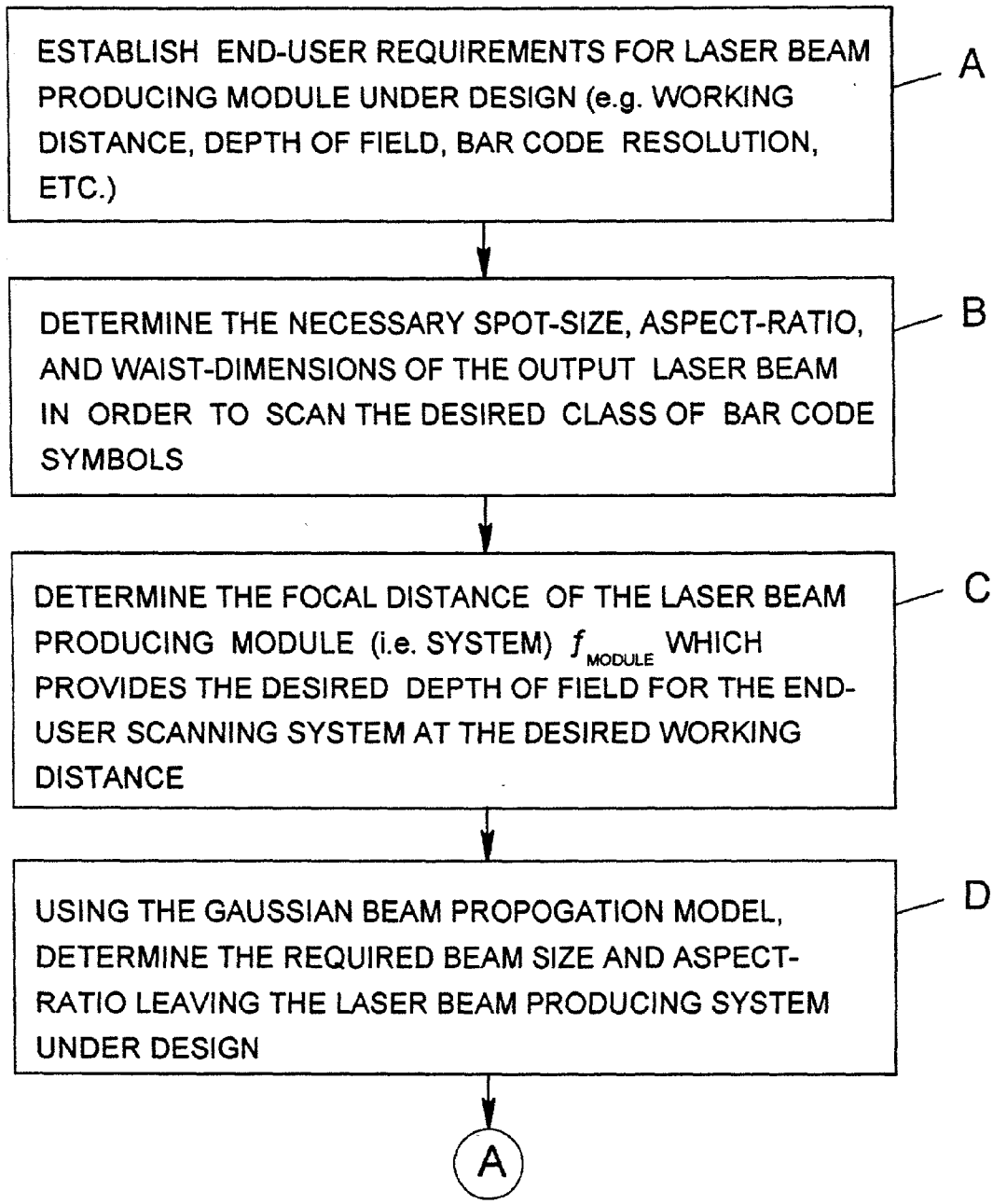

ESTABLISH END-USER REQUIREMENTS FOR LASER BEAM PRODUCING MODULE UNDER DESIGN (e.g. WORKING DISTANCE, DEPTH OF FIELD, BAR CODE RESOLUTION, ETC.)
A
DETERMINE THE NECESSARY SPOT-SIZE, ASPECT-RATIO, AND WAIST-DIMENSIONS OF THE OUTPUT LASER BEAM IN ORDER TO SCAN THE DESIRED CLASS OF BAR CODE SYMBOLS
B
DETERMINE THE FOCAL DISTANCE OF THE LASER BEAM PRODUCING MODULE (i.e. SYSTEM) $f_{MODULE}$ WHICH PROVIDES THE DESIRED DEPTH OF FIELD FOR THE END-USER SCANNING SYSTEM AT THE DESIRED WORKING DISTANCE
C
USING THE GAUSSIAN BEAM PROPOGATION MODEL, DETERMINE THE REQUIRED BEAM SIZE AND ASPECT-RATIO LEAVING THE LASER BEAM PRODUCING SYSTEM UNDER DESIGN
D
A

FIG. 3A1

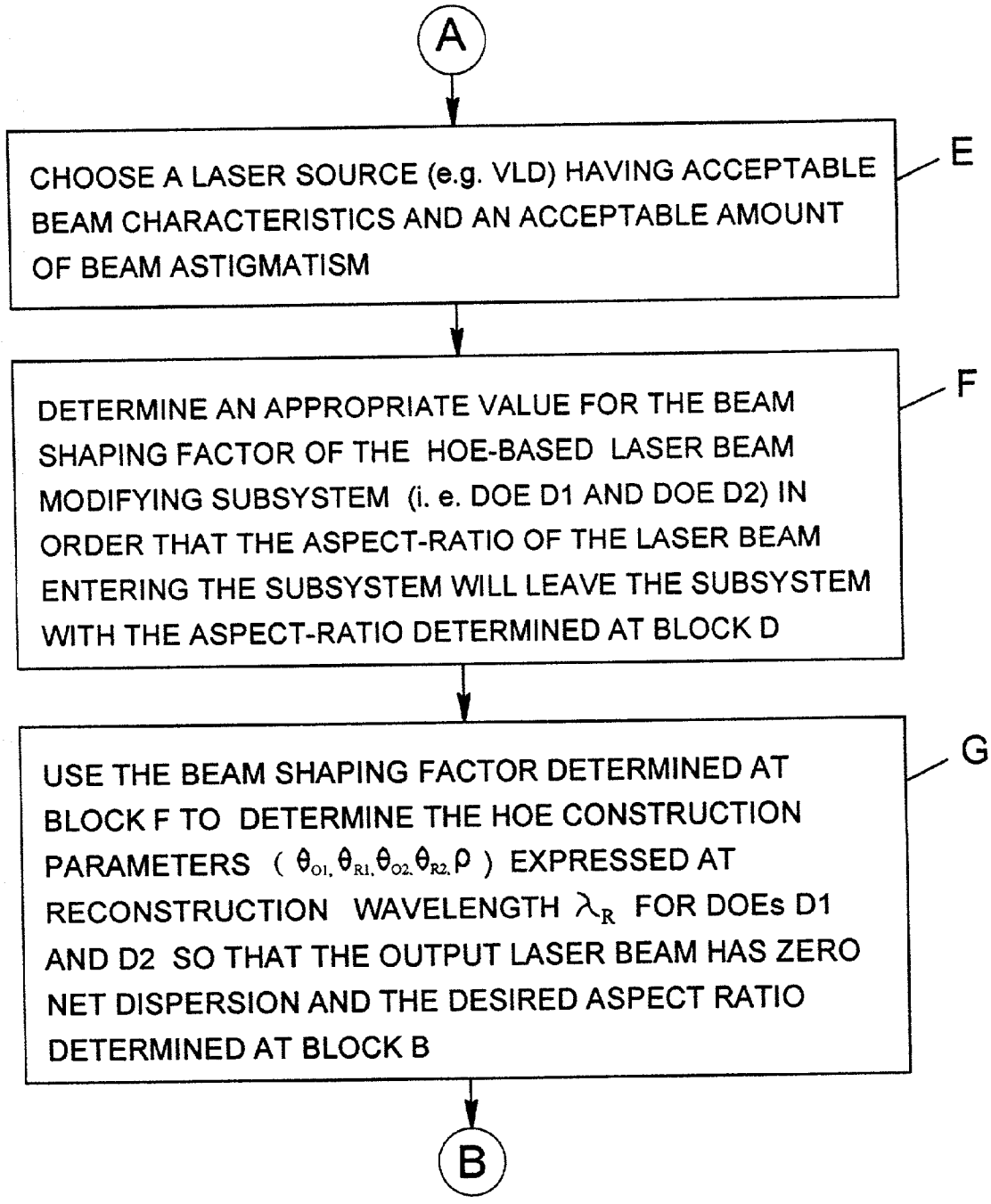

A
CHOOSE A LASER SOURCE (e.g. VLD) HAVING ACCEPTABLE BEAM CHARACTERISTICS AND AN ACCEPTABLE AMOUNT OF BEAM ASTIGMATISM
E
DETERMINE AN APPROPRIATE VALUE FOR THE BEAM SHAPING FACTOR OF THE HOE-BASED LASER BEAM MODIFYING SUBSYSTEM (i. e. DOE D1 AND DOE D2) IN ORDER THAT THE ASPECT-RATIO OF THE LASER BEAM ENTERING THE SUBSYSTEM WILL LEAVE THE SUBSYSTEM WITH THE ASPECT-RATIO DETERMINED AT BLOCK D
F
USE THE BEAM SHAPING FACTOR DETERMINED AT BLOCK F TO DETERMINE THE HOE CONSTRUCTION PARAMETERS ( $\theta_{O1}, \theta_{R1}, \theta_{O2}, \theta_{R2}, \rho$ ) EXPRESSED AT RECONSTRUCTION WAVELENGTH $\lambda_R$ FOR DOEs D1 AND D2 SO THAT THE OUTPUT LASER BEAM HAS ZERO NET DISPERSION AND THE DESIRED ASPECT RATIO DETERMINED AT BLOCK B
G
B

FIG. 3A2

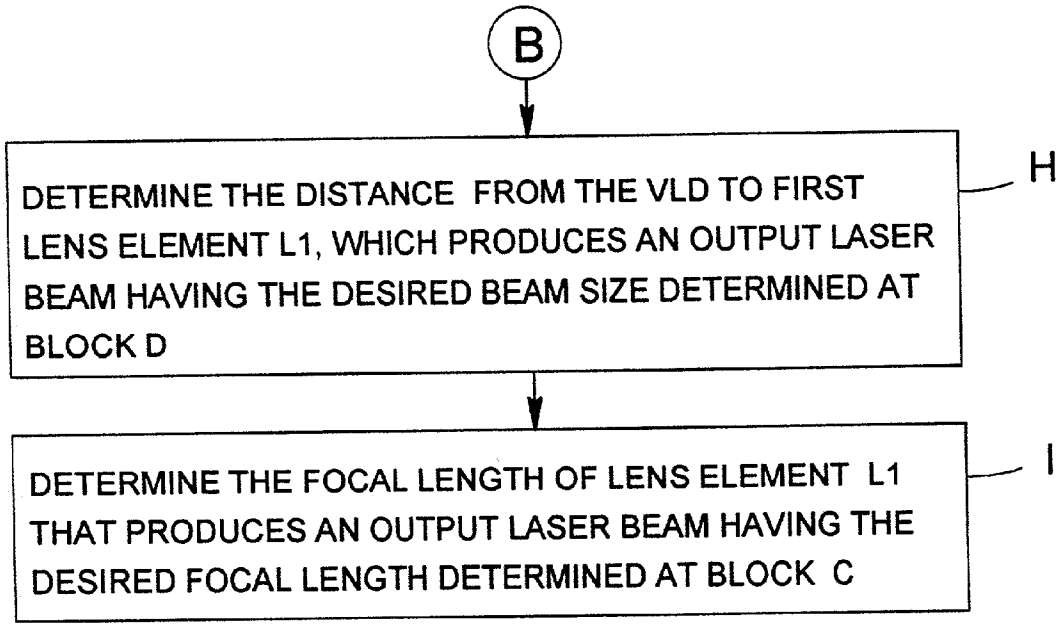

B
DETERMINE THE DISTANCE FROM THE VLD TO FIRST LENS ELEMENT L1, WHICH PRODUCES AN OUTPUT LASER BEAM HAVING THE DESIRED BEAM SIZE DETERMINED AT BLOCK D
H
DETERMINE THE FOCAL LENGTH OF LENS ELEMENT L1 THAT PRODUCES AN OUTPUT LASER BEAM HAVING THE DESIRED FOCAL LENGTH DETERMINED AT BLOCK C
I

FIG. 3A3

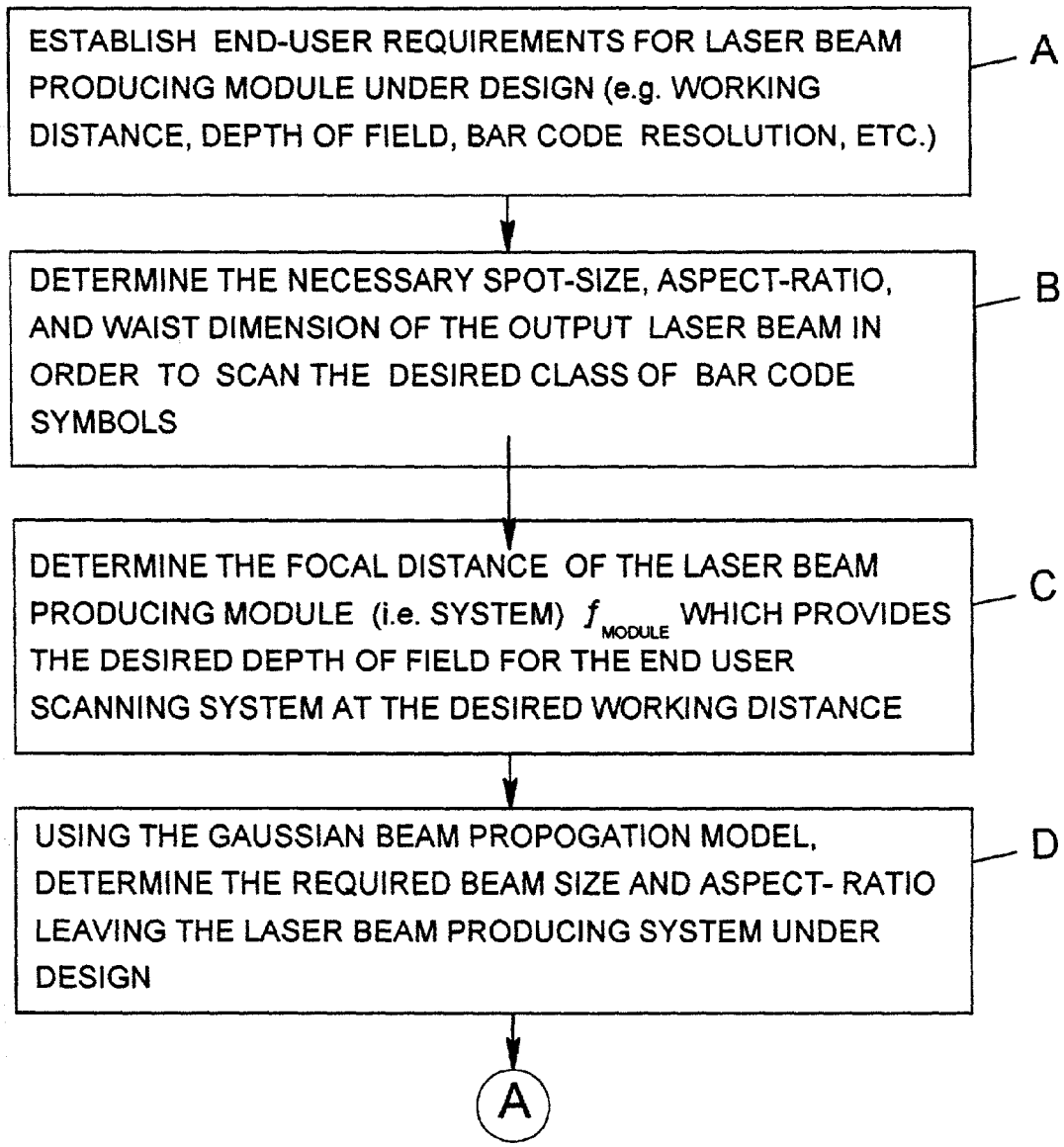

ESTABLISH END-USER REQUIREMENTS FOR LASER BEAM PRODUCING MODULE UNDER DESIGN (e.g. WORKING DISTANCE, DEPTH OF FIELD, BAR CODE RESOLUTION, ETC.)
A
DETERMINE THE NECESSARY SPOT-SIZE, ASPECT-RATIO, AND WAIST DIMENSION OF THE OUTPUT LASER BEAM IN ORDER TO SCAN THE DESIRED CLASS OF BAR CODE SYMBOLS
B
DETERMINE THE FOCAL DISTANCE OF THE LASER BEAM PRODUCING MODULE (i.e. SYSTEM) $f_{MODULE}$ WHICH PROVIDES THE DESIRED DEPTH OF FIELD FOR THE END USER SCANNING SYSTEM AT THE DESIRED WORKING DISTANCE
C
USING THE GAUSSIAN BEAM PROPOGATION MODEL, DETERMINE THE REQUIRED BEAM SIZE AND ASPECT- RATIO LEAVING THE LASER BEAM PRODUCING SYSTEM UNDER DESIGN
D
A

FIG. 3B1

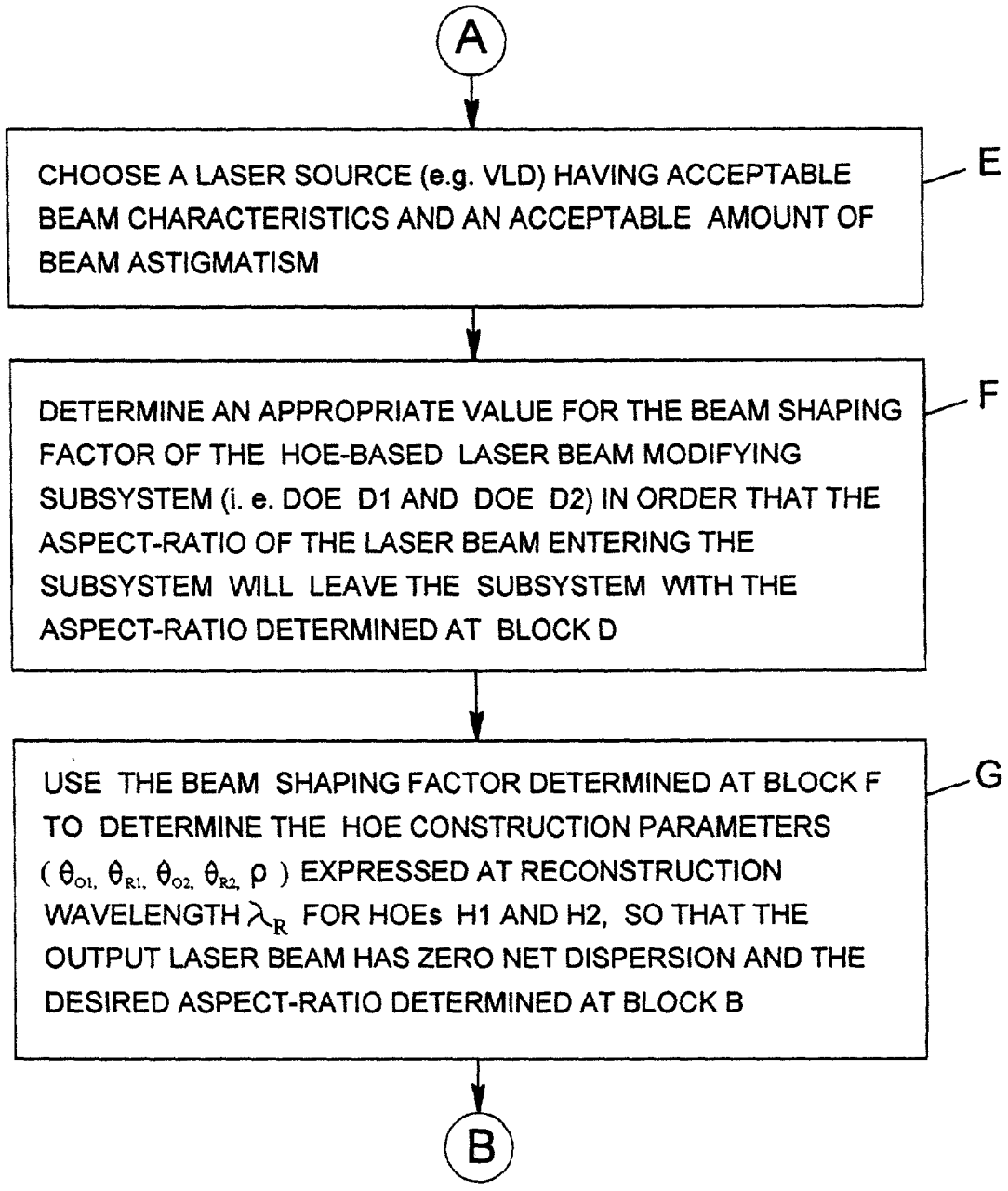

A
CHOOSE A LASER SOURCE (e.g. VLD) HAVING ACCEPTABLE BEAM CHARACTERISTICS AND AN ACCEPTABLE AMOUNT OF BEAM ASTIGMATISM
E
DETERMINE AN APPROPRIATE VALUE FOR THE BEAM SHAPING FACTOR OF THE HOE-BASED LASER BEAM MODIFYING SUBSYSTEM (i. e. DOE D1 AND DOE D2) IN ORDER THAT THE ASPECT-RATIO OF THE LASER BEAM ENTERING THE SUBSYSTEM WILL LEAVE THE SUBSYSTEM WITH THE ASPECT-RATIO DETERMINED AT BLOCK D
F
USE THE BEAM SHAPING FACTOR DETERMINED AT BLOCK F TO DETERMINE THE HOE CONSTRUCTION PARAMETERS ( $\theta_{O1}$, $\theta_{R1}$, $\theta_{O2}$, $\theta_{R2}$, $\rho$ ) EXPRESSED AT RECONSTRUCTION WAVELENGTH $\lambda_R$ FOR HOEs H1 AND H2, SO THAT THE OUTPUT LASER BEAM HAS ZERO NET DISPERSION AND THE DESIRED ASPECT-RATIO DETERMINED AT BLOCK B
G
B

FIG. 3B2

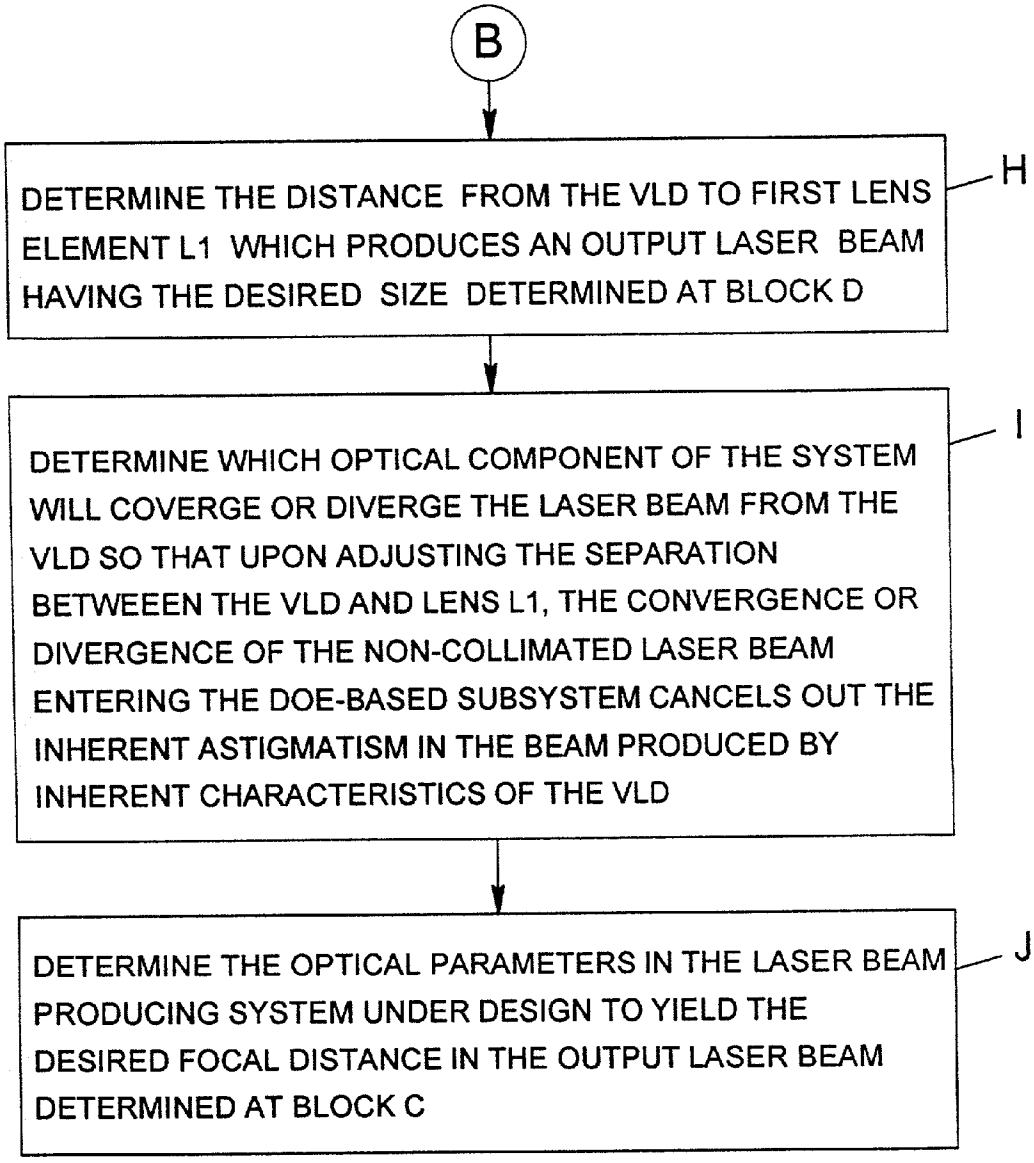

B
DETERMINE THE DISTANCE FROM THE VLD TO FIRST LENS ELEMENT L1 WHICH PRODUCES AN OUTPUT LASER BEAM HAVING THE DESIRED SIZE DETERMINED AT BLOCK D
H
DETERMINE WHICH OPTICAL COMPONENT OF THE SYSTEM WILL COVERGE OR DIVERGE THE LASER BEAM FROM THE VLD SO THAT UPON ADJUSTING THE SEPARATION BETWEEEN THE VLD AND LENS L1, THE CONVERGENCE OR DIVERGENCE OF THE NON-COLLIMATED LASER BEAM ENTERING THE DOE-BASED SUBSYSTEM CANCELS OUT THE INHERENT ASTIGMATISM IN THE BEAM PRODUCED BY INHERENT CHARACTERISTICS OF THE VLD
I
DETERMINE THE OPTICAL PARAMETERS IN THE LASER BEAM PRODUCING SYSTEM UNDER DESIGN TO YIELD THE DESIRED FOCAL DISTANCE IN THE OUTPUT LASER BEAM DETERMINED AT BLOCK C
J

FIG. 3B3

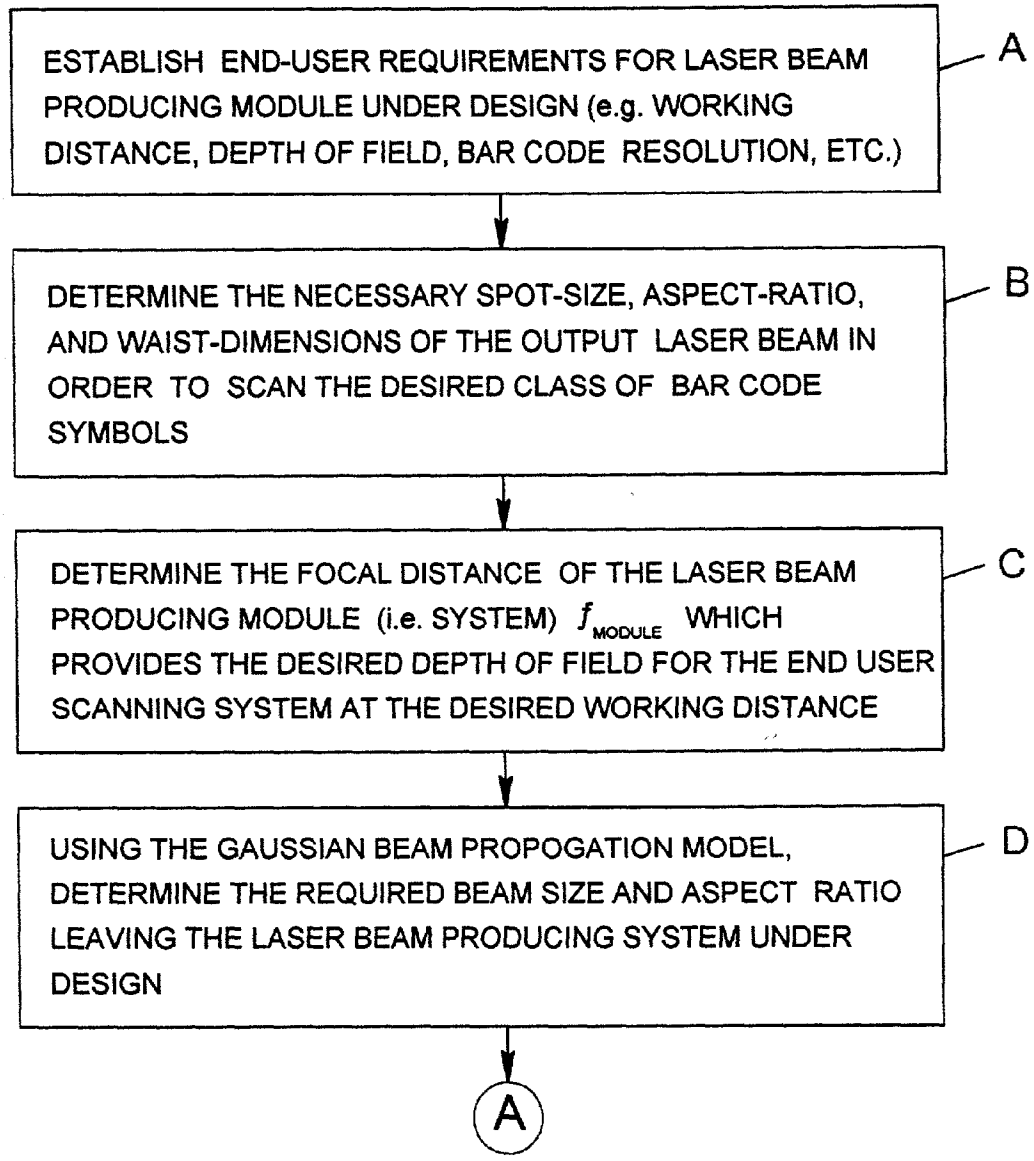

ESTABLISH END-USER REQUIREMENTS FOR LASER BEAM PRODUCING MODULE UNDER DESIGN (e.g. WORKING DISTANCE, DEPTH OF FIELD, BAR CODE RESOLUTION, ETC.)
A
DETERMINE THE NECESSARY SPOT-SIZE, ASPECT-RATIO, AND WAIST-DIMENSIONS OF THE OUTPUT LASER BEAM IN ORDER TO SCAN THE DESIRED CLASS OF BAR CODE SYMBOLS
B
DETERMINE THE FOCAL DISTANCE OF THE LASER BEAM PRODUCING MODULE (i.e. SYSTEM) $f_{MODULE}$ WHICH PROVIDES THE DESIRED DEPTH OF FIELD FOR THE END USER SCANNING SYSTEM AT THE DESIRED WORKING DISTANCE
C
USING THE GAUSSIAN BEAM PROPOGATION MODEL, DETERMINE THE REQUIRED BEAM SIZE AND ASPECT RATIO LEAVING THE LASER BEAM PRODUCING SYSTEM UNDER DESIGN
D
A

FIG. 3C1

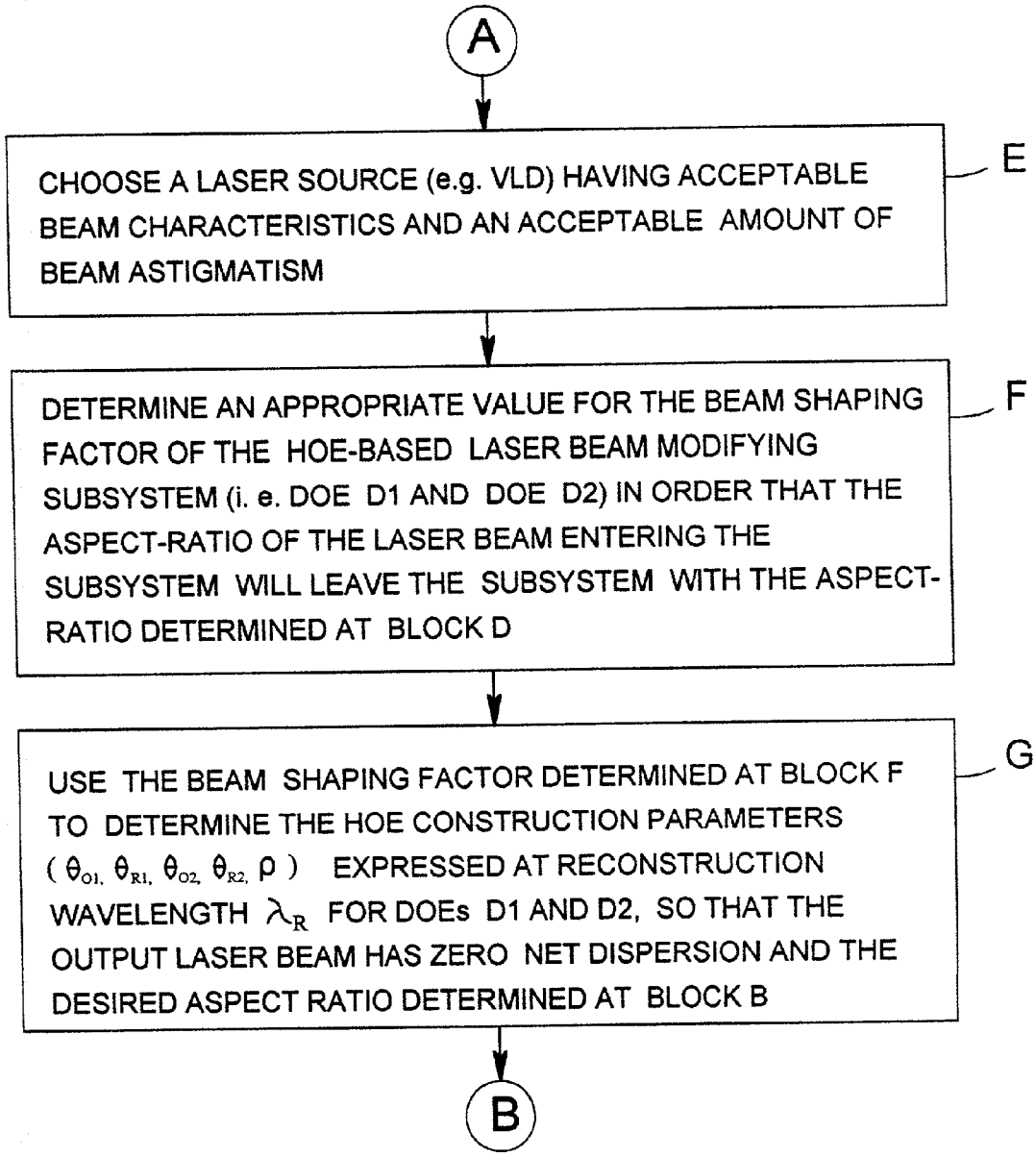

A
CHOOSE A LASER SOURCE (e.g. VLD) HAVING ACCEPTABLE BEAM CHARACTERISTICS AND AN ACCEPTABLE AMOUNT OF BEAM ASTIGMATISM
E
DETERMINE AN APPROPRIATE VALUE FOR THE BEAM SHAPING FACTOR OF THE HOE-BASED LASER BEAM MODIFYING SUBSYSTEM (i. e. DOE D1 AND DOE D2) IN ORDER THAT THE ASPECT-RATIO OF THE LASER BEAM ENTERING THE SUBSYSTEM WILL LEAVE THE SUBSYSTEM WITH THE ASPECT-RATIO DETERMINED AT BLOCK D
F
USE THE BEAM SHAPING FACTOR DETERMINED AT BLOCK F TO DETERMINE THE HOE CONSTRUCTION PARAMETERS ( $\theta_{O1}$, $\theta_{R1}$, $\theta_{O2}$, $\theta_{R2}$, $\rho$ ) EXPRESSED AT RECONSTRUCTION WAVELENGTH $\lambda_R$ FOR DOEs D1 AND D2, SO THAT THE OUTPUT LASER BEAM HAS ZERO NET DISPERSION AND THE DESIRED ASPECT RATIO DETERMINED AT BLOCK B
G
B

FIG. 3C2

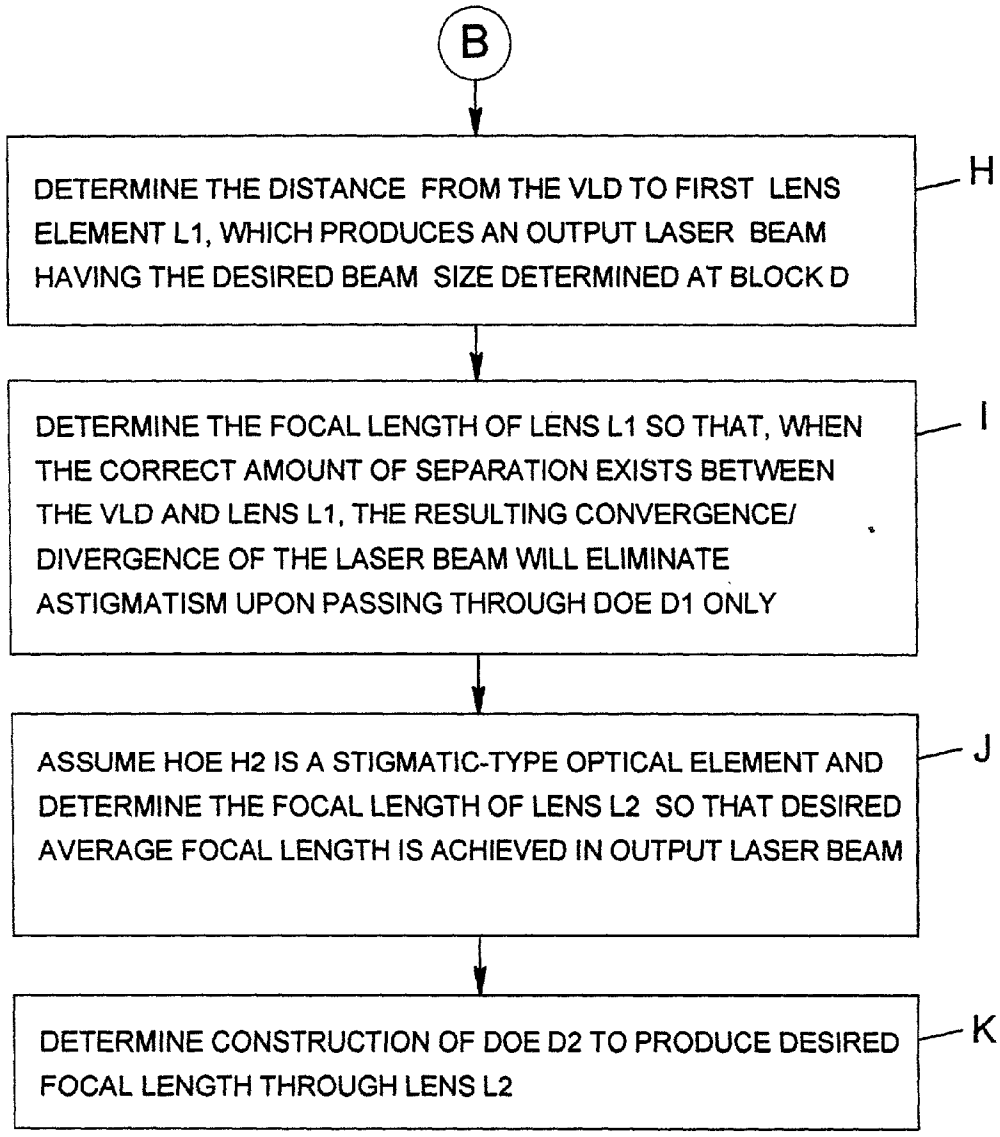

B
DETERMINE THE DISTANCE FROM THE VLD TO FIRST LENS ELEMENT L1, WHICH PRODUCES AN OUTPUT LASER BEAM HAVING THE DESIRED BEAM SIZE DETERMINED AT BLOCK D
H
DETERMINE THE FOCAL LENGTH OF LENS L1 SO THAT, WHEN THE CORRECT AMOUNT OF SEPARATION EXISTS BETWEEN THE VLD AND LENS L1, THE RESULTING CONVERGENCE/ DIVERGENCE OF THE LASER BEAM WILL ELIMINATE ASTIGMATISM UPON PASSING THROUGH DOE D1 ONLY
I
ASSUME HOE H2 IS A STIGMATIC-TYPE OPTICAL ELEMENT AND DETERMINE THE FOCAL LENGTH OF LENS L2 SO THAT DESIRED AVERAGE FOCAL LENGTH IS ACHIEVED IN OUTPUT LASER BEAM
J
DETERMINE CONSTRUCTION OF DOE D2 TO PRODUCE DESIRED FOCAL LENGTH THROUGH LENS L2
K

FIG. 3C3

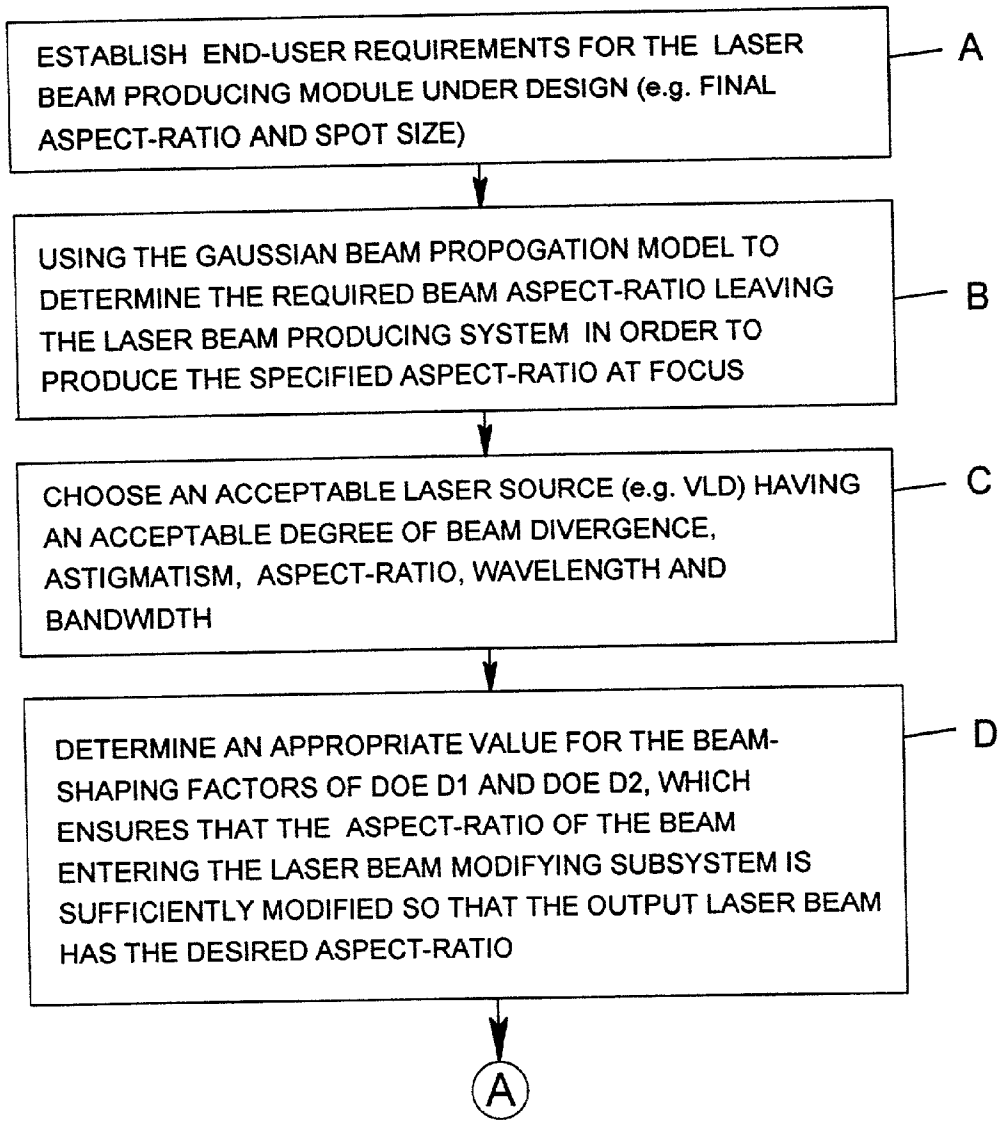

ESTABLISH END-USER REQUIREMENTS FOR THE LASER BEAM PRODUCING MODULE UNDER DESIGN (e.g. FINAL ASPECT-RATIO AND SPOT SIZE)
A
USING THE GAUSSIAN BEAM PROPOGATION MODEL TO DETERMINE THE REQUIRED BEAM ASPECT-RATIO LEAVING THE LASER BEAM PRODUCING SYSTEM IN ORDER TO PRODUCE THE SPECIFIED ASPECT-RATIO AT FOCUS
B
CHOOSE AN ACCEPTABLE LASER SOURCE (e.g. VLD) HAVING AN ACCEPTABLE DEGREE OF BEAM DIVERGENCE, ASTIGMATISM, ASPECT-RATIO, WAVELENGTH AND BANDWIDTH
C
DETERMINE AN APPROPRIATE VALUE FOR THE BEAM-SHAPING FACTORS OF DOE D1 AND DOE D2, WHICH ENSURES THAT THE ASPECT-RATIO OF THE BEAM ENTERING THE LASER BEAM MODIFYING SUBSYSTEM IS SUFFICIENTLY MODIFIED SO THAT THE OUTPUT LASER BEAM HAS THE DESIRED ASPECT-RATIO
D
A

FIG. 3D1

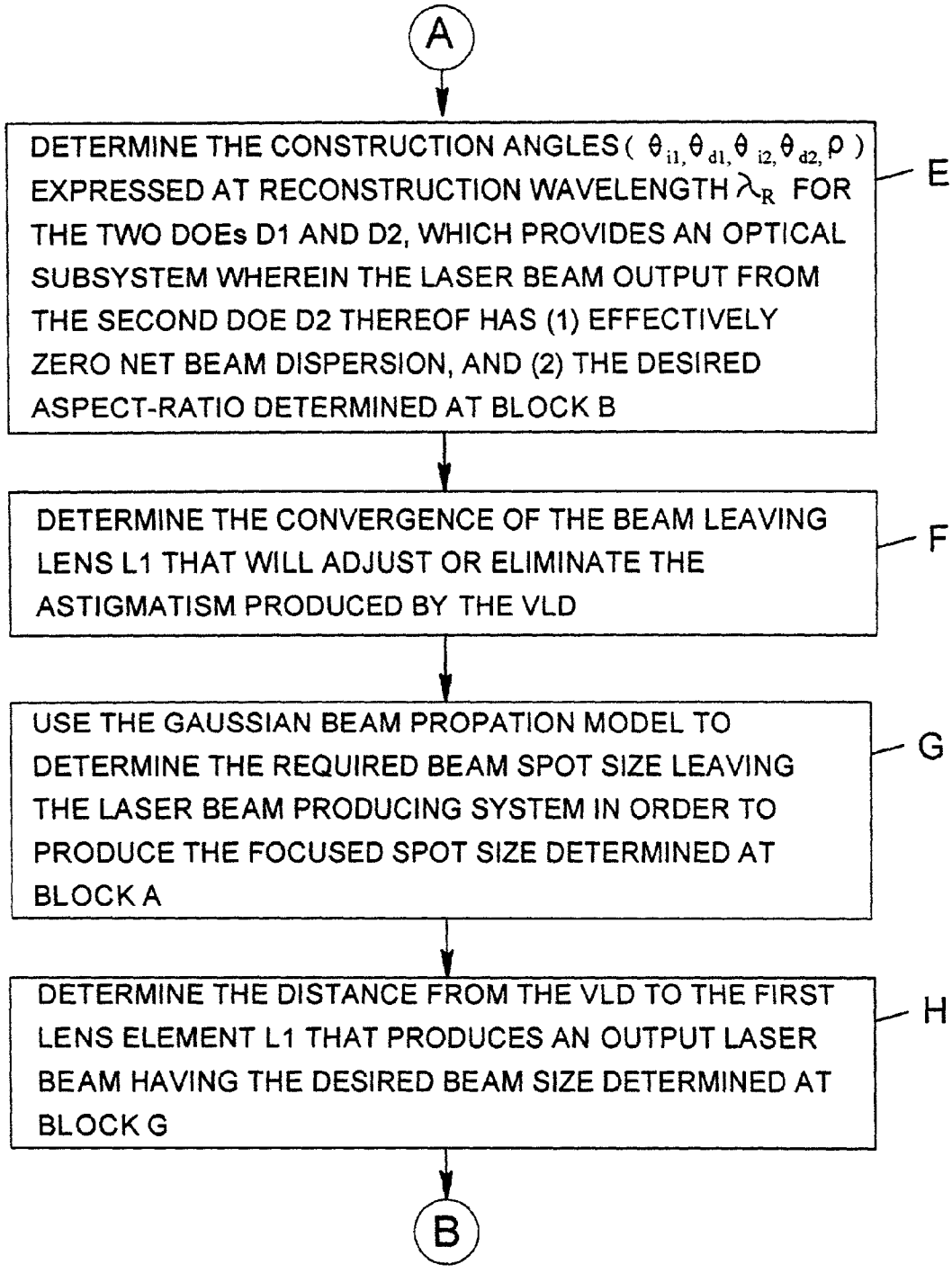

A
DETERMINE THE CONSTRUCTION ANGLES ( $\theta_{i1}, \theta_{d1}, \theta_{i2}, \theta_{d2}, \rho$ ) EXPRESSED AT RECONSTRUCTION WAVELENGTH $\lambda_R$ FOR THE TWO DOEs D1 AND D2, WHICH PROVIDES AN OPTICAL SUBSYSTEM WHEREIN THE LASER BEAM OUTPUT FROM THE SECOND DOE D2 THEREOF HAS (1) EFFECTIVELY ZERO NET BEAM DISPERSION, AND (2) THE DESIRED ASPECT-RATIO DETERMINED AT BLOCK B
E
DETERMINE THE CONVERGENCE OF THE BEAM LEAVING LENS L1 THAT WILL ADJUST OR ELIMINATE THE ASTIGMATISM PRODUCED BY THE VLD
F
USE THE GAUSSIAN BEAM PROPATION MODEL TO DETERMINE THE REQUIRED BEAM SPOT SIZE LEAVING THE LASER BEAM PRODUCING SYSTEM IN ORDER TO PRODUCE THE FOCUSED SPOT SIZE DETERMINED AT BLOCK A
G
DETERMINE THE DISTANCE FROM THE VLD TO THE FIRST LENS ELEMENT L1 THAT PRODUCES AN OUTPUT LASER BEAM HAVING THE DESIRED BEAM SIZE DETERMINED AT BLOCK G
H
B

FIG. 3D2

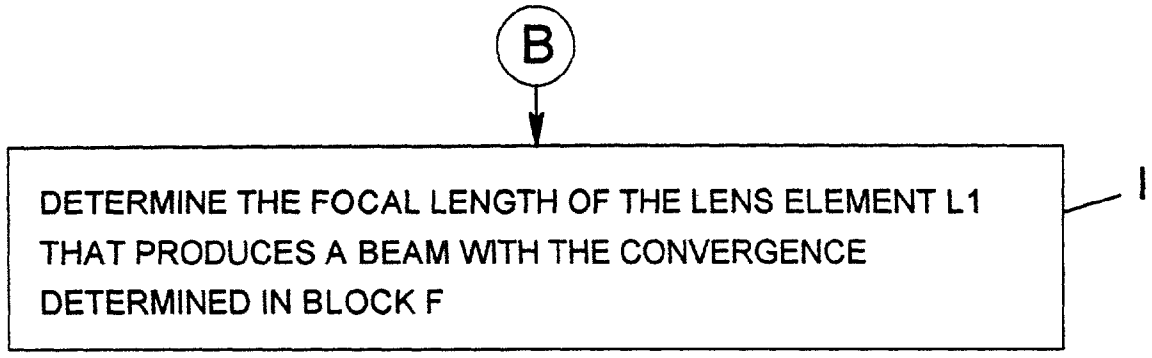

B
DETERMINE THE FOCAL LENGTH OF THE LENS ELEMENT L1 THAT PRODUCES A BEAM WITH THE CONVERGENCE DETERMINED IN BLOCK F
I

FIG. 3D3

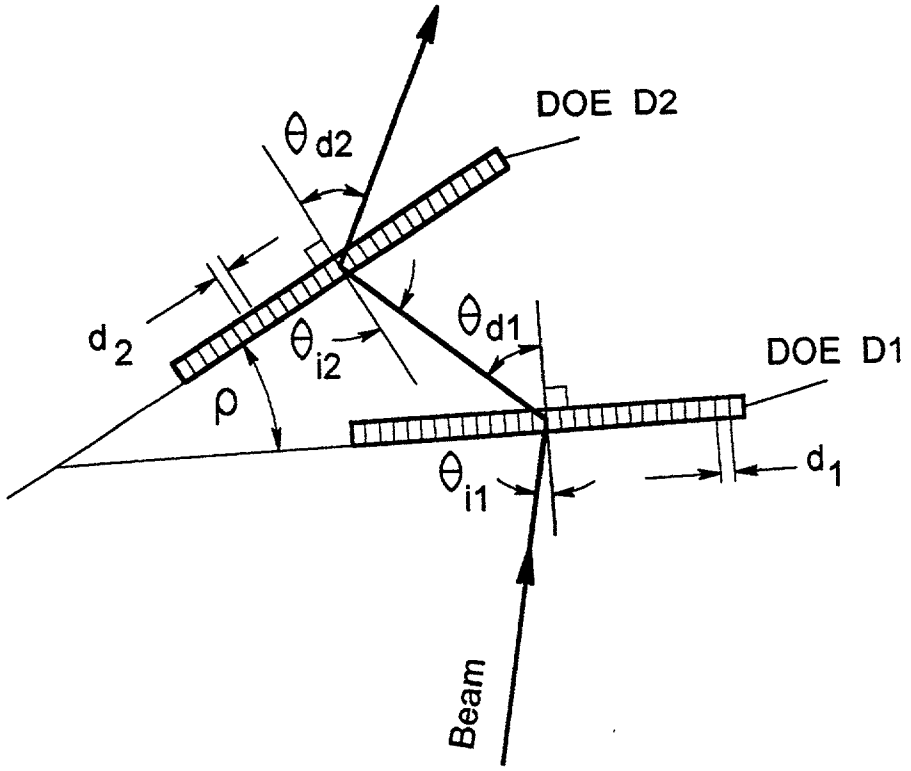



FIG. 3E

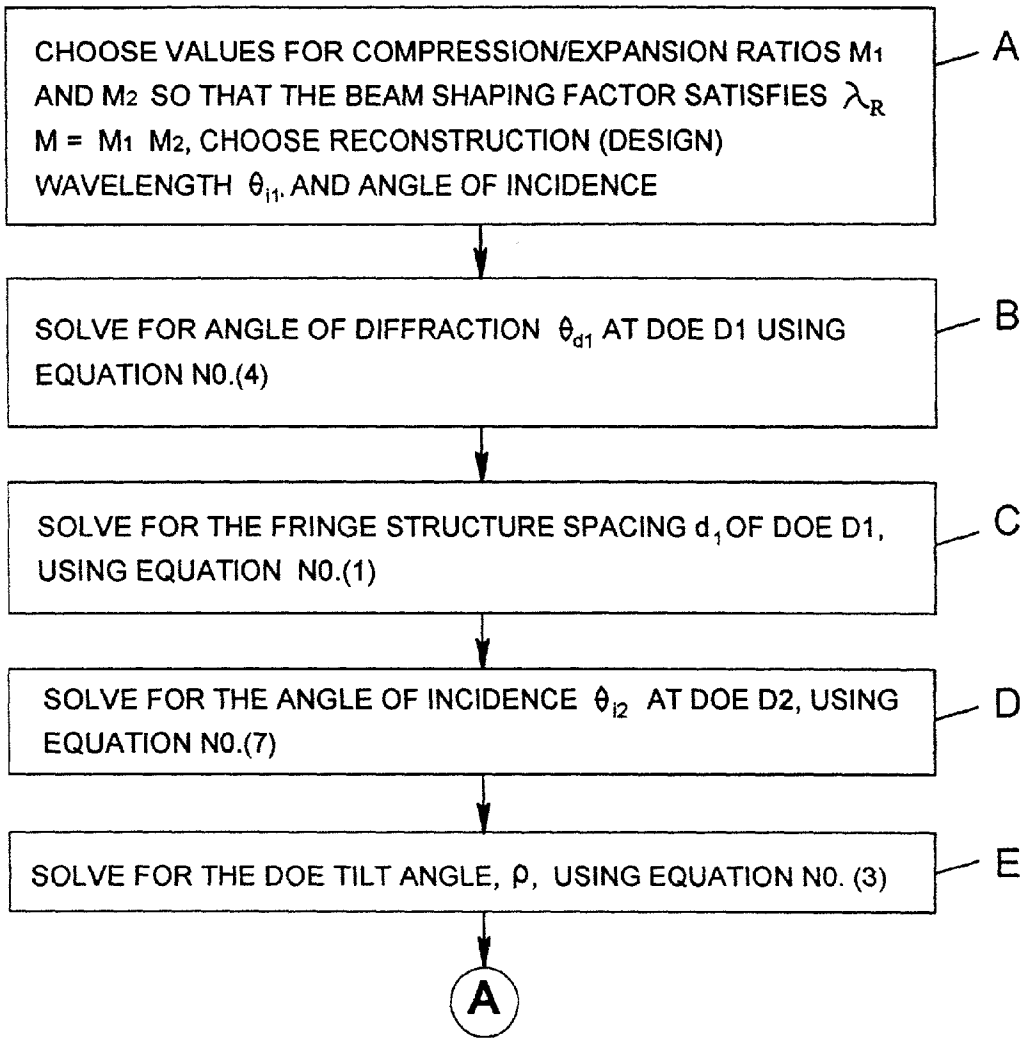

CHOOSE VALUES FOR COMPRESSION/EXPANSION RATIOS M1 AND M2 SO THAT THE BEAM SHAPING FACTOR SATISFIES $\lambda_R$ M = M1 M2, CHOOSE RECONSTRUCTION (DESIGN) WAVELENGTH $\theta_{i1}$, AND ANGLE OF INCIDENCE
A
SOLVE FOR ANGLE OF DIFFRACTION $\theta_{d1}$ AT DOE D1 USING EQUATION N0.(4)
B
SOLVE FOR THE FRINGE STRUCTURE SPACING $d_1$ OF DOE D1, USING EQUATION N0.(1)
C
SOLVE FOR THE ANGLE OF INCIDENCE $\theta_{i2}$ AT DOE D2, USING EQUATION N0.(7)
D
SOLVE FOR THE DOE TILT ANGLE, ρ, USING EQUATION N0. (3)
E
A

FIG. 3F1

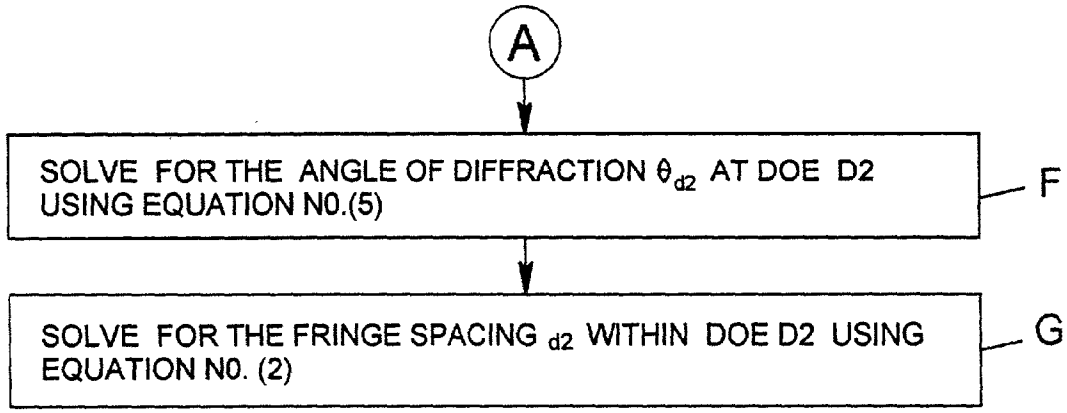

A
SOLVE FOR THE ANGLE OF DIFFRACTION $\theta_{d2}$ AT DOE D2 USING EQUATION N0.(5)
F
SOLVE FOR THE FRINGE SPACING $_{d2}$ WITHIN DOE D2 USING EQUATION N0. (2)
G

FIG. 3F2

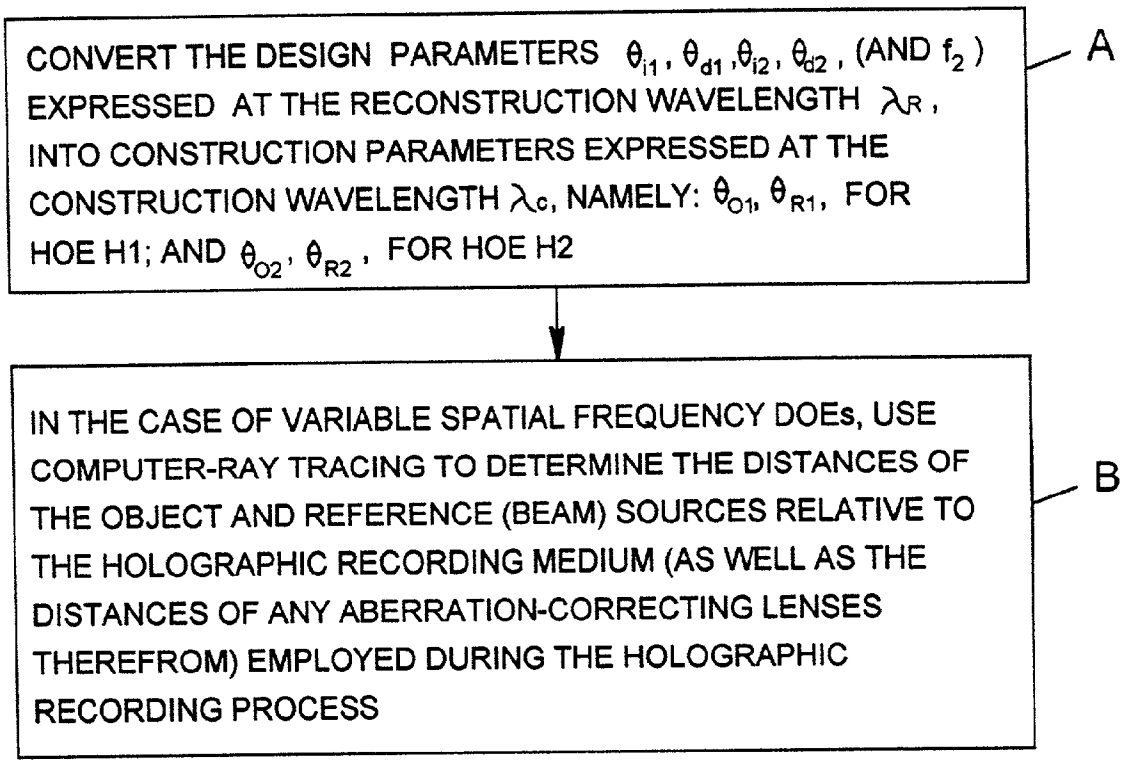
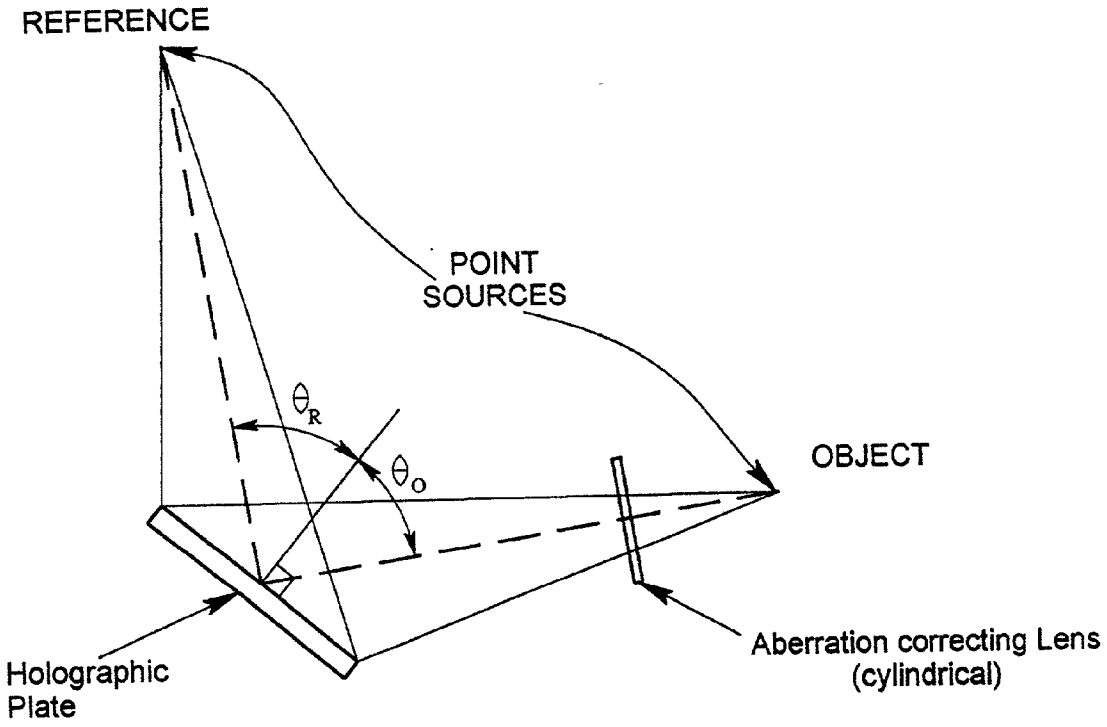

CONVERT THE DESIGN PARAMETERS $\theta_{i1}$, $\theta_{d1}$, $\theta_{i2}$, $\theta_{d2}$, (AND $f_2$) EXPRESSED AT THE RECONSTRUCTION WAVELENGTH $\lambda_R$, INTO CONSTRUCTION PARAMETERS EXPRESSED AT THE CONSTRUCTION WAVELENGTH $\lambda_c$, NAMELY: $\theta_{O1}$, $\theta_{R1}$, FOR HOE H1; AND $\theta_{O2}$, $\theta_{R2}$, FOR HOE H2
A
IN THE CASE OF VARIABLE SPATIAL FREQUENCY DOEs, USE COMPUTER-RAY TRACING TO DETERMINE THE DISTANCES OF THE OBJECT AND REFERENCE (BEAM) SOURCES RELATIVE TO THE HOLOGRAPHIC RECORDING MEDIUM (AS WELL AS THE DISTANCES OF ANY ABERRATION-CORRECTING LENSES THEREFROM) EMPLOYED DURING THE HOLOGRAPHIC RECORDING PROCESS
B

FIG. 4A




$\theta_R$ = REFERENCE BEAM ANGLE OF INCIDENCE

$\theta_O$ = OBJECT BEAM ANGLE OF INCIDENCE

FIG. 4B

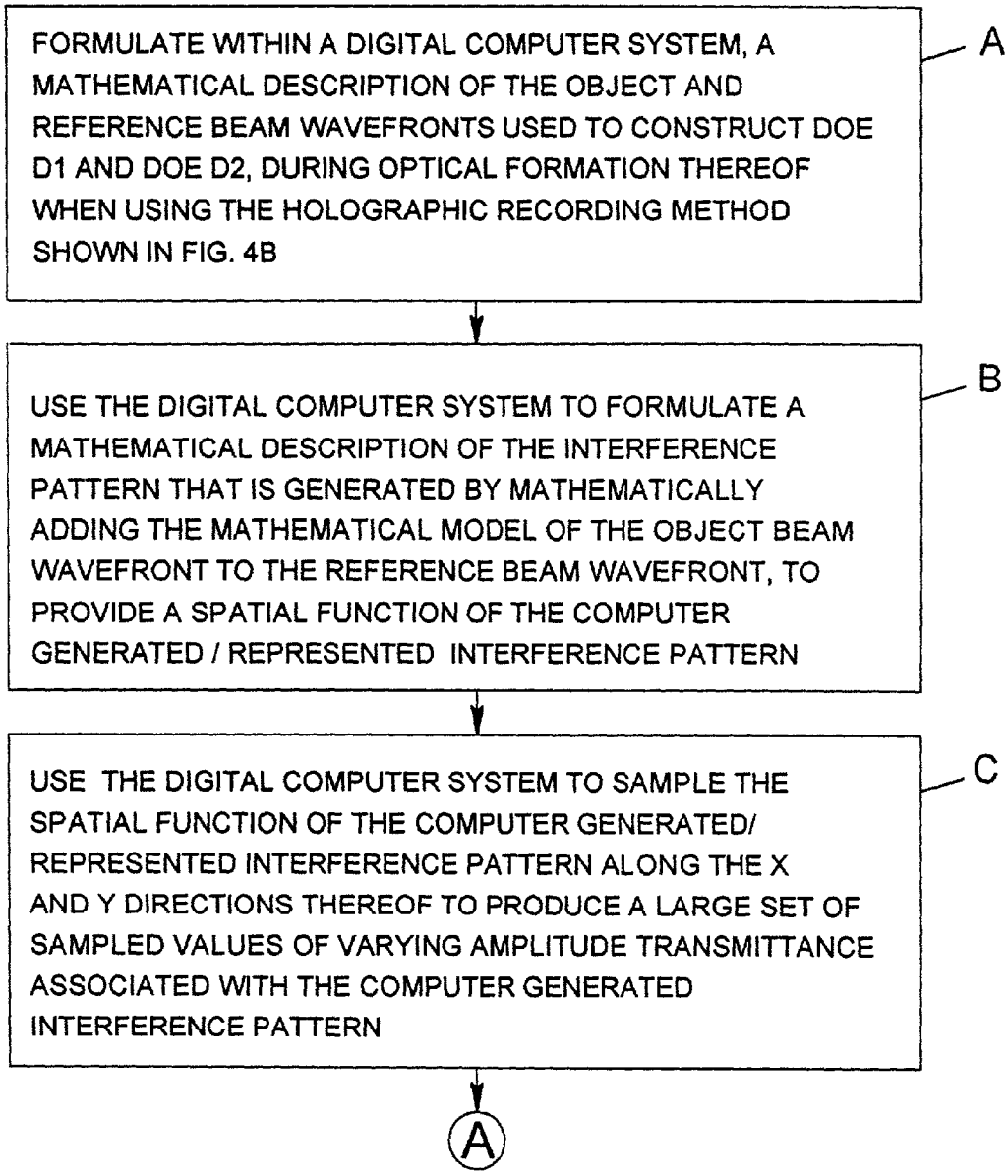

FORMULATE WITHIN A DIGITAL COMPUTER SYSTEM, A MATHEMATICAL DESCRIPTION OF THE OBJECT AND REFERENCE BEAM WAVEFRONTS USED TO CONSTRUCT DOE D1 AND DOE D2, DURING OPTICAL FORMATION THEREOF WHEN USING THE HOLOGRAPHIC RECORDING METHOD SHOWN IN FIG. 4B
A
USE THE DIGITAL COMPUTER SYSTEM TO FORMULATE A MATHEMATICAL DESCRIPTION OF THE INTERFERENCE PATTERN THAT IS GENERATED BY MATHEMATICALLY ADDING THE MATHEMATICAL MODEL OF THE OBJECT BEAM WAVEFRONT TO THE REFERENCE BEAM WAVEFRONT, TO PROVIDE A SPATIAL FUNCTION OF THE COMPUTER GENERATED / REPRESENTED INTERFERENCE PATTERN
B
USE THE DIGITAL COMPUTER SYSTEM TO SAMPLE THE SPATIAL FUNCTION OF THE COMPUTER GENERATED/ REPRESENTED INTERFERENCE PATTERN ALONG THE X AND Y DIRECTIONS THEREOF TO PRODUCE A LARGE SET OF SAMPLED VALUES OF VARYING AMPLITUDE TRANSMITTANCE ASSOCIATED WITH THE COMPUTER GENERATED INTERFERENCE PATTERN
C
A

FIG. 4C1

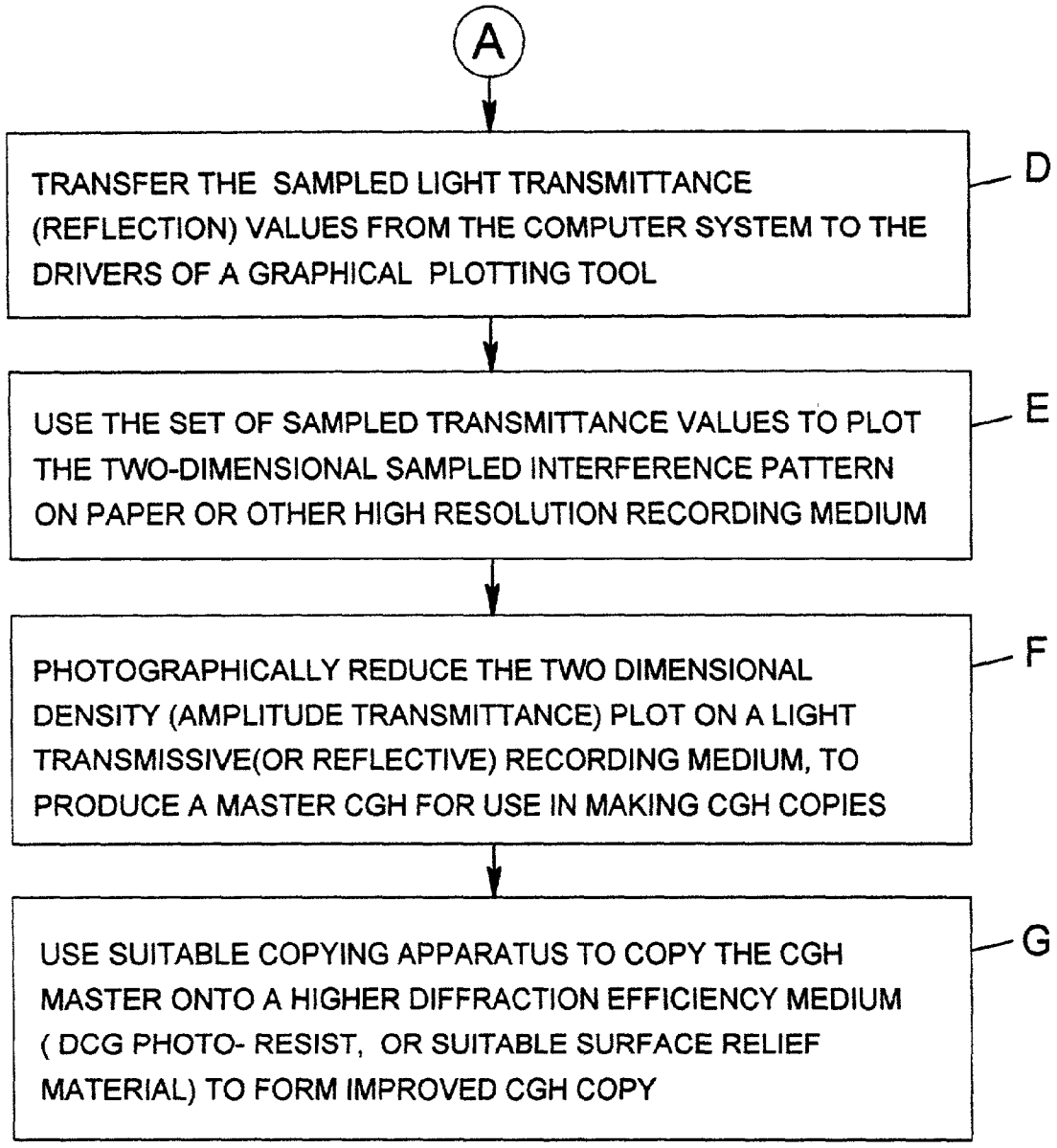

A
TRANSFER THE SAMPLED LIGHT TRANSMITTANCE (REFLECTION) VALUES FROM THE COMPUTER SYSTEM TO THE DRIVERS OF A GRAPHICAL PLOTTING TOOL
D
USE THE SET OF SAMPLED TRANSMITTANCE VALUES TO PLOT THE TWO-DIMENSIONAL SAMPLED INTERFERENCE PATTERN ON PAPER OR OTHER HIGH RESOLUTION RECORDING MEDIUM
E
PHOTOGRAPHICALLY REDUCE THE TWO DIMENSIONAL DENSITY (AMPLITUDE TRANSMITTANCE) PLOT ON A LIGHT TRANSMISSIVE(OR REFLECTIVE) RECORDING MEDIUM, TO PRODUCE A MASTER CGH FOR USE IN MAKING CGH COPIES
F
USE SUITABLE COPYING APPARATUS TO COPY THE CGH MASTER ONTO A HIGHER DIFFRACTION EFFICIENCY MEDIUM ( DCG PHOTO- RESIST, OR SUITABLE SURFACE RELIEF MATERIAL) TO FORM IMPROVED CGH COPY
G

FIG. 4C2

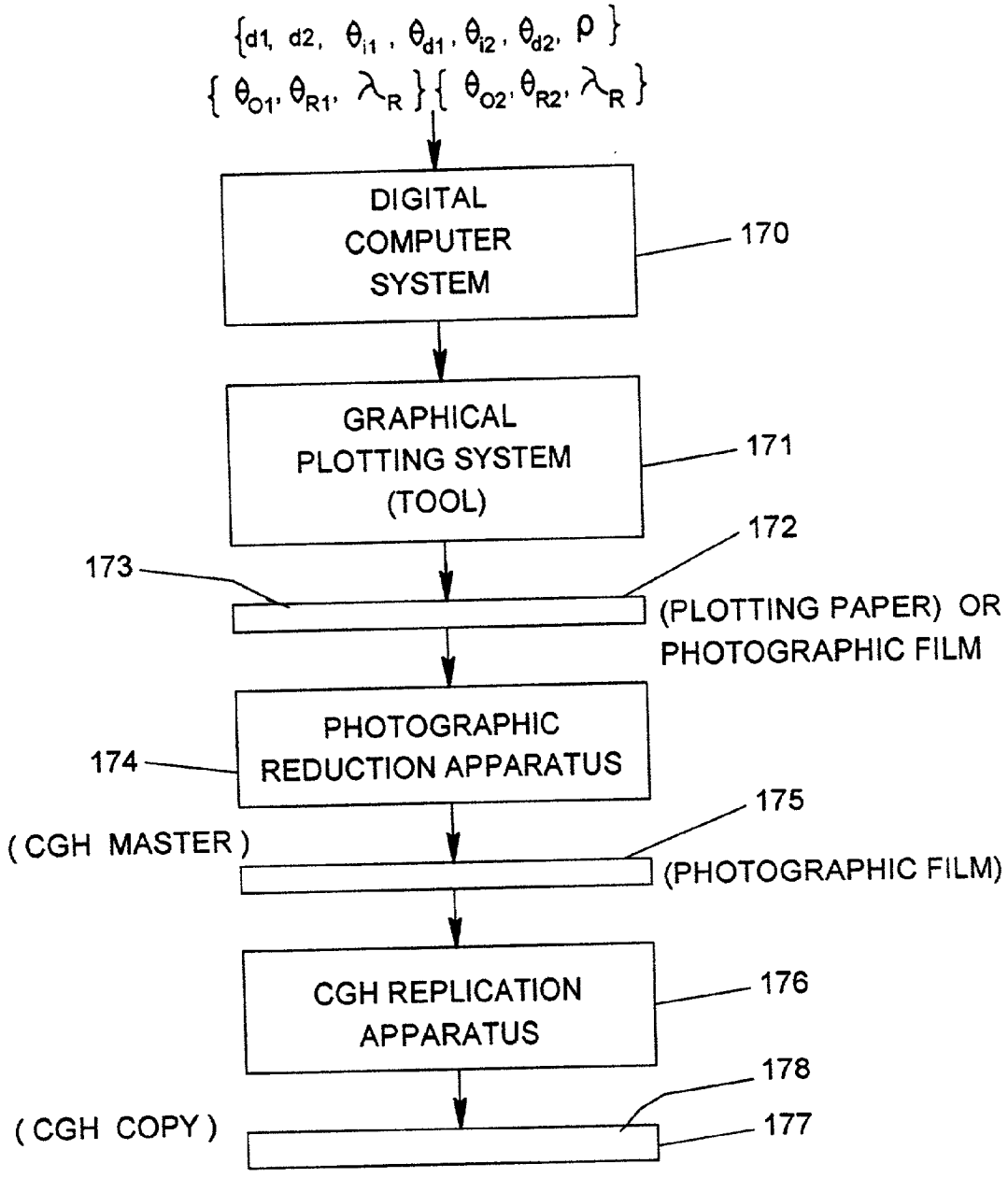

{d1, d2, θi1, θd1, θi2, θd2, ρ }
{ θO1, θR1, λR }{ θO2, θR2, λR }
DIGITAL COMPUTER SYSTEM
170
GRAPHICAL PLOTTING SYSTEM (TOOL)
171
172
173
(PLOTTING PAPER) OR PHOTOGRAPHIC FILM
PHOTOGRAPHIC REDUCTION APPARATUS
174
175
(CGH MASTER)
(PHOTOGRAPHIC FILM)
CGH REPLICATION APPARATUS
176
178
(CGH COPY)
177

FIG. 4D

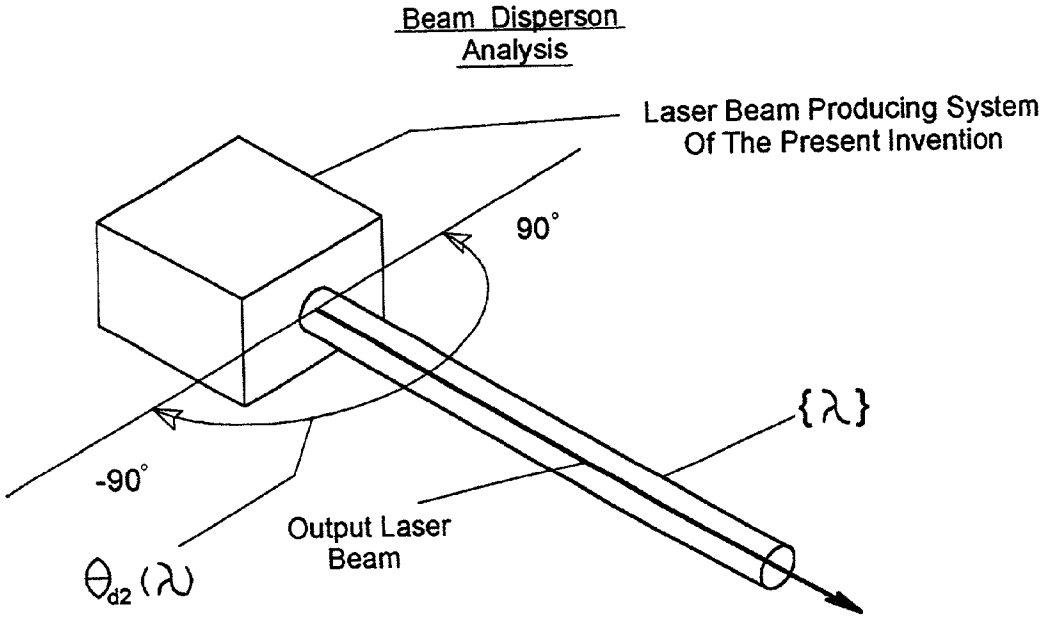



FIG. 5A

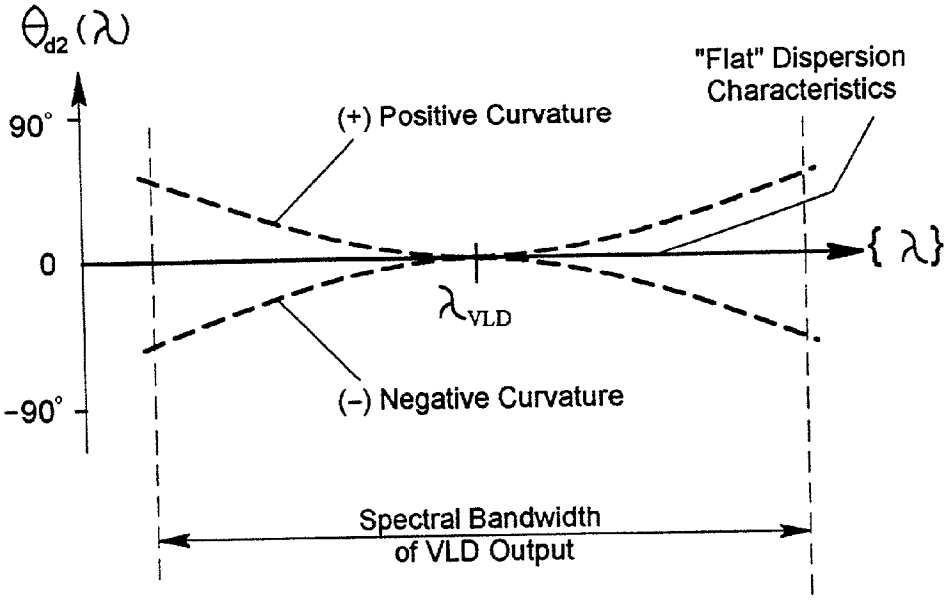



FIG. 5B1

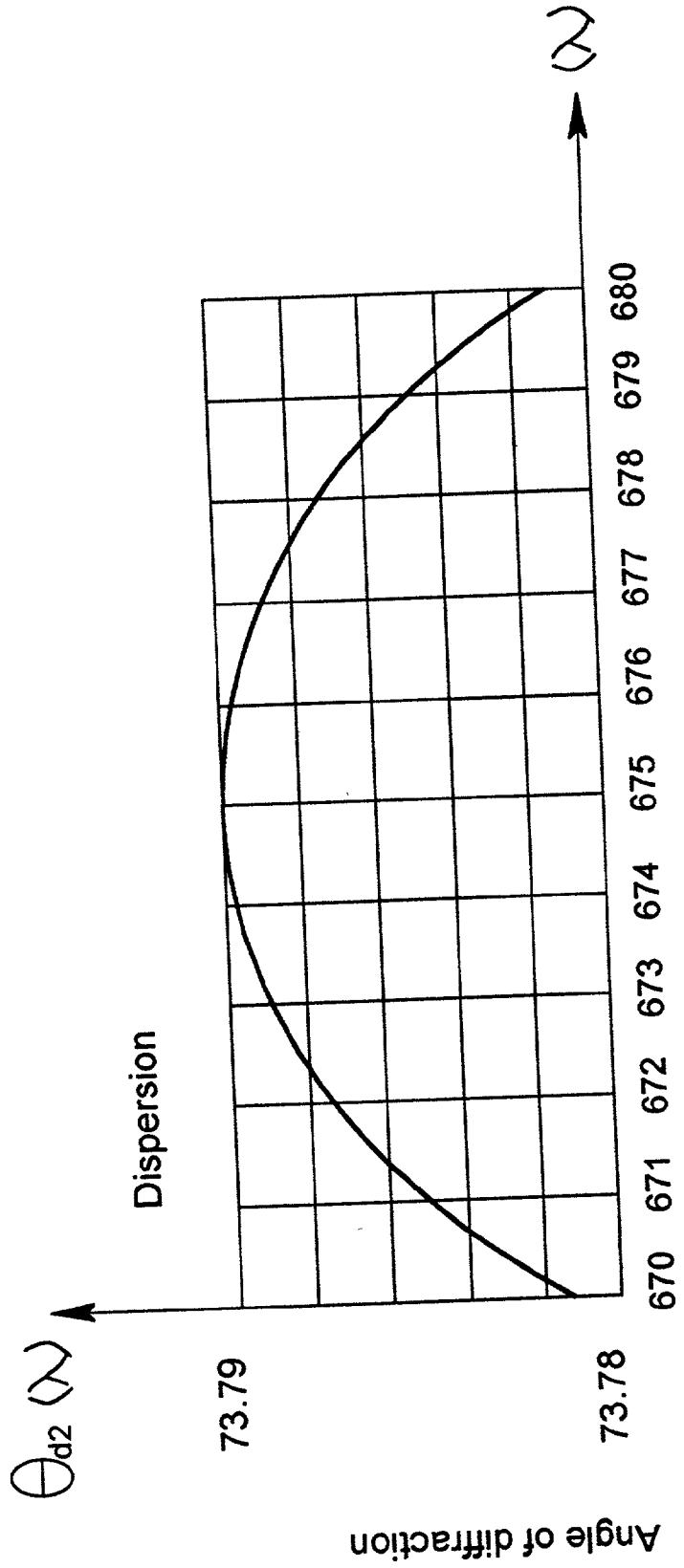

λ
680
679
678
677
676
675
674
673
672
671
670
Wavelength (nm)
Dispersion
$\theta_{d2}$ (λ)
73.79
73.78
Angle of diffraction

FIG. 5B2

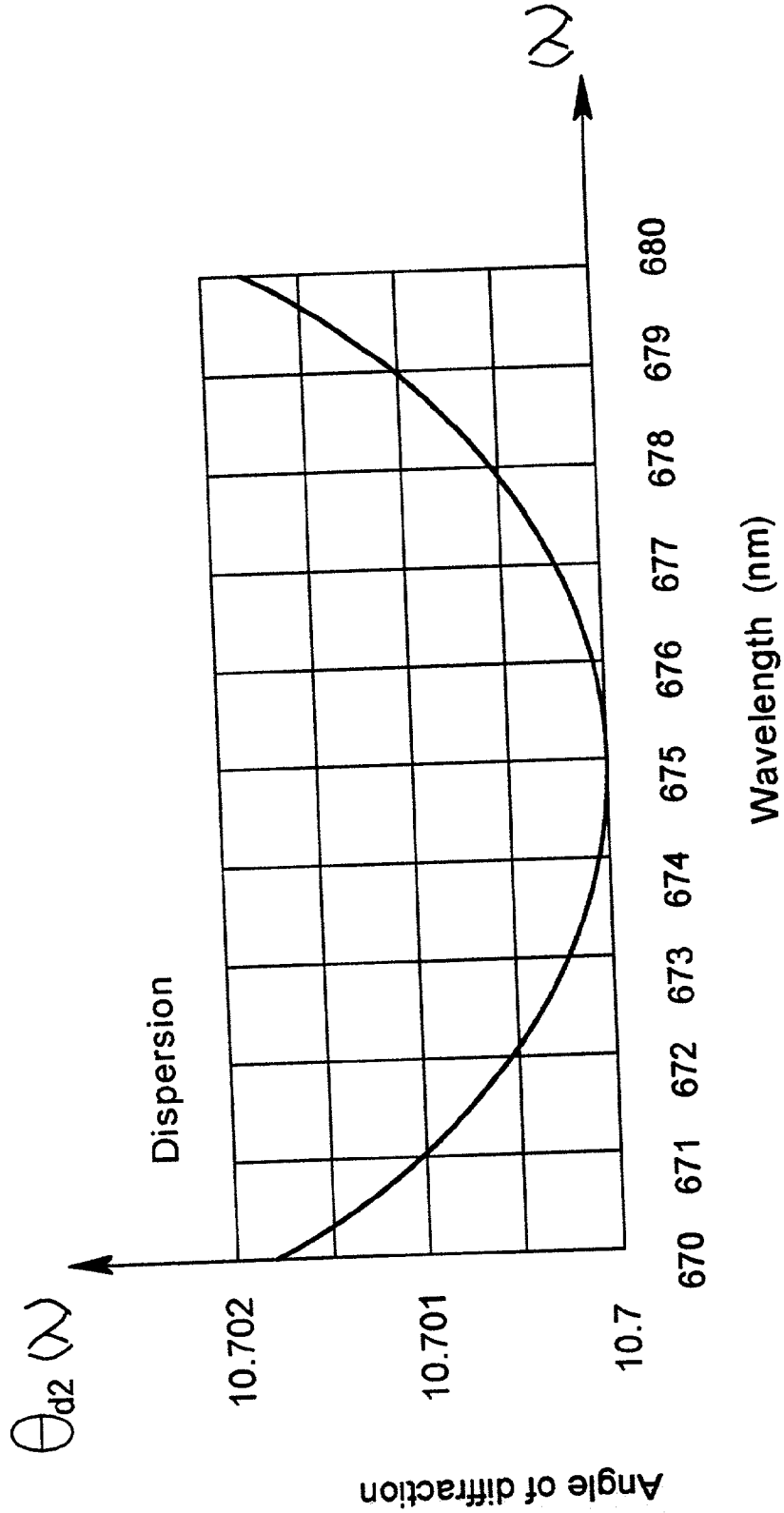

λ
Dispersion
$\theta_{d2}$ (λ)
10.702
10.701
10.7
Angle of diffraction
670 671 672 673 674 675 676 677 678 679 680
Wavelength (nm)

FIG. 5B3

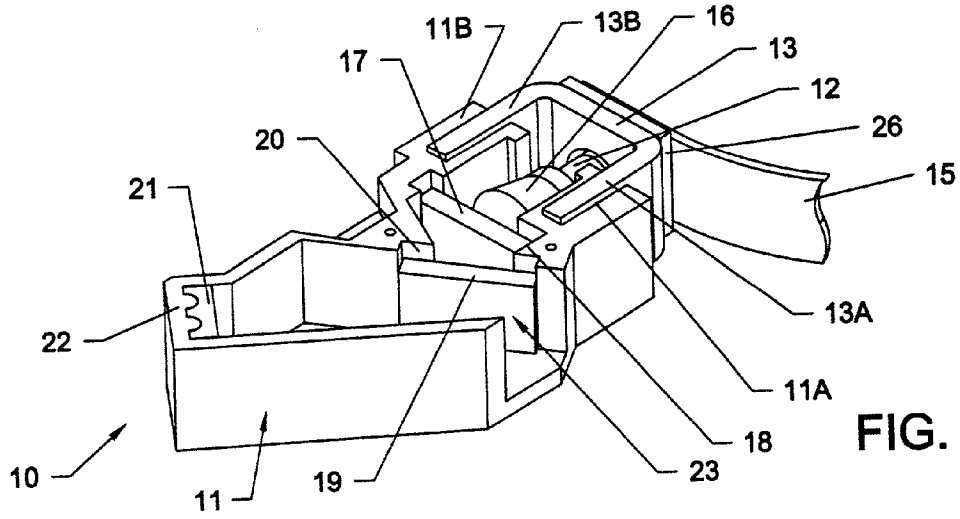



FIG. 6A

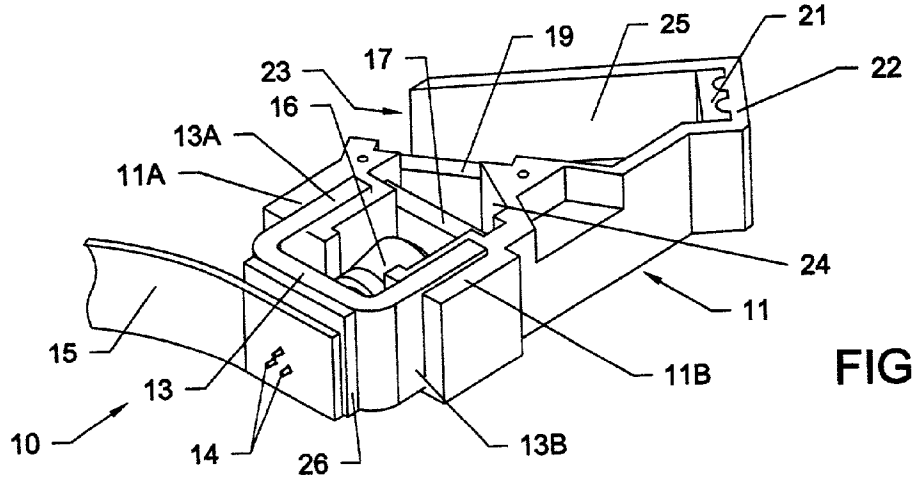



FIG. 6B

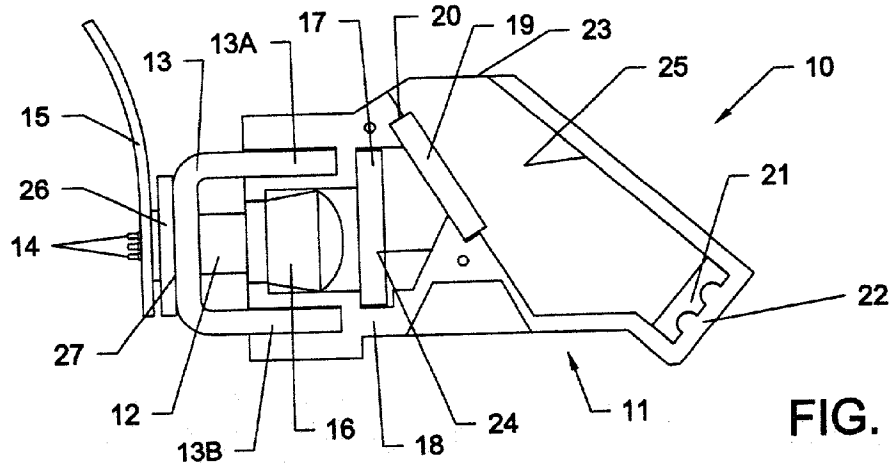



FIG. 6C

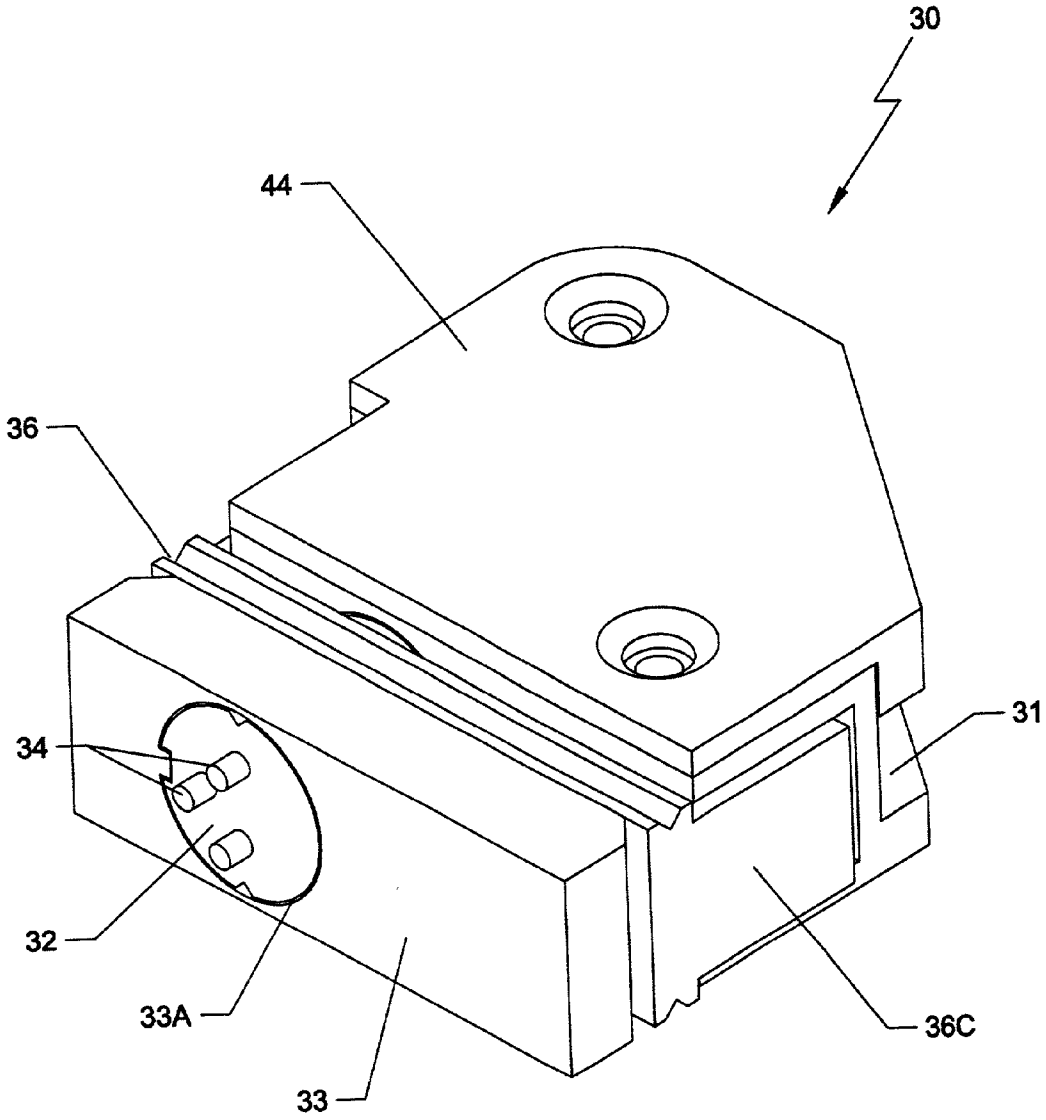



FIG. 7A

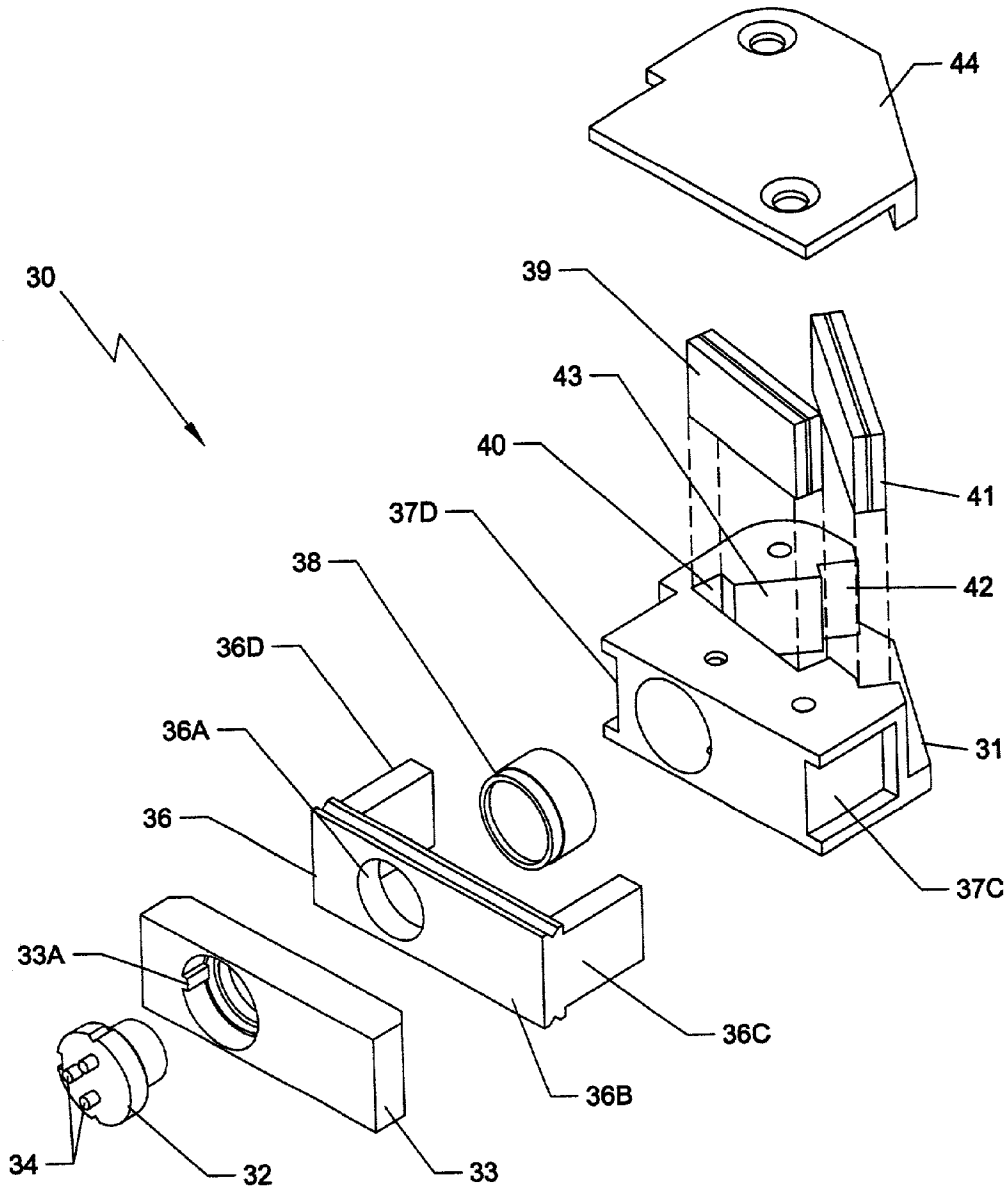



FIG. 7B

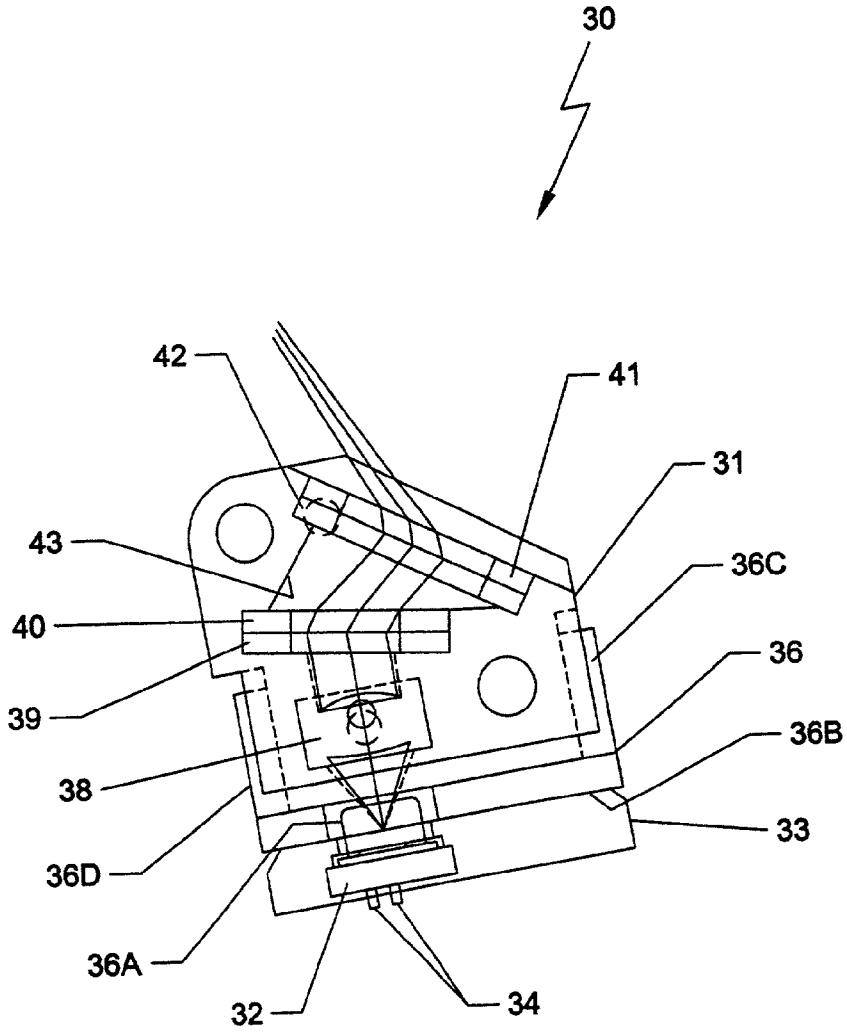



FIG. 7C

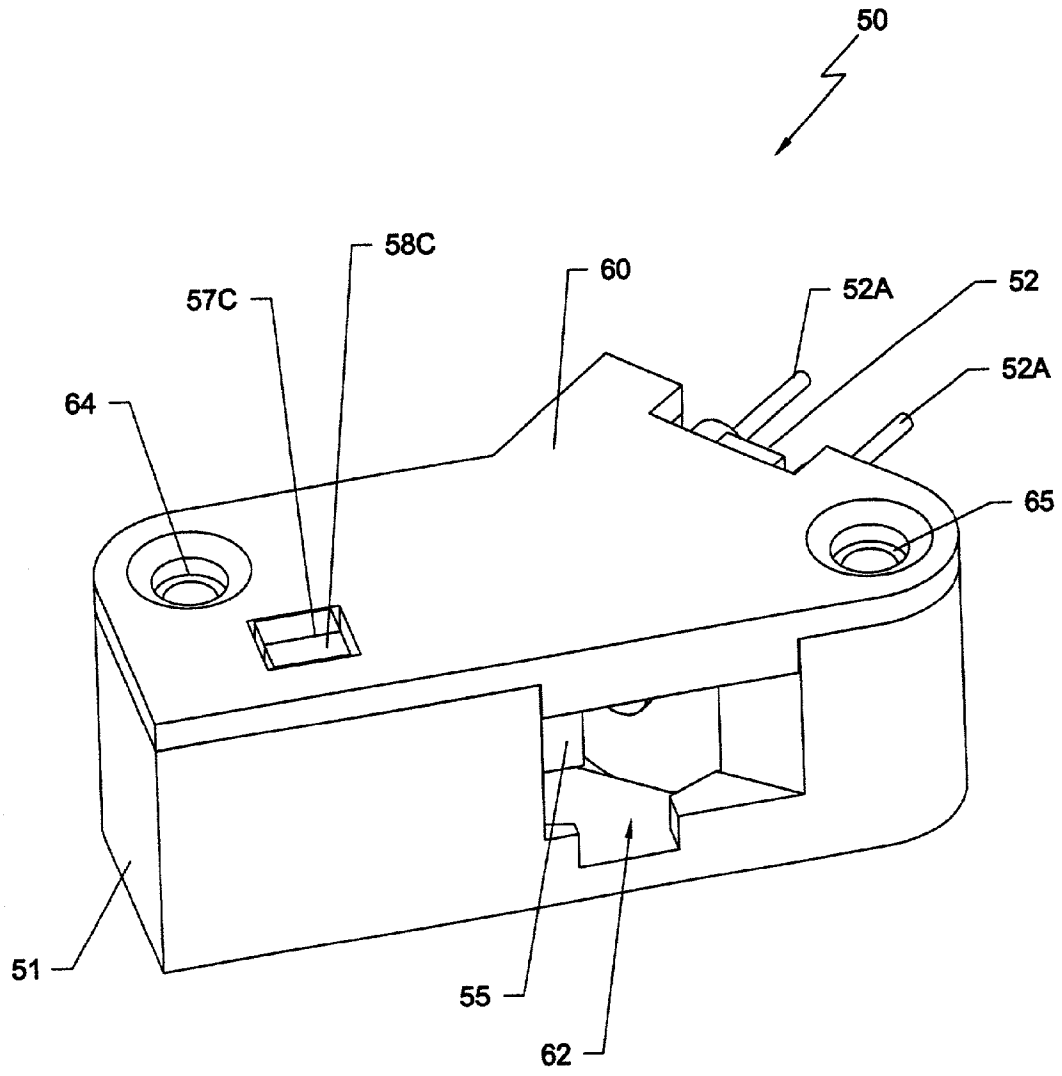



FIG. 8A

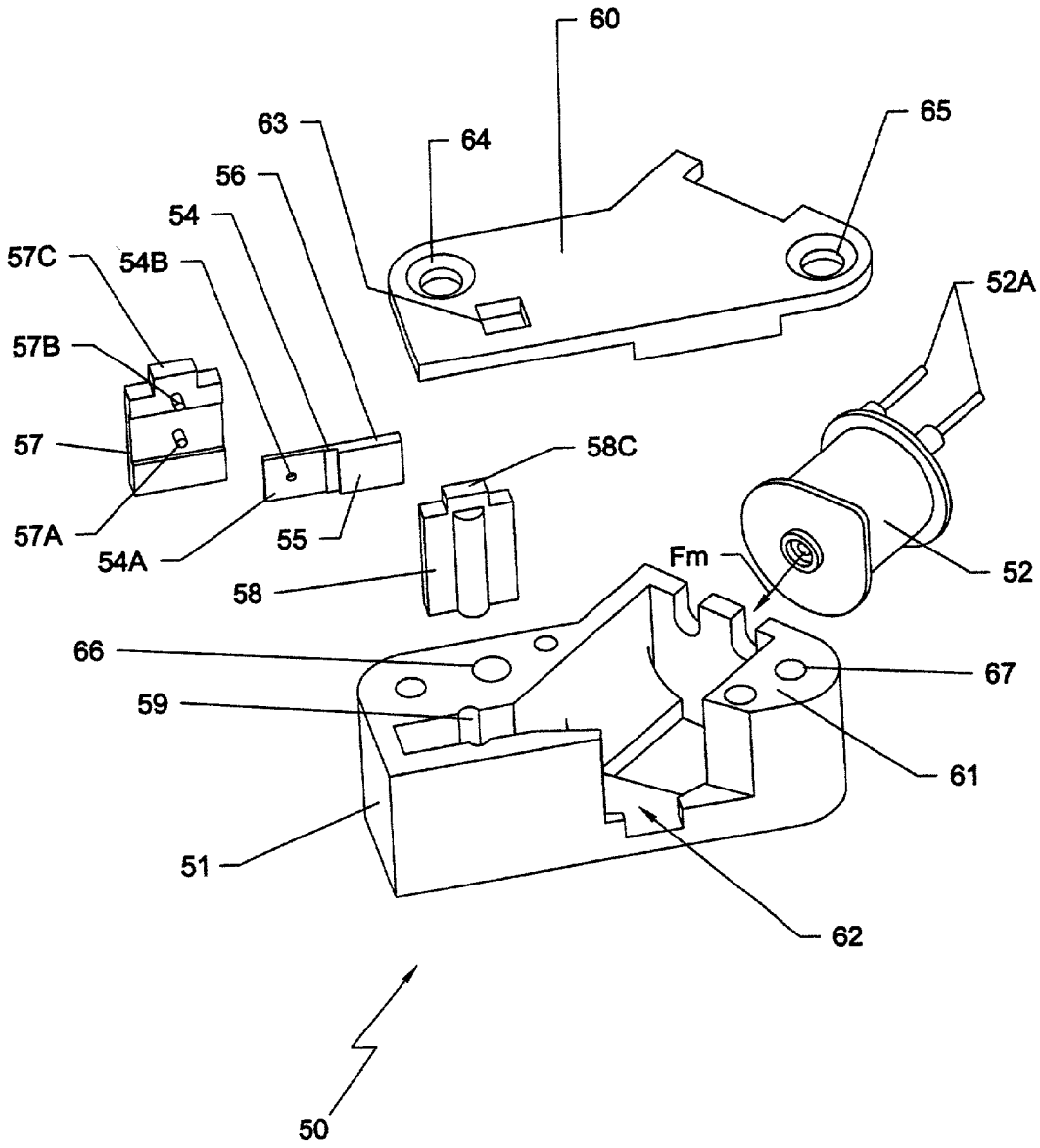

60
63
64
65
56
54
57C
54B
52A
57B
57
58C
57A
54A
55
Fm
52
58
66
67
59
61
51
62
50

FIG. 8B

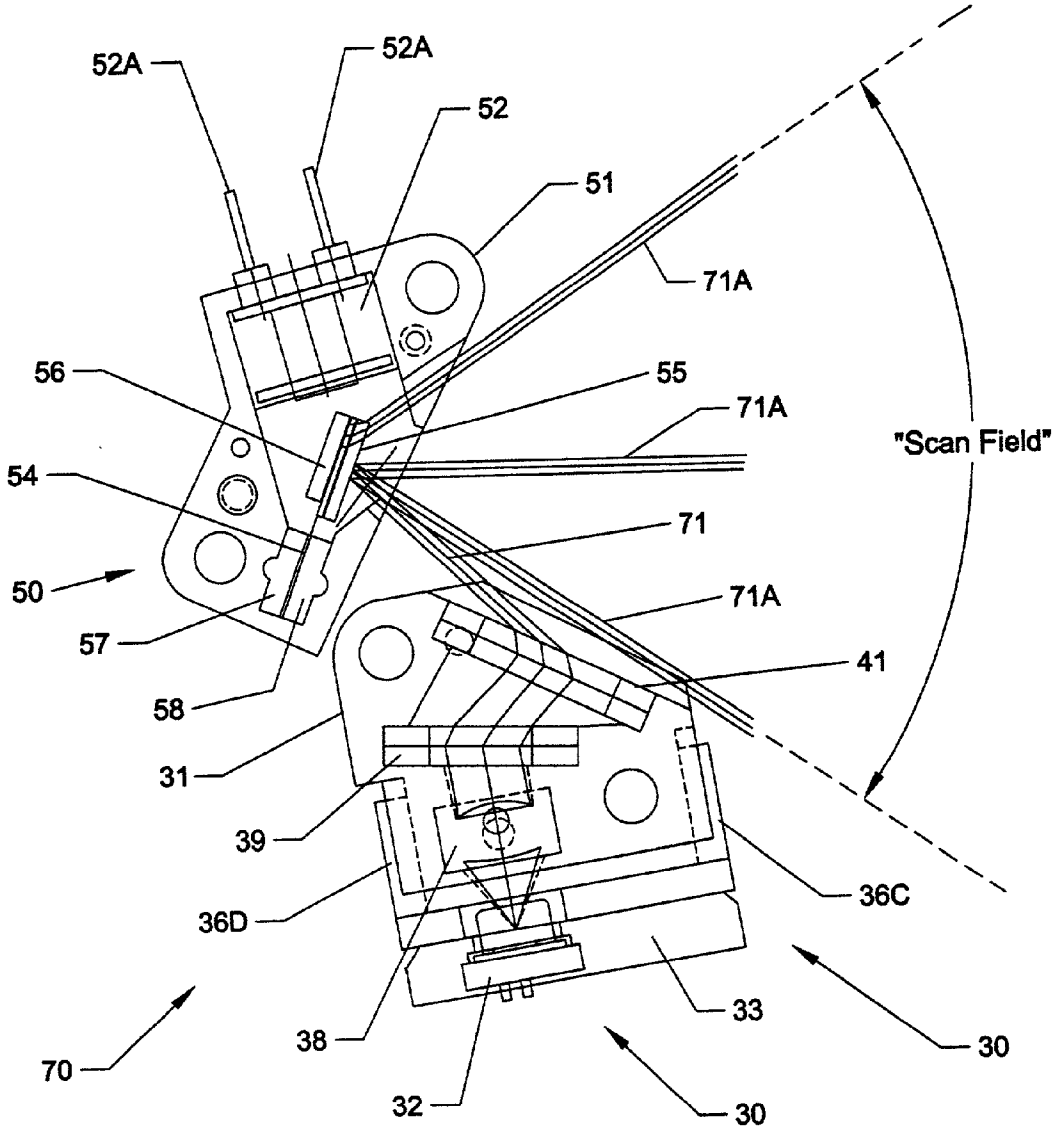

52A
52A
52
51
71A
56
55
71A
"Scan Field"
54
71
50
71A
57
41
58
31
39
36C
36D
33
38
30
70
32
30

FIG. 9

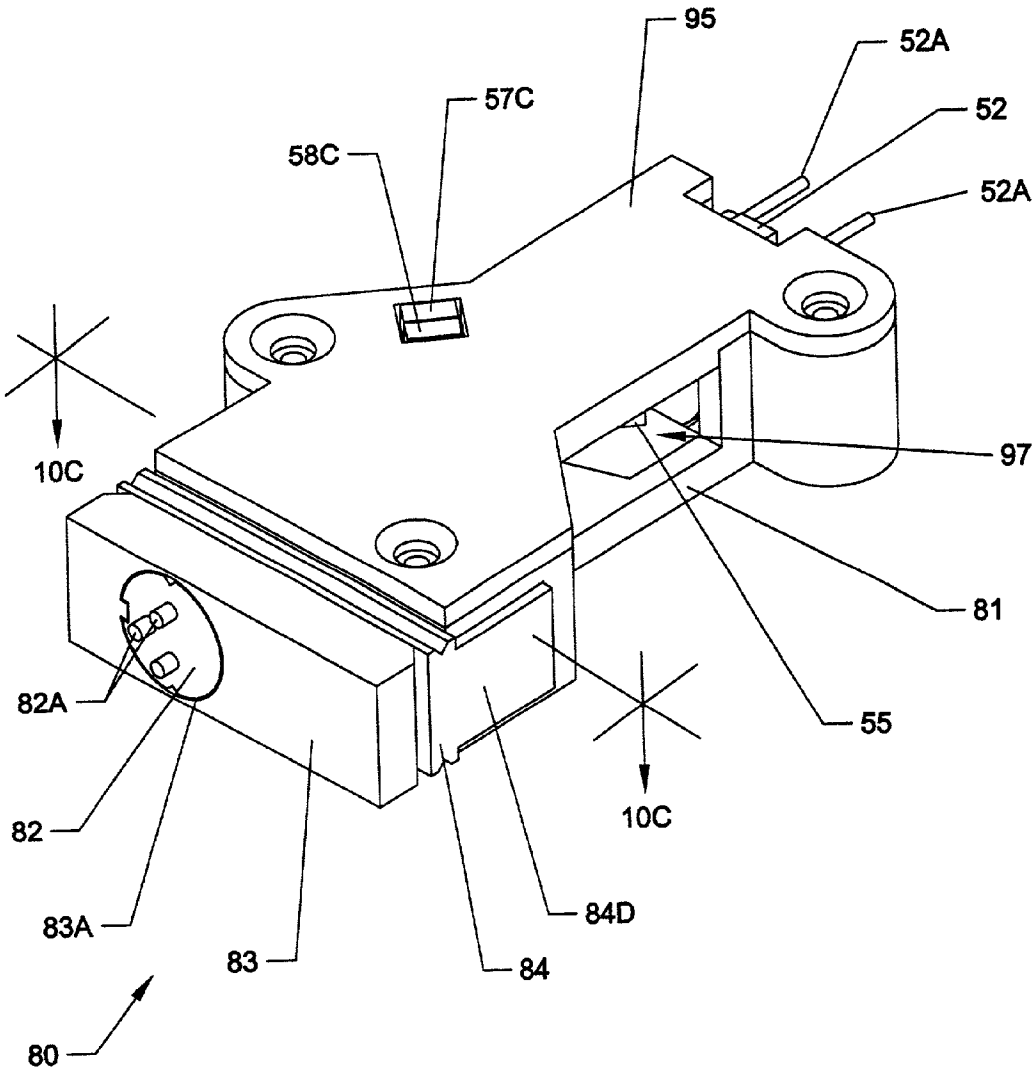



FIG. 10A

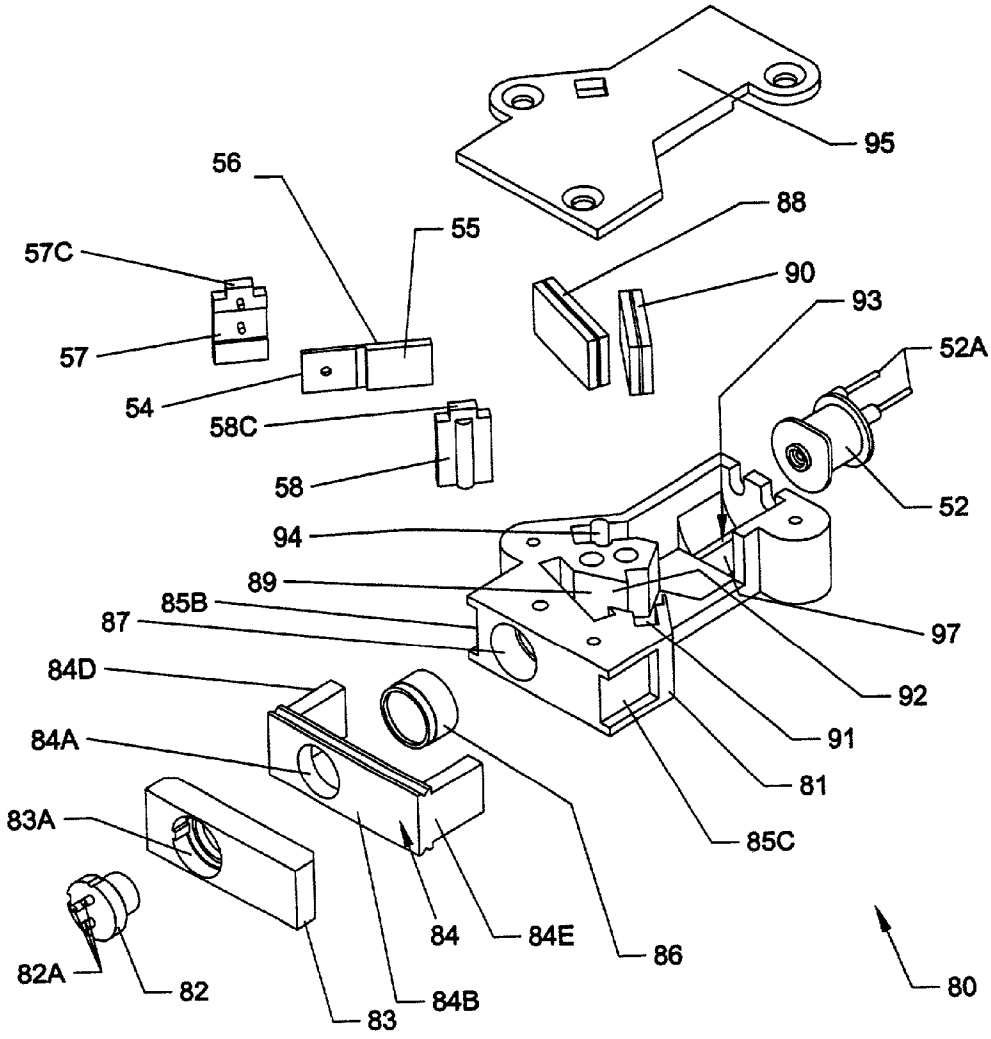

95
56
88
55
57C
90
93
57
52A
54
58C
52
58
94
89
85B
97
87
84D
92
84A
91
81
83A
85C
84
84E
86
82A
82
84B
83
80

FIG. 10B

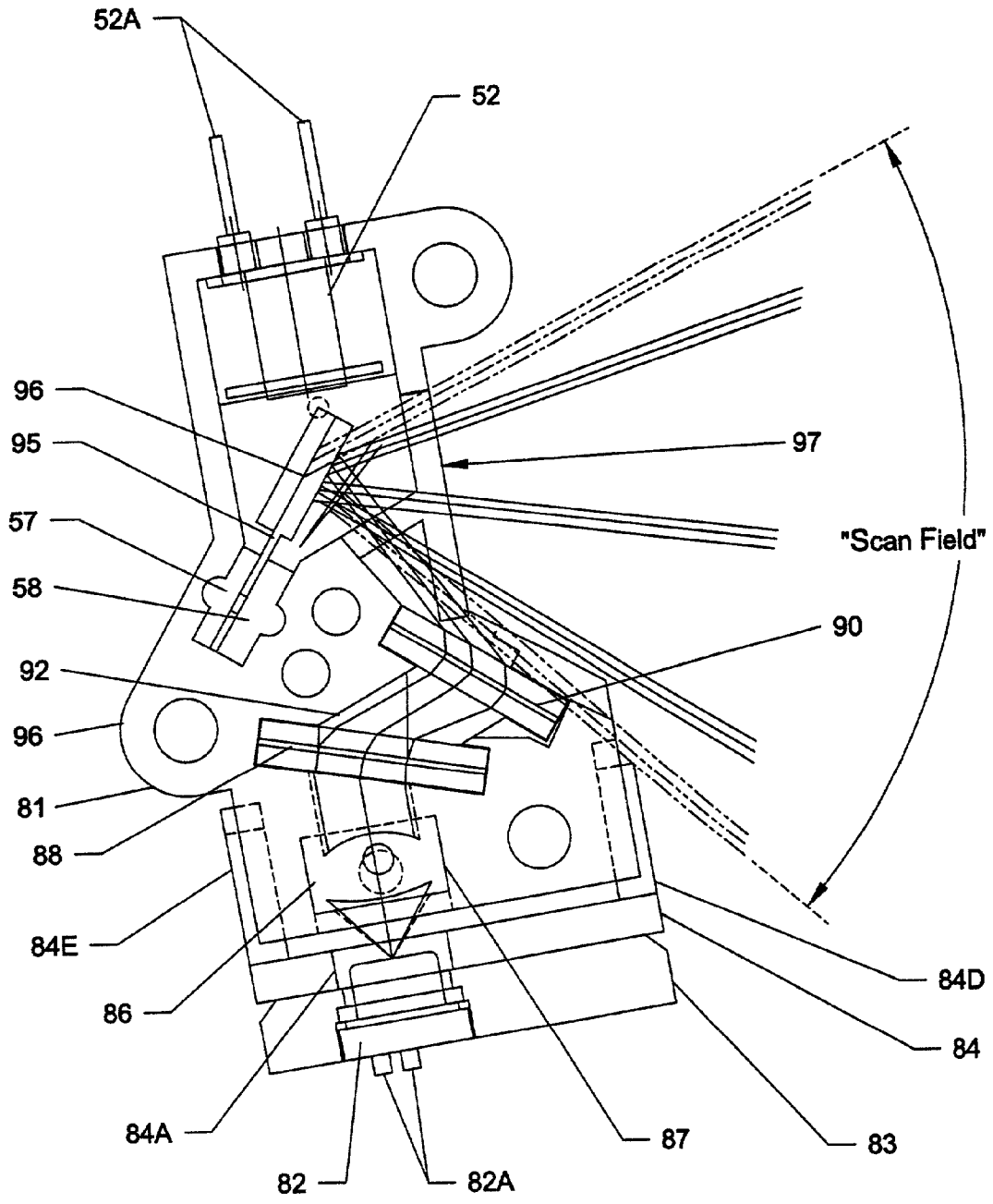

52A
52
96
95
57
58
92
96
81
88
84E
86
84A
82
82A
87
83
84
84D
97
"Scan Field"
90

FIG. 10C

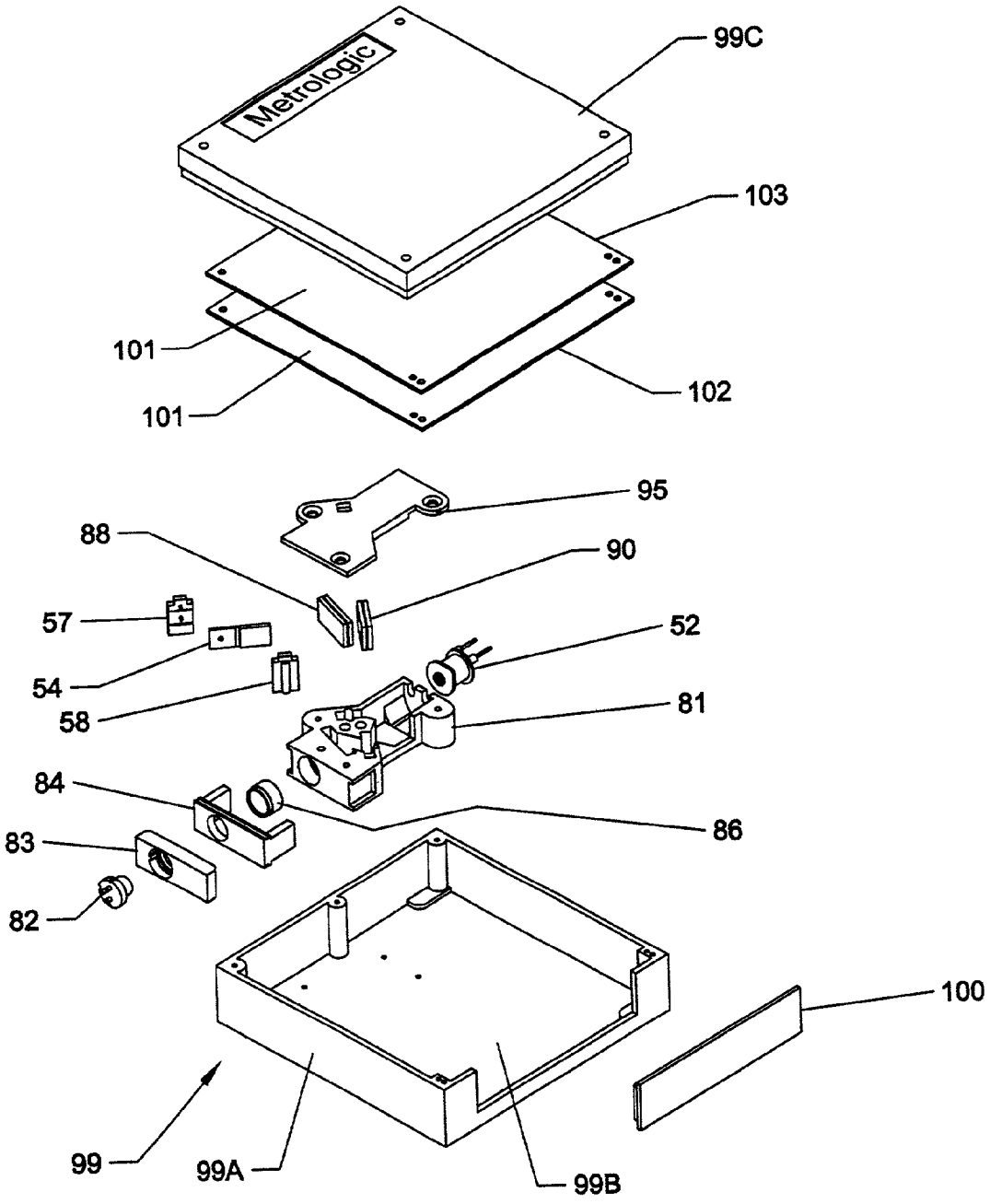

Metrologic
99C
103
101
101
102
95
88
90
57
52
54
81
58
84
86
83
82
100
99
99A
99B

FIG. 10D

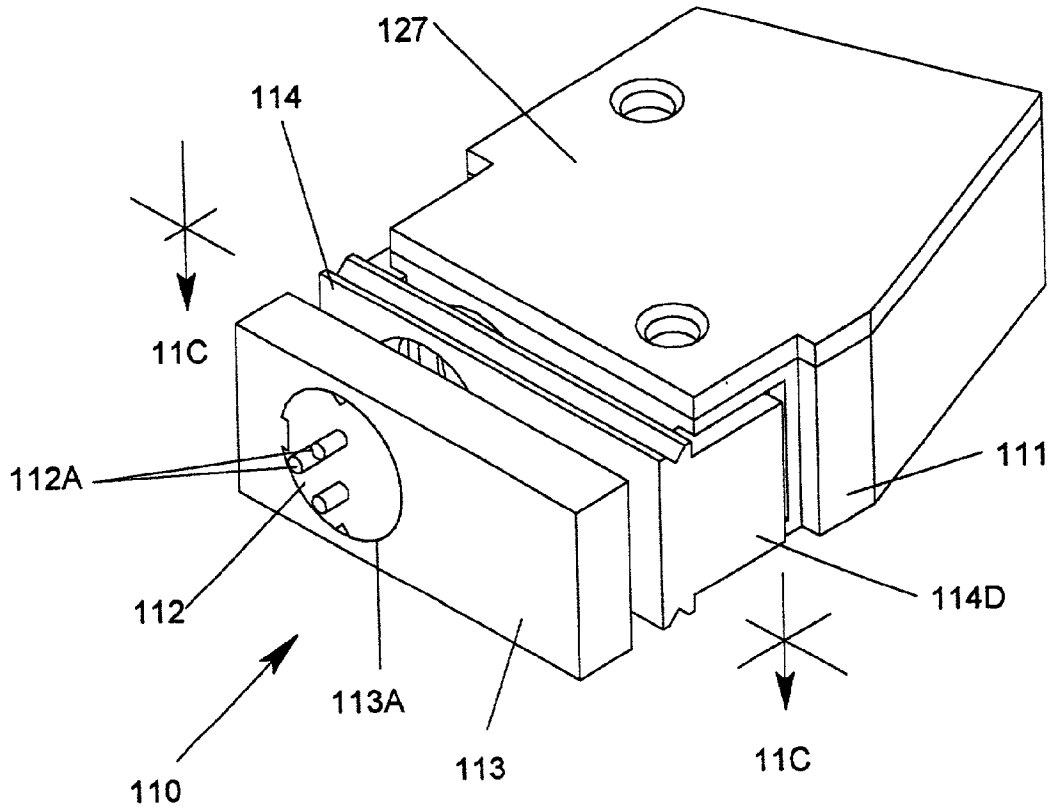



FIG. 11A

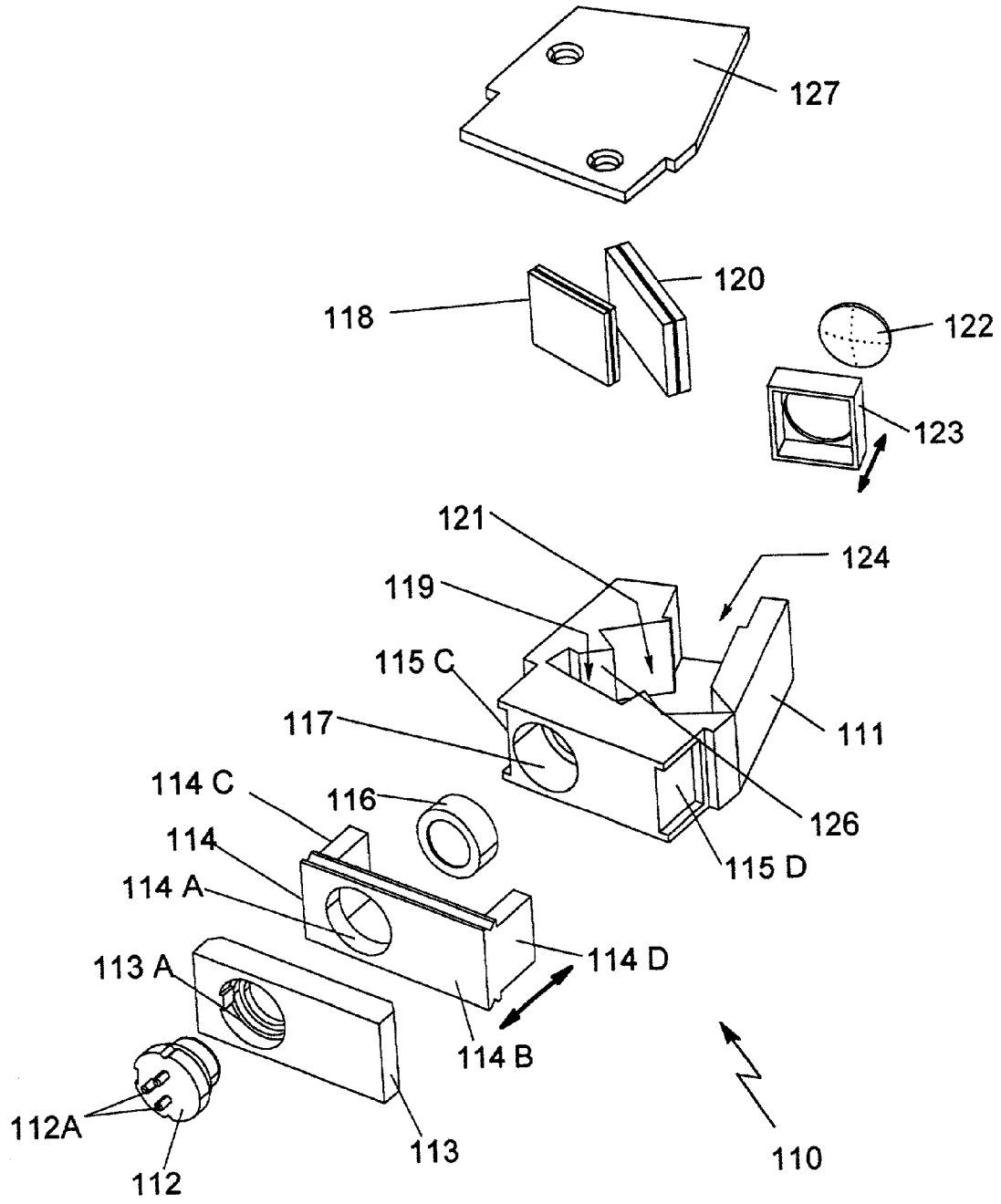

127
120
118
122
123
121
124
119
115 C
117
111
114 C
116
126
114
115 D
114 A
113 A
114 D
114 B
112A
113
110
112

FIG. 11B

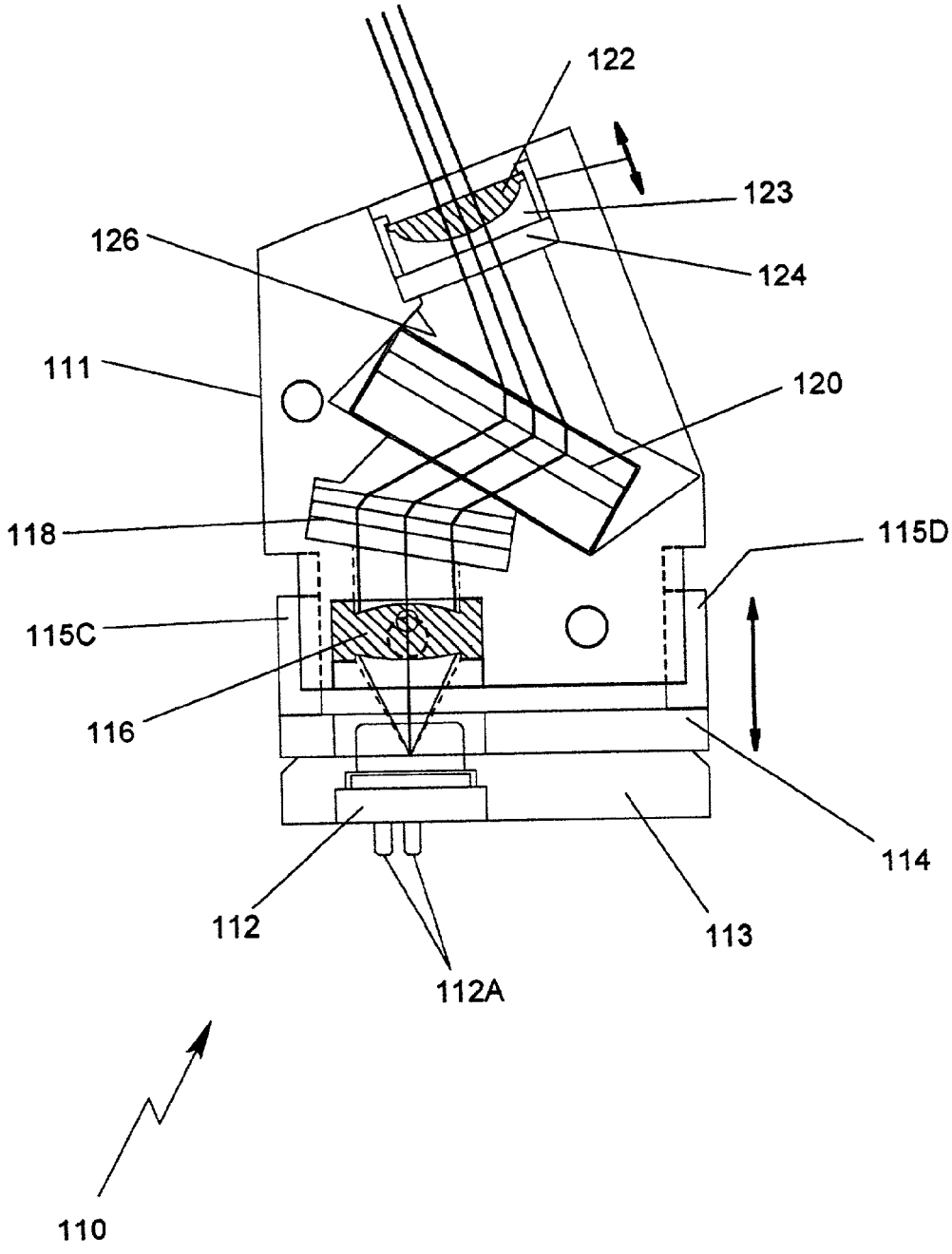



FIG. 11C

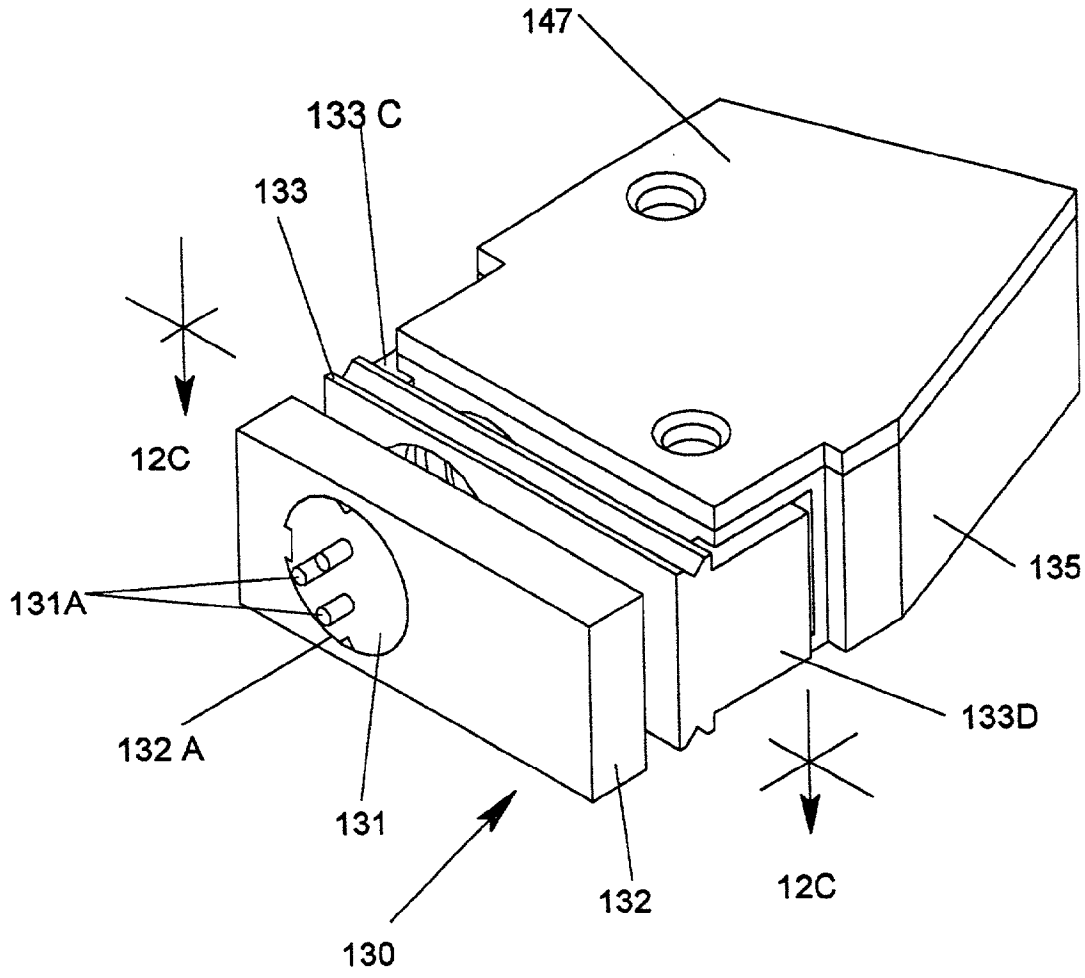



FIG. 12A

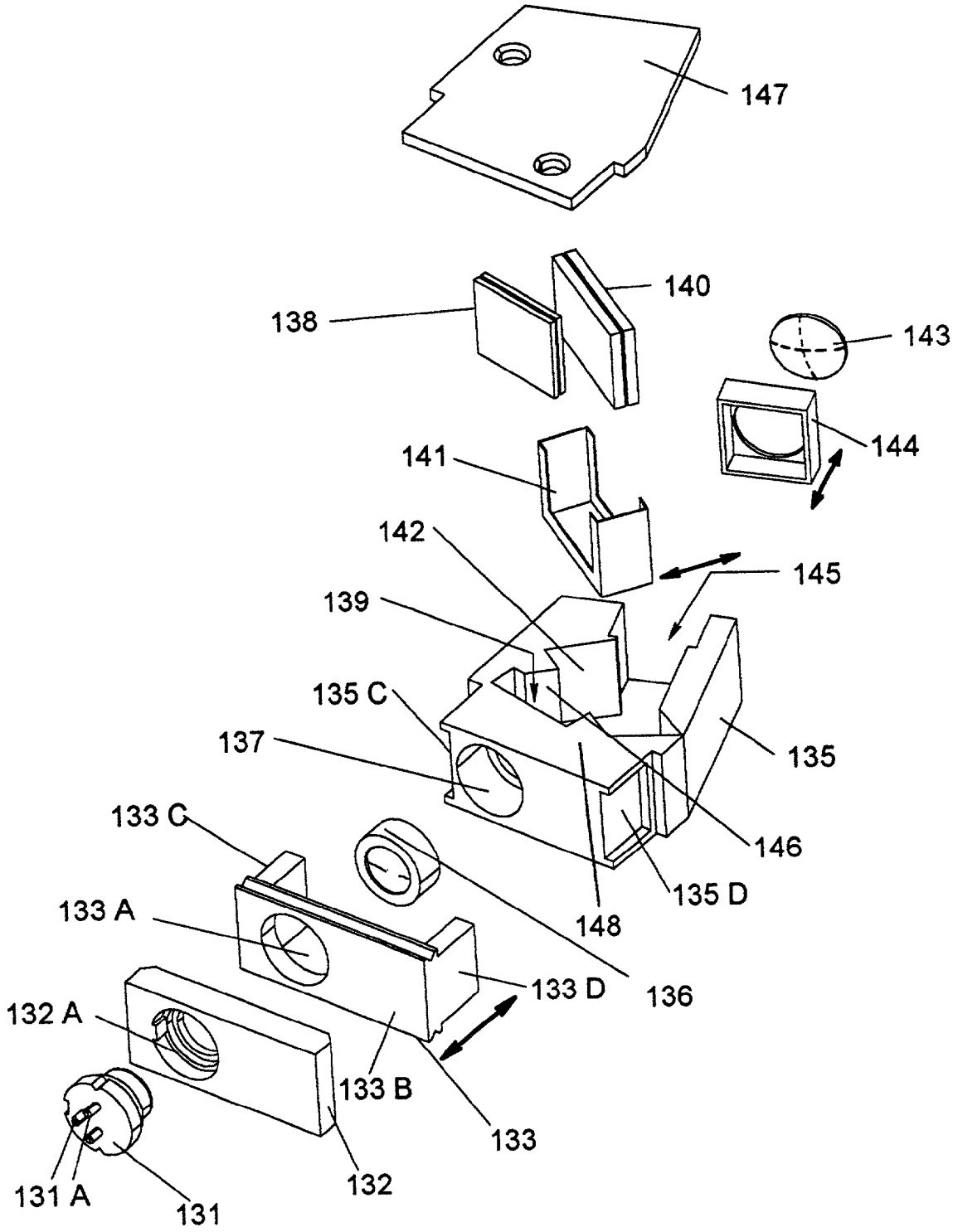

147
140
138
143
144
141
142
145
139
135 C
137
135
146
133 C
135 D
148
133 A
136
133 D
132 A
133 B
133
132
131 A
131

FIG. 12B

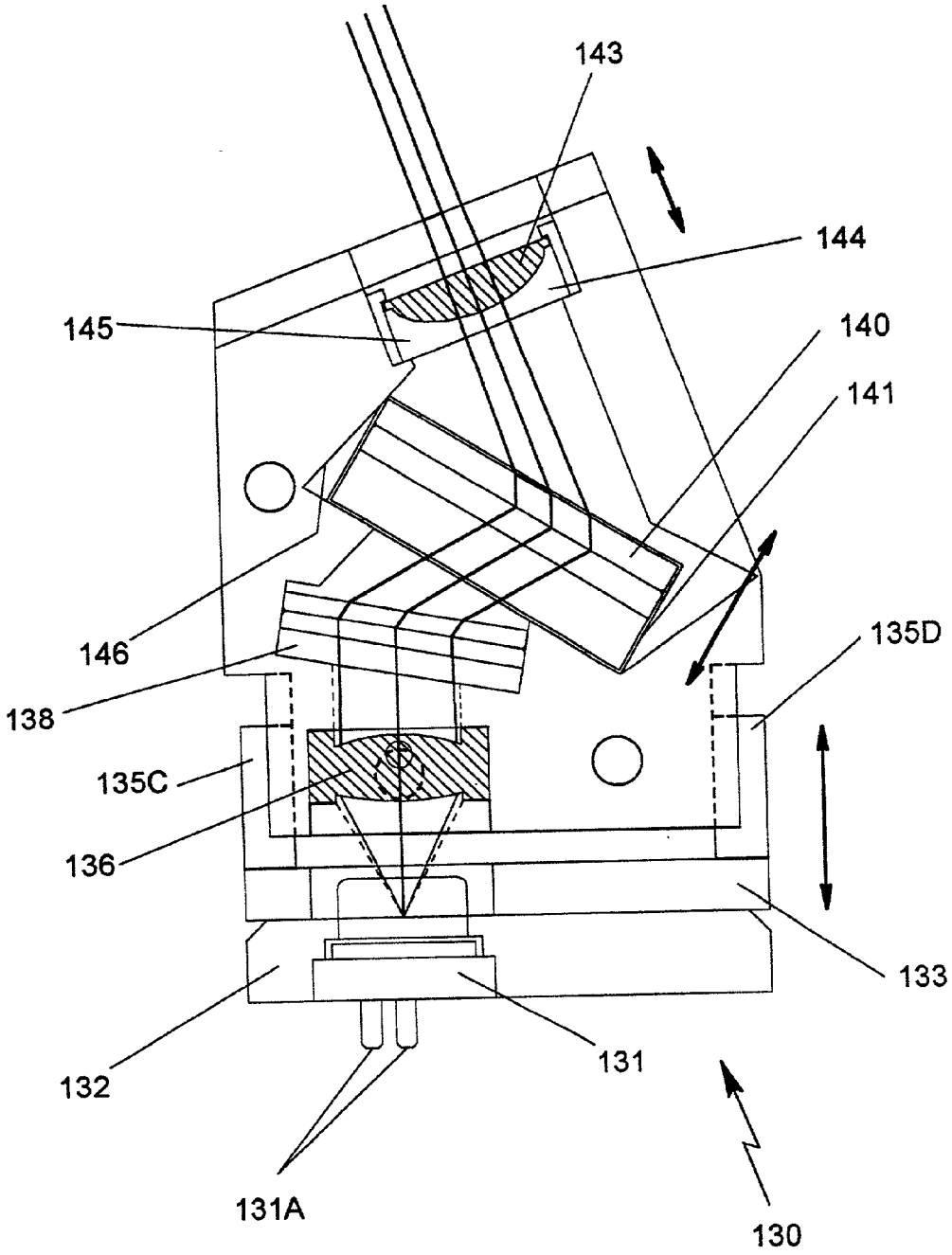



FIG. 12C

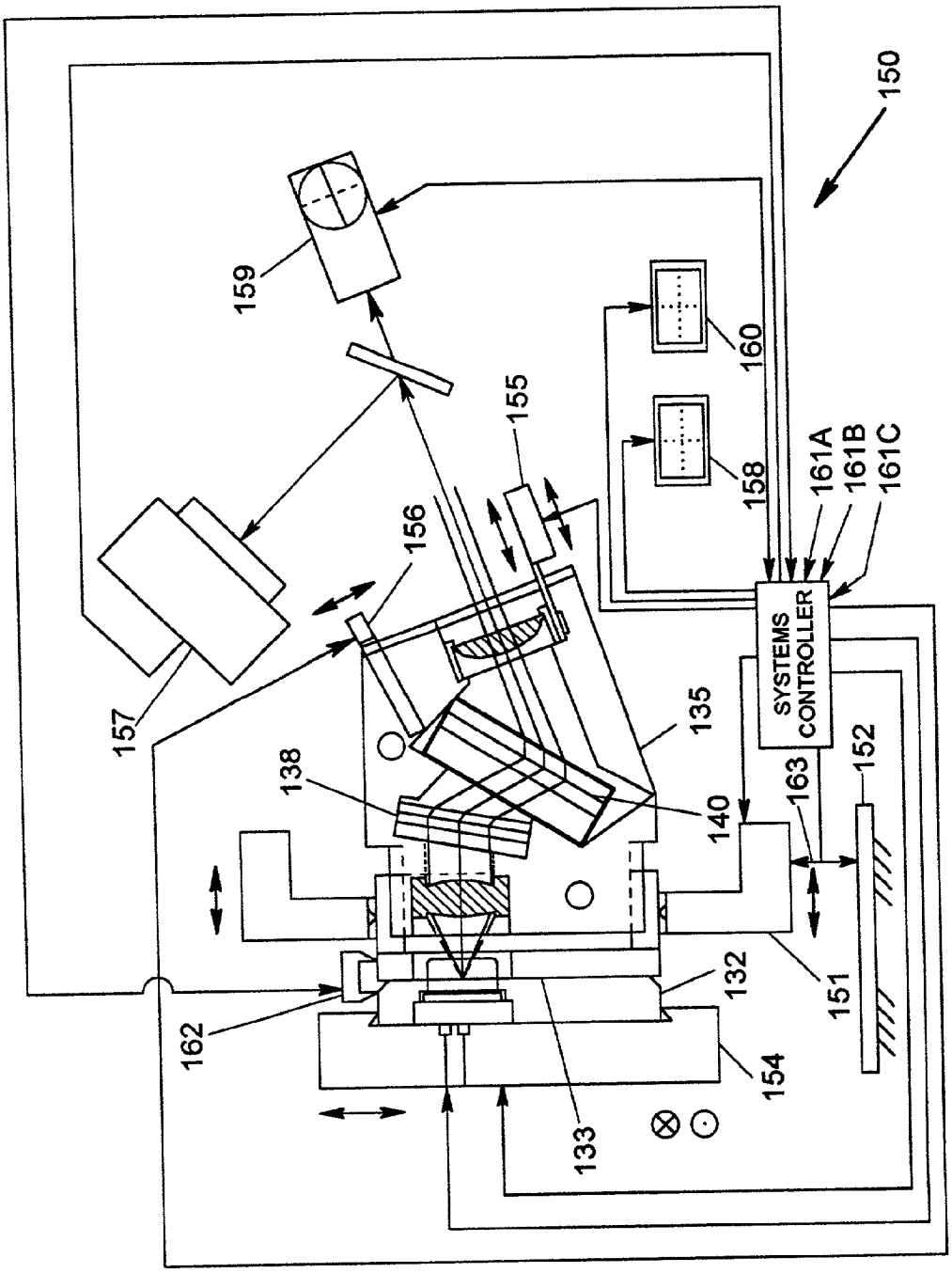

150
159
160
155
158
161A
161B
161C
156
157
SYSTEMS CONTROLLER
135
138
152
163
140
132
151
162
154
133

FIG. 13

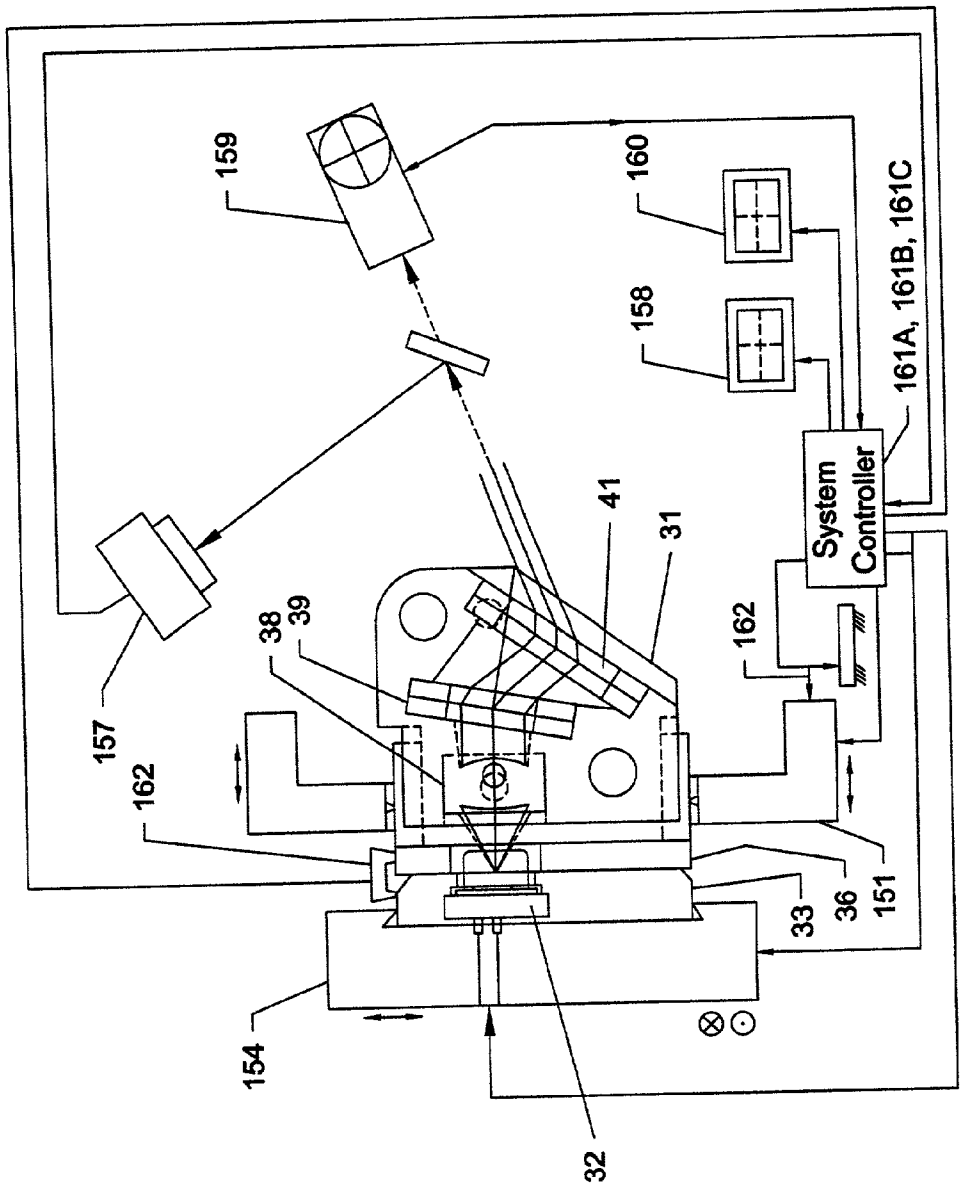

159
160
158
161A, 161B, 161C
System Controller
41
31
38
39
162
157
162
36
151
33
154
32

FIG. 14
(Case A)

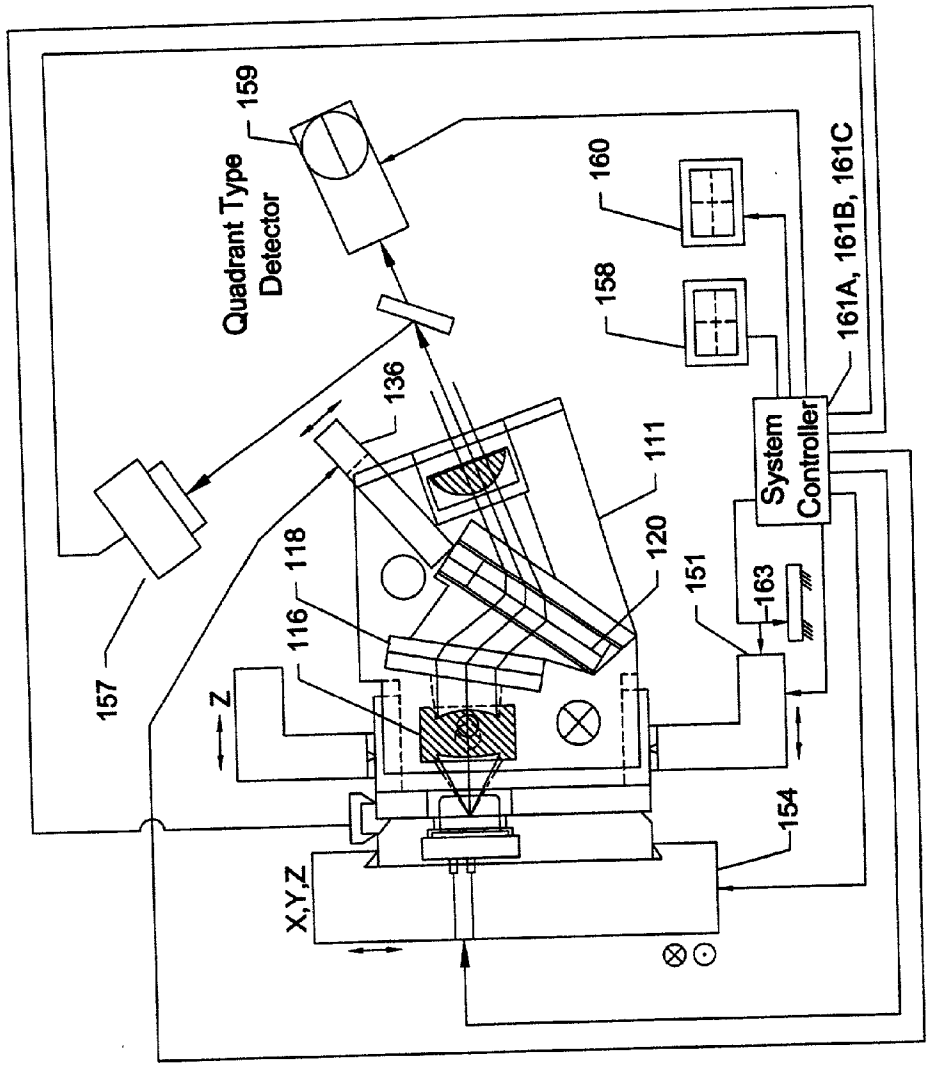

159
Quadrant Type Detector
160
158
161A, 161B, 161C
136
System Controller
111
120
118
151
163
116
157
Z
154
X,Y,Z

FIG. 15
(Case B)

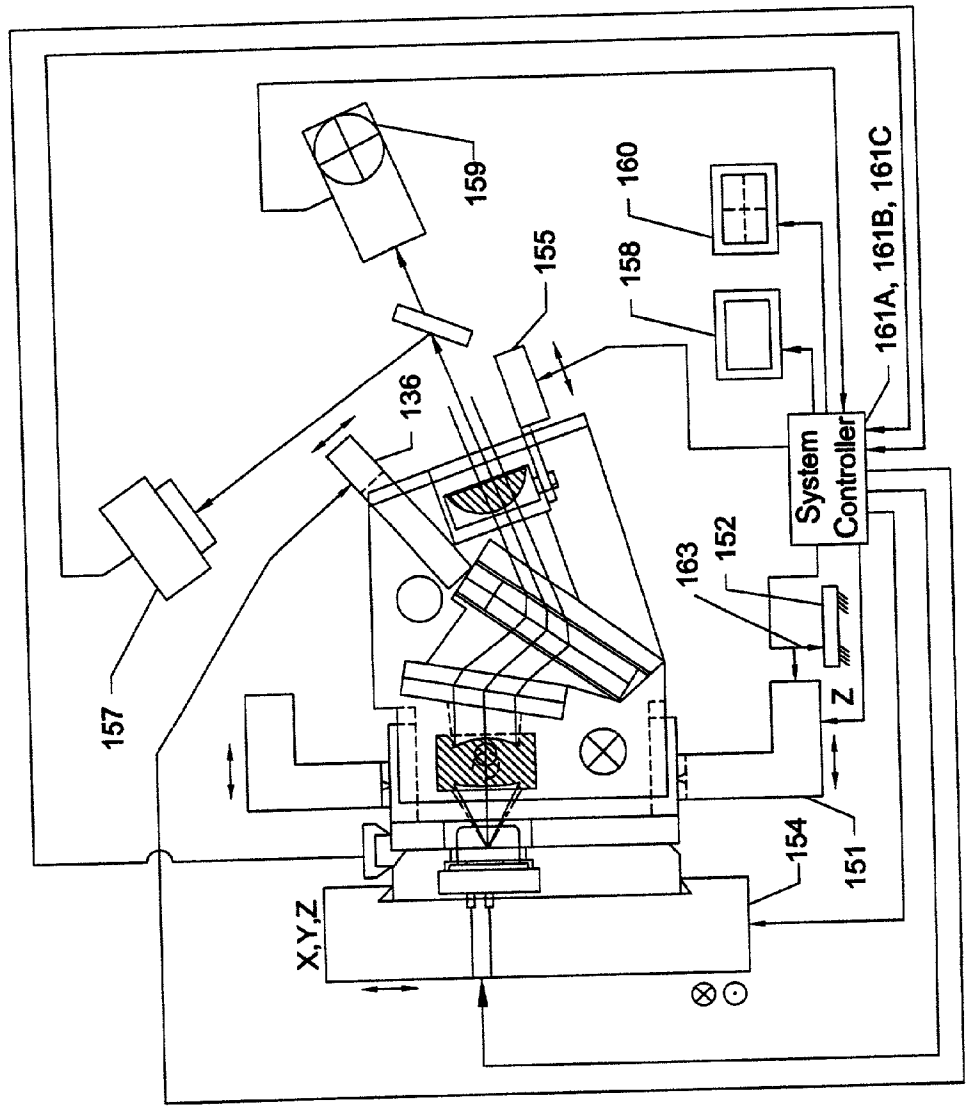

159
160
155
158
161A, 161B, 161C
136
System Controller
163
152
157
Z
154
151
X,Y,Z

FIG. 16
(Case C)

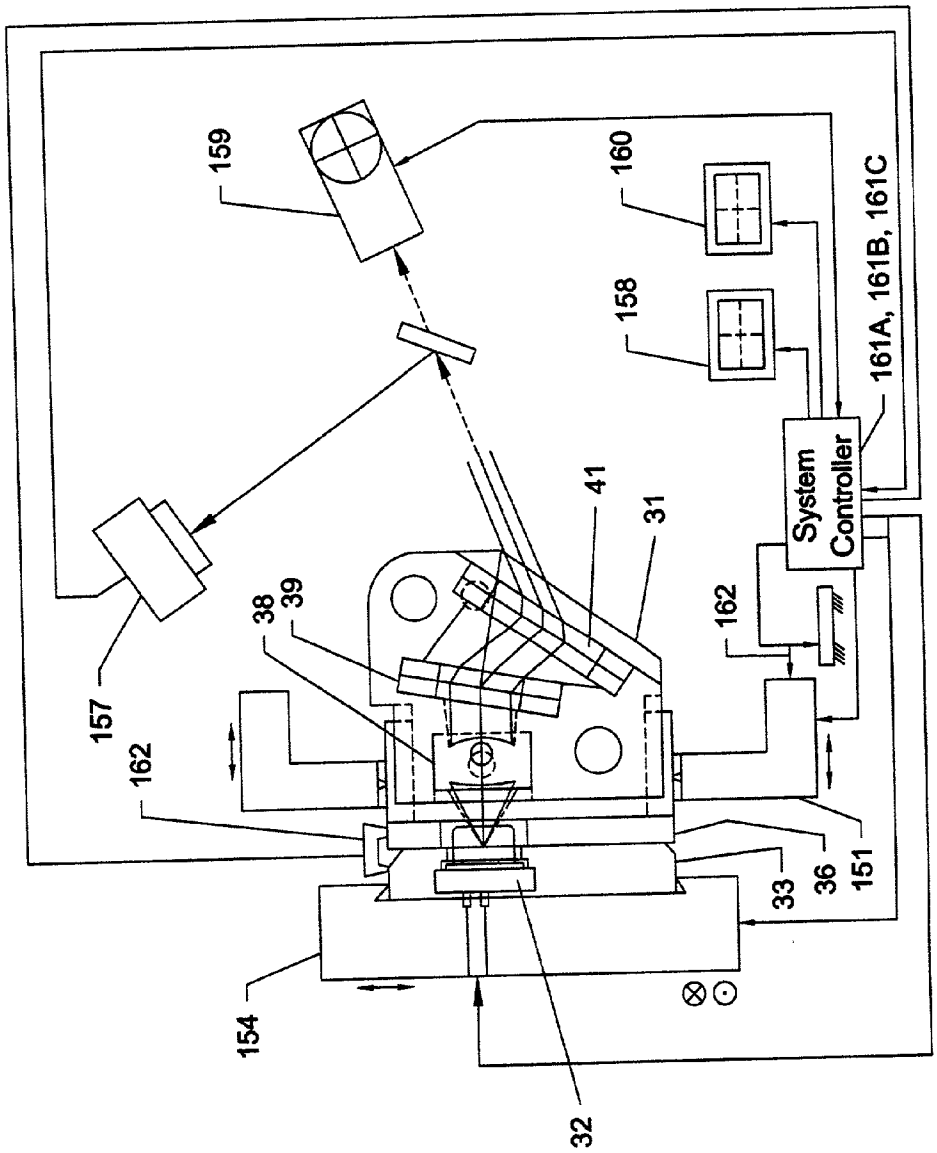

159
160
158
161A, 161B, 161C
System Controller
41
31
38
39
162
157
162
151
36
33
154
32

FIG. 17
(Case D)

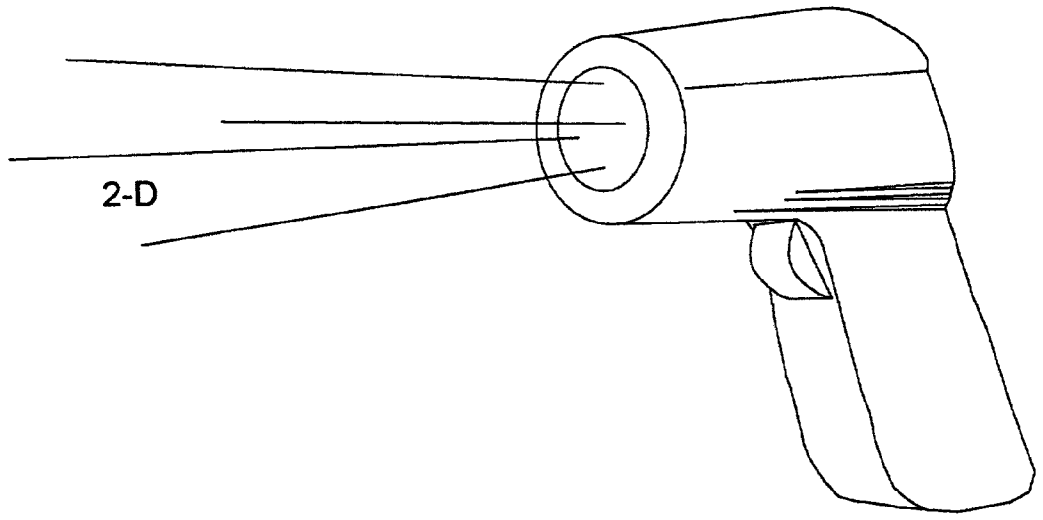



FIG. 18

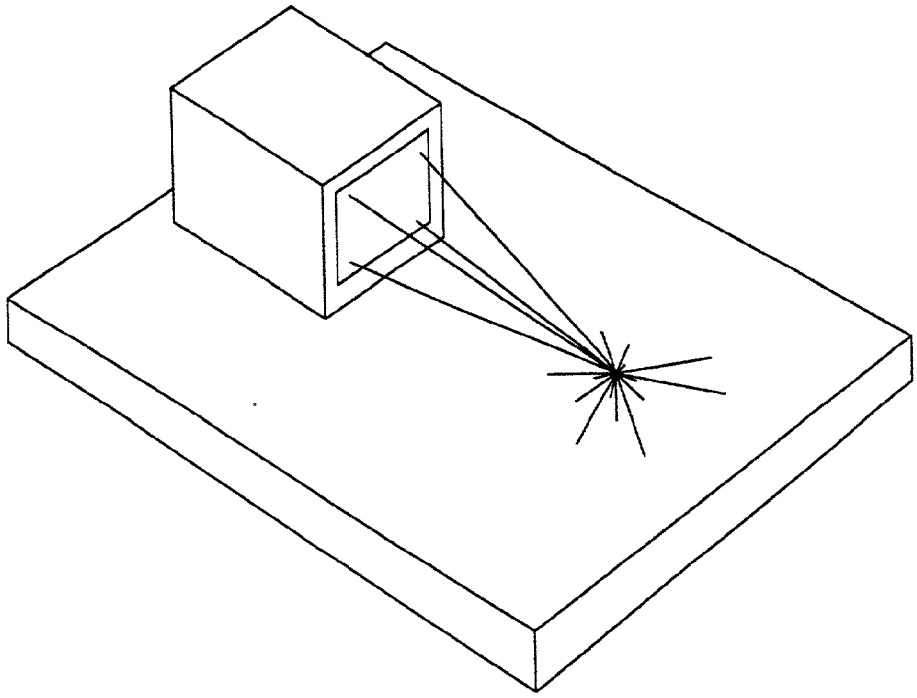


FIG. 19

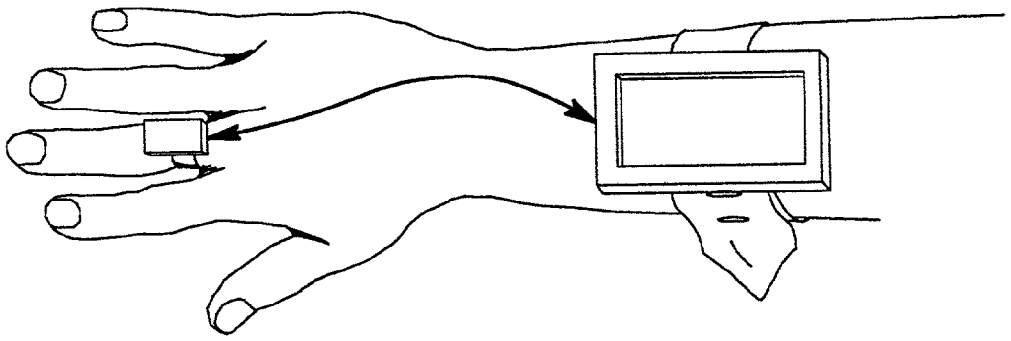


FIG. 20

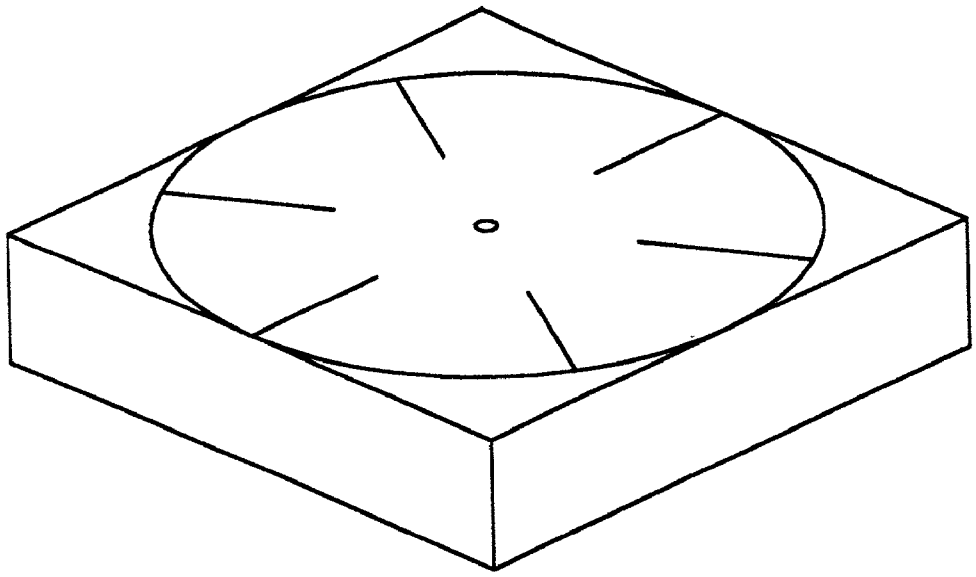


FIG. 21

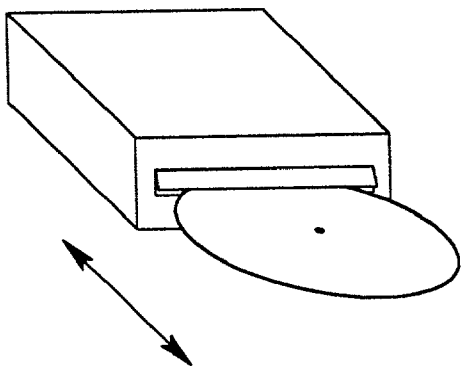


FIG. 22

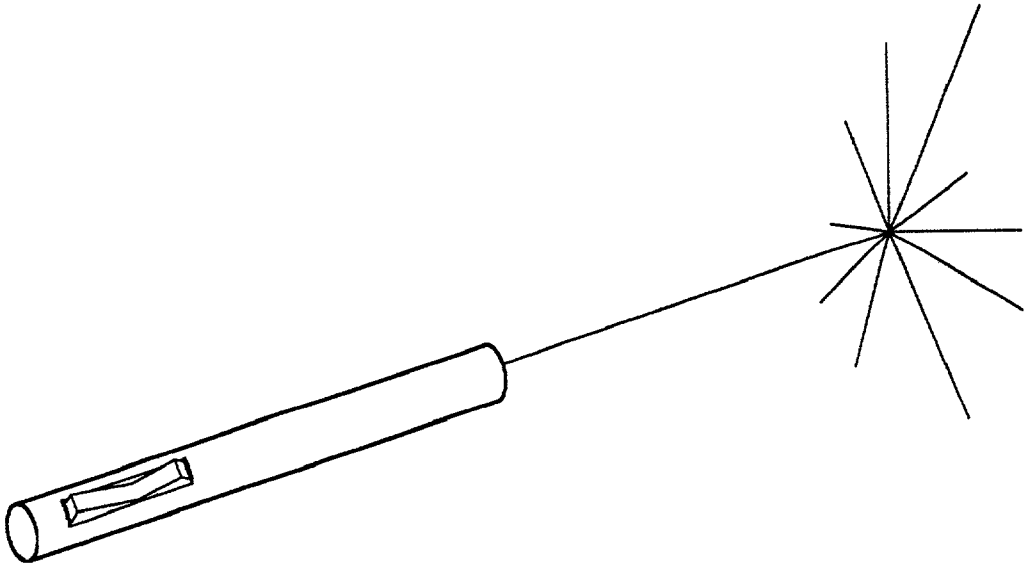


FIG. 23

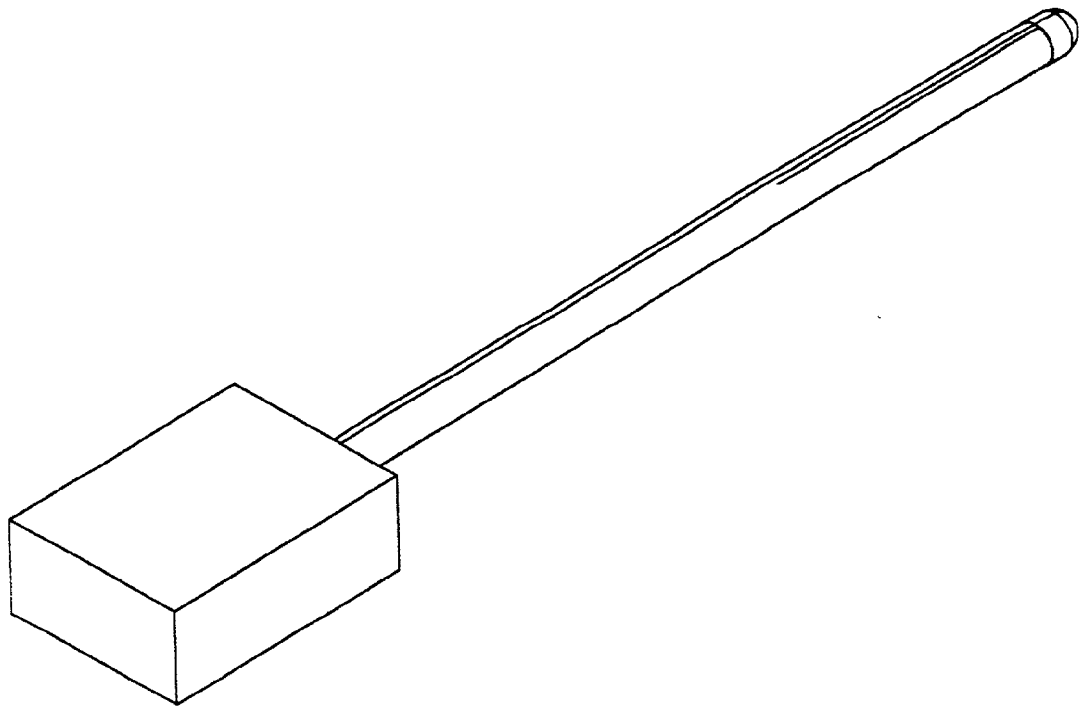


FIG. 24

# DOE-BASED SYSTEMS AND DEVICES FOR PRODUCING LASER BEAMS HAVING MODIFIED BEAM CHARACTERISTICS

[0001] The present Application relates to: copending application Ser. No. 09/071,512 filed May 1, 1998; copending application Ser. No. 08/573,949 filed Dec. 18, 1995; copending application Ser. No. 08/726,522 filed Oct. 7, 1995; copending application Ser. No. 08/886,806 filed Apr. 22, 1997; copending application Ser. No. 08/854,832 filed May 12, 1997; and copending application Ser. No. 08/949,915 filed Oct. 14, 1997; each said Application being commonly owned by Metrologic Instruments, Inc. of Blackwood, N.J. and incorporated herein by reference in its entirety.

## BACKGROUND OF THE INVENTION

[0002] 1. Field of Invention

[0003] The present invention relates generally to diffractive optical element (DOE) based optical systems of ultra-compact design capable of modifying the inherent elliptical, divergent, eccentric and astigmatic characteristics of laser beams produced from laser diode sources, such as visible laser diodes (VLDs).

[0004] 2. Brief Description of the Prior Art

[0005] Laser diodes or visible laser diodes (VLD) are often used as light sources in many scientific_and engineering applications. While laser diodes offer significant advantages over other laser sources, e.g. gas lasers, in terms of efficiency, size, and cost, they nevertheless suffer from several undesirable optical characteristics, namely: high beam divergence, elliptical beam profile, and astigmatism. In order to use laser diodes in many communication, data-storage, scanning, and imaging applications, these inherent deficiencies in laser diodes must be corrected.

[0006] While complex refractive-optics type systems (employing anamorphic lenses and the like) have been developed for the purpose of correcting for laser diode characteristics, such systems are generally bulky and expensive, and thus ill-suited for use in numerous applications.

[0007] U.S. Pat. Nos. 5,247,162 and B1 4,816,660 disclose the use of a lens and aperture-stop to shape the laser beam produced from a VLD for use in laser scanners. While this technique provides an inexpensive way of shaping the cross-section of a VLD laser beam, it does so at the expense of a substantial loss in beam power. Moreover, this "pin-hole" technique is incapable of correcting for astigmatism in laser beams produced by VLDs.

[0008] In recent years, alternative approaches to VLD beam shaping and correction have been developed. Such alternative techniques include, for example, the use of: integrated-optics lenses; computer-generated hologram (CGH) gratings; micro-Fresnel lenses; waveguide optics; and holographic optical elements (HOEs).

[0009] The use of HOEs for beam collimation, shaping/profiling and astigmatism-correction has received great attention, as such devices can be made inexpensively and small in size to be used in CD-ROM players, consumer-products and analytical instruments employing VLDs and the like. Examples of prior art laser diode beam-correction techniques employing HOEs are disclosed in the following journal articles: "Efficient Beam-Correcting Holographic Collimator For Laser Diodes" by A. Aharoni, et al., published in Vol. 17, No. 18, OPTICS LETTERS, Sep. 15, 1992, at pages 1310-1312; "Beam-Correcting Holographic Doublet For Focusing Multimode Laser Diodes" by A. Aharoni, et al. published in Vol. 18, No. 3, OPTICS LETTERS, Feb. 1, 1993, at pages 179-181; and "Design of An Optical Pickup Using Double Holographic Lenses" by Hiroyasu Yoshikawa, et al., published in SPIE, Vol. 2652, 1996, at pages 334-340.

[0010] While the above-cited prior art publications disclose dual-HOE optics systems for beam-collimation, beam-shaping and astigmatism correction, such prior art design methods do not enable the design and construction of laser beams having any degree of astigmatism, focal-distance, spot-size, focused-spot aspect-ratio, and zero dispersion. These are critical requirements in many laser scanning bar code reading applications.

[0011] Prior art HOE-based systems do not address the fact that commercial VLDs suffer from beam eccentricity (i.e. poor beam pointing characteristics). Consequently, it has not been possible to successfully carry out many design objectives by virtue of the fact that assumptions made during system design are not satisfied during design realization.

[0012] Accordingly, there is a great need in the art for an improved method of designing and constructing optical systems for modifying the elliptical, divergent, eccentric and astigmatic characteristics of laser beams inherently produced from commercial-grade laser diodes, while avoiding the shortcomings and drawbacks of prior art systems, devices, and methodologies.

## OBJECTS AND SUMMARY OF THE PRESENT INVENTION

[0013] Thus, it is a primary object of the present invention to provide an improved method of designing optical systems for modifying the inherent elliptical, divergent, eccentric and astigmatic characteristics of a laser diodes, while avoiding the shortcomings and drawbacks of prior art systems, devices, and methodologies.

[0014] Another object of the present invention is to provide a novel laser beam modification system employing a plurality of diffractive optical elements (DOEs) for modifying the size and shape of a laser beam produced from a commercial-grade laser diode, such as a VLD, over an extended range which has hitherto been impossible to achieve using conventional techniques, while avoiding the introduction of dispersion in the output laser beam which is commonly associated with prior art HOE doublets and the like.

[0015] Another object of the present invention is to provide such a DOE-based laser beam modifying system, wherein the inherent astigmatism characteristics associated with a VLD are eliminated or minimized.

[0016] Another object of the present invention is to provide a DOE-based laser beam modifying system, wherein beam dispersion is minimized, or normal dispersion or reverse dispersion characteristics are provided for any given beam compression or expansion ratio, by selecting the proper angle between the two DOEs of the system.

[0017] Another object of the present invention is to provide a DOE-based laser beam modifying system, wherein beam dispersion is minimized for the system acting alone, or fine-tuned to compensate for the dispersion of other elements preceding it or following the system.

[0018] Another object of the present invention is to provide a laser beam modifying system capable of producing a laser beam having a desired spot-size over a specified depth of field, achieved by focusing the laser beam with a lens (or variable DOE of a selected type), and then reshaping the laser beam using a pair of DOEs.

[0019] Another object of the present invention is to provide a laser beam producing system employing a set of beam-modifying DOEs which produce zero dispersion while simultaneously providing any desired aspect-ratio for the beam leaving (exiting) the second DOE.

[0020] Another object of the present invention it to provide a HOE-based laser beam modifying system adapted for use in a broad range of applications employing VLDs, which includes, but is not limited to, laser scanning applications.

[0021] Another object of the present invention it to provide a CGH-based laser beam modifying system adapted for use in a broad range of applications employing VLDs, which includes, but is not limited to, laser scanning applications.

[0022] Another object of the present invention is to provide an ultra-compact DOE-based device capable of collimating or focusing laser beams produced from astigmatic VLDs while minimizing dispersion beam dispersion and correcting for beam ellipticity.

[0023] A further object of the present invention is to provide an ultra-compact optics module for modifying the aspect-ratio of laser beams produced by VLDs, while eliminating beam astigmatism introduced by virtue of the inherent astigmatic difference in the VLD, and minimizing dispersion in the output laser beam created by wavelength-dependent variations in the spectral output of the VLD, such as superluminescence, multi-mode lasing, and laser mode hopping.

[0024] Another object of the present invention is to provide a novel optical-bench module which enables easy mounting and alignment of selected components of the laser beam producing systems of the present invention so that the inherently elliptical beam produced from commercial VLDs is simply aligned on the optical axis of the system.

[0025] Another object of the present invention is to provide a novel DOE-based laser beam producing device, wherein refractive optics (L1) having an axially symmetric surface profile characteristics are disposed between the laser diode source (VLD) and the diffractive optics (e.g. DOEs D1 and D2), to enable the use the DOEs to modify (e.g. correct or eliminate) astigmatism in the output laser beam, while simplifying the manufacture of the refractive optics (Li) and diffractive optics (DOEs D1 and D2), reducing the cost of optical elements, and simplifying parameter alignment during the assembly process.

[0026] Another object of the present invention is to provide a novel optics module employing a pair of DOEs configured in the beam compression mode, wherein the total expansion factor (M) of the DOE combination is less than one, so that the size of the laser beam in the plane of diffraction is compressed without changing the beam size in the dimension perpendicular to the plane of diffraction.

[0027] Another object of the present invention is to provide a novel optics module employing a pair of DOEs configured in the beam expansion mode, wherein the total expansion factor (M) of the DOE combination is greater than one, so that the size of the laser beam in the plane of diffraction is expanded without changing the beam size in the dimension perpendicular to the plane of diffraction.

[0028] A further object of the present invention is to provide a novel light diffractive optics module for incorporation into small laser scanning devices, such as laser scan-engines, as well as replacing conventional prisms and anamorphic lenses used in VLD-based optical systems such as optical storage devices, CD-ROM players and recorders, and like systems and devices.

[0029] Another object of the present invention is to provide a DOE-based optics module for modifying the aspect-ratio of a VLD beam while simultaneously controlling beam dispersion to minimize the overall dispersion of the optical system in which it is being used.

[0030] Another object of the present invention is to provide such an optics module, wherein beam astigmatism inherently associated with VLDs is eliminated or minimized.

[0031] Another object of the present invention is to provide a novel method for designing a dual-HOE laser beam modifying system, in which a pair of equations are solved under a given set of conditions which ensures that beam dispersion is eliminated and a desired expansion factor (M) is obtained.

[0032] Another object of the present invention is to provide such an optical design method, wherein analytical and spreadsheet-type programs are combined in an integrated fashion to allow for easy design and analysis of the optics module under consideration.

[0033] Another object of the present invention is to provide a dual-DOE optics module particularly designed for replacing "pinhole" type beam shaping modules used in laser scanning bar code symbol readers.

[0034] Another object of the present invention is to provide a novel system for precisely and rapidly aligning the parameters of the optics modules of the present invention to enable the inexpensive mass production of such optical systems and devices for widespread use in diverse fields of endeavor.

[0035] Another object of the present invention is to provide such a parameter alignment system, wherein micro-adjustment of the optical components of the laser beam producing modules of the present invention are carried out in a fully automated manner under microcomputer control, thereby allowing (i.e. enabling) mass-production of DOE-based laser beam producing modules which satisfy high quality-control (QC) measures.

[0036] Another object of the present invention is to provide a novel method of designing an ultra-compact HOE-based device for producing a laser beam having a selected set of beam characteristics obtained by modifying the astigmatic, elliptical light beams produced from inexpensive VLDs.

[0037] Another object of the present invention is to provide a hand-held laser scanner, wherein the laser beam producing system of the present invention is embodied to enable the production of laser beams for bar code scanning operations.

[0038] Another object of the present invention is to provide a body-wearable laser scanner, wherein the laser beam producing system of the present invention is embodied to enable the production of laser beams for bar code scanning operations.

[0039] Another object of the present invention is to provide a laser scanning-engine, wherein the laser beam producing system of the present invention is embodied to enable the production of laser beams for bar code scanning operations.

[0040] Another object of the present invention is to provide in-counter scanners, projection scanners, pass-through (passive) scanners, laser pointers, and the like, wherein the laser beam producing system of the present invention is embodied.

[0041] Another object of the present invention is to provide a holographic laser scanner, wherein one or more laser beam producing modules of the present invention are embodied to enable the production of a plurality of laser beams for bar code scanning operations.

[0042] Another object of the present invention is to provide a CD-ROM playing unit, wherein the laser beam producing system of the present invention is embodied to enable the production of laser beams for reading information digitally recorded within a CD-ROM or like recording device.

[0043] Another object of the present invention is to provide a laser-based instrument, wherein the laser beam producing system of the present invention is embodied to enable the production of laser beams for diagnosis or detection of various conditions.

[0044] These and other objects of the present invention will become apparent hereinafter and in the claims to Invention.

## BRIEF DESCRIPTION OF THE DRAWINGS

[0045] In order to more fully understand the Objects of the Present Invention, the following Detailed Description of the Illustrative Embodiments should be read in conjunction with the accompanying Figure Drawings, wherein:

[0046] **FIG. 1** is a schematic representation of a general model for the DOE-based laser beam producing system of the present invention, showing its laser source and the DOE-based laser beam modifying subsystem;

[0047] **FIG. 1A** is a schematic representation of the dual-DOE optical subsystem used in the various illustrative embodiments of the laser beam producing system of the present invention, identifying the geometrical optical parameters employed in the design of this subsystem;

[0048] **FIG. 2A** is a geometrical optics model of the first illustrative embodiment of the DOE-based laser beam producing subsystem according to the principles of the present invention;

[0049] **FIG. 2B** is a geometrical optics model of the second illustrative embodiment of the DOE-based laser beam producing subsystem according to the principles of the present invention, realized using a transmission-type DOE for both DOE1 and DOE2;

[0050] **FIG. 2B1** is a geometrical optics model of the second illustrative embodiment of the DOE-based laser beam producing subsystem according to the principles of the present invention, realized using reflection-type DOEs for both DOE1 and DOE2;

[0051] **FIG. 2B2** is a geometrical optics model of the second illustrative embodiment of the DOE-based laser beam producing subsystem according to the principles of the present invention, realized using a transmission-type DOE for DOE1 and a reflection-type DOE for DOE2;

[0052] **FIG. 2B3** is a geometrical optics model of the second illustrative embodiment of the DOE-based laser beam producing subsystem according to the principles of the present invention, realized using a reflection-type DOE for DOE1 and a transmission-type DOE for DOE2;

[0053] **FIG. 2C** is a geometrical optics model of the third illustrative embodiment of the DOE-based laser beam producing subsystem according to the principles of the present invention;

[0054] **FIG. 2D** is a geometrical optics model of the fourth illustrative embodiment of the DOE-based laser beam producing subsystem according to the principles of the present invention;

[0055] **FIG. 2E** is a geometrical optics model of the fifth illustrative embodiment of the DOE-based laser beam producing subsystem according to the principles of the present invention;

[0056] **FIG. 2F** is a geometrical optics model of the sixth illustrative embodiment of the DOE-based laser beam producing subsystem according to the principles of the present invention;

[0057] **FIG. 2G** is a geometrical optics model of the seventh illustrative embodiment of the DOE-based laser beam producing subsystem according to the principles of the present invention;

[0058] **FIG. 2H** is a geometrical optics model of the eighth illustrative embodiment of the DOE-based laser beam producing subsystem according to the principles of the present invention;

[0059] **FIG. 2I** is a geometrical optics model of the ninth illustrative embodiment of the DOE-based laser beam producing subsystem according to the principles of the present invention;

[0060] **FIG. 2J** is a geometrical optics model of the tenth illustrative embodiment of the DOE-based laser beam producing subsystem according to the principles of the present invention;

[0061] **FIG. 2K** is a geometrical optics model of the eleventh illustrative embodiment of the DOE-based laser beam producing subsystem according to the principles of the present invention;

[0062] **FIG. 2L** is a geometrical optics model of the twelfth illustrative embodiment of the DOE-based laser beam producing subsystem according to the principles of the present invention;

[0063] **FIG. 2M** is a geometrical optics model of the thirteenth illustrative embodiment of the DOE-based laser beam producing subsystem according to the principles of the present invention;

[0064] **FIG. 2N** is a geometrical optics model of the fourteenth illustrative embodiment of the DOE-based laser beam producing subsystem according to the principles of the present invention;

[0065] FIGS. **3A1** through **3A3** set forth a flow chart illustrating the steps involved in carrying out the method of designing DOE-based laser beam producing systems according to the present invention, wherein astigmatism can be tolerated and adjustment of the focal-length of the resulting stigmatic beam is not required;

[0066] FIGS. **3B1** through **3B3** set forth a flow chart illustrating the steps involved in carrying out the method of designing DOE-based laser beam producing systems, wherein astigmatism correction is desired and adjustment of the focal-length of the resulting stigmatic beam is not required;

[0067] FIGS. **3C1** through **3C3** set forth a flow chart illustrating the steps involved in carrying out the method of designing DOE-based laser beam producing systems, wherein astigmatism correction and adjustment of the focal-length of the resulting stigmatic beam are required;

[0068] FIGS. **3D1** through **3D3**, taken together show a flow chart, set forth a flow chart illustrating the steps involved in carrying out the method of designing DOE-based laser beam producing systems, wherein astigmatism correction is desired and adjustment of the focal-length of the resulting stigmatic beam and delta-focusing are not required;

[0069] **FIG. 3E** is a "central-ray" type geometrical optics model of the DOE-based laser beam modifying subsystem employed within each of the illustrative embodiments of the laser beam producing systems of the present invention;

[0070] FIGS. **3F1** through **3F3** set forth a flow chart illustrating the steps involved in carrying out the method of designing the DOE-based laser beam modifying subsystem of the present invention so that pre-selected design criteria is satisfied;

[0071] **FIG. 4A** sets forth a flow chart illustrating a preferred method of converting the design parameters of a HOE into its construction parameters expressed at the construction wavelength;

[0072] **FIG. 4B** is a schematic diagram showing apparatus for recording HOEs to be used in the dual-HOE subsystem specified in **FIG. 4A**;

[0073] FIGS. **4C1** and **4C2** collectively set forth a flow chart illustrating the basic steps involved in constructing a CGH implementation of the DOE-based laser beam modifying subsystem hereof;

[0074] **FIG. 4D** is a schematic diagram showing apparatus for generating and recording master CGHs, and producing copies thereof for use in DOE-based subsystems in accordance with the principles of the present invention;

[0075] **FIG. 5A** is a schematic diagram of an optical arrangement for analyzing dispersion in the laser beam output from the DOE-based laser beam modifying subsystem of the present invention;

[0076] **FIG. 5B** is a generalized graphical representation of two different dispersion characteristics of a laser beam producing system of the present invention when operated in different modes of operation, shown plotted as a function of output wavelength;

[0077] **FIG. 5B1** is a graphical representation of the dispersion characteristics of an exemplary laser beam producing system of the type shown in FIGS. **2A** and **7A-7C**, showing a negative (concave down) curvature when plotted as a function of output wavelength;

[0078] **FIG. 5B2** is a graphical representation of the dispersion characteristics of a laser beam producing system of the type shown in FIGS. **2A** and **7A-7C** if the direction of propagation of the laser beam is reversed, thereby exhibiting a positive (concave upward) curvature, plotted as a function of output wavelength;

[0079] **FIG. 6A** is a first perspective view of a first illustrative embodiment of a laser beam producing module according to the present invention, wherein its VLD laser source is adjustable relative to its imaging lens (**L1**) and pair of stationary-mounted HOEs and beam directing mirror so that the elliptical beam produced from the VLD is aligned relative to the optical axes of the HOEs in order to minimize laser beam dispersion and to control the aspect-ratio of the output laser beam in a desired manner;

[0080] **FIG. 6B** is a second perspective view of the laser beam producing module shown in **FIG. 6A**;

[0081] **FIG. 6C** is a plan view of the laser beam producing module shown in **FIG. 6A**;

[0082] **FIG. 7A** is a perspective view of a second illustrative embodiment of the laser beam producing module of the present invention, wherein its VLD laser source is adjustable relative to its imaging lens (**L1**) and pair of stationary-mounted HOEs so that the inherently off-axis elliptical beam produced from the VLD is aligned relative to the optical axes of the HOEs in order to minimize beam dispersion and control the aspect ratio of the output laser beam in a desired manner;

[0083] **FIG. 7B** is an exploded view of the laser beam producing module of the present invention shown in **FIG. 7A**, showing its heat-sink plate, VLD, VLD-yoke, lens **L1**, HOES **H1** and **H2**, optics module base, and cover plate;

[0084] **FIG. 7C** is a plan view of the laser beam producing module shown in **FIG. 7A**;

[0085] **FIG. 8A** is a perspective view of a miniature laser scanning module for use in connection with laser beam producing modules of the present invention;

[0086] **FIG. 8B** is an exploded view of the laser beam scanning module of the present invention shown in **FIG. 8A**, showing its scanning element, mounting plates, electromagnet, support base, and cover plate;

[0087] **FIG. 9** is a plan view of the laser beam producing module of the present invention shown in **FIG. 7A** configured for cooperation with the laser beam scanning module shown in **FIG. 8A**;

[0088] **FIG. 11A** is perspective view of the third illustrative embodiment of the laser beam producing module of the present invention, wherein a laser beam scanning mechanism is integrated therein and its VLD laser source is adjustable relative to its imaging lens (L1) and pair of stationary-mounted HOEs so that the inherently off-axis elliptical beam produced from the VLD is aligned relative to the optical axes of the HOEs in order to minimize laser beam dispersion, and control the aspect-ratio of the output laser beam in a desired manner;

[0089] **FIG. 10B** is an exploded view of the laser beam producing module shown in **FIG. 10A**, showing its heat-sink plate, VLD, VLD-yoke, lens L1, HOES H1 and H2, optics module base, scanning element, mounting plates, electromagnet, and cover plate;

[0090] **FIG. 10C** is a cross-section view of the laser beam producing module taken along line **10C-10C**;

[0091] **FIG. 10D** is an exploded perspective view of the laser beam producing module of **FIG. 10A** mounted within a miniature housing of a laser beam scanning engine;

[0092] **FIG. 11A** is a perspective view of a fourth illustrative embodiment of the laser beam producing module of the present invention, wherein its VLD laser source is adjustable relative to its imaging lens (L1) and so that the inherently off-axis elliptical beam produced from the VLD is aligned relative to the optical axes of the HOEs in order to minimize laser beam dispersion, control the aspect-ratio of the output laser beam in a desired manner, and correct for astigmatism in the output laser beam, the focal length of the second lens (L2) is adjustable to fine-tune the focal-length of the output laser beam as required by the application to which the laser beam producing system is put;

[0093] **FIG. 11B** is an exploded view of the laser beam producing module shown in **FIG. 11A**, showing its subcomponents and mechanisms enabling the adjustment of the position of the VLD relative to the lens L1 and the position of HOE H2 relative to HOE H1;

[0094] **FIG. 11C** is a cross-section view of the laser beam producing module taken along line **11C-11C** shown in **FIG. 11A**;

[0095] **FIG. 12A** is a perspective view of the fifth illustrative embodiment of the laser beam producing module of the present invention, wherein a laser beam scanning mechanism is integrated therein and its VLDlaser source is adjustable relative to its imaging lens (L1) so that the inherently off-axis elliptical beam produced from the VLD is aligned relative to the optical axes of the HOEs in order to minimize laser beam dispersion, and control the aspect-ratio of the output laser beam in a desired manner, correction for astigmatism in the output laser beam;

[0096] **FIG. 12B** is an exploded view of the laser beam producing module shown in **FIG. 12A** showing its subcomponents and mechanisms enabling the adjustment of the position of the VLD relative to the lens L1, the position of HOE H2 relative to HOE H1, and the focal length of lens L2 which can be realized as a compound lens system;

[0097] **FIG. 12C** is a cross-section view of the laser beam producing module taken along line **12C-12C** shown in **FIG. 12A**;

[0098] **FIG. 13** is a schematic representation of a parameter adjustment system for aligning the optical components within the various types of laser beam producing modules of the present invention disclosed herein;

[0099] **FIG. 14** is a schematic diagram of the laser beam producing module of **FIG. 7A** installed upon the parameter adjustment system of **FIG. 13**, for aligning optical components in the module so that laser beam dispersion is minimized and the aspect-ratio of the output laser beam is controlled in a desired manner;

[0100] **FIG. 15** is a schematic diagram of the laser beam producing module shown in **FIG. 11A** installed upon the parameter adjustment system of **FIG. 13**, for aligning optical components of the module so that laser beam dispersion is minimized, the aspect-ratio of the output laser beam is controlled in a desired manner, and astigmatism in the output laser beam is corrected, e.g. eliminated;

[0101] **FIG. 16** is a schematic diagram of the laser beam producing module shown in **FIG. 12A** installed upon the parameter adjustment system of **FIG. 13**, for aligning the optical components of the module so that laser beam dispersion is minimized, the aspect-ratio of the output laser beam is controlled in a desired manner, astigmatism in the output laser beam is corrected, and adjustment of the focal-length of the resulting stigmatic beam is achieved;

[0102] **FIG. 17** is a schematic diagram of the laser beam producing module shown in **FIG. 12A** installed upon the parameter adjustment system of **FIG. 13**, for aligning the optical components of the module so that laser beam dispersion is minimized, and astigmatism in the output laser beam is corrected, without focus control or focal length adjustment;

[0103] **FIG. 18** is a schematic representation of a hand-supportable laser scanning system constructed in accordance with the present invention, wherein one or more DOE-based laser beam producing systems of the present invention are configured and driven by a synchronized driver circuit for producing a 2-D laser scanning pattern suitable for omni-directional or raster scanning of bar code symbols;

[0104] **FIG. 19** is a schematic representation of a fixed-type projection laser scanning system, wherein a laser beam producing subsystem of the present invention is used to produce a laser beam having desired beam characteristics for omni-directional laser scanning;

[0105] **FIG. 20** is a schematic representation of a body-wearable laser scanning system which embodies an DOE-based laser beam producing module of the present invention within its finger-mounted scanning module;

[0106] **FIG. 21** is a schematic representation of a holographic laser beam scanning system, wherewith a plurality of laser beam producing modules of the present invention cooperate with a holographic laser scanning disc and a plurality of wavelength-compensation gratings to produce an omni-directional scanning pattern within a 3-D scanning volume;

[0107] **FIG. 22** is a schematic representation of a CD-ROM player in which a laser beam producing module according to the present invention is integrated;

[0108] **FIG. 23** is a schematic representation of a laser beam pointing device, wherein a laser beam producing module according to the present invention is embodied; and

[0109] **FIG. 24** is a schematic representation of an analytical instrument, in which a laser beam producing module according to the present invention is employed for detection or diagnosis of a particular condition.

## DETAILED DESCRIPTION OF THE ILLUSTRATIVE EMBODIMENTS OF THE PRESENT INVENTION

[0110] In accordance with one broad aspect of the present invention, illustrated in **FIG. 1**, novel apparatus **1** employs a light-diffractive optical subsystem **2** for modifying the inherent beam characteristics of a laser beam **3** generated from a laser diode source **4** (e.g. visible laser diode or VLD). Preferably, the laser diode source **4** has the so-called heterostructure or double-heterostructure, or multi-quantum well construction. The laser beam output from the laser diode source **4** is modified by optical subsystem **2**, and the modified beam characteristics associated therewith, are suited by design for use in particular applications. Hereinafter, apparatus according to this first aspect of the present invention, adapted for modifying the characteristics of laser beams produced from laser diode sources, shall be referred to as "a laser beam modifying subsystem".

[0111] Each embodiment of the laser beam-modifying system of the present invention is designed using the beam characteristics of the particular laser source **4** employed in the system. As shown in **FIG. 1A**, the optical subsystem **2** comprises: a lens element (**L1**); and at least two light diffractive optical elements (DOEs), indicated by **D1** and **D2**, respectively, in **FIG. 1A**. The primary function of optical subsystem **2** is to modify the laser beam produced from the laser diode source **4** so that the resulting laser beam **5** output from DOEs **D1** and **D2** has predetermined (modified) beam characteristics that are suited by design for use in particular applications. Hereinafter, apparatus according to this second aspect of the present invention, adapted for producing laser beams having predetermined beam characteristics, shall be referred to as "laser beam producing system".

[0112] In defining the laser beam modifying (optics) subsystem **2**, the angle of incidence of the laser beam from the lens **L1** onto the front surface of the first diffractive optical element (DOE) **D1** is specified by $\theta_{i1}$, whereas the angle of diffraction therefrom is specified by $\theta_{d1}$. The angle of incidence of the laser beam from the first DOE **D1** onto the front surface of second fixed DOE **D2** is specified by $\theta_{i2}$, whereas the angle of diffraction therefrom is specified by $\theta_{d2}$. The angle $\rho$ between the surfaces of the two DOEs **D1** and **D2** as:

$$\rho=\theta_{d1}-\theta_{i2}$$

[0113] These five parameters $\theta_{i1}$, $\theta_{d1}$, $\theta_{i2}$, $\theta_{d2}$, and $\rho$ completely define the dual-DOE subsystem, and thus provide four degrees of freedom within the geometrical optics model thereof.

[0114] Hereinbelow, a number of illustrative embodiments of the laser beam producing system according to the present invention will now be described in great detail. In such illustrative embodiments shown in the figures of the accompanying Drawings, like structures and elements shall be indicated by like reference numerals.

## DESCRIPTION OF ILLUSTRATIVE SYSTEM EMBODIMENTS OF THE LASER BEAM-PRODUCING SYSTEM OF THE PRESENT INVENTION

[0115] In each of the fourteen illustrative embodiments described below, the laser beam is produced from a VLD **4** having the so-called heterostructure or double-heterostructure, or multi-quantum well construction. In a typical VLD, the beam divergence will be less in the direction parallel to the VLD junction. Also, in all commercially produced VLDs, the electric field (E-field) of the laser beam is oriented (i.e. polarized) in a direction parallel to the narrow divergence direction of the beam, which is generally parallel to the junction of the VLD.

[0116] In order to understand the operation of commercial VLDs which inherently produce astigmatic beams, it will be helpful to construct a model thereof, as done in copending application Ser. No. 08/573,949 filed Dec. 18, 1995, incorporated herein by reference. According to this model, the laser beam exiting the diode source is deemed to be generated from a combination of sources, namely: a S "source" and a P "source" coaxially located inside the VLD, but separated by a distance referred to as the astigmatic difference or simply the astigmatism of the VLD. Each wave source in this model creates an independent cylindrical wavefront which interacts with the other wave source to create an effect on the resulting wavefront that results in the astigmatism. In the case where the astigmatism is zero, the two cylindrical sources coincide and the resultant wavefront is spherical. The P source is considered the source of origin of the narrow divergence portion of the beam (and thus P shall hereinafter refer to the direction parallel to the VID junction). The S source is considered the source of origin of the wide direction of the beam (and thus S—derived from the German word "Senkrecht" meaning "perpendicular"—shall hereinafter refer to the direction perpendicular to the VLD junction).

[0117] Ideally, to ensure the highest diffraction efficiency of the laser beam transmitted through the DOEs **D1** and **D2**, the diffracted laser beam at angle $\theta_{d1}$ should be in the "plane of incidence" of the incoming beam at DOE **D1**. In accordance with standard definitions, the "plane of incidence" shall mean the plane containing the incident light ray at DOE **D1** and the normal to the surface of DOE **D1** at the point of incidence thereon. It is not possible to define a plane of incidence for a cone of rays incident the surface of lens **L1**. Also, the diffracted laser beam at angle $\theta_{d2}$ relative to DOE **D2** should be in the "plane of incidence" of the incident beam at DOE **D2**, and the plane of incidence at DOE **D1** should be coplanar with the plane of incidence at DOE **D1** (i.e. disposed within a common plane), to ensure the highest possible light diffraction efficiency as the laser beam passes through the dual-DOE beam modifying subsystem **6**. Regardless of how the DOEs are implemented (e.g. as HOEs, CGHs, surface-relief holograms, etc), the fringe structure of the DOEs must be arranged perpendicular to the (common) plane of incidence at the DOEs in order to achieve maximum light diffraction efficiency through this subsystem. With this general arrangement, it is noted that all modifications to the laser beam exiting the VLD (e.g. compression or expansion) will occur within the "common plane of incidence" passing through DOEs **D1** and **D2**.

[0118] Depending on the application at hand, there may be a need to compress or expand a particular dimension of the astigmatic laser beam exiting from the VLD. In order to perform such beam modifying functions upon this laser beam, the individual expansion ratios for DOEs D1 and D2, designated by $M_1$ and $M_2$, respectively, will be selected by the optical system designer so that the beam-shaping factor (e.g. expansion ratio) of the DOE-subsystem, $M=M_1M_2$, is greater than unity when beam expansion is required, and less than unity when beam compression is required. In the DOE subsystem, the individual expansion ratios are given by the following formulas: $M_1=D_{output1}/D_{input1}$ and $M_2=D_{output2}/D_{input2}$, wherein D represents dimension of the beam in the compression/expansion direction (i.e. common plane of incidence of DOEs D1 and D2).

[0119] There are four general cases of laser beam modification that may be carried out by any particular embodiment of the laser beam producing system of the present invention. These cases will now be briefly described below to provide an overview of the system of the present invention.

[0120] In the first general case of beam modification, the wider dimension of the laser beam requires compression by the DOE-based subsystem. In this case, the DOEs D1 and D2 are designed so that the beam-shaping factor M thereof is less than unity and the narrower dimension of the laser beam exiting the VLD is oriented perpendicular to the "common" plane of incidence passing through DOEs D1 and D2. As this latter condition is satisfied by orienting the VLD junction (and thus its narrower beam dimension and polarization direction) perpendicular to the common plane of incidence, the laser beam incident o n DOE D1 is said to be "S-polarized" or "S-incident" on the surface of DOE D1, that is the E-field of the incident laser beam is perpendicular to the common plane of incidence. In this configuration, the wider dimension of the laser beam is disposed within the common plane of incidence (wherein diffraction occurs) so that beam compression results as desired by the design, while the narrower beam dimension is disposed perpendicular thereto (wherein no diffraction occurs) so that no beam compression results along this dimension as desired by the design. In this case, an elliptical laser beam can be made less elliptical or circular.

[0121] In the second general case of beam modification, the narrower dimension of the laser beam requires compression by the DOE-based subsystem. In this case, the DOEs D1 and D2 are designed so that the beam-shaping factor M thereof is less than unity and the narrower dimension of the laser beam exiting the VLD is oriented parallel to the "common" plane of incidence passing through DOEs D1 and D2. As this latter condition is satisfied by orienting the VID junction (and thus its narrower beam dimension and polarization direction) parallel to the common plane of incidence, the laser beam incident on DOE D1 is said to be "P-polarized" or "P-incident" on the surface of DOE D1, that is the E-field of the incident laser beam is parallel to the common plane of incidence. In this configuration, the narrower dimension of the laser beam is disposed within the common plane of incidence (wherein diffraction occurs) so that beam compression results as desired by the design, while the wider beam dimension is disposed perpendicular thereto (wherein no diffraction occurs) so that no beam compression results along this dimension as desired by the design. In this case, an elliptical laser beam can be made more elliptical.

[0122] In the third general case of beam modification, the wider dimension of the laser beam requires expansion by the DOE-based subsystem. In this case, the DOEs D1 and D2 are designed so that the beam-shaping factor M thereof is greater than unity and the narrower dimension of the laser beam exiting the VID is oriented perpendicular to the "common" plane of incidence passing through DOEs D1 and D2. As this latter condition is satisfied by orienting the VLD junction (and thus its narrower beam dimension and polarization direction) perpendicular to the common plane of incidence, the laser beam incident o n DOE D1 is said to be "S-polarized" or "S-incident" on the surface of DOE D1, that is the E-field of the incident laser beam is perpendicular to the common plane of incidence. In this configuration, the wider dimension of the laser beam is disposed within the common plane of incidence (wherein diffraction occurs) so that beam expansion results as desired by the design, while the narrower beam dimension is disposed perpendicular thereto (wherein no diffraction occurs) so that no beam expansion results along this dimension as desired by the design. In this case, an elliptical laser beam can be made more elliptical.

[0123] In the fourth general case of beam modification, the narrower dimension of the laser beam requires expansion by the DOE-based subsystem. In this case, the DOEs D1 and D2 are designed so that the beam-shaping factor M thereof is greater than unity and the narrower dimension of the laser beam exiting the VLD is oriented parallel to the "common" plane of incidence passing through DOEs D1 and D2. As this latter condition is satisfied by orienting the VLD junction (and thus its narrower beam dimension and polarization direction) parallel to the common plane of incidence, the laser beam incident on DOE D1 is said to be "P-polarized" or "P-incident" on the surface of DOE D1, that is the E-field of the incident laser beam is parallel to the common plane of incidence. In this configuration, the narrower dimension of the laser beam is disposed within the common plane of incidence (wherein diffraction occurs) so that beam expansion results as desired by the design, while the wider beam dimension is disposed perpendicular thereto (wherein no diffraction occurs) so that no beam expansion results along this dimension as desired by the design. In this case, an elliptical laser beam can be made less elliptical or circular.

[0124] Using the above-described principles, numerous embodiments of the laser beam producing system of the present invention can be designed and constructed using various types of enabling technologies. Below, fourteen different illustrative embodiments of the laser beam producing system hereof shall be described in detail. In each of these illustrative embodiments of the present invention, the angles of incidence and diffraction at the DOEs are the only parameters that determine whether the incident laser beam is compressed or expanded. For a fixed set of DOE angles, the polarization direction of the laser beam will determine whether the aspect ratio of the elliptical beam is increased or decreased. This is due to the direct relationship that exists between the narrow dimension and the polarization direction of the laser beam exiting a VLD.

[0125] In each of the beam compression embodiments, an S-polarized beam as well as a P-polarized beam incident

DOE D1 will be compressed. The difference between such cases is that the elliptical S-polarized beam will become less elliptical while the P-polarized beam will become more elliptical. In many instances where beam compression is desired or required, an S-polarized beam will be preferred as its beam aspect ratio will be reduced while its beam cross-section is made smaller.

[0126] In each of the beam expansion embodiments, an S-polarized beam as well as a P-polarized beam incident DOE D1 will be expanded. The difference between such cases is that the elliptical S-polarized beam will become more elliptical while the P-polarized beam will become less elliptical. In many instances where beam expansion is desired or required, a P-polarized beam will be preferred as its beam aspect ratio will be reduced while its beam cross-section is made larger.

[0127] First Illustrative System Embodiment of the Laser Beam Producing System of the Present Invention

[0128] In **FIG. 2**A, the first illustrative embodiment of the laser beam producing system hereof ("System Embodiment No. 1") comprises: a laser beam source, such as a visible laser diode (VLD), (e.g. Sony Model SLD1122VS) for producing a laser beam from its junction typically having divergent and elliptical beam characteristics; a collimating lens (L1), realizable as a refractive lens e.g. a 4/35 mm lens, a HOE, other type of DOE, a grin lens, one or more zone plate(s), etc., for collimating the laser beam as it is transmitted through collimating lens L1 and through the system in a S-incident manner; a fixed spatial-frequency diffractive optical element (DOE), i.e. diffraction grating, indicated by D1 having a beam expansion factor $M_1$; and a fixed spatial-frequency diffractive optical element (DOE) indicated by D2, having a beam expansion factor $M_2$. Collectively, the collimating lens (L1), the fixed spatial-frequency DOE H1 and the fixed spatial-frequency DOE D2 comprise a laser beam-modifying (sub)system in accordance with the present invention. Each of the DOEs in this system embodiment can be realized as a transmission-type HOE, a computer-generated hologram (CGHs), a surface-relief hologram, or other diffractive optical element.

[0129] In this embodiment, the total beam-shaping factor ($M=M_1M_2$) for the laser beam modifying subsystem is less than unity (1), that is M1*M2<1, and thus the laser beam leaving the collimating lens (L1) is compressed in one dimension. Notably, there will be many cases in which the beam shaping factor is less than unity, including, for example: where M1<1 and M2<1; where M1=1 and M2<1; and where M1<1 and M2=1. In the Beam Compression Mode, one of the cross-sectional dimensions of the laser beam from the VLD is compressed at the output of the system to a predetermined dimension. Typically, although not necessarily, the wider cross-sectional dimension of the laser beam will be the one that is compressed. For example, if the beam is S-polarized at DOE D1, then the widest cross-sectional dimension of the laser beam from the VLD is compressed at the output of the system to a predetermined dimension. If the beam is P-polarized, then the narrowest dimension of the laser beam from the VLD is compressed at the output of the system to a predetermined dimension, thereby making the laser beam even more elliptical in cross-section.

[0130] In the laser beam producing system shown in **FIG. 2**A, the aspect-ratio of the output laser beam is controlled and dispersion in the output laser beam produced therefrom eliminated for the central ray (and minimized for off-center rays) for any given beam expansion ratio at each of the DOEs, by way of selecting the right combination of angles of incidence and diffraction for the two DOEs D1 and D2 indicated by $\theta_{i1}$, $\theta_{d1}$, $\theta_{i2}$ and $\theta_{d2}$ which, in turn, determine the proper angle between the two DOEs, indicated by $\rho$. In this embodiment, the (x,y,z) position of the VLD is adjustable relative to lens L1 during the parameter alignment stage of the system assembly process in order to set the focal length of the output laser beam to the desired value and to align the VLD to the optical axis of lens L1. The (x,y,z) position of the VLD has no effect on dispersion except insofar as the x, y position effects the angle of incidence $\theta_{i1}$ at H1. If the laser beam output from the VLD is not aligned along the optical axis of L1, then dispersion may not be zeroed or minimized as the beam will not pass through the DOEs are designed. In this embodiment, astigmatism in the output laser beam is not minimized or otherwise controlled. Consequently, there will be a number of applications to which this system embodiment can be put with satisfactory result.

[0131] Notably, in the embodiment of the laser beam producing system shown in **FIG. 2**A, the convergence of the beam leaving collimating lens L1 must be adjusted to provide the proper image distance to the focal point of the system, and therefore it cannot be used to control or eliminate the astigmatism that is inherent in the laser beam leaving the VLD. In the case of Scan-Engine and like type applications, where the laser scanning device is realized within an ultra-small volume, laser beam astigmatism is not a problem as the increase (i.e. elongation) in spot-size in the non-scan-dimension helps reduce the problems associated with paper noise, described in U.S. Pat. No. 4,748,316, incorporated herein by reference.

[0132] Second Illustrative System Embodiment of the Laser Beam Producing System of the Present Invention

[0133] In **FIG. 2**B, the second illustrative embodiment of the laser beam producing system hereof ("System Embodiment No. 2") comprises: a laser beam source, such as a visible laser diode (VLD), for producing a laser beam from its junction having divergent and elliptical characteristics; a collimating lens (L1), realizable as a refractive lens e.g. a 4/35 mm lens, a HOE, other type of DOE, a grin lens, one or more zone plate(s), etc., for collimating the laser beam as it is transmitted through collimating lens L1 and through the system in a S-incident manner; a fixed spatial-frequency diffractive optical element (DOE), i.e. diffraction grating, indicated by D1 having a beam expansion factor $M_1$; and a fixed spatial-frequency diffractive optical element (DOE), i.e. diffraction grating, indicated by D2, having a beam expansion factor $M_2$; and a focusing lens L2, realizable as a refractive lens, a HOE, a DOE, a grin lens, zone plate(s) or the like, disposed after DOE D2 for focusing the output laser beam to a desired or required point in space. Collectively, the collimating lens L1, the fixed spatial-frequency DOE D1, the fixed spatial-frequency DOE D2, and focusing lens L2, comprise a laser beam modifying subsystem in accordance with the present invention. Each of the DOEs in this system embodiment can be realized as a transmission-type HOE, a CGH, a surface-relief hologram, or other diffractive optical element.

[0134] In this embodiment, the total beam-shaping factor ($M=M_1M_2$) for the laser beam modifying subsystem is less than unity (1), that is M1*M2<1, and thus the laser beam leaving the collimating lens (L1) is compressed in one dimension. Notably, there will be many cases in which the beam shaping factor is less than unity, including, for example: where M1<1 and M2<1; where M1=1 and M2<1; and where M1<1 and M2=1. In the Beam Compression Mode, one of the cross-sectional dimensions of the laser beam from the VLD is compressed at the output of the system to a predetermined dimension. Typically, although not necessarily, the wider cross-sectional dimension of the laser beam will be the one that is compressed. In this embodiment, the total beam-shaping factor ($M=M_1M_2$) for the laser beam subsystem is less than unity (1), and thus the laser beam leaving the collimating lens (L1) is compressed in one dimension.

[0135] In the laser beam producing system shown in **FIG. 2**B, the aspect-ratio of the output laser beam can be controlled and dispersion in the output laser beam produced therefrom can be eliminated (or minimized) for any given beam expansion ratio at each of the DOEs, by way of selecting the right combination of angles of incidence and diffraction for the two DOEs D1 and D2 indicated by $\theta_{i1}$. $\theta_{d1}$, $\theta_{i2}$ and $\theta_{d2}$ which, in turn, determine the proper angle between the two DOEs, indicated by $\rho$.

[0136] In this embodiment of the laser beam producing system, the inherent astigmatism of the laser beam leaving the VLD can be either adjusted or eliminated by choosing proper divergence or convergence of the laser beam leaving the collimating lens L1. The (x,y,z) position of visible laser diode VLD is adjustable relative to the lens L1 during the parameter adjustment stage of the system assembly process, in order to adjust the divergence or convergence of the beam leaving lens L1 and to align the VLD to the optical axis of lens L1. Also, the position of lens L2 is adjustable along its optical axis relative to DOE D2 during the alignment stage of the system assembly process in order to set the focal length of the output laser beam to the desired value.

[0137] In the illustrative embodiments described hereinabove, DOEs D1 and D2 are realized using either transmission-type or reflection-type light diffractive optical elements (e.g. reflection-type volume HOES). It is understood, however, that this illustrative embodiment of the present invention can be realized using reflection-type volume DOEs (e.g. reflection-type HOEs and CGHs) as well. In functional equivalent of the system shown in **FIG. 2**B, and operates in the Beam Compression Mode.

[0138] Third Illustrative System Embodiment of the Laser Beam Producing System of the Present Invention

[0139] In **FIG. 2**C, the third illustrative embodiment of the laser beam producing system hereof ("System Embodiment No. 3") comprises: a laser beam source, such as a visible laser diode (VLD), for producing a laser beam from its junction a collimating lens (L1), realizable as a refractive lens, a HOE, a DOE, a grin lens, zone plate(s) or the like, for collimating the laser beam as it is transmitted through collimating lens L1 and through the system in a S-incident manner; a fixed spatial-frequency diffractive optical element (DOE), i.e. diffraction grating, indicated by D1 having a beam expansion factor $M_1$; and a variable spatial-frequency diffractive optical element (DOE) indicated by D2, having a beam expansion factor $M_2$. Collectively, the collimating lens L1, the fixed spatial-frequency DOE D1 and the variable spatial-frequency DOE D2 comprise a laser beam-modifying (sub)system in accordance with the present invention. Each of the DOEs in this system embodiment can be realized as a transmission-type HOE, a CGH, a surface-relief hologram, or other diffractive optical element.

[0140] In this embodiment, the total beam-shaping factor ($M=M_1M_2$) for the laser beam modifying subsystem is less than unity (1), that is M1*M2<1, and thus the laser beam leaving the collimating lens (L1) is compressed in one dimension. There will be many cases in which the beam shaping factor is less than unity, including, for example: where M1<1 and M2<1; where M1=1 and M2<1; and where M1<1 and M2=1. In the Beam Compression Mode, one of the cross-sectional dimensions of the laser beam from the VLD is compressed at the output of the system to a predetermined dimension. Typically, although not necessarily, the wider cross-sectional dimension of the laser beam will be the one that is compressed.

[0141] In the laser beam producing system shown in **FIG. 2**C, the aspect-ratio of the output laser beam can be controlled and dispersion in the output laser beam produced therefrom is eliminated (or minimized) for any given beam expansion ratio at each of the DOEs, by way of selecting the right combination of angles of incidence and diffraction for the two DOEs D1 and D2 indicated by $\theta_{i1}$, $\theta_{d1}$, $\theta_{i2}$ and $\theta_{d2}$, which, in turn, determine the proper angle between the two DOEs, indicated by $\rho$.

[0142] In this embodiment of the laser beam producing system, the inherent astigmatism of the laser beam leaving the VLD is adjusted or eliminated by choosing proper divergence or convergence of the laser beam leaving the collimating lens L1. The (x,y) position of visible laser diode VLD is adjustable relative to the lens L1 during the parameter adjustment stage of the system assembly process, in order to adjust the divergence or convergence of the beam leaving lens L1. The z position of visible laser diode (VLD) is adjustable relative to the lens L1 during the parameter adjustment stage of the system assembly process, in order to align the VLD with respect to the optical axis of lens L1. Also, the position of DOE D2 is adjustable along its optical axis relative to DOE D1 during the alignment stage of the system assembly process in order to set the focal length of the output laser beam to the desired value.

[0143] Fourth Illustrative System Embodiment of the Laser Beam Producing System of the Present Invention

[0144] In **FIG. 2**D, the fourth illustrative embodiment of the laser beam producing system hereof ("System Embodiment No. 4") comprises: a laser beam source, such as a visible laser diode (VLD), for producing an elliptical divergent laser beam from its junction; a collimating lens (L1), realizable as a refractive lens, a HOE, or other DOE, a grin lens, zone plate(s), etc., for collimating the laser beam as it is transmitted through collimating lens L1 and through the system in a S-incident manner; a fixed spatial-frequency diffractive optical element (DOE), i.e. diffraction grating, indicated by D1; a variable spatial-frequency diffractive optical element (DOE) indicated by D2 and adjustably mounted to enable, during the alignment stage of the system adjustment process, the principal plane of DOE D2 to be translated along its optical axis relative to the principal plane

of DOE D1 without modifying the tilt angle therebetween; and a focusing lens (L2), realizable as a refractive lens, a HOE, a DOE, a grin lens, zone plate(s) or the like, disposed after the second DOE D2 and having a focal length which is can be adjusted to enable the focusing of the output laser beam to some predetermined focal point in space, during the alignment stage of the system assembly process. Collectively, the collimating lens L1, the fixed spatial-frequency DOE D1, the variable spatial-frequency DOE D2, and the focusing lens L2 comprise a laser beam-modifying subsystem in accordance with the present invention. Each of the DOEs in this system embodiment can be realized as a transmission-type HOE, a CGH, a surface-relief hologram, or other diffractive optical element.

[0145] In this illustrative embodiment of the optical system of the present invention, focusing lens L2 is disposed after the second focusing DOE D2 in order to provide additional optical power to the exiting laser beam. In general, lens L2 can be as a single lens whose position can be adjusted relative to the second DOE D2, or as a compound lens system having a focal length that can be adjusted so as to adjust the focal length of the output laser beam. This second optical arrangement L2 would be useful in applications where, for example, multiple focusing HOEs as are commonly arranged on a holographic scanning disc (disclosed in application Ser. No. 08/573,949) or where several different single HOEs of differing optical power were available to be placed in the system. One of these HOEs on the disc could be presented to the laser beam producing system hereof in the position of DOE D2 and effectively vary the focal distance of the output laser beam about an average focal point established by the lens L2, a process which shall be referred to hereinafter as "delta-focusing". This delta-focusing feature yields the benefits of reduced spot aberrations due to the optical power of DOE D2 as well as increased modularity of the system.

[0146] In this embodiment, the total beam-shaping factor ($M=M_1M_2$) for the laser beam modifying subsystem is less than unity (1), that is M1*M2<1, and thus the laser beam leaving the collimating lens (L1) is compressed in one dimension. There will be many cases in which the beam shaping factor is less than unity, including, for example: where M1<1 and M2<1; where M1=1 and M2<1; and where M1<1 and M2=1. In the Beam Compression Mode, one of the cross-sectional dimensions of the laser beam from the VLD is compressed at the output of the system to a predetermined dimension. Typically, although not necessarily, the wider cross-sectional dimension of the laser beam will be the one that is compressed.

[0147] In the laser beam producing system shown in **FIG. 2D**, the aspect-ratio of the output laser beam can be controlled and dispersion in the output laser beam eliminated (or minimized) for any given beam expansion or beam compression ratio at each of the DOEs, by selecting the right combination of angles of incidence and diffraction for the two DOEs D1 and D2 indicated by $\theta_{i1}$, $\theta_{d1}$, $\theta_{i2}$ and $\theta_{d2}$, which, in turn, determine the proper angle between the two DOEs, indicated by $\rho$.

[0148] In this embodiment of the laser beam producing system, the inherent astigmatism of the laser beam leaving the VLD is adjusted or eliminated by choosing proper divergence or convergence of the laser beam leaving the collimating lens L1. The (x,y) position of visible laser diode VLD is adjustable relative to the lens L1 during the parameter adjustment stage of the system assembly process, in order to adjust the divergence or convergence of the beam leaving lens L1. The z position of visible laser diode VLD is adjustable relative to the lens L1 during the parameter adjustment stage of the system assembly process, in order to align the VLD relative to the optical axis of lens L1. Also, the position of second lens L2 is adjustable along its optical axis relative to DOE D2 during the alignment stage of the system assembly process. The function of this second lens L2 is to set the average focal length of the output laser beam to the desired value for use by the delta-focusing subsystem.

[0149] Fifth Illustrative System Embodiment of the Laser Beam Producing System of the Present Invention

[0150] In **FIG. 2E**, the fifth illustrative embodiment of the laser beam producing system hereof ("System Embodiment No. 5") comprises: a laser beam source, such as a visible laser diode (VLD), for producing a laser beam from its junction; a collimating (non-focusing) lens (L1), realizable as a refractive lens, a HOE or other DOE, a grin lens, zone plate(s), etc., for collimating the laser beam as it is transmitted through collimating lens L1 and through the system in a P-incident manner; a fixed spatial-frequency diffractive optical element (DOE), i.e. diffraction grating, indicated by D1; and a fixed spatial-frequency diffractive optical element (DOE) indicated by D2. Collectively, the collimating lens L1, the fixed spatial-frequency DOE D1 and the fixed spatial-frequency DOE D2 comprise a laser beam-modifying (sub)system in accordance with the present invention. Each of the DOEs in this system embodiment can be realized as a transmission-type HOE, a CGH, a surface-relief hologram, or other diffractive optical element.

[0151] In this embodiment, the total beam-shaping factor ($M=M_1M_2$) for the laser beam modifying subsystem is greater than unity (1), that is M1*M2>1, and thus the laser beam leaving the collimating lens (L1) is expanded in one dimension. There will be many cases in which the beam shaping factor is greater than unity, including, for example: where M1>1 and M2>1; where M1=1 and M2>1; and where M1>1 and M2=1. In the Beam Expansion Mode, one of the cross-sectional dimensions of the laser beam from the VLD is expanded at the output of the system to a predetermined dimension. Typically, although not necessarily, the narrower cross-sectional dimension of the laser beam will be the one that is expanded.

[0152] In the laser beam producing system shown in **FIG. 2E**, the aspect-ratio of the output laser beam can be controlled and dispersion in the output laser beam produced therefrom is eliminated (or minimized) for any given beam expansion ratio at each of the DOEs, by way of selecting the right combination of angles of incidence and diffraction for the two DOEs D1 and D2 indicated by $\theta_{i1}$, $\theta_{d1}$, $\theta_{i2}$ and $\theta_{d2}$, which, in turn, determine the proper angle between the two DOEs, indicated by $\rho$.

[0153] In this embodiment, the (x,y) position of the VLD is adjustable relative to lens L1 during the parameter alignment stage of the system assembly process in order to set the focal length of the output laser beam to the desired value. The z position of the VLD is adjustable relative to lens L1 during the parameter alignment stage of the system assembly process in order to align the VLD to the optical axis of lens L1.

[0154] Notably, in the embodiment of the laser beam producing system shown in **FIG. 2**E, the convergence of the beam leaving collimating lens **L1** must be adjusted to provide the proper image distance to the focal point of the system, and therefore it cannot be used to control or eliminate the astigmatism that is inherent in the laser beam leaving the VLD. In the case of Scan-Engine and like type applications, where the laser scanning device is realized within an ultra-small volume, laser beam astigmatism is not a problem as the increase (i.e. elongation) in spot-size in the non-scan-dimension helps reduce the problems associated with paper noise, described in U.S. Pat. No. 4,748,316, supra.

[0155] Sixth Illustrative System Embodiment of the Laser Beam Producing System of the Present Invention

[0156] In **FIG. 2**F, the sixth illustrative embodiment of the laser beam producing system hereof ("System Embodiment No. 6") comprises: a laser beam source, such as a visible laser diode (VLD), for producing a laser beam from its junction; a collimating lens (**L1**), realizable as a refractive lens, a HOE or other DOE, a grin lens, zone plate(s), etc., for collimating the laser beam as it is transmitted through collimating lens **L1** and through the system in a P-incident manner; a fixed spatial-frequency diffractive optical element (DOE), i.e. diffraction grating, indicated by **D1**; a fixed spatial-frequency diffractive optical element (DOE) indicated by **D2**; and a focusing lens (**L2**), realizable as a refractive lens, a HOE, a DOE, a grin lens, zone plate(s) or the like, disposed after the second DOE **D2** for focusing the output laser beam to some point in space. Collectively, the collimating lens **L1**, the fixed spatial-frequency DOE **D1**, the fixed spatial-frequency DOE **D2**, and focusing lens **L2** comprise a laser beam-modifying (sub)system in accordance with the present invention. Each of the DOEs in this system embodiment can be realized as a transmission-type HOE, a CGH, a surface-relief hologram, or other diffractive optical element.

[0157] In this embodiment, the total beam-shaping factor ($M=M_1M_2$) for the laser beam modifying subsystem is greater than unity (1), that is **M1***M2>1, and thus the laser beam leaving the collimating lens (**L1**) is expanded in one dimension. There will be many cases in which the beam shaping factor is greater than unity, including, for example: where **M1**>1 and **M2**>1; where **M1**=1 and **M2**>1; and where **M1**>1 and **M2**=1. In the Beam Expansion Mode, one of the cross-sectional dimensions of the laser beam from the VLD is expanded at the output of the system to a predetermined dimension. Typically, although not necessarily, the narrower cross-sectional dimension of the laser beam will be the one that is expanded.

[0158] In the laser beam producing system shown in **FIG. 2**F, aspect-ratio control is achieved and dispersion in the output laser beam is eliminated (or minimized) for any given beam expansion ratio at each of the DOEs, by way of selecting the right combination of angles of incidence and diffraction for the two DOEs **D1** and **D2** indicated by $\theta_{i1}$, $\theta_{d1}$, $\theta_{i2}$ and $\theta_{d2}$, which, in turn, determine the proper angle between the two DOEs, indicated by $\rho$.

[0159] In this embodiment of the laser beam producing system, the inherent astigmatism of the laser beam leaving the VLD is either adjusted or eliminated by choosing proper divergence or convergence of the laser beam leaving the collimating lens **L1**. The (x,y) position of visible laser diode VLD is adjustable relative to the lens **L1** during the parameter adjustment stage of the system assembly process in order to adjust the divergence or convergence of the beam leaving lens **L1**. The z position of visible laser diode VLD is adjustable relative to the lens **L1** during the parameter adjustment stage of the system assembly process in order to align the VLD to the optical axis of lens **L1**. Setting the focal length of output laser beam is achieved by adjusting the position of lens **L2** relative to DOE **D2** during the alignment stage of the assembly process.

[0160] Seventh Illustrative System Embodiment of the Laser Beam Producing System of the Present Invention

[0161] In **FIG. 2**G, the seventh illustrative embodiment of the laser beam producing system hereof ("System Embodiment No. 7") comprises: a laser beam source, such as a visible laser diode (VLD), for producing a laser beam from its junction; a collimating lens (**L1**), realizable as a refractive lens, HOE or other DOE, a grin lens, zone plate(s), etc., for collimating the laser beam as it is transmitted through collimating lens **L1** and through the system in a P-incident manner; a fixed spatial-frequency diffractive optical element (DOE), i.e. diffraction grating, indicated by **D1**; and a variable spatial-frequency diffractive optical element (DOE) indicated by **D2**, which can be translated along the optical axis relative to the principal plane of DOE **D1** during the alignment stage of the system assembly process. Collectively, the collimating lens **L1**, the fixed spatial-frequency DOE **D1** and the variable spatial-frequency DOE **D2** comprise a laser beam-modifying (sub)system in accordance with the present invention. Each of the DOEs in this system embodiment can be realized as a transmission-type DOE, a CGH, a surface-relief hologram, or other diffractive optical element.

[0162] In this embodiment, the total beam-shaping factor ($M=M_1M_2$) for the laser beam modifying subsystem is greater than unity (1), that is **M1***M2>1, and thus the laser beam leaving the collimating lens (**L1**) is expanded in one dimension. There will be many cases in which the beam shaping factor is greater than unity, including, for example: where **M1**>1 and **M2**>1; where **M1**=1 and **M2**>1; and where **M1**>1 and **M2**=1. In the Beam Expansion Mode, one of the cross-sectional dimensions of the laser beam from the VLD is expanded at the output of the system to a predetermined dimension. Typically, although not necessarily, the narrower cross-sectional dimension of the laser beam will be the one that is expanded.

[0163] In the laser beam producing system shown in **FIG. 2**G, aspect-ratio control is achieved and dispersion in the output laser beam is eliminated (or minimized) for any given beam expansion ratio at each of the DOEs, by way of selecting the right combination of angles of incidence and diffraction for the two DOEs **D1** and **D2** indicated by $\theta_{i1}$, $\theta_{d1}$, $\theta_{i2}$ and $\theta_{d2}$ which, in turn, determine the proper angle between the two DOEs, indicated by $\rho$.

[0164] In this embodiment of the laser beam producing system, the inherent astigmatism of the laser beam leaving the VLD is either adjusted or eliminated by choosing proper divergence or convergence of the laser beam leaving the collimating lens **L1**. The (x,y) position of visible laser diode VLD is adjustable relative to the lens **L1** during the parameter adjustment stage of the system assembly process, in

order to adjust the divergence or convergence of the beam leaving lens L1. The z position of visible laser diode VLD is adjustable relative to the lens L1 during the parameter adjustment stage of the system assembly process in order to align the VLD to the optical axis of lens L1. Also, the position of DOE D2 is adjustable along its optical axis relative to DOE D1 during the alignment stage of the system assembly process in order to set the focal length of the output laser beam to the desired value.

[0165] Eighth Illustrative System Embodiment oof the Laser Beam Producing System of the Present Invention

[0166] In **FIG. 2**H, the eighth illustrative embodiment of the laser beam producing system hereof ("System Embodiment No. 8") comprises: a laser beam source, such as a visible laser diode (VLD); a collimating lens (L1) realizable as a refractive lens, a HOE, a CGH or other DOE, a grin lens, zone plate(s), etc., for collimating the laser beam as it is transmitted through collimating lens L1 and through the system in a P-incident manner; a fixed spatial-frequency diffractive optical element (DOE), i.e. diffraction grating, indicated by D1; a variable spatial-frequency diffractive optical element (DOE) indicated by D2, adjustably mounted relative to DOE D1; and a focusing lens (L2), realizable as a refractive lens, a HOE, a DOE, grin lens, zone plate(s) or the like, disposed after the second DOE D2, and adjustably mounted relative thereto, for focusing the output laser beam to some point in space. Collectively, the collimating lens L1, the fixed spatial-frequency DOE D1, the variable spatial-frequency DOE D2 and focusing lens L2 comprise a laser beam-modifying (sub)system in accordance with the present invention. Each of the DOEs in this system embodiment can be realized as a transmission-type HOE, a CGH, a surface-relief hologram, or other diffractive optical element.

[0167] In this illustrative embodiment of the optical system of the present invention, focusing lens L2 is disposed after the second focusing DOE D2 in order to provide additional optical power to the exiting laser beam. This optical arrangement would be useful in applications employing delta-focusing. This delta-focusing yields the benefits of reduced spot aberrations due to the optical power of DOE D2 as well as increased modularity of the system.

[0168] In this embodiment, the total beam-shaping factor ($M=M_1M_2$) for the laser beam modifying subsystem is greater than unity (1), that is M1*M2>1, and thus the laser beam leaving the collimating lens (L1) is expanded in one dimension. There will be many cases in which the beam shaping factor is greater than unity, including, for example: where M1>1 and M2>1; where M1=1 and M2>1; and where M1>1 and M2=1. In the Beam Expansion Mode, one of the cross-sectional dimensions of the laser beam from the VLD is expanded at the output of the system to a predetermined dimension. Typically, although not necessarily, the narrower cross-sectional dimension of the laser beam will be the one that is expanded.

[0169] In the laser beam producing system shown in **FIG. 2**H, aspect-ratio control is achieved and dispersion in the output laser beam is eliminated (or minimized) for any given beam expansion ratio at each of the DOEs, by way of selecting the right combination of angles of incidence and diffraction for the two DOEs D1 and D2 indicated by $\theta_{i1}$, $\theta_{d1}$, $\theta_{i2}$ and $\theta_{d2}$, which, in turn, determine the proper angle between the two DOEs, indicated by $\rho$.

[0170] In this embodiment of the laser beam producing system, the inherent astigmatism of the laser beam leaving the VLD is either adjusted or eliminated by choosing proper divergence or convergence of the laser beam leaving the collimating lens L1. The (x,y) position of visible laser diode VLD is adjustable relative to the lens L1 during the parameter adjustment stage of the system assembly process, in order to adjust the divergence or convergence of the beam leaving lens L1. The z position of visible laser diode VLD is adjustable relative to the lens L1 during the parameter adjustment stage of the system assembly process, in order to align the VLD to the optical axis of lens L1. Also, the position of lens L2 is adjustable along its optical axis relative to DOED2 during the alignment stage of the system assembly process in order to set the average focal length of the output laser beam to the desired value for use by the delta-focusing system.

[0171] Ninth Illustrative System Embodiment of the Laser Beam Producing System of the Present Invention

[0172] In **FIG. 21**, the ninth illustrative embodiment of the laser beam producing system hereof ("System Embodiment No. 9") comprises: a laser beam source, such as a visible laser diode (VLD), for producing a laser beam from its junction; a collimating lens (L1), realizable as a refractive lens, a HOE, CGH or other DOE, a grin lens, zone plate(s), etc., for collimating the laser beam as it is transmitted through collimating lens L1 and through the system in an S-incident manner; a fixed spatial-frequency diffractive optical element (DOE), i.e. diffraction grating, indicated by D1; a fixed spatial-frequency diffractive optical element (DOE) indicated by D2; and a focusing lens (L2), realizable as a refractive lens, holographic optical element (HOE), diffractive optical element (DOE), grin lens, zone plate(s) or the like, disposed between DOE D1 and DOE D2 and adjustably translatable along its optical axis for focusing the output laser beam to some point in space. Collectively, the collimating lens L1, the fixed spatial-frequency DOE D1, the fixed spatial-frequency DOE D2, and focusing lens L2 comprise a laser beam-modifying (sub)system in accordance with the present invention. Each of the DOEs in this system embodiment can be realized as a transmission-type HOE, a CGH, a surface-relief hologram, or other diffractive optical element.

[0173] In this embodiment, the total beam-shaping factor ($M=M_1M_2$) for the laser beam modifying subsystem is less than unity (1), that is M1*M2<1, and thus the laser beam leaving the collimating lens (L1) is compressed in one dimension. Notably, there will be many cases in which the beam shaping factor is less than unity, including, for example: where M1<1 and M2<1; where M1=1 and M2<1; and where M1<1 and M2=1. In the Beam Compression Mode, one of the cross-sectional dimensions of the laser beam from the VLD is compressed at the output of the system to a predetermined dimension. Typically, although not necessarily, the wider cross-sectional dimension of the laser beam will be the one that is compressed.

[0174] In the laser beam producing system shown in **FIG. 2**I, aspect-ratio control is achieved and dispersion in the output laser beam is eliminated (or minimized) for any given beam expansion or beam compression ratio at each of the DOEs, by way of selecting the right combination of angles of incidence and diffraction for the two DOEs D1 and D2

indicated by $\theta_{i1}$, $\theta_{d1}$, $\theta_{i2}$ and $\theta_{d2}$, which, in turn, determine the proper angle between the two DOEs, indicated by $\rho$.

[0175] In this embodiment of the laser beam producing system, lenses L1 and L2 are chosen such that the desired focus is achieved and the inherent astigmatism of the laser beam leaving the VLD is either adjusted or eliminated. Neither lens L1 nor L2 independently set the astigmatism nor the focus. Rather the combined set of lenses produce the combined result.

[0176] The (z) position of visible laser diode VLD is adjustable relative to the lens L1 during the parameter adjustment stage of the system assembly process, in order to adjust the divergence or convergence of the beam leaving lens L1 to produce a predetermined amount of astigmatism at a predetermined distance. The (x,y) position of visible laser diode VLD is adjustable relative to the lens L1 during the parameter adjustment stage of the system assembly process, in order to align the VLD to the optical axis of lens L1. Also, the position of lens L2 is adjustable along its optical axis between DOE D1 and DOE D2 during the alignment stage of the system assembly process in order to set the desired focus as well as the desired amount of astigmatism of the output laser beam.

[0177] Tenth Illustrative System Embodiment of the Laser Beam Producing System of the Present Invention

[0178] In **FIG. 2J**, the tenth illustrative embodiment of the laser beam producing system hereof ("System Embodiment No. 10") comprises: a laser beam source, such as a visible laser diode (VLD), for producing a laser beam from its junction; a collimating lens (L1), realizable as a refractive lens, a HOE, CGH or other DOE, a grin lens, zone plate(s), etc., for collimating the laser beam as it is transmitted through collimating lens L1 and through the system in a S-incident manner; a fixed spatial-frequency diffractive optical element (DOE), i.e. diffraction grating, indicated by D1; a variable spatial-frequency diffractive optical element (DOE) indicated by D2, adjustably translatable relative to the principal plane of DOE D1 during the alignment stage of the system assembly process; and a focusing lens (L2), realizable as a refractive lens, a HOE, a DOE, a grin lens, zone plate(s) or the like, disposed between DOE D1 and DOE D2 and adjustably translatable along its optical axis during the parameter alignment stage of the system assembly process for focusing the output laser beam to some point in space. Collectively, the collimating lens L1, the fixed spatial-frequency DOE D1, the variable spatial-frequency DOE D2, and focusing lens L2 comprise a laser beam-modifying (sub)system in accordance with the present invention. Each of the DOEs in this system embodiment can be realized as a transmission-type HOE, a CGH, a surface-relief hologram, or other diffractive optical element.

[0179] In this illustrative embodiment of the optical system of the present invention, focusing lens L2 is disposed between DOE D1 and DOE D2 in order to provide additional optical power to the exiting laser beam. This optical arrangement would be useful in applications employing delta-focusing. This delta-focusing yields the benefits of reduced spot aberrations due to the optical power of DOE D2 as well as increased modularity of the system.

[0180] In this embodiment, the total beam-shaping factor ($M=M_1M_2$) for the laser beam modifying subsystem is less than unity (1), that is M1*M2<1, and thus the laser beam leaving the collimating lens (L1) is compressed in one dimension. Notably, there will be many cases in which the beam shaping factor is less than unity, including, for example: where M1<1 and M2<1; where M1=1 and M2<1; and where M1<1 and M2=1. In the Beam Compression Mode, one of the cross-sectional dimensions of the laser beam from the VLD is compressed at the output of the system to a predetermined dimension. Typically, although not necessarily, the wider cross-sectional dimension of the laser beam will be the one that is compressed.

[0181] In the laser beam producing system shown in **FIG. 2J**, beam aspect-ratio control is achieved and dispersion in the output laser beam is eliminated (or minimized) for any given beam expansion or beam compression ratio at each of the DOEs, by way of selecting the right combination of angles of incidence and diffraction for the two DOEs D1 and D2 indicated by $\theta_{i1}$, $\theta_{d1}$, $\theta_{i2}$ and $\theta_{d2}$, which, in turn, determine the proper angle between the two DOEs, indicated by $\rho$.

[0182] In this embodiment of the laser beam producing system, the inherent astigmatism of the laser beam leaving the VLD can be either adjusted or eliminated by choosing proper divergence or convergence of the laser beam leaving the collimating lens L1. The (x,y) position of visible laser diode VLD is adjustable relative to the lens L1 during the parameter adjustment stage of the system assembly process, in order to adjust the divergence or convergence of the beam leaving lens L1. The (z) position of visible laser diode VLD is adjustable relative to the lens L1 during the parameter adjustment stage of the system assembly process, in order to align the VLD to the optical axis of lens L1. Also, the position of lens L2 is adjustable along its optical between DOE D1 and DOE D2 during the alignment stage of the system assembly process in order to set the average focal length of the output laser beam to the desired value for use by the delta-focusing system.

[0183] Eleventh Illustrative System Embodiment of the Laser Beam Producing System of the Present Invention

[0184] In **FIG. 2K**, the eleventh illustrative embodiment of the laser beam producing system hereof ("System Embodiment No. 11") comprises: a laser beam source, such as a visible laser diode (VLD), for producing a laser beam from its junction; a collimating lens (L1), realizable as a refractive lens, a HOE or other DOE, a grin lens, zone plate(s), etc., for collimating the laser beam as it is transmitted through collimating lens L1 and through the system in a P-incident manner; a fixed spatial-frequency diffractive optical element (DOE), i.e. diffraction grating, indicated by D1; a fixed spatial-frequency diffractive optical element (DOE) indicated by D2; and a focusing lens (L2), realizable as a refractive lens, holographic optical element (HOE), diffractive optical element (DOE), grin lens, zone plate(s) or the like, between DOE D1 and DOE D2 and adjustably translatable along its optical axis during the alignment stage of the system assembly process for focusing the output laser beam to some point i n space. Collectively, the collimating lens L1, the fixed spatial-frequency DOE D1, the fixed spatial-frequency DOE D2, and the focusing lens L2 comprise a laser beam-modifying (sub)system in accordance with the present invention. Each of the DOEs in this system

embodiment can be realized as a transmission-type HOE, a CGH, a surface-relief hologram, or other diffractive optical element.

[0185] In this embodiment, the total beam-shaping factor ($M=M_1M_2$) for the laser beam modifying subsystem is greater than unity (1), that is M1*M2>1, and thus the laser beam leaving the collimating lens (L1) is expanded in one dimension. There will be many cases in which the beam shaping factor is greater than unity, including, for example: where M1>1 and M2>1; where M1=1 and M2>1; and where M1>1 and M2=1. In the Beam Expansion Mode, one of the cross-sectional dimensions of the laser beam from the VLD is expanded at the output of the system to a predetermined dimension. Typically, although not necessarily, the narrower cross-sectional dimension of the laser beam will be the one that is expanded.

[0186] In the laser beam producing system shown in **FIG. 2**K, beam aspect-ratio is controlled and dispersion in the output laser beam is eliminated (or minimized) for any given beam expansion ratio at each of the DOEs, by way of selecting the right combination of angles of incidence and diffraction for the two DOEs D1 and D2 indicated by $\theta_{i1}$, $\theta_{d1}$, $\theta_{i2}$ and $\theta_{d2}$ which, in turn, determine the proper angle between the two DOEs, indicated by p.

[0187] In this embodiment of the laser beam producing system, lenses L1 and L2 are chosen such that the desired focus is achieved and the inherent astigmatism of the laser beam leaving the VLD is either adjusted or eliminated. Neither lens L1 nor L2 independently set the astigmatism nor the focus. Rather the combined set of lenses produce the combined result.

[0188] The (z) position of visible laser diode VLD is adjustable relative to the lens L1 during the parameter adjustment stage of the system assembly process, in order to adjust the divergence or convergence of the beam leaving lens L1 to produce a predetermined amount of astigmatism at a predetermined distance. The (x,y) position of visible laser diode VLD is adjustable relative to the lens L1 during the parameter adjustment stage of the system assembly process, in order to align the VLD to the optical axis of lens L1. Also, the position of lens L2 is adjustable along its optical axis between DOE D1 and DOE D2 during the alignment stage of the system assembly process in order to set the desired focus as well as the desired amount of astigmatism of the output laser beam.

[0189] Twelfth Illustrative System Embodiment of the Laser Beam Producing System of the Present Invention

[0190] In **FIG. 2**L, the twelfth illustrative embodiment of the laser beam producing system hereof ("System Embodiment No. 12") comprises: a laser beam source, such as a visible laser diode (VLD), for producing a laser beam from its junction; a collimating lens (L1), realizable as a refractive lens, a HOE, CGH or other DOE, a grin lens, zone plate(s), etc., for collimating the laser beam as it is transmitted through collimating lens L1 and through the system in a P-incident manner; a fixed spatial-frequency diffractive optical element (DOE), i.e. diffraction grating, indicated by D1; a variable spatial-frequency diffractive optical element (DOE) indicated by D2, adjustably translatable relative to the principal plane of DOE D1 during the alignment stage of the system assembly process; and a focusing lens (L2), realizable as a refractive lens, a HOE, a CGH or other a DOE, a grin lens, zone plate(s) or the like, disposed between DOE D1 and DOE D2 and adjustably translatable along its optical axis during the parameter alignment stage of the system assembly process for focusing the output laser beam to some point in space. Collectively, the collimating lens (L1), the fixed spatial-frequency DOE (D1) and the variable spatial-frequency DOE (D2) comprise a laser beam-modifying (sub)system in accordance with the present invention. Each of the DOEs in this system embodiment can be realized as a transmission-type HOE, a CGH, a surface-relief hologram, or other diffractive optical element.

[0191] In this illustrative embodiment of the optical system of the present invention, focusing lens L2 is disposed between DOE D1 and DOE D2 in order to provide additional optical power to the exiting laser beam. This optical arrangement would be useful in applications employing delta-focusing. This delta-focusing yields the benefits of reduced spot aberrations due to the optical power of DOE D2 as well as increased modularity of the system.

[0192] In this embodiment, the total beam-shaping factor ($M=M_1M_2$) for the laser beam modifying subsystem is greater than unity (1), that is M1*M2>1, and thus the laser beam leaving the collimating lens (L1) is expanded in one dimension. There will be many cases in which the beam shaping factor is greater than unity. including, for example: where M1>1 and M2>1; where M1=1 and M2>1; and where M1>1 and M2=1. In the Beam Expansion Mode, one of the cross-sectional dimensions of the laser beam from the VLD is expanded at the output of the system to a predetermined dimension. Typically, although not necessarily, the narrower cross-sectional dimension of the laser beam will be the one that is expanded.

[0193] In the laser beam producing system shown in **FIG. 2**L, beam aspect-ratio control is achieved and dispersion in the output laser beam is eliminated (or minimized) for any given beam expansion ratio at each of the DOEs, by way of selecting the right combination of angles of incidence and diffraction for the two DOEs D1 and D2 indicated by $\theta_{i1}$, $\theta_{d1}$, $\theta_{i2}$ and $\theta_{d2}$ which, in turn, determine the proper angle between the two DOEs, indicated by $\rho$.

[0194] In this embodiment of the laser beam producing system, the inherent astigmatism of the laser beam leaving the VLD can be either adjusted or eliminated by choosing proper divergence or convergence of the laser beam leaving the collimating lens L1. The (x,y) position of visible laser diode VLD is adjustable relative to the lens L1 during the parameter adjustment stage of the system assembly process, in order to adjust the divergence or convergence of the beam leaving lens L1. The (z) position of visible laser diode VLD is adjustable relative to the lens L1 during the parameter adjustment stage of the system assembly process, in order to align the VLD to the optical axis of lens L1. Also, the position of lens L2 is adjustable along its optical axis between DOE D1 and DOE D2 during the alignment stage of the system assembly process in order to set the average focal length of the output laser beam to the desired value for use by the delta-focusing system.

[0195] Thirteenth Illustrative System Embodiment of the Laser Beam Producing System of the Present Invention

[0196] In **FIG. 2**M, the thirteenth illustrative embodiment of the laser beam producing system hereof ("System

Embodiment No. 13") comprises: a laser beam source, such as a visible laser diode (VLD), for producing a laser beam from its junction; an imaging lens (L1), realizable as a refractive lens, a HOE or other DOE, a grin lens, zone plate(s), etc., for imaging the laser source to the focal distance as it is transmitted through imaging lens L1 and through the system in a S-incident manner; a fixed spatial-frequency diffractive optical element (DOE), i.e. diffraction grating, indicated by D1; and a fixed spatial-frequency diffractive optical element (DOE) indicated by D2. Collectively, the collimating lens Li, the fixed spatial-frequency DOE D1 and the fixed spatial-frequency DOE D2 comprise a laser beam-modifying (sub)system in accordance with the present invention. Each of the DOEs in this system embodiment can be realized as a transmission-type HOE, a CGH, a surface-relief hologram, or other diffractive optical element.

[0197] In this embodiment, the total beam-shaping factor ($M=M_1M_2$) for the laser beam modifying subsystem is less than unity (1), that is M1*M2<1, and thus the laser beam leaving the collimating lens (L1) is compressed in one dimension. Notably, there will be many cases in which the beam shaping factor is less than unity, including, for example: where M1<1 and M2<1; where M1=1 and M2<1; and where M1<1 and M2=1. In the Beam Compression Mode, one of the cross-sectional dimensions of the laser beam from the VLD is compressed at the output of the system to a predetermined dimension. Typically, although not necessarily, the wider cross-sectional dimension of the laser beam will be the one that is compressed.

[0198] In the laser beam producing system shown in **FIG. 2M**, beam aspect-ratio control is achieved and dispersion in the output laser beam is eliminated (or minimized) for any given beam expansion ratio at each of the DOEs, by way of selecting the right combination of angles of incidence and diffraction for the two DOEs D1 and D2 indicated by $\theta_{i1}$, $\theta_{d1}$, $\theta_{i2}$ and $\theta_{d2}$, which, in turn, determine the proper angle between the two DOEs previously defined hereinabove.

[0199] Notably, in this embodiment of the laser beam producing system, the convergence of the beam leaving focusing lens L1 need not be adjusted to provide the proper image distance to the focal point of the system, and therefore it can be used to control or eliminate the astigmatism that is inherent in the laser beam leaving the VLD. This embodiment of the laser beam producing system will be useful in applications where astigmatism inherent in the laser beam leaving the VLD must be corrected or eliminated, and there is no need to focus the output laser beam to any particular focal distance using the optics associated with the laser beam producing system.

[0200] Fourteenth Illustrative System Embodiment of the Laser Beam Producing System of the Present Invention

[0201] In **FIG. 2N**, the fourteenth illustrative embodiment of the laser beam producing system hereof ("System Embodiment No. 14") comprises: a laser beam source, such as a visible laser diode (VLD), for producing a laser beam from its junction; a focusing (non-collimating) lens (L1), realizable as a refractive lens, a HOE, CGH or other DOE, a grin lens, zone plate(s), etc., for focusing the laser beam as it is transmitted through focusing lens L1 and through the system in a P-incident manner; a fixed spatial-frequency diffractive optical element (DOE), i.e. diffraction grating, indicated by D1; and a fixed spatial-frequency diffractive optical element (DOE) indicated by D2. Collectively, the focusing lens L1, the fixed spatial-frequency DOE D1 and the fixed spatial-frequency DOE D2 comprise a laser beam-modifying subsystem in accordance with the present invention. Each of the DOEs in this system embodiment can be realized as a transmission-type HOE, a CGH, a surface-relief hologram, or other diffractive optical element.

[0202] In this embodiment, the total beam-shaping factor ($M=M_1M_2$) for the laser beam modifying subsystem is greater than unity (1), that is M1*M2>1, and thus the laser beam leaving the collimating lens (L1) is expanded in one dimension. There will be many cases in which the beam shaping factor is greater than unity, including, for example: where M1>1 and M2>1; where M1=1 and M2>1; and where M1>1 and M2=1. In the Beam Expansion Mode, one of the cross-sectional dimensions of the laser beam from the VLD is expanded at the output of the system to a predetermined dimension. Typically, although not necessarily, the narrower cross-sectional dimension of the laser beam will be the one that is expanded.

[0203] In the laser beam producing system shown in **FIG. 2N**, beam aspect-ratio control and dispersion in the output laser beam is eliminated (or minimized) for any given beam expansion ratio at each of the DOEs, by way of selecting the right combination of angles of incidence and diffraction for the two DOEs D1 and D2 indicated by $\theta_{i1}$, $\theta_{d1}$, $\theta_{i2}$ and $\theta_{d2}$, which, in turn, determine the proper angle between the two DOEs, indicated by $\rho$.

[0204] In System Embodiment No. **14** shown in **FIG. 2N**, the convergence of the beam leaving focusing lens L1 need not be adjusted to provide the proper image distance to the focal point of the system, and therefore it can be used to control or eliminate the astigmatism that is inherent in the laser beam leaving the VLD. This embodiment of the laser beam producing system will be useful in applications where astigmatism inherent in the laser beam leaving the VLD must be corrected or eliminated, and there is no need to focus the output laser beam to any particular focal distance using the optics associated with the laser beam producing system.

[0205] In each of the fourteen illustrative embodiments described hereinabove, it is preferred that optical elements L1 and L2 have axially symmetric optical properties (i.e. lenses L1 and L2 are stigmatic optical elements). In the preferred embodiments, where L1 and L2 are both refractive lenses, the lens surface profiles should be axially symmetric in order to allow for the use of both spheric and aspheric lenses. In most cases, the sub-system consisting of the VLD and lens L1, performs outside of the realm of paraxial optics; therefore lens L1 will typically be aspheric in order to minimize the spherical aberration common in non-paraxial systems. Also in most cases, the use of lens L2 typically satisfies the requirements of paraxial analysis; therefore, use of a spheric lens for this optical element is usually acceptable.

[0206] A major advantage of using an optical element with axial symmetry to realize lens L1 is that it is then be possible to use diffractive optics to modify (e.g. correct or eliminate) astigmatism in the output laser beam. Notably, if one were to realize lens L1 using an optical element not having axial symmetry, then diffractive elements (e.g. DOEs D1 and D2) could no longer be used to eliminate or correct astigmatism

in the output laser beam, and that cylindrical or toroidal lenses would be required for astigmatism control or elimination. Notably, there are number of important advantages obtained when using diffractive optics (rather than astigmatic refractive optics) to correct or eliminate astigmatism in the output laser beam astigmatism, namely: (1) simplification of the manufacture of the refractive optics (L1) as well as the diffractive optics (D1 and D2); (2) reduction in the cost of optical elements; and (3) simplification of parameter alignment during the assembly process.

[0207] Methods for Designing Laser Beam Producing Systems of the Illustrative System Embodiments of the Present Invention Where Focus Control is Desired but Neither Astigmatism Correction bor Delta-focusing are Required: System Embodiments Nos. (1) & (5)

[0208] System Embodiment Nos. (1) and (5) of the laser beam producing system of the present invention can be designed using the below-described design methodology, wherein the steps thereof are set forth in FIGS. **3A1** through **3A3**.

[0209] As indicated at Block A in **FIG. 3A**, the first step in the design method involves establishing end-user requirements for the laser beam producing module under design. In bar code symbol scanning applications, where the laser beam output from the system under design is to be used to scan the elements of bar code symbols, such end-user requirements will typically include, for example, the working distance from the scanner, the depth of field of the scanning system, the type of bar code symbols that the laser beam must read, the minimal width of the elements in the bar code symbols, etc.

[0210] As indicated at Block B, the second step in the design method involves determining the necessary spot-size, aspect-ratio and waist dimensions of the output laser beam in order to scan the desired bar code determined during step (1) described at Block A.

[0211] As indicated at Block C, the third step in the design method involves determining the module focal distance, $f_{module}$, that will provide the desired depth of field for the end-user scanning system at the desired working distance.

[0212] As indicated at Block D in **FIG. 3A1**, the fourth step in the design method involves using a Gaussian beam propagation model to determine the required beam size and aspect-ratio leaving the laser beam producing system. Notably, the steps at Blocks B, C and D are somewhat interconnected inasmuch as the spot-size, depth-of-field, and focal distance of the output laser beam, are all aspects of Gaussian beam propagation. The values of each of these parameters have an effect on the other parameters. Therefore, it is understood that the order in which such parameters are determined, may be different from embodiment to embodiment.

[0213] As indicated at Block E in **FIG. 3A2**, the fifth step in the design method involves choosing an acceptable laser source (e.g. a VLD). In an ideal world, criteria for acceptability may include limits on beam divergence and amount of astigmatism, as well as aspect ratio, wavelength, and bandwidth. However, in practice, such criteria will be satisfied by ensuring that the aspect ratio of the beam leaving the VLD is not too large for compression by the DOE-based subsystem.

[0214] As indicated at Block F in **FIG. 3A2**, the sixth step in the design method involves determining an appropriate value for the beam-shaping factors of DOEs D1 and D2 which ensures that the aspect-ratio of the beam entering the laser beam-modifying subsystem (D1 and D2) from the VLD is sufficiently modified so that output laser beam has the desired aspect ratio determined at Block D described above. Notably, the beam-shaping factor M (also called the expansion ratio), defined as $M=M_1M_2$, provides beam compression within the laser beam modifying subsystem when $M<1$, and provides beam expansion within the laser beam modifying subsystem when $M>1$.

[0215] As indicated at Block G in **FIG. 3A2**, the seventh step in the design method involves using the beam-shaping factor determined at Block F, to determine the design angles, $\theta_{i1}$, $\theta_{d1}$, $\theta_{i2}$ and $\theta_{d2}$ (expressed at the reconstruction/design wavelength, $\lambda_R$) for the two DOEs D1 and D2, which provides an optical subsystem wherein the laser beam output from the second DOE D2 thereof has (1) effectively zero net beam dispersion, and (2) the desired aspect-ratio determined at Block B in **FIG. 3A1**. Notably, this step of the design method involves designing the dual-DOE laser beam modifying subsystem using either of the optical design procedures described in detail hereinbelow, As indicated at Block H in **FIG. 3A3**, the eighth step in the design method involves determining the theoretical distance from the VLD to the first lens element L1 that produces an output laser beam having the desired beam size determined at Block D. Notably, this computation is carried out assuming a VLD beam having an elliptical spot aligned along the optical axis of lens Li.

[0216] As indicated at Block I in **FIG. 3A3**, the ninth step in the design method involves determining the focal length of lens element L1 that produces an output laser beam having the desired focus determined at Block C in **FIG. 3A1**.

[0217] Methods for Designing Laser Beam Producing Systems of the Illustrative System Embodiments of the Present Invention Where Focus Control and Astigmatism Correction are Desired and Delta-focusing is not Required: System Embodiments Nos. (2), (3), (6), (7), (9), & (11)

[0218] System Embodiment Nos. (2), (3), (6), (7), (9) and (11) of the laser beam producing system of the present invention can be designed using the below-described design methodology, wherein the steps thereof are set forth in FIGS. **3B1** through **3B2**.

[0219] As indicated at Block A in **FIG. 3B1**, the first step in the design method involves establishing end-user requirements for the laser beam producing module under design. In bar code symbol scanning applications, where the laser beam output from the system under design is to be used to scan the elements of bar code symbols, such end-user requirement will typically include, for example, the working distance from the scanning system, the depth of field of the scanning system, the type of bar code symbols that the laser beam must read, the minimal width of the elements in the bar code symbols, etc.

[0220] As indicated at Block B, the second step in the design method involves determining the necessary spot-size, aspect-ratio and waist dimensions of the output laser beam in order to scan the desired bar code determined during step (1) described in Block A.

[0221] As indicated at Block C, the third step in the design method involves determining the module focal distance, $f_{module}$, that will provide the desired depth of field for the end-user scanning system.

[0222] As indicated at Block D in **FIG. 3B1**, the fourth step in the design method involves using a Gaussian beam propagation model to determine the required beam-size and aspect-ratio leaving the laser beam producing system. Notably, the steps at Blocks B, C and D are somewhat interconnected inasmuch as the beam spot-size, depth-of-field, and focal distance are all aspects of Gaussian beam propagation. The values of each of these parameters have an effect on the other parameters. Therefore, it is understood that the order in which such parameters are determined may be different, from embodiment to embodiment.

[0223] As indicated at Block E in **FIG. 3B2**, the fifth step in the design method involves choosing an acceptable laser source (e.g. a VLD). Criteria for acceptability may include limits on beam divergence and amount of astigmatism, as well as aspect ratio, wavelength, and bandwidth.

[0224] As indicated at Block F in **FIG. 3B2**, the sixth step in the design method involves determining an appropriate value for the beam-shaping factor of DOEs D1 and D2 which ensures that the aspect-ratio of the beam entering the laser beam-modifying subsystem (D1 and D2) from the VLD is sufficiently modified so that output laser beam has the desired aspect-ratio determined at Block D described above. Notably, the beam-shaping factor M (also called the expansion ratio), defined as $M=M_1M_2$, provides beam compression within the laser beam modifying subsystem when $M<1$, and provides beam expansion within the laser beam modifying subsystem when $M>1$.

[0225] As indicated at Block G in **FIG. 3B2**, the seventh step in the design method involves using the beam-shaping factor determined at Block F, to determine the design angles, $\theta_{i1}$, $\theta_{d1}$, $\theta_{i2}$ and $\theta_{d2}$ (expressed at the reconstruction wavelength, $\lambda_R$) for the two DOEs D1 and D2, which provides an optical subsystem wherein the laser beam output from the second DOE D2 thereof has (1) effectively zero net beam dispersion, and (2) the desired aspect-ratio determined at Block B in **FIG. 3A1**. Notably, this step of the design method involves designing the dual-DOE laser beam modifying subsystem using either of the optical design procedures described in detail hereinbelow.

[0226] As indicated at Block H in **FIG. 3B3**, the eighth step in the design method involves determining the distance from the VLD to the first lens element L1 that produces an output laser beam having the desired beam size determined at Block D. Notably, this calculation is carried out assuming that the elliptical beam produced from the VLD **4** is aligned along the optical axis of lens L1.

[0227] The remaining design procedure diverges for the present embodiments ((2), (3), (6), (7), (9) and (11)); therefore, the remaining steps will be handled below on a by embodiment basis.

[0228] System Embodiment Nos. (2) & (6):

[0229] For System Embodiment Nos. (2) and (6), the ninth step in the design method involves determining the focal length of lens L1 so that, when the correct amount of separation exists between the VLD and lens L1, the resulting convergence/divergence of the laser beam will eliminate astigmatism upon passing through both DOEs D1 and D2.

[0230] The tenth step in the design method for embodiments (2) and (6) involves determining the focal length of lens L2 in order to focus the beam at the desired focal point determined at Block C in **FIG. 3B1**.

[0231] System Embodiment Nos. (3) & (7):

[0232] For System Embodiment Nos. (3) and (7), the ninth step in the design method involves determining the focal length of lens L1 so that, when the correct amount of separation exists between the VLD and lens L1, the resulting convergence/divergence of the laser beam will eliminate astigmatism upon passing through DOE D1 only.

[0233] The tenth step in the design method for embodiments (3) and (7) involves determining the design parameters of DOE D2 in order to focus the beam at the desired focal point determined at Block C in **FIG. 3B1**. In these embodiments, DOE D2 is a stigmatic element.

[0234] System Embodiment Nos. (9) &(11):

[0235] For System Embodiment Nos. (9) and (11), the ninth step in the design method involves determining the focal length of lens L1 so that, when the correct amount of separation exists between the VLD and lens L1, the resulting convergence/divergence of the laser beam will produce a predetermined amount of astigmatism upon passing through DOE D1 only.

[0236] The tenth step in the design method for embodiments (9) and (11) involves determining the focal length of lens L2 in order to focus the beam at the desired focal point determined at Block C in **FIG. 3B1**. The known astigmatic beam entering lens L2 will be focused through DOE D2 resulting in a focused, stigmatic spot.

[0237] Methods for Designing Laser Beam Producing Systems of the Illustrative System Embodiments of the Present Invention Where Focus Control, Astigmatism Correction and Delta-focusing in Output Laser Beam are Desired: System Embodiments Nos. (4), (8), (10) (12)

[0238] System Embodiment Nos. (4), (8), (10) and (12) of the laser beam producing system hereof can be designed using the below-described design methodology, wherein the steps thereof are set forth in FIGS. **3C1** through **3C**.

[0239] As indicated at Block Ain **FIG. 3C1**, the first step in the design method involves establishing end-user requirements for the laser beam producing module under design. In bar code symbol scanning applications, where the laser beam output from the system under design is to be used to scan the elements of bar code symbols, such end-user requirement will typically include, for example, the working distance from the scanning system, the depth of field of the scanning system, the type of bar code symbols that the laser beam must read, the minimal width of the elements in the bar code symbols, etc.

[0240] As indicated at Block B, the second step in the design method involves determining the necessary spot-size, aspect-ratio and waist dimensions of the output laser beam in order to scan the desired bar code determined during step (1) described above.

[0241] As indicated at Block C, the third step in the design method involves determining the module focal distance, $f_{module}$, that will provide the desired depth of field for the end-user scanning system at the desired working distance.

[0242] As indicated at Block D in **FIG. 3C1**, the fourth step in the design method involves using a Gaussian beam propagation model to determine the required beam-size and aspect-ratio leaving the laser beam producing system. Notably, the steps at Blocks B, C and D are somewhat interconnected inasmuch as the beam spot-size, depth-of-field, and focal distance are all aspects of Gaussian beam propagation. The values of each of these parameters have an effect on the other parameters. Therefore, it is understood that, from embodiment to embodiment, the order of determination of such parameters may be different.

[0243] As indicated at Block E in **FIG. 3C2**, the fifth step in the design method involves choosing an acceptable laser source (e.g. a VLD). Criteria for acceptability may include limits on beam divergence and amount of astigmatism, as well as aspect ratio, wavelength, and bandwidth.

[0244] As indicated at Block F in **FIG. 3C2**, the sixth step in the design method involves determining an appropriate value for the beam-shaping factors of DOEs D1 and D2 which ensures that the aspect-ratio of the beam entering the laser beam-modifying subsystem (D1 and D2) from the VLD is sufficiently modified so that output laser beam has the desired aspect-ratio determined at Block D described above. Notably, the beam-shaping factor M (also called the expansion ratio), defined as $M=M_1M_2$, provides beam compression within the laser beam modifying subsystem when $M<1$, and provides beam expansion within the laser beam modifying subsystem when $M>1$.

[0245] As indicated at Block G in **FIG. 3C2**, the seventh step in the design method involves using the Beam Shaping Factor determined at Block F, to determine the design angles, $\theta_{i1}$, $\theta_{d1}$, $\theta_{i2}$ and $\theta_{d2}$, (expressed at the reconstruction wavelength, $\lambda_R$) for the two DOEs D1 and D2, which provides an optical subsystem wherein the laser beam output from the second DOE D2 thereof has (1) effectively zero net beam dispersion, and (2) the desired aspect-ratio determined at Block B in **FIG. 3A1**. Notably, this step of the design method involves designing the dual-HOE laser beam modifying subsystem using either of the optical design procedures described in detail hereinbelow.

[0246] As indicated at Block H in **FIG. 3C3**, the eighth step in the design method involves determining the distance from the VLD to the first lens element L1 that produces an output laser beam having the desired beam size determined at Block D.

[0247] As indicated in Block I in **FIG. 3C2**, the ninth step in the design method involves determining the focal length of lens L1 so that, when the correct amount of separation exists between the VLD and lens L1, the resulting convergence/divergence of the laser beam will eliminate astigmatism upon passing through DOE D1 only.

[0248] As indicated at Block J in **FIG. 3C3**, the tenth step of the design method is to assume DOE D2 to be a stigmatic optical element with no optical power (it is not, in general, for System Embodiment Nos. 4, 8, 10, 12) and then determine the focal length of the final lens element L2 in the system such that the desired "average" focal distance of the output laser beam is achieved.

[0249] As indicated at Block Kin **FIG. 3C3**, the eleventh step of the design method involves determining the design parameters of HOE D2 that produce the desired delta-focus of the laser beam through the lens L2.

[0250] Methods for Designing Laser Beam Producing Systems of the Illustrative System Embodiments of the Present Invention Where Astigmatism Correction is Desired but Neither Focus Control nor Delta-focusing are Required: System Embodiments Nos. (13) & (14)

[0251] System Embodiment Nos. (13) and (14) of the laser beam producing system of the present invention can be designed using the below-described design methodology, wherein the steps thereof are set forth in FIGS. **3D1** through **3D3**.

[0252] As indicated at Block A in **FIG. 3D1**, the first step in the design method involves establishing end-user requirements for the laser beam producing module under design. These embodiments are similar in structure to System Embodiment Nos. (1) and (5). However, since the design goal here is different, the use will be different as will the end-user requirements. For the sake of this discussion, the chosen requirements will be a set final aspect ratio and beam spot size. Notably for this discussion, the beam-shaping that occurs will necessarily be aspect-ratio reduction. It is understood that one skilled in the art could adjust this design procedure to meet a different combination of end-user requirements.

[0253] As indicated at Block B in **FIG. 3D1**, the second step in the design method involves using a Gaussian beam propagation model to determine the required beam aspect-ratio leaving the laser beam producing system in order to produce the specified aspect-ratio at focus.

[0254] As indicated at Block C in **FIG. 3D1**, the third step in the design method involves choosing an acceptable laser source (e.g. a VLD). Criteria for acceptability may include limits on beam divergence and amount of astigmatism, as well as aspect ratio, wavelength, and bandwidth.

[0255] As indicated at Block D in **FIG. 3D1**, the fourth step in the design method involves determining an appropriate value for the beam-shaping factors of DOEs D1 and D2 which ensures that the aspect-ratio of the beam entering the laser beam-modifying subsystem (D1 and D2) from the VLD is sufficiently modified so that output laser beam has the desired aspect ratio determined at Block B described above. Notably, the beam-shaping factor M (also called the expansion ratio), defined as $M=M_1M_2$, provides beam compression within the laser beam modifying subsystem when $M<1$, and provides beam expansion within the laser beam modifying subsystem when $M>1$.

[0256] As indicated at Block E in **FIG. 3D2**, the fifth step in the design method involves using the beam-shaping factor determined at Block D, to determine the design angles, $\theta_{i1}$, $\theta_{d1}$, $\theta_{i2}$ and $\theta_{d2}$, (expressed at the reconstruction wavelength, $\lambda_R$) for the two DOEs D1 and D2, which provides an optical subsystem wherein the laser beam output from the second DOE D2 thereof has (1) effectively zero net subsystem is represented using a "central-ray" model, as shown in **FIG. 3E**. Using this reasonable modeling assumption,

DOE D1 can be represented as a first fixed spatial-frequency hologram having fringe-spacing d1, whereas DOE D2 can be represented as a second fixed spatial-frequency hologram having fringe-spacing d2. This central-ray model provides a perfect description for the central ray of the laser beam, in all cases herein considered, but less than a perfect description for non-collimated rays (i.e. rays not parallel to the center ray of the laser beam). If the beam passing through DOEs D1 and D2 has a relatively large f/#. then the effect of the non-collimated rays will be negligible.

[0257] In defining the laser beam modifying (optics) subsystem, the angle of incidence of the laser beam from lens L1 onto the front surface of first fixed-spatial-frequency DOE (D1) is specified by $\theta_{i1}$, whereas the angle of diffraction therefrom is specified by $\theta_{d1}$, as illustrated in **FIG. 3E**. The angle of incidence of the laser beam from the first fixed spatial-frequency DOE D1 onto the front surface of second fixed spatial-frequency DOE D2 is specified by $\theta_{i2}$, whereas the angle of diffraction therefrom is specified by $\theta_{d2}$. These four parameters $\theta_{i1}$, $\theta_{d1}$, $\theta_{i2}$ and $\theta_{d2}$, completely define the dual-DOE subsystem hereof, and thus provides four degrees of freedom within the geometrical optics model thereof. Applying the well known "diffraction grating" equation to the first and second DOEs, D1 and D2, respectively, the following two system equations are obtained:

$$\frac{\lambda_R}{d_1} = \sin\theta_{i1} + \sin\theta_{d1} \quad \text{(Eq. 1)}$$

$$\frac{\lambda_R}{d_2} = \sin\theta_{i2} + \sin\theta_{d2} \quad \text{(Eq. 2)}$$

[0258] wherein the parameter $\lambda_R$ is the design (i.e. reconstruction) wavelength of the laser beam used during reconstruction, and parameters $d_1$ and $d_2$ are the surface spacing of the fringes within the first and second DOEs D1 and D2. respectively.

[0259] Using simple geometry, the following expression is obtained:

$$\rho=\theta_{d1}-\theta_{i2} \quad \text{(Eq. 3)}$$

[0260] wherein ρ, the DOE tilt angle, is the angle formed between the surfaces of the two DOEs D1 and D2 within the laser beam modifying subsystem under design. Notably, parameter ρ has been previously defined in the geometrical optics model used to design the laser beam production modules disclosed in Applicant's copending U.S. patent application Ser. No. 08/573,949 filed Dec. 18, 1995, incorporated herein by reference.

[0261] The above-described geometrical optics model will be used to determine the optimum configuration of the dual-DOE subsystem which produces an output laser beam having minimum beam dispersion and prescribed beam aspect-ratio. Notably, correction for laser beam astigmatism is not addressed in this modeling procedure; however, this does not preclude the ability to control astigmatism when this procedure is used. The dual-DOE subsystem contains four degrees of design freedom, wherein two of those degrees of freedom are removed by requiring minimum dispersion and a specific beam expansion. This leaves two additional degrees of freedom in the design process to meet some additional design goals.

[0262] Specifying the Design Criteria for the Laser Beam Modifying Subsystem of the Present Invention

[0263] In the illustrative embodiments, the dual-DOE laser beam modifying subsystem must satisfy two design constraints, namely: (1) for an input laser beam having a first specified beam aspect-ratio, produce an output laser beam having a second specified beam aspect-ratio; and (2) produce an output laser beam, wherein the dispersion characteristics or "dispersion" thereof (defined by $d\theta_{d2}/d\lambda$) are minimized over the spectral bandwidth of the VLD beam.

[0264] The first design constraint is achieved by compressing or expanding one dimension of the laser beam incident upon the first DOE D1. Thus, this design constraint is best described as the beam-shaping factor (e.g. expansion ratio), M. which is equal to the product of the individual expansion ratios for DOEs D1 and D2, designated by $M_1$ and $M_2$, respectively, wherein $M_1=D_{output1}/D_{input1}$ and $M_2=D_{output2}/D_{input2}$, and D represents dimension of the beam in the compression/expansion direction (i.e. common plane of incidence of DOEs D1 and D2). In order to meet this design constraint, the following equations must be satisfied:

$$M_1 = \frac{\cos\theta_{d1}}{\cos\theta_{i1}} \quad \text{(Eq. 4)}$$

$$M_2 = \frac{\cos\theta_{d2}}{\cos\theta_{i2}} \quad \text{(Eq. 5)}$$

[0265] The second constraint (i.e. relating to minimizing dispersion) is achieved by satisfying the following equation:

$$d_2 \cos\theta_{i2}=d_1 \cos\theta_{d1} \quad \text{(Eq. 6)}$$

[0266] wherein parameters $d_1$ and $d_2$ are the surface spacing of the fringes within the first and second DOEs D1 and D2, respectively.

[0267] A First Procedure for Designing the Dual-DOE Subsystem so that the Prespecified Design Constraints are Satisfied

[0268] An optimal design for the dual-DOE laser beam modifying subsystem hereof, which satisfies the above-specified design constraints, can be determined using the following procedure in conjunction with the geometrical optics model described above.

[0269] As indicated at Block A in **FIG. 3F1**, the first step of the design procedure involves choosing values for the beam compression/expansion ratios $M_1$ and $M_2$ such that the total desired Beam Shaping Factor M satisfies the expression $M=M_1M_2$. Also, at this stage of the design method, the design (i.e. reconstruction) wavelength $\lambda_R$, and the angle of incidence $\theta_{i1}$, are chosen by the DOE-subsystem designer.

[0270] As indicated at Block B in **FIG. 3F1**, the second step of the design procedure involves solving for the angle of diffraction $\theta_{d1}$ at DOE D1 using Equation No. (4) set forth above.

[0271] As indicated at Block C in **FIG. 3F1**, the third step of the design procedure involves solving for the fringe structure (surface) spacing $d_1$ of DOE D1. using Equation No. (1) set forth above.

[0272] As indicated at Block D in **FIG. 3F1**, the fourth step of the design procedure involves solving for the angle of incidence $\theta_{i2}$ at DOE D**2**, using the following equation:

$$\theta_{i2} = \arctan\left[\frac{1}{2}\left(M_2^2 K - K + \frac{1}{K}\right)\right] \quad \text{(Eq. 7)}$$

$$\text{where } K = \frac{d_1 \cos\theta_{d1}}{\lambda}$$

[0273] As indicated at Block E in **FIG. 3F1**, the fifth step of the design procedure involves solving for the DOE tilt angle ρ, using Equation No. (3).

[0274] As indicated at Block F in **FIG. 3F2**, the sixth step of the design procedure involves solving for the angle of diffraction $\theta_{d2}$ at DOE D**2**. using Equation No. (5).

[0275] As indicated at Block G in **FIG. 3F2**, the seventh step of the design procedure involves solving for the fringe surface spacing $d_2$ within DOE D**2**, using Equation No. (2).

[0276] The above described parameters specify the design parameters for the dual-DOE subsystem at the reconstruction wavelength $\lambda_R$ which typically be specified by the characteristic wavelength of the VLD used to realize the laser beam producing system under design.

[0277] A Second Procedure for Determining the Design Angles for the Diffractive Optical Elements within the Laser Beam Modifying Subassembly of the System of the Present Invention

[0278] According to the second design procedure, the two equations for (1) zero beam dispersion and (2) the desired beam aspect-ratio are solved and then graphed (i.e. plotted) to determine the intersection of the two functions which yields the design point at which both design requirements are simultaneously satisfied. Typically, a few iterations of the solutions of the equations will be required to determine the design point to an acceptable level of precision. This procedure has been described in detail in Applicant's copending application Ser. No 08/573,949, incorporated herein by reference.

[0279] Notably, the graphical approach described hereinabove provides additional information about the residual dispersion that will exist when the wavelength of the VLD laser beam differs from the design wavelength. The graphical approach also provides information regarding the rate of change of dispersion as a function of laser beam wavelength, which is useful in particular applications. Such information can also be obtained from the model employed in the First Procedure described above using Equation (8) which will be described in greater detail hereinafter.

[0280] Considerations when Designing the DOE-based Subsystem of the Present Invention

[0281] When designing a DOE-based laser beam modifying subsystem hereof using either of the design procedures set forth above, the following factors should be considered.

[0282] First, it is desirable to select angles of incidence and diffraction that are not too large or too different in magnitude. This will make the construction of the DOEs simpler. This is an example of a supplementary goal that can be met by exercising the aforementioned unused degrees of freedom in the laser beam modifying subsystem design. Second, it is desirable to have the angular separation between the incident beam at DOE D**1** and the diffracted beam at DOE D**2** greater than zero so as to avoid interference between the zero-order beam from DOE D**1** and the diffracted beam from DOE D**2**. As this may be difficult to do, it may be necessary to provide a blocking plate or surface between the two DOEs as shown in illustrative embodiments of the present invention in **FIGS. 6C**. **10**C and **11**C. Notably, in such illustrative embodiments, the blocking plate is provided as an integral part of the module housing.

[0283] Considerations on Aspect-ratio Control and Beam Dispersion Minimization/Elimination

[0284] Provided that the desired parameters are reasonable, the system and assembly methods of the present invention enable the construction of optical systems capable of producing output laser beams having (1) a desired beam aspect-ratio and (2) zero or minimum beam dispersion. These design objectives can be accomplished over a fairly wide range of beam aspect-ratios, angles of incidence and diffraction, and angles between the two DOES. For all of the system embodiments herein, beam dispersion correction is perfect only for the center ray in the system. However, if the angle of the cone of rays passing through the laser beam modifying subsystem is relatively small, then beam dispersion correction, while not perfect, will be acceptable in many applications. In bar code scanning applications where, for example, the f-number of the focusing cone of light rays is generally on the order of 200 or more (so that the full angle subtended by the cone of light rays (i.e. the full cone angle) is less than 0.3 degrees), beam dispersion correction will be more than adequate for all rays within the light cone incident on the DOEs D**1** and D**2**.

[0285] Considerations on Astigmatism Correction

[0286] When proceeding to eliminate astigmatism in the output laser beam from the laser beam producing module, the resulting pair of designed DOEs does not change in any way. In accordance with the principles of the present invention. astigmatism correction is accomplished by adjusting the separation between the VLD and the first lens L**1** during the alignment stage of the system assembly process of the present invention. The amount of adjustment is dependent on the fixed parameters of the DOE pair (e.g. diffraction angles and angle between DOEs D**1** and D**2**) and the beam characteristics of each VLD used in the construction of each laser beam producing system.

[0287] Notably, it is possible to specifically design the laser beam modifying subsystem to eliminate a specific amount of astigmatism for a given desired focus as accomplished, for example, in System Embodiment Nos. (13) and (14). When designing such systems, the beam-shaping factor, M, can be specifically chosen to eliminate astigmatism. In all of the other system embodiments disclosed herein the beam shaping factor M is used to control aspect-ratio. However, when designing a system to eliminate astigmatism, it is understood that aspect-ratio control will be sacrificed in order to reduce astigmatism. The specific system embodiments disclosed herein can be modified using such teachings to provide numerous other types of system designs in accordance with the principle of the present invention.

[0288] The inherent astigmatism of the laser beam produced from the VLD is modified or eliminated by adjusting

the convergence or divergence of the beam incident on the dual-DOE laser beam-modifying subsystem hereof. If the laser beam-modifying subsystem is used to expand the narrower dimension of the VLD beam or to compress the wider dimension of the VLD beam (i.e. aspect-ratio reduction), then the astigmatism is minimized by using a converging beam incident on the laser beam-modifying subsystem. If the laser beam-modifying subsystem is used to compress the narrower dimension of the VLD beam or to expand the wider dimension of the VLD beam (i.e. aspect-ratio enlargement), then the astigmatism is minimized by using a diverging beam incident on the laser beam-modifying subsystem.

[0289] Considerations on Adjustment of the Focal Length of the Stigmatic Output Laser Beam

[0290] Relatively simple optics following the laser beam-modifying subsystem, as shown in **FIG. 2H, 2J**, and 2L, can be used to focus the astigmatism-free (stigmatic) beam produced by the subsystem. By placing a second lens L2 after the variable spatial-frequency DOE D2, as in System Embodiment Nos. 4 and 8. or before the variable spatial-frequency DOE D2, as in System Embodiments Nos. 10 and 12, the laser beam producing system is provided with a means for adjusting (i.e. fine-tuning) the focal length the stigmatic output laser beam. This feature is advantageous in applications where, for example, the laser beam producing system functions as an optical subsystem within a larger optical system, and the laser beam output therefrom is to be further modified in terms of focal length and the like.

[0291] Analyzing the Dispersion Associated with the Laser Beam Output from the Laser Beam Producing System Designed in Accordance with the Principles of the Present Invention

[0292] Having designed a laser beam producing system using the above-described design procedure, the dispersion characteristics thereof can be analyzed by using the following equation:

$$\theta_{d2}(\lambda_R) = \arcsin\left[\frac{\lambda_R}{d_2} + \sin\rho\sqrt{1-\left(\frac{\lambda_R}{d_1}-\sin\theta_{i1}\right)^2} - \cos\rho\left(\frac{\lambda_R}{d_1}-\sin\theta_{i1}\right)\right] \quad \text{(Eq. 8)}$$

[0293] Equation (8) can be used to plot the deflection (i.e. diffraction) angle of each wavelength component in the laser beam output from any laser beam producing system designed and constructed in accordance with the principles of the present invention. A geometrical optics model is presented in **FIG. 5A** for dispersion analysis of the output laser beam. A graphical representation of dispersion analysis is provided in **FIG. 5**B, showing a plot of diffraction angle $\theta_{d2}$ as a function of wavelength component of the output laser beam. Inasmuch as the sole objectives for the DOE-subsystem design process described hereinabove are shaping the laser beam without introducing dispersion. the values for the expansion factors $M_1$ and $M_2$ and angle of incidence $\theta_{i1}$ specified at Block A in **FIG. 3**E1 can be varied to obtain virtually any acceptable solution (provided that the !Beam Shaping Factor $M=M_1M_2$ is satisfied).

[0294] Using the Beam Dispersion Equation (Eq. **8**) set forth above, one can predict the behavior of the laser beam producing system, as well as design a system that will perform in the manner required by any particular application at hand.

[0295] Unlike conventional optical elements, the dispersion of the DOE-based laser beam-modifying subsystem can be adjusted so that the function $\theta_{d2}(\lambda)$ exhibits a minimum or a maximum value reflected in a graphical representation thereof. The maximum or minimum point is the precise design point of zero dispersion. If desired or required by any particular application, the dispersion characteristics can be modified in a variety of ways.

[0296] For example, if the DOE-based subsystem hereof is used to compress the laser beam produced from the subsystem comprising the VLD and lens L1, as in the illustrative embodiments shown in **FIGS. 2A, 2B**, 2C, 2D, **21**, 2J, and 2M, then the minimum dispersion curve for the laser beam output from the resulting laser beam producing system will have a negative curvature (i.e. its graphical representation is concave downward), as illustrated in **FIGS. 5 and** 5B1. If the DOE-based system hereof is used to expand the laser beam produced from the subsystem comprising the VLD and lens L1, as in the illustrative embodiments shown in **FIGS. 2E, 2F**, 2G, 2H, 2K, 2L, and 2N, then the minimum dispersion curve for the laser beam output from the resulting laser beam producing system will have a positive curvature (i.e. its graphical representation is concave upward), as illustrated in **FIGS. 5 and** 5B2.

[0297] If DOE-based subsystem hereof neither expands nor compresses the input laser beam (i.e. the Beam Shaping Factor M of the subsystem is unity), then the dispersion curve for the output laser beam will be perfectly flat, as illustrated in **FIG. 5B**. This unique case occurs only when the two DOEs D1 and D2 of the subsystem are arranged parallel to each other and the laser beam entering the DOE D1 is parallel to the beam leaving the DOE D2.

[0298] Various Options Available for Implementing the DOE-based Laser Beam Modifying Subsystem of the Present Invention

[0299] In general, there are a variety of different techniques available for implementing (i.e. realizing) the DOEs of the DOE-based subsystem **2** described in great detail hereinabove. One technique known in the art would involve the use of conventional "optically-based" holographic recording techniques, wherein each designed DOE of the subsystem is realized as a volume transmission hologram (HOE) constructed by the interference of a laser "object" beam and a laser "reference" beam within a photosensitive recording medium. Another technique known in the art would involve the use of computer generated holographic techniques, wherein each designed DOE of the subsystem is realized as a copy of computer-generated hologram (CGH) by computer modeling the interference pattern and producing the same through printing techniques to produce a hologram having performance characteristics specified during the design process. Other techniques, while less preferred, could involve the use o f micro-etching of optical structures to produce "surface-relief holograms" having performance characteristics specified during the design process of the present invention. For purposes of illustration, techniques for producing HOE, CGH and surface-relief implementations of the DOE-based subsystem hereof will be described in greater detail hereinbelow.

[0300] Implementing the DOE-based Subsystem Using Optical-based Holographic Recording Techniques: Two Cases to Consider

[0301] Prior to teaching particular procedures for making fixed spatial frequency and variable spatial frequency HOEs, it will be helpful to provide a brief overview on these different holographic construction techniques.

[0302] Case 1: Constructing Fixed Frequency HOEs

[0303] When constructing a fixed frequency hologram (HOE), the object and reference beams must have the same radius of curvature. In most applications, this is accomplished by collimating the two beams so that we have two wavefronts at the hologram recording medium. The angle between the two beams will determine the spatial frequency of the fixed frequency hologram. The greater the angle, the greater the spatial frequency. The actual spatial frequency of the hologram is, more precisely, a function of the angles of incidence of the two beams at the hologram recording medium and the wavelength of the two beams. The spatial frequency is established by the well known grating equation: d=wavelength/(sin O+sin R), where O is the angle of incidence of the object beam and R is the angle of incidence of the reference beam.

[0304] Case II: Constructing Variable Frequency HOEs

[0305] When constructing a variable frequency hologram (HOE), the object and reference beams must have different radii of curvature. In most applications, this is accomplished by collimating one of the beams and making the other beam a diverging beam. We will choose to call the collimated beam the reference beam. The diverging beam, which we will choose to call the object beam, is generally created by transmitting the object beam portion of the laser beam through a positive lens, such as a microscope objective. The focal point of the converging beam leaving the positive lens then becomes the center of curvature of the object beam. If this positive lens is a spherical lens, the object beam wavefront at the hologram recording medium will be spherical. If the lens is cylindrical lens, with optical power in only one dimension, the object beam wavefront at the hologram recording medium will be cylindrical. In the case of cylindrical wavefront, some additional spherical optics is generally employed to expand the cylindrical beam along the axis of the cylinder without modifying the wavefront in that direction. That is, in the direction parallel to the cylindrical axis of the wavefront the beam will appear to be collimated.

[0306] As in the fixed frequency hologram, the wavelength of the beams and the angles of incidence of the two beams at the hologram recording medium will determine the spatial frequency of the hologram. However, in this case, the angle of incidence of the object is not constant since the beam has spherical (or cylindrical) wavefront. The angle of incidence of any beam at the point of incidence of any surface is the angle between the normal to the surface and the incoming ray at the point of incidence. And the incoming ray, by definition, is just the normal to the wavefront. But for a spherical, or cylindrical, wavefront, the normal to the wavefront will not be constant across the wavefront. The angle of incidence for the object beam will be the angle between the normal to the surface and the line running from the point of incidence to the center of curvature of the object beam. Since this angle will vary with position on the hologram recording medium, then, from the grating equation, the spatial frequency will also vary with position on the hologram recording medium. That is, we will have a variable frequency hologram.

[0307] The spatial frequency of this variable frequency hologram will vary in both (x and y) dimensions of the plane of the hologram recording medium when the object beam is a spherical wavefront. The spatial frequency of this variable frequency hologram will vary in only one dimension of the plane of the hologram recording medium when the object beam is a cylindrical wavefront.

[0308] Having provided an overview on these different construction techniques, it is now appropriate to disclose hereinbelow preferred procedure of constructing both fixed and variable spatial frequency HOEs.

[0309] A Procedure for Constructing Fixed and Variable Spatial Frequency Hoes

[0310] As indicated at Block A in **FIG. 4A**, the design parameters $\theta_{i1}$, $\theta_{d1}$, $\theta_{i2}$ and $\theta_{d2}$ and $f_2$ (i.e. focal length of DOE D2 in the case of variable spatial frequency DOEs) expressed at the reconstruction wavelength $\lambda_R$ are converted into construction parameters expressed at the construction wavelength $\lambda_C$ namely: object and reference beam angles $\theta_{O1}$ and $\theta_{R1}$ for HOE H1 at construction wavelength $\lambda_C$; and object and reference beam angles $\theta_{O2}$ and $\theta_{R2}$, respectively, for HOE H2. This parameter convention process can be carried out using, for example, the conversion method described on Pages 163-164 and FIGS. **28A1** through **28D** and **FIG. 29** of International Publication No. WO/9722945, based on corresponding U.S. application Ser. Nos. 08/573,949 and 08/726,522, each of which is incorporated herein by reference. Notably, instances where the design (reconstruction) wavelength $\lambda_R$ is equal to the construction wavelength $\lambda_C$ and there is no need for wavelength correction or conversion, then the design parameters can be used for the construction parameters in a manner well known in the art.

[0311] As indicated at Block B in **FIG. 4A**, it will be necessary, in the case of variable spatial frequency DOEs, to use computer ray-tracing analysis in order to determine the distances of the object and reference sources relative to the recording medium (as well as the distances of any aberration-correcting lenses therefrom) which are employed during the holographic recording process, schematically depicted in **FIG. 4B** for the case of a variable spatial frequency HOE. In the case of fixed spatial frequency DOEs, computer ray-tracing analysis is not necessary. Notably, in this case, the location of the object and reference sources relative to the recording medium will be effectively located at infinitely (e.g. realized by the use of collimating mirrors or the like).

[0312] Having computed the construction parameters for HOE H1 and HOE H2, the HOEs can then be constructed using the holographic recording system illustrated in **FIG. 4B**, using the volume holographic recording techniques detailed in International Publication No. WO/9722945, supra. Regarding. non-VLD type astigmatism, the method used to construct HOE H1 should seek to minimize the astigmatism that would normally occur when a widely diverging beam is incident on a glass plate with parallel surfaces. This type of astigmatism can be minimized in many instances if, for example, the HOE is constructed

using: (1) the same type of laser as is used in the end-user scanning system; and (2) the same illumination geometry as is used in the end-user scanning system. While applying the above conditions is helpful in many instances, it is understood that it is not always necessary, nor is it always possible to do so.

[0313] Implementing the DOE-based Subsystem Using Computer-generated Holographic (CGH) Recording Techniques

[0314] The values obtained for design parameters $\theta_{i1}$, $\theta_{d1}$, $\theta_{i2}$ and $\theta_{d2}$, $d_1$, $d_2$ and $f_2$ (focal length of variable frequency DOE) associated with the dual-DOE subsystem can be used to derive construction parameters necessary to construct a dual-CGH implementation thereof. A suitable procedure for this type of implementation will be described below.

[0315] As indicated at Block A in **FIG. 4C1**, the first step of the method involves formulating, within a digital computer system **170**, a mathematical description of the object and reference beam wavefronts at the design wavelength $\lambda_R$. Typically, standard diffraction integrals, such as the Kirchhoff integral, can be used to produce mathematical descriptions of these wavefronts. Such mathematical descriptions can be derived from the design parameters {e.g., for DOE D1, such parameters include $\theta_{i1}$, $\theta_{d1}$, $\theta_{i2}$ and $\theta_{d2}$, the image produced by DOE D1 (i.e. reference source point) and image produced from DOE D2 (i.e. object source point)}. In particular, a mathematical description for the object and reference beam wavefronts at the design wavelengths $\lambda_R$ for DOE D1 can be formulated as Kirchhoff integrals using the design parameters for DOE D1, expressed at the reconstruction (i.e. design) wavelength $\lambda_R$. Also, a mathematical description for the object and reference beam wavefronts at the design wavelength for DOE D2 can be formulated as Kirchhoff integrals using the design parameters for DOE D2, expressed at the reconstruction wavelength $\lambda_R$. Notably. using the CGH implementation technique, there typically will be no need to make any corrections for the construction wavelength as the CGH has been previously constructed for aberration-free performance at the reconstruction wavelength (which is specified by the commercial-grade VLD selected for use in constructing the laser beam producing system).

[0316] As indicated at Block B in **FIG. 4C1**, the second step of the method involves using the digital computer system **170** to formulate a mathematical description of the "interference pattern" that is generated by mathematically superimposing the mathematical model of the object beam wavefront (e.g. represented by Kirchoff integrals) with the mathematical model of the reference beam wavefront (also represented by Kirchoff integrals). The mathematical description of the interference pattern generated by the computer system **170** provides a "spatial function" of the interference pattern. In cases where only fixed-spatial frequency DOEs are used to construct the laser beam modifying subsystem, the interference pattern generated by the reference and object wavefronts will b e mathematically represented by a one-dimensional sinusoidal function, expressed in the form of D=A+Bsinfx, where A is a bias level; B is a modulation factor always less than A; and f is the spatial frequency. In cases where a variable spatial frequency DOE is used to construct the laser beam modifying subsystem. the interference pattern generated by the reference and object wavefronts can be mathematically represented by an infinite series of one-dimensional sinusoidal functions.

[0317] As indicated at Block C in **FIG. 4C1**, the third step of the method involves using the digital computer system **170** to sample the spatial function of the computer generated/represented interference pattern along the x and y directions in order to produce a large set of sampled values of varying light transmission associated with the computer generated interference pattern (represented within the computer system **170**). These sampled values correspond to either the light transmittance of the computer generated/represented interference pattern over its x,y spatial extent.

[0318] As indicated at Block D in **FIG. 4C2**, the fourth step of the method involves transferring the sampled light transmittance values from the computer system **170** to the drivers of a graphical plotter or plotting tool **171** shown in **FIG. 4C2**.

[0319] As indicated at Block E in **FIG. 4C2**, the plotting system **171** uses the set of sampled amplitude transmittance values to plot the two-dimensional sampled interference pattern on paper or other recording medium **172**, thereby creating a graphical representation thereof **173** consisting of fine (sampled) dots of particular density, in a way similar to that produced by a digital printing process. In general, the two-dimensional amplitude transmittance function **173** plotted on paper or other recording medium **172** by the plotting tool **171** is usually quite large (i.e. several orders larger than the final CGH master). The two-dimensional plot produced from this step of the method provides a graphical representation of the CGH under construction. For fixed spatial frequency DOEs, the 2-D plot provides a graphical representation of a CGH which functions as a planar diffraction grating. For variable spatial frequency DOEs, the 2-D plot provides a graphical representation of a CGH which functions with some degree of focal power.

[0320] As indicated at Block F in **FIG. 4C2**, two-dimensional amplitude transmittance function **173** plotted on paper at Block Ecan then be photographically reduced on some light transmissive or reflective recording medium, generally photographic film **175** using photographic reduction equipment **174**. The output of this system is a master of the CGH which can be then bleached to improve its diffraction efficiency. However, its diffraction efficiency will always be low because the CGH is a surface relief hologram, not a volume hologram as produced by the optically-based Holographic Recording Method described above. As normal photographic film will often be the medium used for the first recording of the CGH (at Block F), it is expected that resolution of the CGH will not be very high.

[0321] As required by most embodiments of the DOE-based subsystem hereof, the CGH master obtained at Block F can be copied onto some higher efficiency medium, such as DCG, photoresist, or suitable surface relief material **177** using conventional copying apparatus **176** well known in the art. While such copying techniques enable the production of DOEs having greater diffraction efficiencies, these techniques are not without their problems, as explained below.

[0322] For example, copies of a CGH master can be made with high diffraction efficiency in surface relief material by standard pressing operations provided that the aspect ratio of

the surface relief structure (groove depth/groove spacing) is on the order of one. However, it is very difficult to make such copies when the aspect ratio of the surface relief structure is that large.

[0323] Using photoresist CGH copies directly is also difficult because the material is susceptible to damage during handling. Also, sealing the photoresist CGH copies between glass will be required in many applications. However, this will drastically reduce the diffraction efficiency of the photoresist CGH copies if a n index matching fluid is u sed to minimize reflection losses.

[0324] Making DCG copies of the CGH masters at the 488 nm Argon wavelength is a much better method, as the "nearly-contact" copy process will always faithfully reproduce the surface fringe structure of the master, regardless of the wavelength of the copying laser light source. Consequently, the copy holograms will be aberration-free at the wavelength at which the CGH masters were constructed (for use with conventional VLDs). The CGH HOEs will be essentially the same as the photographic plate masters.

[0325] Notably, however, the CGH fabrication technique described above will have little advantage over the optically-based Holographic Recording Method. In fact, this technique will have the significant disadvantage of producing holograms having a much lower resolution. In typical applications, the DOEs will require a resolution of at least 2000 cycles per mm. While the DCG copying method is capable of producing HOE having a resolution better than 2000 cycles per mm, the resolution of the DCG copy can be no greater than that of the CGH master, which, for normal photographic film, will be much less than 2000 cycles per mm. Consequently, when using the CGH implementation technique described hereinabove, it will be desirable (if not necessary) to first record the CGH master in a photographic medium having a very high resolution in order to produce CGH masters having diffraction efficiencies suitable for use in the DOE-based subsystem hereof.

[0326] Having produced a master CGH in the manner described above, copies thereof can be made using various copying techniques known in the art.

[0327] If the illuminating beam transmitted through the CGH copy (during reconstruction) is identical to the reference beam (modeled at Block A), then the object beam (modeled at Block A) will be reconstructed by the interference pattern embodied within the CGH copy. If the illuminating beam transmitted through the CGH copy (during reconstruction) is identical to the object beam (modeled at Block A). then the reference beam (modeled at Block A) will be reconstructed by the interference pattern embodied within the CGH copy.

[0328] Additional details regarding CGH implementation process can found with reference to: Chapter 19 of the book entitled "Optical Holography" by Collier, Burckhardt and Lin (1971), published by Academic Press, incorporated herein by reference.

[0329] Applications of the Laser Beam Producing System of the Present Invention

[0330] In general, each illustrative embodiment of the laser beam producing system described above can be realized in a variety of different ways. For example, in **FIGS. 6A through 10D**, several laser beam production modules of the present invention are disclosed for producing a laser beam having a pre-specified beam aspect-ratio, zero beam dispersion and a predetermined focus. In **FIGS. 11A through 11C**, a laser beam production module of the present invention is shown for producing a laser beam, wherein a pre-specified beam aspect-ratio is achieved, its beam dispersion is zero (or minimized), its focus set to a predetermined distance, and its astigmatism corrected. In **FIGS. 12A through 112C**, a laser beam production module of the present invention is shown for producing a laser beam wherein its aspect-ratio is controlled, its beam dispersion is zero (or minimized), its astigmatism corrected, its focus set to a predetermined distance, and its focal length adjusted. With reference to modified system designs shown in **FIGS. 7A through 7C**, several laser beam production modules of the present invention are disclosed for producing a laser beam having a pre-specified beam aspect-ratio, zero beam dispersion and astigmatism control. For purposes of illustration, HOE-based implementations of these illustrative system embodiments will be described hereinbelow. Equivalent CGH-based implementations thereof can be readily made using the principles disclosed hereinabove.

[0331] Laser Beam Production Module of the First Illustrative System Embodiment for Producing a Stigmatic Laser Beam Having Zero Beam Dispersion, Predetermined Aspect Ratio and Preset Focus (CASE D)

[0332] In **FIGS. 6A, 6B** and 6C, a first illustrative embodiment of the laser beam production system of **FIGS. 2M and 2N** (System Embodiment Nos. 13 and 14) is disclosed. As shown, this optical system is realized in the form of a miniature laser beam producing module **10** comprising an assembly of subcomponents, namely: a module housing **11** made of lightweight plastic and serving as an optics bench for the optical components within the laser beam producing system; a VLD **12**, press-fit mounted through a metal heat sinking plate **26**; a VLD, mounting bracket (i.e. Yoke) **13**, having side projecting **13**A and **13**B slidable within spaced apart recesses **11**A and **11**B respectively formed in the rear portion of the module housing: connected to the terminal **14** of the VLD, for applying a supply voltage and driving the VLD to produce a laser beam having elliptical, divergent, eccentric, and astigmatic characteristics, and a oversized aperture **27** for receiving the case portion (or beam emitting) portion of the VLD and allowing x, y positioning thereof relative to the VLD mounting bracket **13**: a flexible circuit **15**; a focusing lens L**116** for focusing the laser beam produced from the VLD; fixed spatial-frequency HOE H**117**, securely mounted within a first mounting slot **18** formed in the module housing **11**, for modifying the beam characteristics of the laser beam output from focusing lens L**116**; fixed spatial-frequency HOE H**219**, securely mounted within a second mounting slot **20** formed in the module housing **11**, for modifying the beam characteristics of the laser beam produced from HOE H**1** to produce the output laser beam; a beam folding mirror **21**, mounted on side wall surface **22** of the module housing, for directing the output laser beam through the beam output window **23** formed i n the side wall of the module housing; a first radiation-absorbing wall surface **24** formed in the module housing, aligned with the zeroeth-order diffraction beam from HOE H**1**, and absorbing the zeroeth-order diffraction beam produced from HOE H**1**; and second radiation-absorbing wall surface **25** formed in the module housing, aligned with the

zeroeth-order diffraction beam from HOEH2, and absorbing the zeroeth-order diffraction beam produced from HOE H2.

[0333] In an illustrative embodiment of this system design, the VLD **12** can be realized using a SONY Model SLDI122VS laser diode, and the focusing lens L**116** can be realized as a 4.35 mm lens made of an optically transparent plastic. The HOEs H**117** and H**219** can be made using DCG recording material of about **5** microns thick, a construction wavelength of **488** nanometers. These volume transmission holograms can be mounted between a pair of ultra-small plates made from float glass. It is understood, however, that other embodiments of this system design can be made using different types of components and materials, having different design parameters selected or determined for the particular application at hand.

[0334] As shown in **FIG. 6**C, during the alignment stage of the assembly process for the laser beam producing module **10**, the distance between VLD **12** and lens L**116** is adjusted by sliding the VLD mounting bracket **13** within the pair of recesses **11**A and **11**B. As will be explained in greater detail hereinafter, this parameter adjustment mechanism is employed while the system is mounted on a special design fixture specifically crafted for aligning such parameters. When the x, y position of the VLD is properly aligned relative to lens L**1**, by a translation of the VLD/heat-sinking plate subassembly relative to VLD mounting bracket **13** during the alignment stage of the module assembly process, then the output laser beam from the module will have the desired beam aspect-ratio and minimized (or zero) beam dispersion minimized in accordance with the design criteria for this laser beam producing module. Also, the (z) axis position of the VLD is relative to lens L**1** can be adjusted during the alignment stage by sliding VLD mounting bracket **13** within recesses **11**A and **11**B in the module housing until beam astigmatism is eliminated. This parameter alignment process will be described in greater detail hereinafter.

[0335] Laser Beam Producing Module of the Second Illustrative System Embodiment for Producing a Laser Beam Having Focus Control, Controlled Aspect-ratio and Zero Beam Dispersion: CASE A

[0336] In **FIGS. 7A, 7B** and **7**C, a second illustrative embodiment of the laser beam production System Embodiment No. 1) of **FIG. 2M** is disclosed. As shown, this optical system is realized in the form of a miniature laser beam producing module **30** comprising an assembly of subcomponents, namely: a module housing **31** made of lightweight plastic and serving as an optical bench for the optical components within the laser beam producing system; a VLD **32** mounted to a VLD heat-sinking plate **33** through aperture **33**A and producing a visible laser beam having elliptical, divergent and astigmatic beam characteristics in response to a voltage source applied VLD terminal **34** by way of a flexible circuiter like connectors (not shown) well known in the art; a mounting bracket **36** having an aperture **36**A for receiving the barrel portion of the casing of the VLD **32** and a mounting surface **36**B for affixing the associated heat-sinking plate **33** and premounted VLD **32** thereto, and also having side projections **36**C and **36**D for slidable receipt within spaced apart recesses **37**C and **37**D formed in the rear portion of the module housing; a collimating lens L**138** for focusing the laser beam produced from the VLD; fixed spatial-frequency HOE H**139**, securely mounted within a first mounting slot **40** formed in the module housing **31**, for modifying the beam characteristics of the laser beam output from focusing lens L**138**; fixed spatial-frequency HOE H**241**, securely mounted within a second mounting slot **42** formed in the module housing **31**, for modifying the beam characteristics of the laser beam produced from HOE H**1** to produce the output laser beam; a radiation-absorbing wall surface **43** formed in the module housing. aligned with the zeroeth-order diffraction beam from HOE H**1**, and absorbing the same during operation of the device; and a housing cover plate **44** for attachment to the top portion of the module housing **31** and securing HOEs H1 and H2 therein.

[0337] In the illustrative embodiment, the VLD **32** can be realized using a SONY Model SLD1122VS laser diode, and the collimating lens L**138** can be realized as a 4.35 mm lens made of an optically transparent plastic. The HOEs H**139** and H**241** can be made using DCG recording material of about 5 microns thickness. at a construction wavelength of **488** nanometers. These volume transmissions holograms can be mounted between a pair of ultra-small plates made from float glass. It is understood, however, that other embodiments of this system design can be made using different types of components and materials, having different design parameters selected or determined for the particular application at hand.

[0338] When the proper x, y position of the VLD **32** relative to the optical axis of lens L**138** is set during the alignment stage of the module assembly process, then the output laser beam from the module will have the desired beam aspect-ratio and minimized (or zero) beam dispersion in accordance with the design criteria for this laser beam producing module. As shown in **FIG. 7**C, during assembly and construction of the laser beam producing module **30**, the distance between VLD **32** and lens L**138** (i.e. "d") is adjusted by sliding the VLD mounting bracket **36** within the pair of recesses **37**C and **37**D in the module housing. As will be explained in greater detail hereinafter, this parameter adjustment mechanism is employed while the system is mounted on an optical bench specially crafted for aligning such parameters.

[0339] Laser Beam Scanning Module Adapted for Use with the Laser Beam Producing Modules of the Present Invention

[0340] In **FIGS. 8A and 8B**, a laser beam scanning module is disclosed for use with any of the laser beam producing modules of the present invention. As shown, the laser beam scanning module **50** comprising an assembly of subcomponents, namely: a module housing **51** made of lightweight plastic and serving as an optical bench for the optical components within the laser beam scanning system: an electromagnetic coil **52** mounted within recess **53** in the module housing, for producing a magnetic force field FM in response to electrical current supplied to the input terminals thereof **52**A; a scanning element **54** supporting a light deflecting element (e.g. mirror, hologram, refractive element, etc.) **55** on the front surface of its free end, and a permanent magnetic element **56** on the rear surface of its free end; a pair of mounting plates **57** and **58** having projections **57**A, **57**B, and matching holes **58**A, **58**B respectively for clamping the base portion **54**A of the scanning element **54**, and securely mounting the same within recess

**59** formed within the module housing **51**, as shown in **FIG. 8B and 9**; and a housing cover plate **60** for attachment to the top surface **61** of the module housing **51**, and securing the scanning mechanism components therewithin, while forming a scanning window **62** through which a laser beam produced from a laser beam producing module hereof can pass to the scanning element and be deflected therefrom out through the scanning window across the scan field of the resulting scanning system. Details regarding the design and construction of the scanning mechanism formed by the electromagnet **52**, the scanning element **54** and the scanning element anchoring mechanism (formed by plates **57** and **58**, and recess **56**) are disclosed in copending application Ser. No. 08/931,694 filed Sep. 16, 1997, and incorporated herein by reference in its entirety. It is understood, however, that there are other scanning mechanisms that may be embodied within the module housing **51** described above, for use in conjunction with the laser beam producing modules of the present invention.

[**0341**] As shown in **FIG. 8**A, when scanning element mounting plates **57** and **58** are inserted within the mounting recess **59** in the module housing, the top projections **57**C and **58**C thereof protrude slightly above the top surface of the module housing and through aperture **63** in the housing cover plate. Screws (not shown for clarity of illustration) can then be passed through holes formed in holes **64** and **65** in the cover plate **60** and inserted into threaded holes **66** and **67** in the module housing **51**. In this assembled configuration, the scanning window **62** is completely formed and provides access to the scanning element disposed within the housing. In alternative embodiments, a transparent plate can be mounted over the scanning window to prevent dust, dirt and the like from entering the scanning mechanism embodied within the module housing.

[**0342**] Miniature Laser Beam Scanning System Formed by Arranging a Laser Beam Producing Module of the Present Invention with a Laser Beam Scanning Module

[**0343**] In **FIG. 9**, there is shown a miniature laser beam scanning system formed by arranging the laser beam producing module **70** shown in **FIG. 7** with the laser scanning module **50**, shown in **FIG. 8A**. This novel arrangement provides a laser scanning system for use in laser scanning engines of the general type disclosed. for example, in copending application Ser. No 08/292,237 filed Aug. 17, 1994, incorporated herein by reference. As shown in **FIG. 9**, the output laser beam **71** from the laser beam producing module **70** is directed onto the mirror on the light deflecting element (e.g. mirror) **55** within the laser scanning module **50**. As the scanning element oscillates about its anchored base portion, the laser beam **71**A reflected off the mirror element **55** is scanned over the scanning region of the scanning system. Modules **70** and **50** can be mounted upon optical bench of various types employed, for example, for bar code symbol scanning systems, and the like.

[**0344**] Integrated Laser Beam Producing and Scanning Module According to a First Illustrative System Embodiment of the Present Invention

[**0345**] In **FIGS. 10A, 10B** and **10**C, a laser scanning device is shown, wherein the laser scanning subsystem shown in **FIG. 8A** is integrated with a laser beam producing subsystem of **FIG. 7A**. As shown, integrated scanning device **80** comprises an assembly of subcomponents, namely: a module housing **81** made of lightweight plastic and serving as an optical bench for the optical components within the laser beam producing and scanning systems alike; a VLD **82** mounted to a VLD heat-sinking plate **83** through aperture **83**A and producing a visible laser beam having elliptical, eccentric, divergent, and astigmatic beam characteristics in response to a voltage source applied to terminals **82**A by way of a flexible circuit or other conductive structures well known in the art; a mounting bracket **84** having an aperture **84**A for receiving a portion of the casing of the VLD **82** and a plane surface **84**B affixing the associated heat-sinking plate **83** thereto, and also having side projections **84**D and **84**E for slidable receipt within spaced apart recesses **85**B and **85**C formed in the rear portion of the module housing **81**; a collimating lens L**186** for focusing the laser beam produced from the VLD; fixed spatial-frequency HOE H**188**, securely mounted within a first mounting slot **89** formed in the module housing **81**, for modifying the beam characteristics of the laser beam output from collimating lens L**186**; fixed spatial-frequency HOE H**290**, securely mounted within a second mounting slot **91** formed in the module housing **81**, for modifying the beam characteristics of the laser beam produced from HOE H**1** to produce the output laser beam; a radiation-absorbing wall surface **92** formed in the module housing, aligned with the zeroeth-order diffraction beam from HOE H**1**, and absorbing the zeroeth-order diffraction beam produced from HOE H1; electromagnetic (i.e. coil) **52** mounted within recess **93** in the module housing, for producing a magnetic force field in response to electrical current supplied to the input terminals thereof; scanning element **54** supporting light deflecting element (e.g. mirror, hologram. refractive element, etc.) **55** on the front surface of its free end, and permanent magnetic element **56** on the rear surface of its free end; mounting plates **57** and **58** for clamping the base portion of the scanning element **54**, and mounting the same within recess **94** formed within the module housing **81**; and a housing cover plate **95** for attachment to the top surface **96** of the module housing **81**, and securing the laser beam producing and scanning mechanism components therewithin, while forming a scanning window **97** through which a scanned laser beam can be projected out into a scan field for scanning.

[**0346**] In **FIG. 10**D, the subcomponents of integrated scanning engine are shown mounted within a miniature housing **99** having a base portion **99**A and cover plate **99**C. Typically, the length, and width dimensions of the housing **99** will be substantially smaller than a matchbox and can be realized as small as a sugar-cube using presently available enabling technology. As shown, a plastic window or filter **100** can be mounted over the scanning window to protect entry of dust, dirt and the like into the interior of the scan engine where there are optical components. Module housing **81** can be mounted to the bottom half of the scan engine housing **99**A shown in **FIG. 10D**. The scan engine can include a photodetector, analog and digital signal processing circuits **101** realized or printed circuit boards **102** and **103**, as taught in copending application Ser. No. 08/292,237 filed on Aug. 17, 1994.

[0347] Laser Beam Producing Module for Producing a Stigmatic Laser Beam Having Focus Control, Controlled Aspect-ratio and Zero Beam Dispersion (CASE B)

[0348] In **FIGS. 11A, 11B** and **11**C, an illustrative embodiment of the laser beam production System Embodiment Nos. 2 and 6 of **FIGS. 2B and 2F**) is disclosed. It is understood, however, that designs according to System Embodiments 3, 7, 9 and 11 may be used as well in the construction of this class of laser beam producing module.

[0349] As shown in **FIGS. 11A through 11C**, this optical system is realized in the form of a miniature laser beam producing module **110** comprising an assembly of subcomponents, namely: a module housing **111** made of lightweight plastic and serving as an optical bench for the optical components within the laser beam producing system; a VLD **112** mounted to a VLD heat sinking plate **113** through aperture **113**A and producing a visible laser beam having elliptical, eccentric, divergent and astigmatic beam characteristics in response to a voltage source applied to terminals **112**A by way of a flexible circuit or like structure well known in the art; a mounting bracket **114** having an oversized aperture **114**A for receiving a portion of the casing of the VLD **112** and planar surface **114**B for affixing the associated heat-sinking plate **113** thereto, and also having side projections **114**C and **114**D for slidable receipt within spaced apart recesses **115**C and **115**D formed in the rear portion of the module housing; a focusing lens L**1116** for focusing the laser beam produced from the VLD; a bore **117** formed in module housing **111** for mounting lens L**1116** therein; fixed spatial-frequency HOE H**1118**, securely mounted within a first mounting slot **119** formed in the module housing **111**, for modifying the beam characteristics of the laser beam output from focusing lens L**1116**; fixed spatial-frequency HOE H**2120**, fixedly mounted within a second mounting slot **121**, formed in the module housing **111**, for modifying the beam characteristics of the laser beam produced from HOE H1; a focusing lens L**2122** mounted within a lens-support bracket **123**, slidably mounted within a third mounting slot **124** formed in the module housing, for adjustable movement of lens L**2122** along the optical axis of HOE H**2120** to adjust the focal-length of output laser beam; a radiation-absorbing wall surface **126** formed in the module housing, aligned with the zeroeth-order diffraction beam from HOE H1, and absorbing the zeroeth-order diffraction beam produced from HOE H1; and a housing cover plate **127** for attachment to the top portion of the module housing **111** and securing HOEs H**11** and H**2** and focusing lens L**2** therein.

[0350] In an illustrative embodiment of this system design, VLD **112** can be realized using a SONY Model SLDI **122**VS laser diode, the focusing lens L**1116** can be realized using a 4.35 mm lens, and the focusing lens L**2122** can be realized using a 250 mm lens, to provide an output focal distance of about **10** inches from the module. The HOEs H**1** and H**2** can be made using DCG recording material, of 5 microns film thickness, at a construction wavelength of 480 nanometers. These volume transmission holograms can be mounted between a pair of ultra-small plates made from float glass. It is understood, however, that other embodiments of this system design can be made using different types of components and materials, having different design parameters selected o r determined for the particular application at hand.

[0351] As shown in **FIG. 11**C, during assembly and alignment of the laser beam producing module **110**, the distance between VLD **112** and lens L**1116** is adjusted by sliding the VLD mounting bracket **114** within the pair of recesses **115**C and **115**D in the module housing, and the distance between the lens L**2122** and HOE H**2120** is adjusted by sliding lens-support bracket **124** within the recess **124** in module housing along the optical axis of HOE H**2**. As will be explained in greater detail hereinafter, these parameter adjustment mechanisms are employed while the optics system is mounted on an optical bench specially crafted for aligning such parameters.

[0352] Laser Beam Producing Module for Producing a Stigmatic Laser Beam Having Focus Control, Controlled Aspect-ratio, Zero Beam Dispersion, and Adjustable Focal-length (CASE C)

[0353] In **FIGS. 12A, 12B** and **12**C, an illustrative embodiment of the laser beam production System Embodiment Nos. 4 and 8 of **FIGS. 2D and 2H**) is disclosed. It is understood, however, that such a design can be realized using System Embodiment Nos. 10 and 12, as well.

[0354] As shown in **FIGS. 12A, 12B** and **12**C, this optical system is realized in the form of a miniature laser beam producing module **130** comprising an assembly of subcomponents, namely: a module housing **135** made of lightweight plastic and serving as an optical bench for the optical components within the laser beam producing system; a VLD **131** mounted to a VLD heat sinking plate **132** through aperture **132**A and producing a visible laser beam having elliptical, divergent, eccentric, and astigmatic beam characteristics in response to a voltage source applied to terminal **131**A by way of a flexible circuit or like conductive elements well known in the art; a mounting bracket **133** having an aperture **133**A for receiving a portion of the casing of the VLD **131** and, a planar surface **133**B for affixing the associated heat-sinking plate **132** thereto, and also having side projections **133**C and **133**D for slidable receipt within spaced apart recesses **135**C and **135**D formed in the rear portion of the module housing; a focusing lens L**1136** for focusing the laser beam produced from the VLD; a bore **137** for mounting lens **136** within the module housing; fixed spatial-frequency HOE H**1138**, securely mounted within a first mounting slot **139** formed in the module housing **135**, for modifying the beam characteristics of the laser beam output from focusing lens L**1136**; fixed spatial-frequency HOE H**2140**, mounted within a HOE-support bracket **141** that is slidably mounted within a second mounting slot **142** formed in the module housing **135**, for adjustable movement relative to HOE H**1138** (during assembly/alignment) in order to modify the beam characteristics of the laser beam produced from HOE H1; a focusing lens L**2143** mounted within a lens-support bracket **144** that is slidably mounted within a third mounting slot **145** formed in the module housing, for adjustable movement along the optical axis of the system; a radiation-absorbing wall surface **146** formed in the module housing, aligned with the zeroeth-order diffraction beam from HOE H1, and absorbing the zeroeth-order diffraction beam produced from HOE H1; and a housing cover plate **147** for attachment to the top portion **148** of the module housing **135** and securing HOEs H1 and H2 and focusing lens L**2** therein.

[0355] In an illustrative embodiment, the VLD can be realized using a SONY Model SLD1122VS laser diode, the

focusing lens L1 can be realized using a 4.35 mm lens, and the focusing lens L2 is realized using a 250 mm lens. The HOEs H1 and H2 can be made using DCG recording material, of about 5 microns thickness, at construction wavelength **488** nanometers. These volume transmission holograms can be mounted between a pair of ultra-small plates made from float glass. It is understood, however, that other embodiments of this system design can be made using different types of components and materials, having different design parameters selected or determined for the particular application at hand.

[**0356**] As shown in **FIG. 12**C, during assembly and alignment of the laser beam producing module **130**, the distance between VLD **131** and lens L**1136** is adjusted by sliding the VLD mounting bracket **133** within the pair of recesses **135**C and **135**D in the module housing, and the distance between the lens L2 and HOE H**2140** is adjusted by sliding lens-support bracket **144** within the recess **145** in module housing, and the distance between HOE H2 and HOE H1 is adjusted by sliding HOE support bracket M1 within recess **142** in the module housing. As will be explained in greater detail hereinafter, these parameter adjustment mechanisms are employed while the system is mounted on an optical bench specially crafted for aligning such parameters.

[**0357**] The design methods of the present invention provide a way of determining the design and construction parameters for the laser beam producing system of the present invention. However, by virtue of the fact that properties of the VLD are not easily ascertainable in practice, such methods cannot be used to compute the distance between the VLD and lens L1 which results in an output laser beam having zero dispersion and a desired aspect ratio.

[**0358**] The Parameter Adjustment System Used During the Module Assembly and Alignment Procedure of the Present Invention

[**0359**] In **FIG. 13, a** computer-controlled parameter adjustment system of the present invention is shown. For purposes of illustration only, this system is shown in **FIG. 13** with a laser beam producing module of FIGS. **12**A-**12**C (embodying System Embodiment No. 4 for illustration only) mounted to the fixtures of the system. This case was selected because this module requires the maximum number of parameters to be adjusted, thus implicating all of the functions of the parameter adjustment system. As will be illustrated, however, the parameter adjustment system can be used to adjust the parameters of any one of the illustrated embodiment of the present invention in a rapid, highly efficient manner, thereby making the laser beam producing modules hereof suitable for mass production.

[**0360**] As shown in **FIG. 13**, the parameter adjustment system **150** comprises a number of subsystems and subcomponents. namely: a module support platform **151** for supporting and translating (in the z direction during the "loading stage") the module housing (e.g. **135**) of each laser beam producing module (being assembled and adjusted); a VLD support platform **154** for adjustably supporting the VLD (and its mounting structure) along three-coordinate axes relative to the stationary module housing support platform **151** and lens L1; a lens L2 support platform **155** for supporting and translating second lens L2 of the laser beam producing module along one-coordinate axis relative to the stationary module housing support platform **151**; a HOE support platform **156** for supporting and translating HOE H2 of the laser beam producing module along one-coordinate axis (i.e. optical axis) relative to the module housing support platform **151** (i.e. along the optical axis of the system); a beam profiler **157** (such as, for example, Model 0180-XYS Beam Scan from Photon, Santa Clara, Calif.) having a beam scan display monitor **158** connected thereto; a quadrant detector **159** having a quadrant detector display **160** connected thereto; a first computer-controlled translation mechanism **161**A for translating the VLD support platform **154** relative to module housing support platform **151** during analysis of the laser beam output from the HOE-based subsystem of the laser beam producing module **153** using the beam scanner **157** and quadrant detector **159**; a second computer-controlled translation mechanism **161**B for translating the lens L2 support platform **155** relative to module housing support platform **151** during analysis of the laser beam output from the HOE-based subsystem of the laser beam producing module **153** using the beam scanner **157** and the quadrant detector **159**; and a third computer-controlled translation mechanism **161**C for translating the HOE support platform **156** relative to module housing support platform **151** during analysis of the laser beam output from the HOE-based subsystem of the laser beam producing module **153** using the beam scanner **157** and the quadrant detector **159**. As will be explained hereinafter, certain of these subsystems are not employed when adjusting the parameters of particular laser beam producing modules of the present invention, while other of these subsystem are employed when aligning the components of other types of laser beam producing modules. Such details will be described below.

[**0361**] Method of Assembling and Aligning the Subcomponents of Laser Beam Producing Systems of the Illustrative System Embodiments of the Present Invention Design for Instances Where Focusing Control is Desired and Astigmatism Correction and Delta-focusing are Not Desired (System Embodiments Nos. (1) and (5): Case A

[**0362**] In general, when assembling a laser beam producing module based on System Embodiments Nos. 1 and 5, the below described parameter adjustment procedure can be used in conjunction with the parameter adjustment system of **FIG. 13**. The procedure comprises a pre-alignment stage and an alignment stage. During the prealignment stage, the various optical components of the laser beam producing module are installed within their respective mounting locations within the module housing, or within support structure associated with the parameter adjustment system **150**. During the alignment stage, the VLD and lens L1 are aligned in order to achieve the performance characteristics considered during the design stage. Referring to **FIG. 14**, the details of each of these stages will be described below for System Embodiment Nos. 1 and 5. In **FIG. 14**, the module of FIGS. **7**A-**7**C is shown mounted within the fixture of the parameter adjustment system as it embodies System Embodiment Nos. 1 and 5 in their entirety.

[**0363**] Pre-alignment Stage of the Assembly Procedure for System Embodiment Nos. 1 and 5

[**0364**] The first step of the pre-alignment stage of the system assembly procedure involves press fitting the VLD**32**

into VLD heat-sink plate **33** so that the VLD junction is arranged in a predetermined orientation relative to the VLD heat-sink plate.

[**0365**] The second step of the prealignment stage involves mounting HOE H1 (**39**) and HOE H2 (**41**) into their appropriate mounting slots **40** and **42** formed within module housing **31**. Thereafter, the HOEs can be glued or otherwise fixed in position. The third step of the prealignment stage involves inserting lens L1 into the lens recess (e.g. pocket) formed within the module housing. Thereafter, the lens L1 can be glued or otherwise fixed in position.

[**0366**] The fourth step of the prealignment stage involves placing the VLD mounting bracket (i.e. yoke) **36** into appropriate recesses **37**C and **37**D formed in the module housing. Notably, the VLD mounting bracket is held within such recesses by frictional fit and can only be translated along (z) axis of the parameter alignment system (i.e. the x and y directions being fixed by the geometry of these recesses.

[**0367**] The fifth step of the prealignment stage involves placing the module housing **31** onto the module housing support platform **151** so that pins on the bottom surface of the housing module **31** align with corresponding holes formed on the housing module support platform **151**. When housing module **31** is installed in the manner described above, the module housing **31** is then clamped to the module housing support platform **151** by way of screws, pressurized clamps or other releasable fastening devices.

[**0368**] The sixth step of the prealignment stage involves clamping the yoke **36** to affixed holder **164**.

[**0369**] The seventh and last step of the prealignment stage involves attaching the VLD **32** to VLD support platform **154** of the parameter alignment system. In the preferred embodiment, this step can be achieved by sliding the leads of the VLD into a connector provided on the VLD support platform and secured b y clamping, etc. The VLD support platform **154** is capable of movement along the x, y and z axes of the parameter adjustment system **150**.

[**0370**] The Alignment Stage of the Assembly Procedure for System Embodiments Nos, 1 and 5

[**0371**] The first step of the alignment stage of the system assembly procedure involves sliding the module housing support platform **151** towards VLD support platform **151** under the control of microcontroller **161** until the VLD **32** is positioned within oversized aperture **36**A formed within the VLD support **36** positioned within the recesses of the module housing. Notably, at this "load" position, the VLD **32** is free to move within the x and y plane by virtue of the oversized aperture in the VLD mounting yoke, and also along the z axis by virtue of clearance provided between the premounted lens L1 and the outer face of the VLD mounting yoke. As will become apparent hereinafter, such clearance enables the optical axis of each loaded VLD to be aligned with the optical axis of lens L1 as well as attaining the required distance which achieves the desired focus (for System Embodiment Nos. 1 and 5) or control of astigmatism (for all System Embodiments except Nos. 13 and 14) as specified during the design stage described in detail above.

[**0372**] The second step of the alignment stage of the procedure involves locking the position the module housing support platform **151** relative to the underlying optical bench **151** (arranged in its "loaded" configuration). This locking operation can be carried out using a computer-controlled locking mechanism **163** known in the art.

[**0373**] The third step of the alignment stage of the procedure involves locking the VLD heat-sink plate **32** to the VLD support platform **154** locking using mechanism **162** so that the VLD heat-sink plate is prevented from undergoing rotation in the x-y plane during alignment of the VLD relative to the lens L1 during the subsequent steps of the alignment procedure. This condition will ensure that the VLDjunction is prevented from rotation during the alignment procedure. which may involve translation of the VLD junction in the x, y and/or z axes of the system in order to secure the performance parameters of the module established during the design stage.

[**0374**] The fourth step of the alignment stage of the procedure involves applying a biasing force on the VLD support yoke **36** (in the direction of the VLD heat-sink plate **33**) so that the plate-like portion of the VLD support yoke gently engages the VLD heat-sink plate **33** in order that the surface of the VLD heat-sink plate and planar portion of the VLD support yoke assume the same z coordinate position during x, y alignment operations, while permitting relative movement between these two plate-like structures along the x-y plane of the system.

[**0375**] The fifth step of the alignment stage of the procedure involves supplying electrical power to the VLD **32** so that it produces a laser beam which is transmitted through lens L1 and HOEs H1 and H2.

[**0376**] The sixth step of the alignment stage of the procedure involves translating the VLD support platform **154** in the x-y plane until the output laser beam strikes the center of the quadrant detector **159**, which has been prealigned relative to the locked-in-position module housing **31** so that first diffraction order beam from HOE H2 (i.e. the optical axis thereof disposed in the plane of diffraction at diffraction angle $\theta_{d2}$) passes through the center of the quadrant-type photodetector **159**. When the output laser beam strikes the center of the quadrant-type photodetector, then the design geometry will be achieved, resulting in minimum beam dispersion and the desired amount of beam shaping by design. Also optimal output power will be transmitted from the module along the optical axis of the system. This condition is based on the reasonable assumption that the diffraction efficiency of HOEs H1 and H2 will be maximum along the first diffraction order by design, and characteristic wavelength of the VLD is substantially the same as the reconstruction wavelength of HOEs H1 and H2. Notably, this on-center aligned position can be visually detected when the indicator dot on the quadrant detector display unit **160** is aligned with the crosshair thereof. Completion of this step of the procedure will ensure that output power from the laser beam producing module will be as close to the output of the VLD as is practically possible, as well as ensuring that the design requirements have been satisfied.

[**0377**] The seventh step of the alignment stage of the procedure involves gluing or otherwise permanently securing the x-y position of the VLD heat-sinking plate **33** and VLD support bracket **36** in the position determined during the step above. Thereafter, the biasing force applied during the above step of the procedure can be removed.

[0378] The eighth step of the alignment stage of the procedure involves adjusting the position of the subassembly (comprising the VLD **32**, the VLD heat-sink plate **32** and the VLD support yoke **36**) along the z axis of the parameter adjustment system while monitoring the output laser spot at the desired focal length of the module using a beam profiler (i.e. profiling instrument) **157**, as identified above. When the spot size of the output laser beam at the desired focal length is minimum (along either the x or y axis of the system, not both), then VLDsupport yoke **36** is glued or otherwise fixed in position relative to the module housing **31**. Thereafter, the housing cover plate **44** is fastened upon the module housing and then the aligned laser beam producing module is removed from the parameter adjustment system and is ready for use in the system **150** for which it has been designed.

[0379] Method of Assembly and Aligning the Subcomponents of Laser Beam Producing Systems of the Illustrative System Embodiments of the Present Invention Designed for Instances Where Astigmatism Correction and Focus Control are Desired, but not the Adjustment of the Laser Beam Focal Length: System Embodiment Nos. (2), (3), (6), (7), (9) and (11): Case B

[0380] In general, when assembling a laser beam producing module based on System Embodiments Nos. 2 and 6, the parameter adjustment procedure of the present invention can be carried out on the module design shown in FIGS. **11A-11C** supported upon the parameter adjustment system of **FIG. 13**. When assembling a laser beam producing module based on System Embodiments Nos. **9** and **11**, the parameter adjustment procedure of the present invention can be carried out on the module design similar to that shown in FIGS. **11A-11C** (but with lens L**2** disposed between H**1** and h**2**) supported upon the parameter adjustment system of **FIG. 13**. Also, when assembling a laser beam producing module based on System Embodiments Nos. 3 and 7, the parameter adjustment procedure of the present invention can be carried out on the module design similar to the module shown in **FIGS. 12A through 12C** (without lens L**2**) supported upon the parameter adjustment system of **FIG. 13**.

[0381] For each of these groups of system embodiments, the assembly procedure comprises a prealignment stage and an alignment stage. During the prealignment stage, the various optical components of the laser beam producing module are installed within their respective mounting locations within the module housing, or within support structure associated with the parameter adjustment system **150**. During the alignment stage, the VLD and lens L**1** are aligned, as well as HOE H**2** relative to HOE H**1** (and L**2** where applicable) in order to achieve the performance characteristics specified during the design stage. Details of each of these stages will be described below for System Embodiment Nos. 2 and 6, 9 and 11, 3 and 7, with reference to **FIG. 15**.

[0382] Pre-alignment Stage of the Assembly Procedure for System Embodiment Nos. 2 and 6

[0383] The first step of the prealignment stage of the system assembly procedure involves press fitting the VLD **112** into VLD heat-sink plate **113** so that the VLD junction is oriented in it predetermined orientation relative to the VLD heat-sink plate.

[0384] The second step of the prealignment stage involves mounting HOE H**1** and HOE H**2** into their appropriate mounting slots **115**C and **115**D formed within module housing **111**. Thereafter, the HOEs can be glued or otherwise fixed in position.

[0385] The third step of the prealignment stage involves inserting lens L**1** into the lens recess (e.g. bore) **117** formed within the module housing. Thereafter, the lens L**1** can be glued or otherwise fixed in position.

[0386] The fourth step of the prealignment stage involves placing the VLD mounting yoke **114** into appropriate recesses **115**C and **115**D formed in the module housing. Notably, the VLD mounting yoke is held within recesses **115**C and **115**D by frictional fit and can only be translated along z axis of the parameter alignment system (i.e. the x and y directions being fixed by the geometry of the recesses.

[0387] The fifth step of the prealignment stage involves placing the module housing **111** into the module housing support platform **151** so that pins on the bottom surface of the housing module align with corresponding holes formed o n the housing module support platform **151**. When housing module **111** is installed in the manner described above, the module housing is then clamped to the module housing support platform **151** by way of screws, pressurized clamps or other releasable fastening devices.

[0388] The sixth step of the realignment stage involves placing the mounting yoke **114** on its support platform and clamping the same in place.

[0389] The seventh and last step of the prealignment stage involves attaching the VLD **112** to VLD support platform **151** of the parameter alignment system. In the preferred embodiment, this step can be achieved by sliding the leads of the VLD into a connector provided on the VLD support platform. The VLD support platform **154** is capable of movement along the x, y and z axes of the parameter adjustment system **150**.

[0390] Aligment Stage of the Assembly Procedure for System Embodiment Nos. 2 and 6

[0391] The first step of the alignment stage of the system assembly procedure involves sliding the module housing support platform **151** towards VLD support platform **154** under the control of microcontroller **161** until the VLD is positioned within oversized aperture **114**A formed within the VLD support yoke **114** positioned within the recesses of the module housing. Notably, at this "load" position, the VLD is free to move within the x and y plane by virtue of the oversized aperture in the VLD mounting yoke, and also along the z axis by virtue of clearance provided between the premounted lens L**1** and the outer face of the VLD mounting yoke. As will become apparent hereinafter, such clearance enables the optical axis of each loaded VLD to be aligned with respect to the optical axis of lens L**1**.

[0392] The second step of the alignment stage of the procedure involves locking the position the module housing support platform **151** relative to the underlying optical bench (arranged in its "loaded" configuration). This locking operation can be carried out using locking mechanism **162** known under computer control.

[0393] The third step of the alignment stage of the procedure involves locking the VLD heat-sink plate to the VLD support platform **154** so that the VLD heat-sink plate is prevented from undergoing rotation in the x-y plane during

alignment of the VLD relative to the lens L1 during the subsequent steps of the alignment procedure. This condition will ensure that the VLD junction is prevented from rotation during the alignment procedure, which may involve translation of the VLD junction in the x, y and/or z axes of the system in order to secure the performance parameters of the module established during the design stage.

[0394] The fourth step of the alignment stage of the procedure involves applying a biasing force on the VLD support yoke **114** (in the direction of the VLD heat-sink plate **113**) so that the plate-like portion of the VLD support yoke gently engages the VLD heat-sink plate **113** in order that the surface of the VLD heat-sink plate and planar portion of the VLD support yoke assume the same z coordinate position during x, y alignment operations, while permitting relative movement between these two plate-like structures along the x-y plane of the system.

[0395] The fifth step of the alignment stage of the procedure involves supplying electrical power to the VLD **112** so that it produces an output laser beam which is transmitted through lens L1 and HOEs H1 and H2.

[0396] The sixth step of the alignment stage of the procedure involves translating the VLD support platform **154** in the x-y plane until the output laser beam strikes the center of the quadrant photodetector **159**, which has been prealigned relative to the locked-in-position module housing **111** so that first diffraction order beam from HOE H2 (i.e. the optical axis thereof disposed in the plane of diffraction at diffraction angle $\theta_{d2}$) passes through the center of the quadrant-type photodetector. When the output laser beam strikes the center of the quadrant-type photodetector, then the design geometry will be achieved, resulting in minimum beam dispersion and the desired amount of beam shaping by design. Also optimal output power will be transmitted from the module along the optical axis of the system. This condition is based on the reasonable assumption that the diffraction efficiencies of HOEs H1 and H2120 will be maximum along the first diffraction order by design, and characteristic wavelength of the VLD is substantially the same as the reconstruction wavelength of HOEs H1 and H2. Notably, this on-center aligned position can be visually detected when the indicator dot on the quadrant detector display unit **160** is aligned with the cross-hair on the display surface thereof. Completion of this step of the procedure will ensure that the output power of the laser beam producing module will be as close to the output of the VLD as is practically possible, as well as ensuring that the design requirements have been satisfied.

[0397] The seventh step of the alignment stage of the procedure involves gluing or otherwise permanently securing the x-y position of the VLD plate and VLD support yoke in the position determined during the step above. Thereafter, the biasing force applied during the above step of the procedure can be removed.

[0398] The eighth step of the alignment stage of the procedure involves adjusting the position of the subassembly (comprising the VLD **112**, the VLD heat-sink plate **113** and the VLD support yoke **114**) along the z axis of the parameter adjustment system while monitoring the output laser at the desired focal length of the module using beam profiling (scanning) instrument **157**. When the spot size of the output laser beam (at some unknown location along the optical axis HOE H2) is minimum in both the x and y dimensions, then VLD support yoke **114** is glued or otherwise fixed in position relative to the module housing **111**. Notably, the beam profiling instrument will have to be moved along the optical axis of HOE H2 to detect this condition, in which the output laser beam is free of astigmatism. While the output beam may still have elliptical cross-sectional characteristics along its direction of propagation, its beam cross-section will be minimum for both dimensions at this detected point which, by definition. is a stigmatic beam. Thereafter, the VLD support yoke is glued or otherwise fixed to the module housing **111**.

[0399] The ninth step of the alignment stage of the procedure involves inserting lens support bracket **123**, containing prespecified lens L2, into recess **124** formed within the front end of the module housing **111**.

[0400] The tenth step of the alignment stage of the procedure involves adjusting the focal length of the module by translating lens L2 along the optical axis (or adjusting the combined focal length of a lens pair) while monitoring the output laser beam (at the desired focal length of the module set during design) until the spot size of the laser is minimum. In one illustrative embodiment, this is achieved by sliding lens L2 relative to HOE H2. In instances where multiple lens elements are used to construct L2, the spacing if such lenses can be varied to impart the desired focal length to the lens system L2. Notably, in some instances, it may also be desirable or necessary to adjust the (x,y) position of the L2 along the optical axis of the system. Thereafter, the lens L2 mounting bracket is glued or otherwise fixed relative to the module housing. Then the housing cover plate **127** is then fastened upon the top of the module housing and then the aligned laser beam producing module is removed from the parameter adjustment system and is ready for use in the system for which it has been designed.

[0401] Pre-alignment/Alignment Stage of the Assembly Procedure for System Embodiment Nos. 9 and 11

[0402] The prealignment stage for System Embodiments Nos. 9 and 11 is similar to that described for System Embodiments 1, 5, 13 and 14 above with several exceptions. Foremost, in System Embodiment Nos. 9 and 11, second lens L2 is disposed between H1 and H2. Thus, a module similar to that shown in FIGS. **11A-11C**, but with second lens L2 disposed between HOEs H1 and H2. could be used to realize such a system design. Notably, the design of such a module will enable the second lens L2 to be installed within its modified module housing after completing the alignment procedure described above. When the second lens L2 is installed within the module housing, the focal length of the output laser beam can be set by translating lens L2 along the optical axis (or adjusting the focal-length of second lens L2 in appropriate cases).

[0403] Pre-alignment and Alignment Stages of the Assembly Procedure for System Embodiment Nos. 3 and 7

[0404] The prealignment stage of the assembly procedure for System Embodiment Nos. 3 and 7 is different than that described for System Embodiment Nos. 2 and 6 above, in two significant ways. First, HOE H2 is a variable spatial-frequency HOE (having focusing power) which is mounted in a HOE support bracket enabling its principal plane to be translated along its optical axis relative to the principal plane of HOE H1 without modifying the tilt angle P therebetween.

Secondly, in System Embodiment Nos. 3 and 7, there is no second lens L2 as required in System Embodiments Nos. 2 and 6. While such structural differences simplify the pre-alignment stage of the assembly process, they do not alter the procedure for aligning the VLD junction along the x and y axes of the system to minimize beam dispersion, or along the z axis to eliminate beam astigmatism. Notably, after eliminating beam dispersion and correcting for astigmatism, HOE H2 can be translated along its optical axis to set the focal length (i.e. focus) of the output laser beam to that specified during design.

[0405] Method of Assembling and Aligning the Subcomponents of Laser Beam Producing Systems of the Illustrative System Embodiments of the Present Invention Designed for Instances Where Focus Control, Astigmatism Correction and Delta-focusing are Desired: System Embodiments Nos. (4), (8), (10) and (12): Case C

[0406] In general, when assembling a laser beam producing module based on System Embodiments Nos. **4** and **8**, the parameter adjustment procedure of the present invention can be carried out on the module design shown in FIGS. **11**A-**11**C supported upon the parameter adjustment system of **FIG. 13**. When assembling a laser beam producing module based on System Embodiments Nos. 10 and 12, the parameter adjustment procedure of the present invention can be carried out on the module design similar to that shown in FIGS. **11**A-**11**C (but with lens L2 disposed between H1 and H2) supported upon the parameter adjustment system of **FIG. 13**.

[0407] For each of these groups of system embodiments, the assembly procedure comprises a prealignment stage and an alignment stage. During the prealignment stage, various optical components of the laser beam producing module are installed within their respective mounting locations within the module housing, or within support structure associated with the parameter adjustment system **150**. During the alignment stage, the VLD and lens L1 are aligned relative to each other, the focusing lens L2 is aligned relative to HOE H2, and the HOE H2 is aligned relative to HOE H1, in order to achieve the performance characteristics specified during the design stage. Details of each of these stages will be described below for System Embodiment Nos. 4, 8, 10 and 12, with reference to **FIG. 16**.

[0408] Pre-alignment Stage of the Alignment Procedure for System Embodiment Nos. 4 and 8

[0409] The first step of the prealignment stage of the system assembly procedure involves press fitting the VLD **131** into VLD heat-sink plate **132** so that the VLD junction is oriented in it predetermined orientation relative to the VLD heat-sink plate.

[0410] The second step of the prealignment stage involves mounting HOE H1 and HOE H2 (supported in its mounting bracket **141**) into their appropriate mounting slots **139** and **142** formed within module housing **135**. Thereafter, HOE H1 can be glued or otherwise fixed in position, while HOE H2 is permitted to moved along its along its optical axis within the module housing.

[0411] The third step of the prealignment stage involves inserting lens L1 into the lens recess (e.g. pocket) formed within the module housing, so that the planar side of the lens L1 is mounted incident the VLD **131**. Thereafter, the lens L1 can be glued or otherwise fixed in position.

[0412] The fourth step of the prealignment stage involves placing the VLD mounting bracket **133** into appropriate recesses **133**C and **133**D formed in the module housing. Notably, the VLD mounting yoke is held within recesses **133**C and **133**D by frictional fit and can only be translated along z axis of the parameter alignment system (i.e. the x and y directions being fixed by the geometry of the recesses.

[0413] The fifth step of the prealignment stage involves placing the module housing **135** into the module housing support platform **151** so that pins on the bottom surface of the housing module align with corresponding holes formed on the housing module support platform **151**. When housing module **135** is installed in the manner described above, it is then clamped to the module housing support platform **151** by way of screws, pressurized clamps or other releasable fastening devices.

[0414] The sixth step of the prealignment stage involves placing the mounting yoke **114** on its support and clamping the same.

[0415] The seventh and last step of the prealignment stage involves attaching the VLD **131** to VLDsupport platform **154** of the parameter alignment system. In the preferred embodiment, this step can be achieved by sliding the leads of the VLD into a connector provided on the VLD support platform. The VLD support platform **154** is capable of movement along the x, y and z axes of the parameter adjustment system **150**.

[0416] Alignment Stage of the Assembly Procedure for System Embodiment Nos. 4 and 8

[0417] The first step of the alignment stage of the procedure involves sliding the module housing support platform **151** towards VLD support platform **154** under the control of microcontroller **161** until the VLD is positioned within oversized aperture **133**A formed within the VLD support bracket **133** positioned within the recesses of the module housing. Notably, at this "load" position, the VLD is free to move within the x and y plane by virtue of the oversized aperture in the VLD mounting yoke, and also along the z axis by virtue of clearance provided between the pre-mounted lens Ll and the outer face of the VLD mounting yoke. As will become apparent hereinafter, such clearance enables the optical axis of each loaded VLD to be aligned with respect to the optical axis of lens L1 in a manner required to achieve minimal beam dispersion and the desired aspect-ratio specified during the design stage described above.

[0418] The second step of the alignment stage of the procedure involves locking the position the module housing support platform **151** relative to the underlying optical bench **152** (arranged in its "loaded" configuration). This locking operation can be carried out using locking mechanism **162** computer control.

[0419] The third step of the alignment stage of the procedure involves locking the VLD heat-sink plate **132** to the VLD support platform **154** so that the VLD heat-sink plate is prevented from undergoing rotation in the x-y plane during alignment of the VLD **131** relative to the lens L1 during the subsequent steps of the alignment procedure. This

condition will ensure that the VLD junction is prevented from rotation during the alignment procedure, which may involve translation of the VLD junction in the x, y and/or z axes of the system in order to secure the performance parameters of the module established during the design stage.

[0420] The fourth step of the alignment stage of the procedure involves applying a biasing force on the VLD support bracket **133** (in the direction of the VLD heat-sink plate) so that the plate-like portion of the VLD support yoke gently engages the VLD heat-sink plate **132** in order that the surface of the VLD heat-sink plate and planar portion of the VLD support bracket **133** assume the same z coordinate position during x, y alignment operations, while permitting relative movement between these two plate-like structures along the z-x plane of the system.

[0421] The fifth step of the alignment stage of the procedure involves supplying electrical power to the VLD **131** so that it produces an output laser beam which is transmitted through lens L1 and HOEs H1 and H2.

[0422] The sixth step of the alignment stage of the procedure involves translating the VLD support platform **154** in the x-y plane until the output laser beam strikes the center of the quadrant photodetector **159**, which has been prealigned relative to the locked-in-position module housing **135** so that first diffraction order beam from HOE H2 (i.e. the optical axis thereof disposed in the $\theta_{d1}$ plane of diffraction at diffraction angle ) passes through the center of the quadrant-type detector **159**. When the output laser beam strikes the center of the quadrant-type photodetector, then the design geometry will be achieved, resulting in minimum beam dispersion and the desired amount of beam shaping by design. Also optimal output power will be transmitted from the module along the optical axis of the system. This condition is based on the reasonable assumption that the diffraction efficiencies of HOEs H1 and H2 will be maximum along the first diffraction order by design, and characteristic wavelength of the VLD is substantially the same as the reconstruction wavelength of HOEs H1 and H2. Notably, this on-center aligned position can be visually detected when the indicator dot on the quadrant detector display unit **160** is aligned with the cross-hair on the display surface thereof. Completion of this step of the procedure will ensure that output power of the laser beam producing module will be as close to the output power of the VLD as is practically possible, as well as ensuring that the design requirements have been satisfied.

[0423] The seventh step of the alignment stage of the procedure involves gluing or otherwise permanently securing the x-y position of the VLD heat-sink plate **132** and VLD support bracket (yoke) **133** in the position determined during the step above. Thereafter, the biasing force applied during the above step of the procedure can be removed.

[0424] The eighth step of the alignment stage of the procedure involves adjusting the position of the subassembly (comprising the VLD **131**, the VLD heat-sink plate **132** and the VLD support yoke **133**) along the z axis of the parameter adjustment system while monitoring the output laser at the desired focal length of the module using beam profiling instrument **157**. When the spot size of the output laser beam (at some unknown location along the optical axis HOE H2) is minimum in both the x and y dimensions, then VLD support yoke **133** is glued or otherwise fixed in position relative to the module housing **135**. Notably, the beam profiling instrument will have to be moved along the optical axis of HOE H2 to detect this condition, in which the output laser beam is free of astigmatism. While the output beam may still have elliptical cross-sectional characteristics along its direction of propagation, its beam cross-section will be minimum for both dimensions at this detected point which, by definition, is stigmatic beam. Thereafter, the VLD support yoke is glued or otherwise fixed to the module housing **135**.

[0425] The ninth step of the alignment stage of the procedure involves adjusting the position of HOE H2 relative to HOE H1 while monitoring the beam cross-section at a focal point determined during the process) using beam profiling instrument **157**. When the output laser beam is focused to a predetermined focal point, then the position of HOE H2 is glued or otherwise fixed relative to HOE H1.

[0426] The tenth step of the alignment stage of the procedure would involve inserting lens support bracket **144**, containing prespecified lens L2**143**, into recess **145** formed within the front end of the module housing **135**. In the illustrative embodiment, lens mounting bracket **144** can be manually adjusted by a small adjustment screw or like mechanism embodied within the module housing. This adjustment mechanism allows the end-user to fine-tune the resulting focal length of the laser beam producing module as required or desired by the application at hand. In some instances, it is contemplated that the laser beam producing module will be installed within a larger system, in which the output stigmatic laser beam from the module will be further modified for a particular application (e.g. scanning). In such cases, it is understood that the laser beam producing module may be first removed from the module housing support platform **151** of the parameter adjustment system described above, and then installed within the larger system. Thereafter, the resulting larger system can be mounted to a parameter adjustment system of the general type described above in order to set the focal length of the laser beam producing module so that the focal length of the resulting system is achieved. Clearly, there will be may ways in which to fine-tune the focal length of the laser beam producing module of System Embodiment Nos. 4 and 8.

[0427] Then the housing cover plate **147** is fastened upon the top of the module housing, and thereafter the aligned laser beam producing module is removed from the parameter adjustment system and is ready for use in the system **150** for which it has been designed.

[0428] Pre-alignment and Alignment Stages of the Assembly Procedure for System Embodiment Nos. 10 and 12

[0429] The prealignment stage of the assembly procedure for System Embodiment Nos. 10 and 12 is different than that described for System Embodiment Nos. 4 and 8 above, in one significant way. In particular, in System Embodiment Nos. 10 and 12, the second lens L2 is disposed between the HOEs H1 and H2, rather than beyond the HOE H2, as shown in **FIGS. 2J and 2L**. Such structural differences alter the prealignment stage of the assembly process slightly, as well as the procedure for aligning the VLD junction along the x and v axes of the system to minimize beam dispersion, or along the z axis to eliminate beam astigmatism. In particular, beam dispersion is minimized while an "alignment HOE"

with no optical power installed in the position of HOE H2, when the position-adjustable lens L2 is not yet installed within the module housing. Astigmatism is corrected by adjusting the position of the VLD relative to fixed lens L1136. Then an average focal distance for the laser beam producing module is set by inserting lens L2 and adjusting its position within its mounting recess. At this stage, the alignment HOE is removed and HOE H2 is put into place and can be adjusted while on the module housing platform to set a finely tuned focal distance for the laser beam producing module, or alternatively, first installed within a larger optical system, and thereafter adjusted to fine tune the focal length of the module to achieve a particular design objective for the larger optical system, as described hereinabove.

[0430] Method of Assembly and Aligning the Subcomponents of Laser Beam Producing Systems of the Illustrative System Embodiments of the Present Invention Designed for Instances Where Astigmatism Correction is Desired but Neither Focus Control nor Delta-focusing are Required: System Embodiment Nos, (13) and (14): Case D

[0431] In general, when assembling a laser beam producing module based on System Embodiments Nos. 13 and 14, the parameter adjustment procedure of the present invention can be carried out on the module design similar to that shown in FIGS. 7A-7C (but with lens L1 being a focusing lens) supported upon the parameter adjustment system of **FIG. 13**, as shown in **FIG. 17**.

[0432] For this group of system embodiments, the assembly procedure comprises a prealignment stage and an alignment stage. During the prealignment stage, various optical components of the laser beam producing module are installed within their respective mounting locations within the module housing, or within support structure associated with the parameter adjustment system **150**, as described in connection with System Embodiment Nos. 1 and 5. During the alignment stage, the (x,y) position of the VLD is aligned relative to the focusing lens L1 in order to achieve zero beam dispersion for the central ray of the beam and minimized for all others, using the (x,y) alignment procedure described hereinabove. Thereafter, the position of the VLD is adjusted along the z axis in order to eliminate astigmatism in the output laser beam using the z axis alignment procedure described above. Notably, in this System Embodiment, astigmatism elimination is achieved at the expense of the focus control, while minimizing beam dispersion and achieving a limited degree of aspect-ratio control.

[0433] Exemplary Systems and Devices Within Which the Laser Beam Producing System of the Present Invention can be Embodied

[0434] The laser beam producing system of the present invention described in detail hereinabove may, in all of its various embodiments, be embodied within an infinite variety of systems requiring the production of a laser beam having predetermined beam characteristics, substantially free of dispersion. Hereinbelow are just a few exemplary systems and devices within which the laser beam production system can be embodied in accordance with the principles of the present invention. As such, each such system provides a further embodiment of the present invention.

[0435] As illustrated in **FIG. 18**, any one of the laser beam producing devices of the present invention can be incorporated in a hand-supportable laser scanning device

[0436] As illustrated in **FIG. 19**, any one of the laser beam producing devices of the present invention can be incorporated a fixed-projection type laser scanning system.

[0437] As illustrated in **FIG. 20**, any one of the laser beam producing devices of the present invention can be incorporated a body-wearable laser scanning system, as well as a finger-mounted laser scanning system.

[0438] As illustrated in **FIG. 21**, any one of the laser beam producing devices of the present invention can be incorporated a holographic laser scanning system.

[0439] As illustrated in **FIG. 22**, any one of the laser beam producing devices of the present invention can be incorporated a CD-ROM disc playback system.

[0440] As illustrated in **FIG. 23**, any one of the laser beam producing devices of the present invention can be incorporated a laser pointing device.

[0441] As illustrated in **FIG. 24**, any one of the laser beam producing devices of the present invention can be incorporated a medical laser sculpturing system.

[0442] Any of the hand-supportable, body-wearable, or other scanning systems described hereinabove may embody one or more of the following functionalities: the spatially overlapping object detection and laser scan fields taught in U.S. Pat. No. 5,468,951; the long-range/short-range modes of programmable scanning operation taught in U.S. Pat. No. 5,340,971; the power-conserving system-control architecture taught in U.S. Pat. No. 5,424,525; and the RF signal transmission functionalities and acoustical acknowledgement signaling taught in copending U.S. patent application Ser. No. 08/292,237, each of which is commonly owned by Metrologic instruments, Inc. of Blackwood.

[0443] Some Modifications that Readily Come to Mind

[0444] While each of the previous module designs has two DOE's, it is possible to design a module with three or more DOE's if desired or required by a particular application. One possible reason for desiring additional DOEs might be a need for more beam shaping than can reasonably be provided by only two DOE's. While three or more DOEs would be acceptable, one DOE would not be acceptable, due to the excessive amount of dispersion produced by diffractive optics. This is not a problem for multiple DOE's because they can be specifically designed to have a net dispersion of zero when combined together.

[0445] While the illustrative embodiments described hereinabove make reference to using DCG material to fabricate the DOEs within modules, devices and systems of the present invention, it is understood that other types of recording materials such as photo-polymer recording materials (e.g. photo-polymer DMP **128** from DuPont and other vendors) can be used with excellent results. One advantage of using a photo-polymer recording material (e.g. photo-polymer DMP **128** from Dupont) to fabricate the DOEs is that, unlike DCG material, photo-polymer recording materials are easier to handle and less sensitive to moisture.

[0446] In general, the refractive optical elements L1 and L2 employed in the illustrative embodiments disclosed hereinabove can be realized using any suitable optically-transparent material including glass and plastic. In applications having insignificant temperature changes and where

manufacturing cost is an issue, it will be preferred to make lens L1 entirely from plastic material. However, in many applications, wherein the ambient temperature is expected to cycle over a substantial temperature range, it will be preferable to construct such lens from glass material rather than a plastic material, as glass material is less susceptible to thermal variations than plastic material. Consequently, the focal length of lens L1 (which is typically quite short) will not change nearly as much in response to a given temperature change, as compared to a lens L1 made from a plastic material.

[0447] In order to make inexpensive aspheric lens (e.g. L1) which is less sensitive to thermal changes, it is possible to mount an aspherical surface element made from a material other than glass (e.g. molded plastic) onto a spherical lens made from glass. Mounting of the aspherical surface element can be carried out using a suitable optical cement. In general, thermal-related effects in such optical components are proportional to the Temperature Coefficient of Expansion (TCE) and Temperature Coefficient of Refractive Index (TCRI) of the optical material being used. Both of these constants are much greater for plastic than for glass. Thermal-related effects are also a function of the thickness of the material and the relative optical power of the optical element.

[0448] Most of the thickness and thus most of the optical power provided by a two-part lens device (L1) as described above is contained in the glass element component thereof. In this two-part lens device, the plastic aspheric element is made very thin and contains, theoretically, only the amount of aspherical component needed to provide correction of spherical aberration in the incident laser beam. Thus, the plastic aspheric component mounted to the glass component will have very little optical power. Therefore, the overall two-part lens L1 will have thermal properties much closer to a pure glass lens than to a pure plastic lens.

[0449] Alternatively, in applications having significant ambient temperature changes and where the cost of manufacture of the lens L1 is not critical design constraint, it will be preferred to make lens L1 entirely from glass material.

[0450] In the second illustrative embodiment shown in FIGS. 2B, 2B1, 2B2 and 2B3 and described hereinabove (i.e. System Embodiment No. 2), Applicants have taught how DOEs D1 and D2 employed therein can be realized using either transmission-type and/or reflection-type volume holograms (HOEs) for DOE1 and DOE2. It is understood, however, that the other illustrative embodiments of the present invention (System Embodiments Nos. 1 and 3-14) disclosed herein can be realized as well using reflection-type and/or transmission-type volume HOEs. In such alternative realizations of these system embodiments, the only requirement is that the angle of diffraction be different than the angle of incidence for each light diffractive element of the DOE-based device. In general, this requirement can be met using either a transmissive DOE (e.g. transmission HOE) or a reflective DOE (e.g. reflection HOE).

[0451] The various embodiments of the laser beam producing system hereof have been described in connection with linear (1-D) and 2-D code symbol scanning applications. It should be clear, however, that the apparatus and methods of the present invention are equally suited for use in other applications including, for example, scanning alphanumeric characters (e.g. textual information) in optical character recognition (OCR) applications.

[0452] Several modifications to the illustrative embodiments have been described above. It is understood, however, that various other modifications to the illustrative embodiment of the present invention will readily occur to persons with ordinary skill in the art. All such modifications and variations are deemed to be within the scope and spirit of the present invention as defined by the accompanying claims to Invention.

What is claimed is:

1. A laser beam modification system comprising:

a plurality of diffractive optical elements (DOEs) for modifying the size and shape of a laser beam produced from a commercial-grade laser diode, such as a VLD, over an extended range while avoiding the introduction of dispersion in the output laser beam.

2. The laser beam modifying system of claim 1, wherein the inherent astigmatism characteristics associated with said VLD are eliminated or minimized.

3. A DOE-based laser beam modifying system comprising:

a plurality of diffractive optical elements (DOEs) for modifying the size and shape of a laser beam produced from a commercial-grade laser diode, such as a VLD,

wherein beam dispersion is minimized, or normal dispersion or reverse dispersion characteristics are provided for any given beam compression or expansion ratio, by selecting the proper angle between said DOEs.

4. A DOE-based laser beam modifying system, wherein beam dispersion is minimized for the system acting alone, or fine-tuned to compensate for the dispersion of other elements preceding it or following the system.

5. A method of producing a laser beam having a desired spot-size over a specified depth of field, comprising the steps of:

(a) focusing said laser beam with a lens; and

(b) reshaping said laser beam using a pair of diffractive optical elements.

6. The method of claim 5, wherein said lens is realized as refractive element having symmetric surface profile characteristics.

7. The method of claim 5, wherein said lens is realized as variable DOE of a selected type.

8. A laser beam producing system comprising:

a set of first and second beam-modifying holograms which produce zero dispersion while simultaneously providing any desired aspect-ratio for the beam-leaving (exiting) said second beam-modifying hologram.

9. An ultra-compact DOE-based device comprising:

means for collimating or focusing a laser beam produced from a n astigmatic VLD while minimizing dispersion beam dispersion and correcting for beam ellipticity.

10. An ultra-compact optics module comprising:

means for modifying the aspect-ratio of a laser beams produced by a VLD:

means for eliminating beam astigmatism introduced by virtue of the inherent astigmatic difference in said VLD, and

means for minimizing dispersion in the output laser beam created by wavelength-dependent variations in the spectral output of the VLD.

**11**. An optics module comprising:

a pair of DOEs configured in the beam compression mode,

wherein the total expansion factor (M) of the DOE combination is less than one, so that the size of the laser beam in the plane of diffraction is compressed without changing the beam size in the dimension perpendicular to the plane of diffraction.

**12**. An optics module employing a pair of DOEs configured in the beam expansion mode, wherein the total expansion factor (M) of the DOE combination is greater than one, so that the size of the laser beam in the plane of diffraction is expanded without changing the beam size in the dimension perpendicular to the plane of diffraction.

**13**. A light diffractive optics module for incorporation into small laser scanning devices, such as laser scan-engines, as well as replacing conventional prisms and anamorphic lenses used in VLD-based optical systems such as optical storage devices, CD-ROM players and recorders, and like systems and devices.

**14**. A DOE-based optics module comprising:

means for modifying the aspect-ratio of aVLD beam while simultaneously controlling beam dispersion to minimize the overall dispersion of the optical system in which it is being used.

**15**. The DOE-based optics module of claim 14, wherein beam astigmatism inherently associated with said VLD is eliminated or minimized.

**16**. A method for designing a dual-DOE laser beam modifying system, in which a pair of equations are solved under a given set of conditions which ensures that beam dispersion is eliminated and a desired expansion factor (M) is obtained.

**17**. An optical design method, wherein analytical and spreadsheet-type programs are combined in an integrated fashion to allow for easy design and analysis of the optics module under consideration.

**18**. An optics module comprising:

one or more light absorbing surfaces for absorbing one or more zeroeth-order beams diffracted from two or more DOEs employed in said DOE-based optics module.

**19**. A system for precisely and rapidly aligning the parameters of the optics modules of the present invention to enable the inexpensive mass production of such optical systems and devices for widespread use in diverse fields of endeavor.

**20**. A parameter alignment system, comprising:

means for micro-adjustment of the optical components of HOE-based laser beam producing modules under microcomputer control, thereby enabling mass-production of laser beam producing modules which satisfy high quality-control (QC) measures.

**21**. A method of producing a laser beam comprising the steps of:

(a) producing an astigmatic elliptical light beam from a VLD; and

(b) modifying said light beam so that it has a selected set of beam characteristics.

**22**. A hand-held laser scanner, wherein a DOE-based laser beam producing system is embodied for producing a laser beam for bar code scanning operations.

**23**. A body-wearable laser scanner, wherein a DOE-based laser beam producing system is embodied for producing a laser beam for bar code scanning operations.

**24**. A laser scanning-engine, wherein a DOE-based laser beam producing system is embodied for producing a laser beam for bar code scanning operations.

**25**. A holographic laser scanner wherein a DOE-based laser beam producing system is embodied for producing a laser beam for bar code scanning operations.

**26**. A CD-ROM playing unit, wherein a DOE-based laser beam producing svstem is embodied to enable the production of laser beams for reading information digitally recorded within a CD-ROM or like recording device.

**27**. A laser-based instrument, wherein a DOE-based laser beam producing system is embodied to enable the production of laser beams for diagnosis or detection of various conditions.

**28**. A DOE-based subsystem comprising:

a laser diode source for producing a laser beam; and

a pair of DOEs (D1 and D2) designed to satisfy a condition wherein that the beam-shaping factor M of said DOEs is less than unity and the narrower dimension of the laser beam exiting said laser diode source is oriented perpendicular to a common plane of incidence passing through said DOEs D1 and D2.

**29**. The DOE-based subsystem of claim 28, wherein said condition is satisfied by orienting the junction of said laser diode source (and thus its narrower beam dimension and polarization direction) perpendicular to the common plane of incidence, and the E-field of the incident laser beam perpendicular to the common plane of incidence, so that the wider dimension of the laser beam is disposed within the common plane of incidence (wherein diffraction occurs) so that beam compression results, while the narrower beam dimension is disposed perpendicular thereto (wherein no diffraction occurs) so that no beam compression results along said narrower beam dimension.

**30**. A DOE-based subsystem comprising:

a laser diode source for producing a laser beam; and

a pair of DOEs (D1 and D2) designed to satisfy a condition wherein the beam-shaping factor M for said DOEs is less than unity and the narrower dimension of the laser beam exiting said laser diode source is oriented parallel to the common plane of incidence passing through said DOEs D1 and D2.

**31**. The DOE-based subsystem of claim 30, wherein said condition is satisfied by orienting the junction of said laser diode source (and thus its narrower beam dimension and polarization direction) parallel to the common plane of incidence, and the E-field of the incident laser beam parallel to the common plane of incidence, so that the narrower dimension of the laser beam is disposed within the common plane of incidence (wherein diffraction occurs) so that beam compression results, while the wider beam dimension is disposed perpendicular thereto (wherein no diffraction occurs) so that no beam compression results along said wider beam dimension.

**32**. A DOE-based subsystem comprising:

a laser diode source for producing a laser beam; and

a pair of DOEs (D1 and D2) designed to satisfy a condition wherein the beam-shaping factor M thereof is greater than unity and the narrower dimension of the laser beam exiting the VLD is oriented perpendicular to the common plane of incidence passing through said DOEs D1 and D2.

**33**. The DOE-based subsystem of claim 32, wherein said condition is satisfied by orienting the VLD junction (and thus its narrower beam dimension and polarization direction) perpendicular to the common plane of incidence, and the E-field of the incident laser beam perpendicular to the common plane of incidence, so that the wider dimension of the laser beam is disposed within the common plane of incidence (wherein diffraction occurs) so that beam expansion results, while the narrower beam dimension is disposed perpendicular thereto (wherein no diffraction occurs) so that no beam expansion results along said narrower beam dimension.

**34**. A DOE-based subsystem comprising:

a laser diode source for producing a laser beam; and a pair of DOEs (D1 and D2) designed to satisfy a condition wherein the beam-shaping factor M of said DOEs is greater than unity and the narrower dimension of the laser beam exiting said laser diode source is oriented parallel to the common plane of incidence passing through DOEs D1 and D2.

**35**. The DOE-based of claim 34, wherein said condition is satisfied by orienting the junction of said laser diode source (and thus its narrower beam dimension and polarization direction) parallel to the common plane of incidence, and the E-field of the incident laser beam parallel to the common plane of incidence, so that the narrower dimension of the laser beam is disposed within the common plane of incidence (wherein diffraction occurs) so that beam expansion results, while the wider beam dimension is disposed perpendicular thereto (wherein no diffraction occurs) so that no beam expansion results along said wider beam dimension.

**36**. A laser beam producing system comprises:

a laser beam source, such as a visible laser diode (VLD) for producing a laser beam from its junction typically having divergent and elliptical beam characteristics;

a collimating lens (L1) for collimating the laser beam as it is transmitted through collimating lens Ll and through the system in a S-incident manner;

a fixed spatial-frequency diffractive optical element (DOE) denotable by D1 having a beam expansion factor M1; and

a fixed spatial-frequency diffractive optical element (DOE) denotable by D2. having a beam expansion factor $M_2$.

**37**. The laser beam producing system of claim 36, wherein said collimating lens (L1) is realized by an optical element selected from the group consisting of a refractive lens, a HOE, a CGH, other type of DOE, a grin lens, and one or more zone plate(s).

**38**. The laser beam producing system of claim 36, wherein each said DOE is realized by an optical element selected from the group consisting of a HOE, a computer-generated hologram (CGHs), a surface-relief hologram, and other diffractive optical element.

**39**. The laser beam producing system of claim 36, wherein the total beam-shaping factor ($M=M_1M_2$) for the laser beam modifying subsystem is less than unity (1), that is M1*M2<1, and thus the laser beam leaving the collimating lens (L1) is compressed in one dimension.

**40**. A laser beam producing system comprises:

a laser beam source, such as a visible laser diode (VLD), for producing a laser beam from its junction having divergent and elliptical characteristics;

a collimating lens (L1) for collimating the laser beam as it is transmitted through collimating lens L1 and through the system in a S-incident manner;

a fixed spatial-frequency diffractive optical element (DOE) denotable by D1 having a beam expansion factor $M_1$;

a fixed spatial-frequency diffractive optical element (DOE) denotable by D2, having a beam expansion factor $M_2$; and

a focusing lens L2, realizable as a refractive lens, a HOE, a DOE, a grin lens, or zone plate(s), disposed after DOE D2 for focusing the output laser beam to a desired or required point in space.

**41**. The laser beam producing system of claim 40, wherein said collimating lens (L1) is realized by an optical element selected from the group consisting of a refractive lens, a HOE, a CGH, other type of DOE, a grin lens, and one or more zone plate(s).

**42**. The laser beam producing system of claim 40, wherein each said DOE is realized by an optical element selected from the group consisting of a HOE, a computer-generated hologram (CGH), a surface-relief hologram, and other diffractive optical element.

**43**. The laser beam producing system of claim 40, wherein the total beam-shaping factor ($M=M_1M_2$) for the laser beam modifying subsystem is less than unity (1), that is M1*M2<1, and thus the laser beam leaving the collimating lens (L1) is compressed in one dimension.

**44**. A laser beam producing system comprises:

a laser beam source, such as a visible laser diode (VLD), for producing a laser beam from its junction;

a collimating lens (L1) for collimating the laser beam as it is transmitted through collimating lens L1 and through the system in a S-incident manner:

a fixed spatial-frequency diffractive optical element (DOE) denotable by D1 having a beam expansion factor $M_1$; and

a variable spatial-frequency diffractive optical element (DOE) denotable by D2, having a beam expansion factor $M_2$.

**45**. The laser beam producing system of claim 44, wherein said collimating lens (L1) is realized by an optical element selected from the group consisting of a refractive lens, a HOE, a CGH, other type of DOE, a grin lens, and one or more zone plate(s), and wherein each said DOE is realized by an optical element selected from the group consisting of a HOE, a computer-generated hologram (CGHs), a surface-relief hologram, and other diffractive optical element.

**46**. The laser beam producing system of claim 44. wherein the total beam-shaping factor ($M=M_1M_2$) for the laser beam modifying subsystem is less than unity (1), that is MI*M2<1, and thus the laser beam leaving the collimating lens (L1) is compressed in one dimension.

**47**. A laser beam producing system comprises:

a laser beam source, such as a visible laser diode (VLD), for producing an elliptical divergent laser beam from its junction;

a collimating lens (L1) for collimating the laser beam as it is transmitted through collimating lens L1 and through the system in a S-incident manner;

a fixed spatial-frequency diffractive optical element (DOE) denotable by D1;

a variable spatial-frequency diffractive optical element (DOE) denotable by D2 and adjustably mounted to enable, during the alignment stage of the system adjustment process, the principal plane of DOE D2 to be translated along its optical axis relative to the principal plane of DOE D1 without modifying the tilt angle between said DOEs D1 and D2; and

a focusing lens (L2) disposed after the second DOE D2 and having a focal length which is can be adjusted to enable the focusing of the output laser beam to some predetermined focal point in space, during the alignment stage of the system assembly process.

**48**. The laser beam producing system of claim 47, wherein said collimating lens (L1) is realized by an optical element selected from the group consisting of a refractive lens, a HOE, a CGH, other type of DOE, a grin lens, and one or more zone plate(s).

**49**. The laser beam producing system of claim 47, wherein each said DOE is realized by an optical element selected from the group consisting of a HOE, a computer-generated hologram (CGHs), a surface-relief hologram, and other diffractive optical element.

**50**. The laser beam producing system of claim 47, wherein said focusing lens (L2) is realized by an optical element selected from the group consisting of a refractive lens, a HOE, a DOE, a grin lens, and zone plate(s).

**51**. The laser beam producing system of claim 47, wherein the total beam-shaping factor ($M=M_1M_2$) for the laser beam modifying subsystem is less than unity (1), that is MI*M2<1, and thus the laser beam leaving the collimating lens (L1) is compressed in one dimension.

**52**. A laser beam producing system comprises:

a laser beam source, such as a visible laser diode (VLD), for producing a laser beam from its junction;

a collimating lens (L1) for collimating the laser beam as it is transmitted through collimating lens L1 and through the system in a P-incident manner;

a fixed spatial-frequency diffractive optical element (DOE) denotable by D1: and

a fixed spatial-frequency diffractive optical element (DOE) denotable by D2.

**53**. The laser beam producing system of claim 52, wherein said collimating lens (L1) is realized by an optical element selected from the group consisting of a refractive lens, a HOE, a CGH, other type of DOE, a grin lens, and one or more zone plate(s).

**54**. The laser beam producing system of claim 52, wherein each said DOE is realized by an optical element selected from the group consisting of a HOE, a computer-generated hologram (CGHs), a surface-relief hologram, and other diffractive optical element.

**55**. The laser beam producing system of claim 52, wherein the total beam-shaping factor ($M=M_1M_2$) for the laser beam modifying subsystem is greater than unity (1), that is M1*M2>1, and thus the laser beam leaving the collimating lens (L1) is expanded in one dimension.

**56**. A laser beam producing system comprises:

a laser beam source, such as a visible laser diode (VLD), for producing a laser beam from its junction;

a collimating lens (L1) for collimating the laser beam as it is transmitted through collimating lens L1 and through the system in a P-incident manner;

a fixed spatial-frequency diffractive optical element (DOE) denotable by D1;

a fixed spatial-frequency diffractive optical element (DOE) denotable by D2; and

a focusing lens (L2) disposed after the second DOE D2 for focusing the output laser beam to some point in space.

**57**. The laser beam producing system of claim 56, wherein said collimating lens (L1) is realized by an optical element selected from the group consisting of a refractive lens, a HOE, a CGH, other type of DOE, a grin lens, and one or more zone plate(s).

**58**. The laser beam producing system of claim 56, wherein each said DOE is realized by an optical element selected from the group consisting of a HOE, a computer-generated hologram (CGH), a surface-relief hologram, and other diffractive optical element.

**59**. The laser beam producing system of claim 56, wherein said focusing lens (L2) is realized by an optical element selected from the group consisting of a refractive lens, a HOE, a DOE, a grin lens, zone plate(s) or the like, disposed after said second DOE D2, for focusing the output laser beam to some point in space.

**60**. The laser beam producing system of claim 56, wherein the total beam-shaping factor ($M=M_1M_2$) for the laser beam modifying subsystem is greater than unity (1), that is M1*M2>1, and thus the laser beam leaving the collimating lens (L1) is expanded in one dimension.

**61**. A laser beam producing system comprises:

a laser beam source, such as a visible laser diode (VLD), for producing a laser beam from its junction;

a collimating lens (L1) for collimating the laser beam as it is transmitted through collimating lens L1 and through the system in a P-incident manner;

a fixed spatial-frequency diffractive optical element (DOE) denotable by D1; and

a variable spatial-frequency diffractive optical element (DOE) denotable by D2, which can be translated along the optical axis relative to the principal plane of DOE D1 during the alignment stage of the system assembly process.

**62**. The laser beam producing system of claim 61, wherein said collimating lens (Ll) is realized by an optical element

selected from the group consisting of a refractive lens, a HOE, a CGH, other type of DOE, a grin lens, and one or more zone plate(s).

**63**. The laser beam producing system of claim 61, wherein each said DOE is realized by an optical element selected from the group consisting of a HOE, a computer-generated hologram (CGHs), a surface-relief hologram, and other diffractive optical element.

**64**. The laser beam producing system of claim 61, wherein each of said DOEs is realized by an optical element selected from the group consisting of a DOE, a CGH, a surface-relief hologram, and other diffractive optical element.

**65**. The laser beam producing system of claim 61, wherein the total beam-shaping factor ($M=M_1M_2$) for the laser beam modifying subsystem is greater than unity (1), that is M1*M2>1, and thus the laser beam leaving the collimating lens (L1) is expanded in one dimension.

**66**. A laser beam producing system comprises:

a laser beam source, such as a visible laser diode (VLD);

a collimating lens (L1) for collimating the laser beam as it is transmitted through collimating lens L1 and through the system in a P-incident manner;

a fixed spatial-frequency diffractive optical element (DOE) denotable by D1;

a variable spatial-frequency diffractive optical element (DOE) denotable by D2, adjustably mounted relative to DOE D1; and

a focusing lens (L2) disposed after the second DOE D2, and adjustably mounted relative thereto, for focusing the output laser beam to some point in space.

**67**. The laser beam producing system of claim 66, wherein said collimating lens (L1) is realized by an optical element selected from the group consisting of a refractive lens, a HOE, a CGH, other type of DOE, a grin lens, and one or more zone plate(s).

**68**. The laser beam producing system of claim 66, wherein each said DOE is realized by an optical element selected from the group consisting of a HOE, a computer-generated hologram (CGHs), a surface-relief hologram, and other diffractive optical element.

**69**. The laser beam producing system of claim 66, wherein the total beam-shaping factor ($M=M_1M_2$) for the laser beam modifying subsystem is greater than unity (1), that is M1*M2>1, and thus the laser beam leaving the collimating lens (L1) is expanded in one dimension.

**70**. The laser beam producing system of claim 66, wherein each of said DOEs is realized by an optical element selected from the group consisting of a HOE, a CGH, a surface-relief hologram, and other diffractive optical element.

**71**. The laser beam producing system of claim 66, wherein said focusing lens (L2) is realized by an optical element selected from the group consisting of a refractive lens, a HOE, a DOE, a grin lens, and zone plate(s).

**72**. A laser beam producing system comprises:

a laser beam source, such as a visible laser diode (VLD), for producing a laser beam from its junction;

a collimating lens (L1) for collimating the laser beam as it is transmitted through collimating lens L1 and through the system in an S-incident manner;

a fixed spatial-frequency diffractive optical element (DOE) denotable by D1;

a fixed spatial-frequency diffractive optical element (DOE) denotable by D2; and

a focusing lens (L2) disposed between DOE D1 and DOE D2 and adjustably translatable along its optical axis for focusing the output laser beam to some point in space.

**73**. The laser beam producing system of claim 72, wherein said collimating lens (L1) is realized by an optical element selected from the group consisting of a refractive lens, a HOE, a CGH, other type of DOE, a grin lens, and one or more zone plate(s).

**74**. The laser beam producing system of claim 72, wherein each said DOE is realized by an optical element selected from the group consisting of a HOE, a computer-generated hologram (CGHs), a surface-relief hologram, and other diffractive optical element.

**75**. The laser beam producing system of claim 72, wherein the total beam-shaping factor ($M=M_1M_2$) for the laser beam modifying subsystem is less than unity (1), that is M1*M2<1, and thus the laser beam leaving the collimating lens (L1) is compressed in one dimension.

**76**. The laser beam producing system of claim 72, wherein each of said DOEs is realized by an optical element selected from the group consisting of a HOE, a CGH, a surface-relief hologram, and other diffractive optical element.

**77**. The laser beam producing system of claim 72, wherein said focusing lens (L2) is realized by an optical element selected from the group consisting of a refractive lens, holographic optical element (HOE), diffractive optical element (DOE), grin lens, and zone plate(s).

**78**. A laser beam producing system comprises:

a laser beam source, such as a visible laser diode (VLD), for producing a laser beam from its junction;

a collimating lens (L1) for collimating the laser beam as it is transmitted through collimating lens Li and through the system in a S-incident manner;

a fixed spatial-frequency diffractive optical element (DOE) denotable by D1;

a variable spatial-frequency diffractive optical element (DOE) denotable by D2, adjustably translatable relative to the principal plane of DOE D1 during the alignment stage of the system assembly process; and

a focusing lens (L2) disposed between DOE D1 and DOE D2 and adjustable translatable along its optical axis during the parameter alignment stage of the system assembly process for focusing the output laser beam to some point in space.

**79**. The laser beam producing system of claim 78, wherein said collimating lens (L1) is realized by an optical element selected from the group consisting of a refractive lens, a HOE, a CGH, other type of DOE, a grin lens, and one or more zone plate(s).

**80**. The laser beam producing system of claim 79, wherein each said DOE is realized by an optical element selected from the group consisting of a HOE, a computer-generated hologram (CGHs), a surface-relief hologram, and other diffractive optical element.

**81**. The laser beam producing system of claim 79, wherein the total beam-shaping factor ($M=M_1M_2$) for the laser beam modifying subsystem is less than unity (1), that is

M1*M2<1, and thus the laser beam leaving the collimating lens (L1) is compressed in one dimension.

**82**. The laser beam producing system of claim 79, wherein each of the DOEs is realized by an optical element selected from the group consisting of a HOE, a CGH, a surface-relief hologram, and other diffractive optical element.

**83**. The laser beam producing system of claim 79, wherein said focusing lens (L2) is realized by an optical element selected from the group consisting of a refractive lens, a HOE, a DOE, a grin lens, and zone plate(s).

**84**. A laser beam producing system comprises:

a laser beam source, such as a visible laser diode (VLD), for producing a laser beam from its junction;

a collimating lens (L1) for collimating the laser beam as it is transmitted through collimating lens L1 and through the system in a P-incident manner;

a fixed spatial-frequency diffractive optical element (DOE) denotable by D1;

a fixed spatial-frequency diffractive optical element (DOE) denotable by D2; and

a focusing lens (L2) disposed between DOE D1 and DOE D2 and adjustable translatable along its optical axis during the alignment stage of the system assembly process for focusing the output laser beam to some point in space.

**85**. The laser beam producing system of claim 84, wherein said collimating lens (L1) is realized by an optical element selected from the group consisting of a refractive lens, a HOE, a CGH, other type of DOE, a grin lens, and one or more zone plate(s).

**86**. The laser beam producing system of claim 84, wherein each said DOE is realized by an optical element selected from the group consisting of a HOE, a computer-generated hologram (CGHs), a surface-relief hologram, and other diffractive optical element.

**87**. The laser beam producing system of claim 84, wherein each of said DOEs is realized by an optical element selected from the group consisting of a HOE, a CGH, a surface-relief hologram, and other diffractive optical element.

**88**. The laser beam producing system of claim 84, wherein the total beam-shaping factor ($M=M_1M_2$) for the laser beam modifying subsystem is greater than unity (1), that is M1*M2>1, and thus the laser beam leaving the collimating lens (L1) is expanded in one dimension.

**89**. The laser beam producing system of claim 84, wherein said focusing lens (L2) is realized by an optical element selected from the group consisting of a refractive lens, holographic optical element (HOE), diffractive optical element (DOE), grin lens, and zone plate(s) or the like.

**90**. A laser beam producing system comprises:

a laser beam source, such as a visible laser diode (VLD), for producing a laser beam from its junction;

a collimating lens (L1) for collimating the laser beam as it is transmitted through collimating lens L1 and through the system in a P-incident manner;

a fixed spatial-frequency diffractive optical element (DOE) denotable by D1;

a variable spatial-frequency diffractive optical element (DOE) denotable by D2, adjustably translatable relative to the principal plane of DOE D1 during the alignment stage of the system assembly process; and

a focusing lens (L2) disposed between DOE D1 and DOE D2 and adjustably translatable along its optical axis during the parameter alignment stage of the system assembly process for focusing the output laser beam to some point in space.

**91**. The laser beam producing system of claim 90, wherein said collimating lens (L1) is realized by an optical element selected from the group consisting of a refractive lens, a HOE, a CGH, other type of DOE, a grin lens, and one or more zone plate(s).

**92**. The laser beam producing system of claim 90, wherein each said DOE is realized by an optical element selected from the group consisting of a HOE, a computer-generated hologram (CGHs), a surface-relief hologram, and other diffractive optical element.

**93**. The laser beam producing system of claim 90, wherein each of said DOEs is realized by an optical element selected from the group consisting of a HOE, a CGH, a surface-relief hologram, and other diffractive optical element.

**94**. The laser beam producing system of claim 90, wherein the total beam-shaping factor ($M=M_1M_2$) for the laser beam modifying subsystem is greater than unity (1), that is M1*M2>1, and thus the laser beam leaving the collimating lens (L1) is expanded in one dimension.

**95**. A laser beam producing system of claim 90, wherein said focusing lens (L2) is realized by an optical element selected from the group consisting of as a refractive lens, a HOE, a CGH or other a DOE, a grin lens, and zone plate(s).

**96**. A laser beam producing system comprises:

a laser beam source, such as a visible laser diode (VLD), for producing a laser beam from its junction;

an imaging lens (L1) for imaging the laser source to the focal distance as it is transmitted through imaging lens L1 and through the system in a S-incident manner;

a fixed spatial-frequency diffractive optical element (DOE) denotable by D1; and

a fixed spatial-frequency diffractive optical element (DOE) denotable by D2.

**97**. The laser beam producing system of claim 96, wherein said imaging lens (L1) is realized by an optical element selected from the group consisting of a refractive lens, a HOE, a CGH, other type of DOE, a grin lens, and one or more zone plate(s).

**98**. The laser beam producing system of claim 96, wherein each said DOE is realized by an optical element selected from the group consisting of a HOE, a computer-generated hologram (CGHs), a surface-relief hologram, and other diffractive optical element.

**99**. The laser beam producing system of claim 97, wherein the total beam-shaping factor ($M=M_1M_2$) for the laser beam modifying subsystem is less than unity (1), that is M1*M2<1, and thus the laser beam leaving the collimating lens (L1) is compressed in one dimension.

**100**. The laser beam producing system of claim 98, wherein each of the DOEs is realized by an optical element selected from the group consisting of a HOE, a CGH, a surface-relief hologram, and other diffractive optical element.

**101**. The laser beam producing system of claim 99, wherein the total beam-shaping factor ($M=M_1M_2$) for the

laser beam modifying subsystem is less than unity (1), that is M1*M2<1, and thus the laser beam leaving the collimating lens (L1) is compressed in one dimension.

**102**. A laser beam producing system comprises:

a laser beam source, such as a visible laser diode (VLD), for producing a laser beam from its junction;

a focusing lens (L1) for focusing the laser beam as it is transmitted through focusing lens L1 and through the system in a P-incident manner;

a fixed spatial-frequency diffractive optical element (DOE) denotable by D1; and

a fixed spatial-frequency diffractive optical element (DOE) denotable by D2.

**103**. The laser beam producing system of claim 102, wherein said focusing lens (L1) is realized by an optical element selected from the group consisting of a refractive lens, a HOE, a CGH, other type of DOE, a grin lens, and one or more zone plate(s).

**104**. The laser beam producing system of claim 102, wherein each said DOE is realized by an optical element selected from the group consisting of a HOE, a computer-generated hologram (CGHs), a surface-relief hologram, or other diffractive optical element.

**105**. The laser beam producing system of claim 102, wherein the total beam-shaping factor ($M=M_1M_2$) for the laser beam modifying subsystem is greater than unity (1), that is M1*M2>1, and thus the laser beam leaving the collimating lens (L1) is expanded in one dimension.

**106**. The laser beam producing system of claim 102, wherein each of said DOEs is realized by an optical element selected from the group consisting of a HOE, a CGH, a surface-relief hologram, and other diffractive optical element.

**107**. A laser beam production module for producing a laser beam having a pre-specified beam aspect-ratio, zero beam dispersion and a predetermined focus.

**108**. A laser beam production module for producing a laser beam, comprising:

means for achieving a pre-specified beam aspect-ratio;

means for achieving zero or minimum beam dispersion;

means for focusing said laser beam to a predetermined distance; and

means for correcting the astigmatism in said laser beam exiting said module.

**109**. A laser beam production module for producing a laser beam, wherein its aspect-ratio is controlled its beam dispersion is zero (or minimized), its astigmatism corrected, its focus set to a predetermined distance, and its focal length adjusted.

**110**. A laser beam production modules for producing a laser beam having a pre-specified beam aspect-ratio, zero beam dispersion and astigmatism control.

**111**. A laser beam producing device, comprising:

a laser diode source, such as a visible laser diode (VLD), for producing a laser beam from its junction;

a first diffractive optical element (DOE) denotable by D1; and

a second diffractive optical element (DOE) denotable by D2, disposed adjacent said first DOE D1;

refractive optics (L1) having an axially symmetric surface profile characteristics, and being disposed between said laser diode source and said first and second diffractive optic elements (DOEs D1 and D2), so that said DOEs modify (e.g. correct or eliminate) astigmatism in the output laser beam from said device.

**112**. The laser beam producing device of claim 111, wherein said reflective optics comprises an refractive lens (L1).

**113**. The laser beam producing device of claim 112, which further comprises means for adjusting the x, y and z position of said laser diode source, relative to said refractive lens, during assembly of said laser beam producing device, for minimizing dispersion in the output laser beam from said laser beam producing device and for eliminating or minimizing astigmatism in said output laser beam, or focusing said output laser beam to a desired focus.

**114**. A laser beam producing system comprises:

a laser beam source, such as a visible laser diode (VLD), for producing a laser beam from its junction typically having divergent and elliptical beam characteristics;

a collimating lens (L1) for collimating said laser beam as said laser beam is transmitted through said collimating lens L1;

a first diffractive optical element (DOE) denotable by D1; and

a second diffractive optical element (DOE) denotable by D2;

wherein said DOE D1 and DOE D2 are arranged as a light diffractive subsystem, and collimating lens L1 is disposed between said VLD and said light diffractive subsystem so as to modify said laser beam as said laser beam passes from said VLD through said lens L1 and thence through said DOE D1 and DOE D2.

**115**. The laser beam producing system of claim 114, wherein said collimating lens L1 is realized by an element selected from the group consisting of a refractive lens, a HOE, a CGH, other type of DOE, a grin lens, and one or more zone plate(s).

**116**. The laser beam producing system of claim 114, wherein said collimating lens L1 is realized by a multi-part optical device comprising

a spherical component made from a glass or glass-like material, and

an aspherical component mounted onto said spherical component and made from a plastic or plastic-like material.

**117**. The laser beam producing system of claim 114, wherein said DOE D1 and said DOE D2 are both realized using transmission-type DOEs.

**118**. The laser beam producing system of claim 117, wherein said transmission-type DOEs are transmission-type HOEs.

**119**. The laser beam producing system of claim 114, wherein said DOE D1 and said DOE D2 are both realized using reflection-type DOEs.

**120**. The laser beam producing system of claim 119, wherein said reflection-type DOEs are reflection-type HOEs.

**121**. The laser beam producing system of claim 114, wherein said DOE D**1** is realized using a transmission-type DOE and said DOE D**2** is realized using a reflection-type DOE.

**122**. The laser beam producing system of claim 122, wherein said transmission-type DOE is transmission-type HOE, said reflection-type DOE is a reflection-type HOE.

**123**. The laser beam producing system of claim 114, wherein said DOE D**1** is realized using a reflection-type DOE and said DOE D**2** is realized using a transmission-type DOE.

**124**. The laser beam producing system of claim 122, wherein said transmission-type DOE is transmission-type HOE, said reflection-type DOE is a reflection-type HOE.

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