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(54) Title: OPTICAL ARRAY METHOD AND APPARATUS

(57) Abstract

A method and apparatus for splitting, scanning and receiving a beam of light is disclosed. Binary optic array components are used to split, in an angular manner, an input beam into multiple beams, travelling in different directions. Miniaturized array element BOCs arranged in "n" different groups are used, wherein n is dependent upon the number of split beams needed or desired. An offset is introduced between the optical axis of each of the corresponding pair of miniaturized BOCs. By varying the offset over time, the resultant beam(s) can be scanned in one, two or three dimensions. Piezo-electric drivers controlled by a processor may be used to move the array in order to vary the offset. The device may also include a collection area to collect the returned scanned beams by using an array of optic components integrated with the scanner. The collected beams are then focused onto detectors.

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OPTICAL ARRAY METHOD AND APPARATUS

Field of the Invention

This invention relates generally to optical beams, and
5 more particularly to an improved method and apparatus for
using optical arrays for dividing a single optical beam into
multiple beams, scanning single or multiple beams in one or
two dimensions, and collecting the returned scanned beams.

Background of the Invention

10   Binary Optic Components ("BOCs") are complex diffraction
gratings and function based on the particular well known
phenomenon of diffraction of light. As those skilled in the
art will appreciate, any incoming light beam incident on a
complex diffraction grating is diffracted (e.g., see Fig. 4,
15 where diffraction grating 130 diffracts an input beam), with
the characteristics of the resulting output beam(s) dependant
upon the characteristics of the particular grating. In
principle, any desired optical beam distribution can be
computer coded and reproduced in terms of diffraction
20 gratings using electron beam write up techniques.
Subsequently, these grating patterns can be processed using
semiconductor processing technology in order to increase the
diffraction grating efficiency. When the resulting processed
components are illuminated with light beams, the desired
25 output distribution is obtained. In the past, design and
fabrication of BOCs has been used for applications such as
testing optical components and generation of complex optical
distributions.

        Relative to the present invention, the most significant
30 application of BOCs is the fact that several different
miniaturized BOCs can be fabricated on a single substrate,
with a high degree of accuracy. It has been found that the
overall miniaturized BOCs may be fabricated so as to be
identical to one another, to differ from one another, or to
35 include groups of differing miniaturized BOCs. The resulting
overall component is referred to herein as a miniaturized
array element BOC. The present invention includes several

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methods of utilizing these miniaturized array element BOCs,
including splitting, scanning, and/or collecting light beams.

First, a beam splitter is used to divide a light beam
into two or more optical beams with identical or differing
5   properties. An input light beam can normally be split into
two (2) output beams with the help of a single partially
reflecting (or transmitting) mirror or prism (e.g., see Fig.
5A). A combination of several of these components can be
used to split the input beam into several output beams (e.g.,
10 see Fig. 5B). A polarization beam splitter may be used to
divide an input beam based on the polarization
characteristics. On the other hand, light beams may be split
into several beams using a diffraction grating into
"different diffraction orders."

15   Each of the foregoing processes for splitting beams,
however, are limited in several ways. For example, these
methods are characterized by being complex; being bulky
(i.e., requiring several optical elements with optical
coatings); having limited control on output beam intensities
20 (i.e., for diffraction orders); and tending to be very
expensive. The present invention addresses the problems
associated with these devices by utilizing, among other
things, an optic array beam splitter ("OABS"), comprised of
miniaturized array element BOCs.

25   Second, a "scanned" beam can be defined as a beam whose
direction and/or location is changing over time. Such
changes may or may not be repetitious or cyclic. There are
several known ways for scanning a light beam. The most
simple technique consists of a simple motorized or mechanized
30 rotating mirror. In this example, an input light beam
reflected off of the rotating mirror would exit in a
different direction, based on the orientation of the rotating
mirror at a particular time. There are several other
techniques and components which may be used for scanning.
35 Some of the techniques consist of: acousto-optic or electro-
optic Bragg diffraction gratings, while some of the commonly
used components used for scanning are: prisms, and

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holographic optical elements. However, these techniques each
suffer from drawbacks. For example, Bragg diffraction
gratings based scanners are, in general, limited to one-
dimensional scanning, are less efficient, and are expensive.
5   Other commonly used scanners such as prisms, mirrors and
holograms are bulky and require precise, expensive motors.
Furthermore, a single mirror or prism is limited to one
dimensional scanning.

     The present invention addresses the foregoing drawbacks
10   associated with the prior art by utilizing, among other
things, an optical array sensor transmitter ("OAST")
comprised of miniaturized array element BOCs. Although the
scanning of a single light beam using BOC arrays in one
dimension has been reported in the literature (e.g., William
15   Goltas and Michael Holz, SPIE Vol. 1052, 131-41 1989), the
present invention utilizes the process of using an array of
optical components such as BOCs, to scan: i) multiple beams
in one and/or two dimensions, and ii) a single beam in two
dimensions.

20   Third, many devices such as RADARs and bar code readers,
illuminate or intercept targets of mutual interest (i.e., an
aircraft or a bar code) with "scanned" radio waves or laser
beams, and collect the subsequent reflected or scattered
waves or beams ("return beams") to determine the
25   characteristics of the target of interest. These return
beams are generally collected in one of two manners.

     The first manner is a stationary/non-scanning receiver.
The return beams of this first type are normally collected
using a large aperture system and focused on a one-
30   dimensional or two-dimensional detector array, depending upon
a one dimensional or two dimensional transmitted scan beam.
Use of this method requires that each element of the detector
array corresponds to a different direction of the transmitted
scanned beam. Thus, the main disadvantage of this approach
35   is that it requires a large array of detector elements to
capture several directions of the transmitted beam.
Furthermore, the receiver is generally suitable for one

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transmitted scan beam only.

The second manner is a scanning receiver. Here the receiver scans in-sync with the transmission scanning, and normally shares the scanning components with the transmitted
5 beam. As a result, the return beam encounters "positive" (while being transmitted) and "negative" (during return path) scan, resulting in a null scan, and hence the location of return beam is independent of the scanning.

There are two major disadvantages of this approach.
10 First, since the aperture of the receiving optics is normally significantly larger than the transmitter, the null scan option requires that the size of the transmission optics (including the scanning components) be very large, resulting in heavy and costly systems. Second, for multiple beam scans
15 the return beam encounters both the compensating negative scan and compensating de-splitting. Thus, the beam is recombined into a single beam, resulting in only a single return beam. This is undesirable, since multiple beam information in the receiver mode is needed. Therefore, in an
20 optimum system for these applications, compensation (or the negative scan) should be accomplished without sharing the transmitter and receiver apertures, and the receiver beam (or the return beam) should not encounter the de-splitting device or be recombined into a single beam.

25   Therefore, there arises a need for an optical array constructed which can split, scan and collect a beam of light, either collectively or individually. Additionally, the optical array should preferably be constructed of elements which can be fabricated in a single device. By
30 doing so, the device may be constructed robustly and at great efficiencies. Further, the calibrating and adjusting of such a system is greatly reduced. The present invention directly addresses and overcomes the shortcomings of the prior art.

35   Summary of the Invention
The present invention provides an improved optic array beam splitter in order to split in an angular manner an input

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beam into multiple beams, traveling in different directions. The OABS utilizes miniaturized array element BOCs arranged in "n" different groups, wherein n is dependent upon the number of split beams needed or desired. An offset is introduced

5   between the optical axis of each of the corresponding pair of miniaturized BOCs. As used herein "offset" shall refer to the relative shift, both magnitude and direction, between the optical axis of the two optical elements of each BOC corresponding pair.

10   In a second preferred embodiment of a device constructed according to the principles of this invention, the device includes two or more arrays of miniaturized binary optic components (BOC arrays), wherein the second BOC array includes an offset from the first. By then varying the

15 offset over time, the resultant beam(s) can be scanned in one, two or three dimensions. One example of a device which can introduce the movement to the second BOC array is a piezo-electric driver controlled by a processor in order to move in a predetermined manner.

20   According to a third preferred embodiment of a device constructed according to the principles of the present invention, the device includes two or more BOC arrays having an offset from one another, a device to introduce movement to at least one of the BOC arrays relative to the other, and a

25 detector for receiving the returned beams. The returned beams are collected by an array of optic components integrated with the scanner and focused onto detectors (preferably one for each scanned beam).

    Therefore, one feature of the present invention is that

30 the problem of multiple beam splitting, and splitting an input beam into several beams, is simplified into a single discrete assembly comprised of two separate array components which are easily fabricated. A second feature is that the resultant beams may be scanned in a programmable manner in

35 one or two dimensions. A third feature is that the transmitted beams may be collected with optical arrays of optical components which are located on the same component as

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the transmitter arrays which are easily fabricated.

Therefore, according to one aspect of the invention, there is provided an apparatus for splitting a beam of light into a plurality of output beams, comprising: a) a first
5   miniaturized array of at least one binary optical component; and b) a second miniaturized array of at least one binary optical component, wherein each of said components on said second array maps into one of said components on said first array, whereby sets of corresponding components on said first
10   and second array are defined, and wherein at least one of said binary optical components is offset, and wherein the beam of light is split into two or more output beams. There is also provided a method of splitting a beam of light into a plurality of output beams comprising the steps of: a)
15   directing a beam of light onto a first binary optic component; b) directing the resulting beam from said first binary optical component onto a second binary optical component; and c) introducing an offset between said first and second binary optical components, wherein a plurality of
20   output beams were created.

These and other advantages and features which characterize the present invention are pointed out with particularity in the claims annexed hereto and forming a further part hereof. However, for a better understanding of
25   the invention, its advantages and objects attained by its use, reference should be made to the Drawing which forms a further part hereof, and to the accompanying descriptive matter, in which there is illustrated and described preferred embodiments of the present invention.
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Brief Description of the Drawing

In the Drawing, wherein like reference numerals and letters indicate corresponding elements throughout the several views:
35   FIGURE 1 is a schematic representation of a first and second array of optical elements which split an input beam into several output beams in accordance with the principles

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of the present invention;

FIGURE 2A is a schematic representation of a multiple beam scanner using optical array elements in two dimensions;

FIGURE 2B is an enlarged cross-sectional view taken from
5   Fig. 2A;

FIGURE 3 is a schematic representation of an optical array receiver for a multiple beam scanner;

FIGURE 4 is a schematic representation of a complex diffraction grating and diffracted orders;

10 FIGURE 5A is a diagrammatic illustration of beam splitting using partially reflecting mirrors;

FIGURE 5B is a diagrammatic illustration of beam splitting using prisms;

FIGURE 5C is a diagrammatic illustration of multiple beam
15 splitter using a combination of mirrors and prisms;

FIGURE 6A is a diagrammatic illustration of a Galilean telescope with a zero degree offset;

FIGURE 6B is a diagrammatic illustration of a Galilean telescope with a zero degree offset and further illustrating
20 the exit beam traveling at an angle beta depending upon the offset amount;

FIGURE 7A is an illustration of a conventional lens;

FIGURE 7B is an illustration of a binary lens;

FIGURE 7C is a diagrammatic illustration of a Galilean
25 telescope with offset;

FIGURE 7D is a schematic illustration of a binary component Galilean optic with offset;

FIGURE 8 schematically illustrates a binary array representing a Galilean telescope with finite offsets;

30 FIGURE 9 is a cross-section of the two elements of a binary array Galilean telescope with offsets;

FIGURE 10 diagrammatically illustrates two binary arrays used to implement the present OABS;

FIGURE 11 illustrates an eight-beam binary array beam
35 splitter constructed in accordance with the principles of the present invention;

FIGURE 12 diagrammatically illustrates the schematics of

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an OAST;

FIGURE 13 diagrammatically illustrates the schematics of a two-dimensional, eight-beam scan device constructed according to the principles of the present invention;

5   FIGURE 14A diagrammatically illustrates a stationary non-scanning receiver;

FIGURE 14B diagrammatically illustrates a scanning receiver;

FIGURE 15A illustrates both a transmitted and return beam

10 going through both beam splitter and scanner, resulting in a single return beam;

FIGURE 15B illustrates a return beam which does not go through the beam splitter, resulting in multiple return beams;

15   FIGURE 16 diagrammatically illustrates the components of an eight-beam transmitter and receiver;

FIGURES 17A-17C illustrate the computer graphic hologram diffraction efficiency;

FIGURE 18 illustrates the steps in a multilevel CGH; and

20   FIGURES 19A-19B illustrate an example etch profile for one degree misalignment and perfect alignment respectively. FIGURES 20A-20B illustrate two different sets of BOC array elements for generating useful scanning applications.

25   Detailed Description of the Preferred Embodiment

The principles of this invention apply to the dividing of an input light beam into several output beams traveling in different directions; scanning the beams in single or multiple light beams (either generated as divided by the

30 principles of this invention or by another means) in one or two dimensions by translating arrays of optical elements such as binary optic components with respect to each other; and/or including collecting the returns of a predetermined number of optic array scanner transmitter beams through an array of

35 optic components integrated with the scanner and focusing onto a predetermined number of detectors (i.e., one detector for each of the scanned beams). A preferred application for

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this invention is a laser based RADAR (e.g., LADAR) in which:
(i) division of a single beam into multiple beams; (ii) two-
dimensional scan of multiple beams; and (iii) collection of
the return beams can be accomplished. Scanning
5   characteristics utilizing the principles of the present
invention can also be adapted to many other applications such
as laser printing. However, those skilled in the art will
appreciate that such applications are typical of only two of
the innumerable types of applications in which the principles
10   of the present invention can be employed.

Referring now to the Figs., there is illustrated
preferred embodiments of dividing, scanning, and collecting
devices configured in accordance with the principles of the
present invention. Each of these devices and the
15   corresponding embodiments will be described in detail in
order below. For the purposes of clarity, however, a
discussion of a preferred fabrication technique of the BOCs
will be deferred subsequent to the last embodiment.

20   Optic Array Beam Splitter (OABS)
First to be presented is the description of the process
of dividing (splitting) an input light beam into several
output beams using optical array components. The present
approach can be described by an array of miniaturized
25   Galilean telescopes (e.g., see Fig. 6A), arranged in "n"
different groups (n = 1, 2, 3, etc., depending upon the
number of split beams needed or desired). Each group is
characterized with a different amount of "offset" as shown in
Fig. 6B (as also noted above, as used herein "offset" refers
30   to the relative shift, both magnitude and direction, between
the optical axis of the two optical elements of the device
being considered).

Referring to Fig. 6A, a basic Galilean telescope
consisting of two conventional optical elements 131, 132 (a
35   convex or positive lens 131, and a concave or negative lens
132) is illustrated. As will be appreciated by those skilled
in the art, when a light beam 134 traveling parallel to the

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optical axis hits the first lens 131 (convex), it directs the
beam toward its focal point on the optical axis. The second
lens 132 (concave) is located in a way that it recollimates
the beam (i.e., the exit beam 133 travels as a beam of nearly
5   uniform diameter). Thus, the direction of the beam depends
upon the "offset" of the second lens with respect to the
first lens. If the "offset" is zero (as shown in Fig. 6A),
then the two lenses are located along the same axis 135 and
the beam 133 continues in its original direction (prior to
10 the first lens 131). However, if the "offset" is non-zero
(i.e., the optical axis 135' is not along the same axis 135),
then the exit beam 133 travels in a direction other than the
input beam 134. The magnitude and direction of the angular
shift depends upon the amount and orientation of the
15 "offset," as is illustrated in Fig. 6B.

Using this characteristic, an array of miniaturized
Galilean telescopes with "n" different sets of "offsets" will
result in dividing an input beam into "n" different output
beams traveling in different directions. Fig.s 7A and 7B
20 schematically illustrate a conventional lens 131 and a binary
optic lens 136, respectively, while Figs. 7C and 7D
schematically illustrate conventional optics and BOC Galilean
telescopes for different offsets.

From the foregoing, an array of BOC Galilean telescopes
25 with "n" different "offsets" can be defined which will divide
an input beam into "n" different output beams, traveling in
different directions. Referring to Fig. 8 the schematics of
a binary array 80 (using two arrays -array 81 and array 82)
beam splitter 119 are illustrated. Fig. 9 illustrates
30 schematically the representative cross-sections of array 81
and 82.

Example Of A Preferred Embodiment OABS

This section discusses a preferred splitter embodiment
35 119 which was constructed in accordance with the principles
of the present invention. In general, the arrays of binary
optic elements 101, 102 are utilized to angularly split an

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input beam 103 into multiple beams 105, traveling in
different directions. One example of such a device is
illustrated in Fig. 1 and may be accomplished in accordance
with the following. However, those skilled in the art will
5   appreciate that other combinations may be constructed and so
the invention should not be limited by the following example
which uses n = 8.

Referring to Fig. 10 the schematics of two example BOC
arrays 101 and 102 (12 mm x 12 mm each), representing the two
10   optical elements of a "Galilean telescope" are shown. Each
is divided into an array of 5 x 5 identical elements (total
of 25 elements) to start with, and then each of these 25
elements is subdivided into an array of 4 x 4 sub-elements
115, 116, resulting in 400 sub-elements. The sixteen (16)
15   sub-elements, in any of the 25 elements, consist of two
identical elements for eight (8) different "offsets"
corresponding to the desired eight (8) output beams. The
overall array, therefore, consists of 50 elements for a
particular "offset," distributed over the 12 mm x 12 mm BOC,
20   and the 400 elements represent eight (8) different "offsets."
The relative positioning of these different elements in any
one array 101, 102 (corresponding to one optical component of
the Galilean telescope) is not critical. However, the two
arrays 101, 102 are designed in a way that, when the two
25   arrays are aligned with respect to each other, the
positioning of the small elements is such that there is a
one-to-one relation between the two array elements (i.e.,
individual BOCs 136 are matched between arrays 101, 102) so
as to form the desired Galilean telescopes. In other words,
30   pairing of suitable elements is required.

Note that elements of one of these arrays could be made
identical, and only the other array could have "n" different
elements, but with same overall "offsets," with identical
results. The only difference would be that one of the two
35   arrays then would carry the burden of beam splitting rather
than sharing.

The number of paired elements and the locations of the

elements tends to mix the input light 103 to form the eight
beams 105. Therefore, a mixing of the various laser beam
densities occurs. As those skilled in the art will
appreciate, density is not uniform center to edge in a laser.
5 Therefore, preferably this mixing occurs to provide an even
density.

The two arrays 101, 102 were processed using three (3)
mask-levels to increase their diffraction efficiencies, as
discussed below in the Fabrication section. The overall
10 design and processing was performed for a particular laser
beam (characterized by its wavelength - 1.06 micrometer).
The eight beams 105 were designed to exit at an angle of 2.25
degrees with respect to each other, in a particular plane
111, as shown in Fig. 11.

15   Light beam 103 strikes first array 101 on a first side
and each first array 101 element diffracts and focuses the
light. The resultant light beams 104 exit the second side of
the first array 101 and strike the first side of the second
array 102. Due to the offset of each corresponding element
20 of the second array 102 mapped into the first array 101, the
resultant beams 104 are recombined into eight (8) beams 105a-
105h.

Subsequent to fabrication and processing, the two BOC
arrays 101 and 102 were held parallel to each other with a
25 predetermined spacing, and properly aligned to "pair" the
corresponding array elements using a mechanical mount. The
assembly of the two BOC arrays 101 and 102 was illuminated
with the 1.06 micrometer collimated laser beam generated in a
known manner by block 106 (best seen in Fig. 1). The output
30 of the assembly showed eight (8) exit beams 105a-105h with an
approximate 2.25 degree separation with respect to each
other.

Those skilled in the art may appreciate that it may be
possible to mount the two arrays 101 and 102 into a single
35 assembly either by mechanical mounts or by cementing; that it
may also be possible to subdivide the two arrays 1 and 2 into
more than two arrays (i.e., for either simplifying the design

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and fabrication of the arrays and/or cascading the exit beams
to resulting in additional beams or recombination of the
beams); that it may also be possible to change the direction
of the angular beams into several exit beams traveling in
5   same directions using convention and/or binary elements, and
that it may also be possible to select "m" differing elements
on each of the two arrays 101 and 102 to result in "n" exit
beams (i.e., m not equal to n). However, the preferred
embodiment splitter 100 example used herein deals with the
10   process of subdividing the input beams using several
differing optic array elements and "pairing" these elements
to obtain "n" output beams traveling in different directions.

15   Optical Array Scanner Transmitter (OAST)
As will next be described, the present invention also
includes the process of scanning a single (or multiple light
beam(s)) in one or two dimensions by translating the optical
arrays 101 and 102 with respect to each other. For
20   convenience this will be referred to herein as an Optic Array
Scanner Transmitter ("OAST") 120. Fig. 2 schematically
represents an OAST 120.
A "scanned" beam can be defined as a beam whose direction
and/or location is changing in time. Such changes may or may
25   not be repetitious or cyclic. There are several ways in
which a light beam may be scanned which are discussed above.
The present invention, however, includes the process of
utilizing an array of miniaturized optical elements such as
BOCs, to accomplish one or two dimensional scanning of a
30   single or multiple light beam.
The basic concept of the array scanning can be explained,
once again, by considering the Galilean telescope with a non-
zero offset. As mentioned before, the input and output beam
from a Galilean telescope travel in different directions for
35   a non-zero offset. If one of the two optical elements of the
telescope is shifted with respect to the other one in real
time, it would, in turn, result in real time shift or change

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in the direction of the exit beam with respect to the input
beam. If this offset is mechanized to follow a particular
shift pattern, the direction and/or location of the output
beam would therefore change resulting in a scanned beam. If
5 the direction of the "scanned" beam is confined into one
plane, it is referred to as a "one-dimensional scan." On the
other hand, if the direction of the "scanned" beam is not
confined to one plane but in two planes, then it is referred
to as a "two-dimensional scan."
10   Fig. 12 illustrates an OAST 120 utilizing optical arrays
(such as the first and second BOC arrays 101 and 102
discussed above) resulting in a two dimensional scan of
multiple beams 105. The two dimensional scan is indicated in
an X-Y plane 111. Note also that the Fig. 12 is
15 representative of the OABS 109 discussed above as well, in
which an input beam 103 is divided into multiple beams 105,
which are subsequently scanned in two dimensions.

                Example Of A Preferred Embodiment OAST
20   An example OAST scanner may be constructed according to
the principles of the present invention by utilizing the two
arrays of binary components, and the mounting hardware
fabricated while constructing the OABS splitter 119 as
described above. The shifting of the second array with
25 respect to first may be accomplished using Piezo drives 107,
located within the mounting hardware (not shown). An example
of drives which may be used are manufactured by Dr. Lutz
Pickelmann Piezomechanik-Optik of Munich, Germany, having the
model designation PST 150/7/75. As those skilled in the art
30 will appreciate, a total of 2 drives are required to scan in
two dimensions (i.e., one for each axis of scanning
capability).
        In the preferred embodiment grooves are cut in the
interior of two metal frames. The arrays 101, 102 are then
35 placed in the frame. The drives 107 are also cooperatively
mounted within the groove such that everything is in one
plane. The grooves are sized and configured to allow the

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arrays to slide in the groove when acted on by the drives. A
microprocessor 123 is used to actuate the drives 107 in a
known manner.

Referring to Fig. 13, in the preferred example, the
5   example hardware was designed and tested to accomplish the
following:

Overall scan angle along the   :   + and - 1.125 degrees
beam split direction (azimuth)
10

Overall scan angle along the   :   + and 1.7 degrees
orthogonal direction

Optical Array Scanning Transmitter-Receiver (OAST-R)
15   The present invention also may include using the process
of collecting the returns of OAST beams on an array of
optical detectors by an array of optical elements such as
BOCs. An example of an optical array scanning transmitter-
receiver (OAST-R) 121 is shown in Fig. 3. This aspect of the
20   present invention will next be described.

As discussed above, many devices such as RADARs and bar
code readers, illuminate or intercept targets of mutual
interest (e.g., an aircraft or a bar code) with "scanned"
radio waves or laser beams, and collect the subsequent
25   reflected or scattered waves or beams ("return beams") to
determine the characteristics of the target of interest.
These return beams are generally collected in one of the two
ways:
1.   Stationary/non scanning receivers: The returns are
30   collected normally using a large aperture system and focused
on a one-dimensional or two-dimensional detector array,
depending upon a one dimensional or two dimensional
transmitted scan beam, as shown in Fig. 14A. Each element of
the detector array corresponds to different direction of the
35   transmitted scanned beam. The main disadvantage of this
approach is that it requires a large array of detector
elements to capture several directions of the transmitted

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beam. Furthermore, the receiver is generally suitable for
one transmitted scan beam only.

2.   Scanning receivers: Fig. 14B shows the schematics
of a scanned receiver, in which the receiver scans in-sync
5   with the transmission scanning, and normally shares the
scanning components with the transmitted beam. As a result,
the return beam encounters "positive" (while being
transmitted) and "negative" (during return path) scan,
resulting in a null scan, and hence the location of return
10   beam is independent of the scanning. Therefore, the return
beam can be focused on a single detector element. For a
multiple beam transmission scanner, the return beam could be
collected on a single detector as well, in a similar manner.

If both the transmitted and return beams go through the
15   scanning as well as the beam splitting mechanism (as shown in
Fig. 15A), then the ultimate return beam experiences "null
scan" as well as "null beam split." In the case of multiple
beam scan systems, it is, however, generally required to keep
the return beam separate and collect the multiple return
20   beams on separate detectors, so that the characteristic
returns of these multiple beams could be maintained. This,
in principle, can be accomplished easily in those systems
where the "beam splitting" components and the "scanning
components" can be separated from each other (as shown in
25   Fig. 15B). This can be accomplished by redirecting the
return beam from entering the "beam splitting" components.
Such an approach, however, results in poor efficiency due to
50% efficiency of the beam combiner in both transmission and
receiver modes.
30   The processes for multiple beam splitting and scanning of
multiple beams in one and/or two dimensions, using the same
arrays of optical components for both functions has been
discussed above. While this process is unique and
advantageous for its intended use, the problem of collecting
35   the multiple scan beam returns on separate detectors is even
more challenging due to:
The problems encountered including first the necessity of

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a high efficiency transmission and receiver system, while
collecting the "n" return beams on "n" separate detectors.
Additionally, the system required the necessity of ensuring
that for a receiver mode, both "positive scanning" and
5   "negative scanning" are truly compensating to result in "null
scan" at all times. By positive and negative scanning, what
is meant is the transmission and receiving paths taken by the
beam of light. In the embodiments described herein, since
the receive and transmit elements are mounted on the same
10   plate, the light will always result in a null scan.

An example of a preferred embodiment of the present
invention to collect these multiple scanned beams returns
using array of optical elements such as BOCs, is shown in
Fig. 16. The OAST-R is designated generally by 121. It will
15   be appreciated by those skilled in the art that the receiver
function is implemented by surrounding the transmission array
140 of optical elements with identical array elements with
zero offset, wherein these outside array elements 141 are
used for collecting the returns. Since the offset is zero,
20   all these array elements are identical and, therefore, these
elements would not perform beam splitting. On the other
hand, since these array elements are located on the same
substrate as the transmission elements, and since the
scanning is accomplished by the mechanized motion of the
25   entire substrate, the return beam would experience the
"negative" scanning in-sync with the transmission beams
(i.e., all array elements move identically), and therefore
result in null scan.

The overall impact of the foregoing device is that the
30   multiple return beams experience "null scan," but not the
"null beam splitting." Therefore, the return beams can be
collected on an array of "n" detectors 114, one for each of
the multiple scan beams. A lens 113 may be used to focus the
return beams onto the detector array 114 (see Fig. 3).

35

Example Of A Preferred Embodiment OAST-R
One example of a preferred embodiment collector can be

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implemented using binary optic arrays. In particular, the
device can be fabricated with two arrays of overall
dimensions of 36 mm x 36 mm. The central 12 mm x 12 mm
portion 140 is designated for dividing the input beam into
5   eight (8) beams and performing the two dimensional scans per
parameters discussed previously. The outer portion 141 of
the array includes identical elements with zero offset.
Currently, collecting the return beams on an array of eight
(8) detector elements has been achieved. In the preferred
10   embodiment, during beam splitting and subsequent two
dimensional scanning of eight beams, the returns beams are
collected separately on separate detector elements, and the
position of the detectors 114 remains stationary, independent
of the scan beam directions.

15   A detector which could be used, for example, is
manufactured by RCA Electrooptics having a designation
Photodiode C30985E. Those skilled in the art will recognize
that separate detectors or an array detector may be utilized
dependent upon the application of the present invention, and
20   that the type of detector will vary depending on the laser
and the application itself.

                    Binary Element Processing/Fabrication
        Binary elements, which are typically chrome-on-glass
components, are processed to increase their diffraction
25   efficiency. A brief summary of this processing is presented
in this section.

        As an introduction, a diffractive optical element
focuses, or bends, light through diffraction rather than the
reflection or refraction phenomena observed with conventional
30   lenses or mirrors. Diffraction is most commonly observed
when light encounters either periodic structures or regions
where the transmission changes abruptly. The simplest common
diffractive element is a grating used in spectroscopic
applications. More complex diffractive elements have
35   traditionally been recorded using holographic techniques.
These can be as simple as a holographic lens, or as complex
as the hologram imprinted on credit cards.

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Computer generated holography ("CGH") uses computer modeling to generate the periodic structure in a complex diffractive element. The biggest challenge in fabricating a CGH is achieving high diffraction efficiency. In an ideal

5   case, the surface profile within the periodic structure will be parabolic. Using a linear approximation to this curve results in a diffraction efficiency of 99%.

The fabrication of a CGH employs many methods borrowed from semiconductor fabrication. The output from the computer

10   is the information to make a photomask which contains the periodic structure. As shown in Fig.17, this chrome on glass hologram has a diffraction efficiency of only 10%, there is no differentiation between the desired first 1st and the -1st order, and 25% of the light passes through the mask

15   undiffracted.

The efficiency can be improved by etching the mask to achieve a binary phase relief hologram. The etching process removes material where the mask is unprotected, leaving only a binary structure of high and low areas. This process

20   eliminates the undiffracted light, increases the diffraction efficiency to 40%, and still does not differentiate between the 1st and -1st orders. Increasing the complexity of the device and using two masks to achieve four phase levels can improve the efficiency to 81%, while using three masks to

25   achieve eight phase levels can increase the efficiency to 95%.

The process for fabricating a four level CGH is shown in Fig. 18 by steps 1-6. Here, a chrome on glass CGH has been etched to form a binary CGH, and the entire surface has had a

30   layer of chrome and a layer of photoresist deposited on it in the upper diagram. The next diagram shows a second (coarser) pattern being transferred into the photoresist by contact printing. The photoresist is developed, and the chrome is stripped where the photoresist was exposed to yield a chrome

35   on glass pattern to be etched. Chrome is preferred over photoresist as an etch mask because it is etched far less than photoresist in the RIE process. After the RIE etch of

20

the substrate, the remaining chrome is stripped. The part
may be complete at this point, or it may be ready to repeat
the process to obtain an eight, or even sixteen level device.
   When fabricating these devices, there are several

5 considerations for the mask design. Through the use of an
automated lens design program, it is possible to generate a
phase distribution function which dictates the ideal location
of each fringe edge in the CGH. The greatest challenge in
the design of the photomask is the accurate placement of the

10 fringe edges. The language of the mask writing equipment
describes each mask as collection of trapezoidal (or
triangular) areas in which the chrome is to be removed from
the photomask. Further, the photomask generation equipment
writes the mask after rasterizing the pattern with a

15 particular address size. Typically, the address resolution
is 0.1, 0.25, or 0.5 micron, and the minimum width feature
which can be written is about 8 pixels wide. The eight pixel
limitation sets a maximum spatial frequency of the phase
pattern of 1551/mm for an eight phase level mask written with

20 0.1 micron address size. This will diffract 543 nm light by
only 4.9°. For an eight phase mask, the maximum spatial
frequency is 3101/mm.
   The CGH pattern required for certain applications has
only bilateral symmetry, and hence needs a very general

25 algorithm for finding fringe edges. The approach chosen is
to evaluate the phase function on a fine grid of positions
and perform a linear interpolation to find the fringe edges.
The grid spacing is typically chosen to be as large as
possible while the linear interpolation produces errors of

30 less than one twentieth of wave in the phase function. This
encoding accuracy can be changed to suit the needs of the
project. Other encoding methods which can be used if the
phase function is a relatively small perturbation from a
linear grating, or if the fringe pattern has rotational

35 symmetry.
   Further CGH fabrication areas must also be considered.
For example, once the mask is fabricated, the phase relief

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pattern must be etched into the substrate. For one
application CGH, the substrate was chosen to be the finest
level photomask. This reduces the number of lithography
steps. In other cases, a photomask blank is not an
5   acceptable substrate, so even the finest pattern must be
transferred to the substrate.

    The efficiency of the final device is governed primarily
by three parameters; the alignment accuracy, the duty cycle,
and the etch depth. The most critical factor is the
10   alignment accuracy. Fig. 19b shows the ideal etch depth
profile for an 8 level mask. Fig. 19a shows the etch depth
profile with a misalignment of the finest mask of only 1% of
the fundamental period. This is sufficient to reduce the
diffraction efficiency from 95% to 90%. Subjectively, the
15   small spike in etch depth introduced by the misalignment acts
to diffract light into high orders through the inclusion of
the small feature. If this level of misalignment (1% of the
fundamental period) is to be achieved on the finest eight
level CGH, then alignment accuracies of 0.06 micron must be
20   achieved. This is at the extreme edge of the state of the
art for photomask alignments.

    The duty cycle describes the width of an etched feature
relative the width of the unetched adjacent feature. Ideally,
the width of the etched area is exactly half of the etched-
25   unetched pair width. If the width of the features on the
finest mask are 13.5% of the fundamental period rather than
the ideal 12.5%, the diffraction efficiency falls to 92.5%.
This corresponds to a duty cycle of 54% for the finest
features. The duty cycle is controlled primarily by the
30   exposure time when the pattern is transferred from the mask
to the substrate. It can be adjusted by intentionally making
the photomask with features with a duty cycle which differs
from 50%.

    The third contributor to the efficiency is the etch
35   depth. This is less sensitive than the duty cycle or
alignment. An error in the etch depth on the finest level of
20% causes the efficiency to fall by only 0.5%. The other

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levels are somewhat more sensitive. Another consideration in
the etch depth is the uniformity over the plate. The gas
plasma, or Reactive Ion Etching ("RIE"), process used by APA
Optics, the Assignee of the present invention, tends to have
5   five to ten percent etch depth variation over parts as large
as other types of CGH applications.

In the preferred embodiment examples, the BOCs binary
elements will be constructed using up to three (3) mask
levels, with a theoretical diffraction efficiency of 95% of
10 each of the elements. The binary element (or CGH) for the
third mask level would be used as the substrate for the
element. It would not, therefore, include any patterning but
etching only. Subsequently, the second level masks and first
level masks, will be patterned and etched respectively. The
15 etch depth for each of the three mask levels are presented
below:

	Mask Level	Etch Depth
	Third Level	2,956 A - 1/8 wave
	Second Level	5,912 A - 1/4 wave
20	First Level	1'1,824 A - 1/2 wave

It is to be understood that even though numerous
characteristics and advantages of the present invention have
been set forth in the foregoing description, together with
25 details of the structure and function of the invention, the
disclosure is illustrative only and changes may be made in
detail, especially in the fabrication techniques, the number
of levels, and the number of arrays. For example with regard
to the latter, the array may include a collection of sub-
30 arrays, and each of these sub-arrays may be different,
resulting in a set of differing sets of multiple beams (each
set corresponding to a different sub-array). Furthermore,
the parameters of those sub-arrays could, in principle, be
designed such that each set of the multiple beams may provide
35 different scan angle coverages. For example, as illustrated
in Fig. 20B, different components having differing optical
powers may be utilized, resulting in both split beams and

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beams which are scanned in different directions. Those
skilled in the art will recognize that at high optical
powers, the shapes of the rings are much smaller to start
with. Also, the "bullseye" in Fig. 20 is transparent as
5   compared to its counterpart which is opaque. This is due to
positive versus negative lens.

Therefore, the resulting scan using embodiments of the
present invention may be used to scan lines, planes, or
multiple planes with several of the split beams.
10 Additionally, the beams may scan an area dependent upon a
control algorithm used to control the drivers. Therefore,
those skilled in the art will recognize that scanning of
devices (such as the drums of laser printers) may be easily
affected through use of devices constructed in accordance
15 with the principles of this invention. Still further, by
differing the optical powers and/or the resulting angles
between the split beams, a beam with half the magnitude angle
will scan one-half the area of that of a second beam (at a
plane an equidistance away). Accordingly, sub-arrays may be
20 generated which have different scanning properties which may
be useful for different applications.

Other modifications and alterations are well within the
knowledge of those skilled in the art and are to be included
within the broad scope of the appended claims.
25

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What is claimed is:

    1.   An apparatus for splitting a beam of light into a plurality of output beams, comprising:

    a)   a first miniaturized array of at least one binary optical component; and

    b)   a second miniaturized array of at least one binary optical component, wherein each of said components on said second array maps into one of said components on said first array, whereby sets of corresponding components on said first and second array are defined, and wherein at least one of said binary optical components is offset and the beam of light is split into two or more output beams.

    2.   The apparatus of claim 1, wherein each of said corresponding components of said second array are offset from said corresponding components of said first array, whereby each defined set of corresponding components includes a different offset, whereby output beams having differing directions are created.

    3.   The apparatus of claim 1, wherein said components of said first array are all located on a single substrate.

    4.   The apparatus of claim 1, wherein said components of said second array are all located on a single substrate.

    5.   The apparatus of claim 1, wherein said components of said first array are all located on a first single substrate and said components of said second array are all located on a second single substrate.

    6.   The apparatus of claim 2, further comprising means for varying the geometrical position of at least one of said first and second miniaturized arrays relative to said other miniature array, whereby the offsets are varied over time and said split beams are scanned.

    7.   The apparatus of claim 6, wherein said means for varying includes a piezo driver device which is controlled by a microprocessor.

    8.   The apparatus of claim 2, further comprising means for collecting said scanned beam, means for focusing said collected beams, and detector means for receiving said

focussed beams and for detecting the intensity level of said
collected beam.

9.   The apparatus of claim 6, further comprising means
for collecting said scanned beam, means for focusing said
collected beams, and detector means for receiving said
focussed beams and for detecting the intensity level of said
collected beam.

10.   The apparatus of claim 9, wherein said collecting
means is located on one of said first and second substrates.

11.   A beam splitter device comprising: a plurality of
binary optical components, wherein each of said binary
optical components is comprised of an array of complex
diffraction gratings including:

    a)   a first substrate layer comprised of glass; and

    b)   a second raised layer comprised of chrome, said
second layer etched and distributed on said first substrate
layer;

wherein said binary optical components are geometrically
arranged relative to one another such that a beam strikes one
of said binary optical components and is focussed onto a
second said binary optical components where it is split into
a predetermined number of output beams depending upon the
optical axis offset between said first and second binary
optical components.

12.   The beam splitter device of claim 11, wherein said
beam is diffracted by binary absorption.

13.   The beam splitter device of claim 11, wherein said
second layer is etched so as to form raised areas with
lowered areas of said substrate layer located therebetween.

14.   The beam splitter device of claim 13, further
comprising a first intermediate ion-etched level between said
raised and lowered areas.

15.   The beam splitter device of claim 14, wherein the
beam is diffracted by binary phase.

16.   The beam splitter device of claim 14, further
comprising a second intermediate chrome-etched level between
said raised level and said first intermediate level

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17. The beam splitter of claim 16, wherein the beam is diffracted by four phase diffraction.

18. The beam splitter of claim 11, wherein each array of said binary optical components includes a number of components equal to the desired number of output beams.

19. The beam splitter of claim 18, wherein the output beams may be scanned by varying the offset between said binary optical components.

20. An apparatus for splitting a beam of light comprising:

a)   a first binary optical component and a second binary optical component;

b)   wherein said first binary optical component includes a first array of n x m identical optical elements and said second binary optical component includes a second array of optical elements which correspond on a one-to-one basis to said first array;

c)   wherein each of said elements of said first and second array defines an optical axis; and

d)   wherein each of said optical axes of said elements of said second array are offset from the corresponding said optical axis of said elements of said first array, whereby light is diffracted by said first binary component and is split by said second binary component into a number of beams equal to the product of n x m.

21. The apparatus of claim 20, wherein each of said elements of said first and second arrays is subdivided into an array of o x p sub-elements, wherein each of said o x p sub-elements include a predetermined number of identical elements "Q" such that (o x p)/Q equals the number of "offsets" corresponding to the desired number of output beams.

22. The apparatus of claim 21, wherein said first binary component and said second binary component are located on the same substrate.

23. The apparatus of claim 22, further comprising means

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for varying the geometrical position of at least one of said
first and second binary components relative to said other
binary components, whereby the offsets are varied over time
and said split beams are scanned.

5   24. The apparatus of claim 23, wherein said means for
varying includes a piezo driver device which is controlled by
a microprocessor.

        25. The apparatus of claim 23, further comprising means
for collecting said scanned beam, means for focusing said

10 collected beams, and detector means for receiving said
focussed beams and for detecting the intensity level of said
collected beam, and wherein said collecting means is located
on one of said substrates.

        26. A method of splitting a beam of light into a

15 plurality of output beams comprising the steps of:

        a)   directing a beam of light onto a first binary optic
component;

        b)   directing the resulting beam from said first binary
optical component onto a second binary optical component; and

20   c)   introducing an offset between said first and second
binary optical components, wherein a plurality of output
beams are created.

        27. The method of claim 26, further comprising the step
of varying the geometrical position of at least one of said

25 first or second binary optical components relative to said
other binary optical component, whereby the offsets are
varied over time and said split beams are scanned.

        28. The method of claim 27, further comprising the steps
of collecting the returned scanned beams and focusing the

30 collected beams onto a detector, wherein the intensity level
of the collected beams may be determined.

        29. The method of claim 27, further comprising the step
of:

        a)   collecting said scanned beams with said binary optic

35 components without offsets between said collecting
components;

        b)   focusing said collected beams; and

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c)   receiving said focused beams on a detector in order to determine the intensity level of said collected beams.

30.   A method of constructing a beam splitter device comprising the steps of fabricating at least two binary optical components, wherein each of said binary optical components is comprised of an array of complex diffraction gratings fabricated by the steps of:

a)   preparing a first substrate layer comprised of glass; and

b)   etching a second raised layer comprised of chrome on said first substrate layer;
wherein binary optical components are created which when geometrically arranged relative to one another a beam which strikes one of said binary optical components is focused onto said second binary optical component and is split into a predetermined number of output beams depending on the optical axis offset between said first and second binary optical components.

31.   The method of constructing a beam splitter device of claim 30, further comprising the step of ion etching a first intermediate level between said raised and lowered areas.

32.   The method of constructing a beam splitter as recited in claim 31, further comprising the step of chrome etching a second intermediate level between said raised level and said first intermediate level whereby the beam is diffracted by a four phase diffraction.

33.   The method of constructing a beam splitter device as recited in claim 30, further comprising the steps of moving at least one of said fabricated binary optical components relative to said other component so as to scan the output beams.

34.   The method of constructing a beam splitter device as recited in claim 33, further comprising the steps of fabricating a receiver area on said binary optical components for collecting returned scanned beams and focusing the collected returned scanned beams onto detector means for determining the intensity.

FIG.1
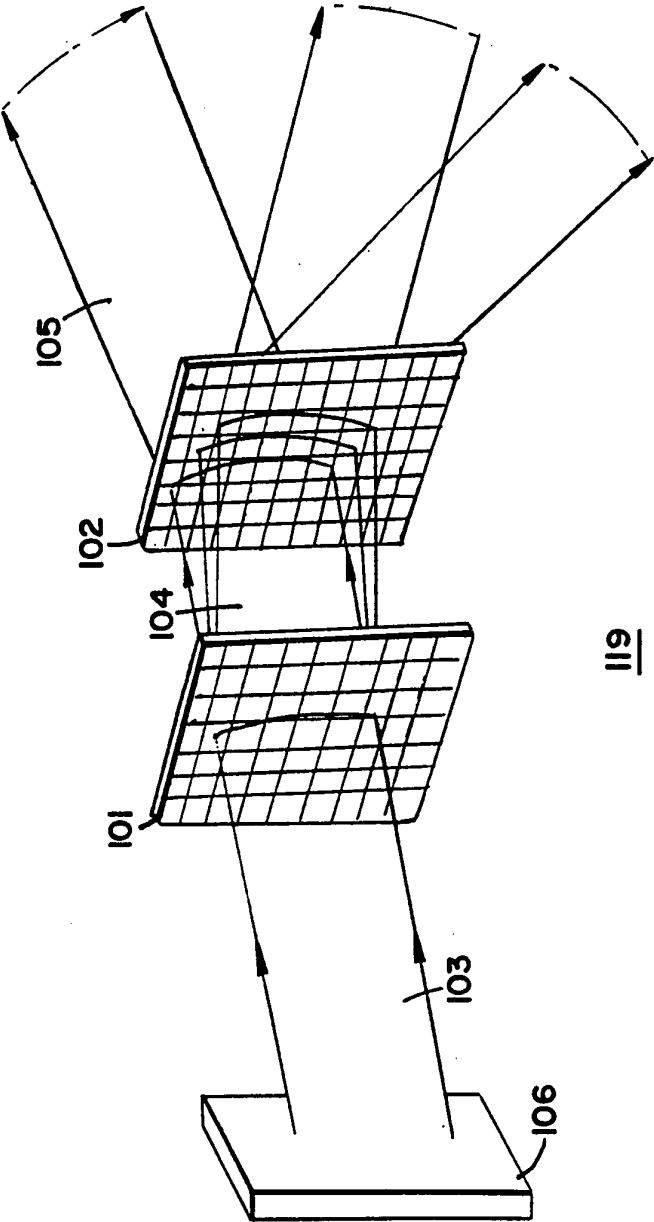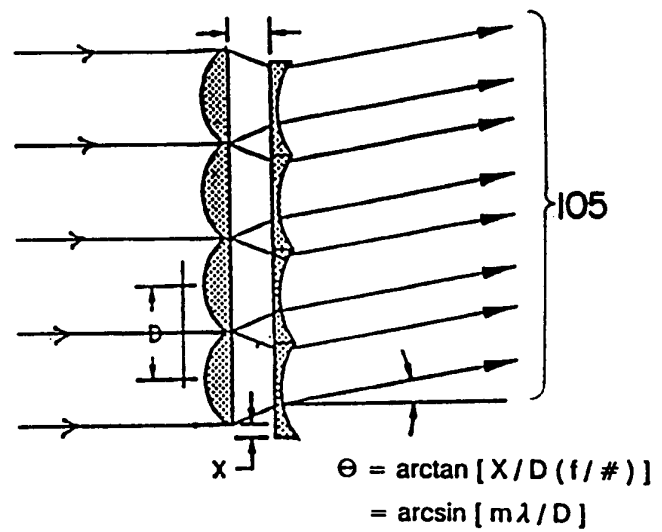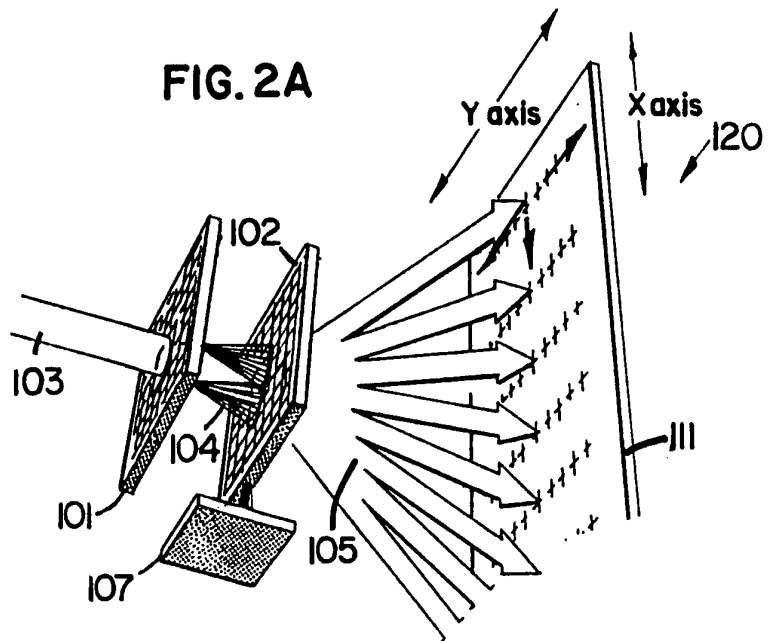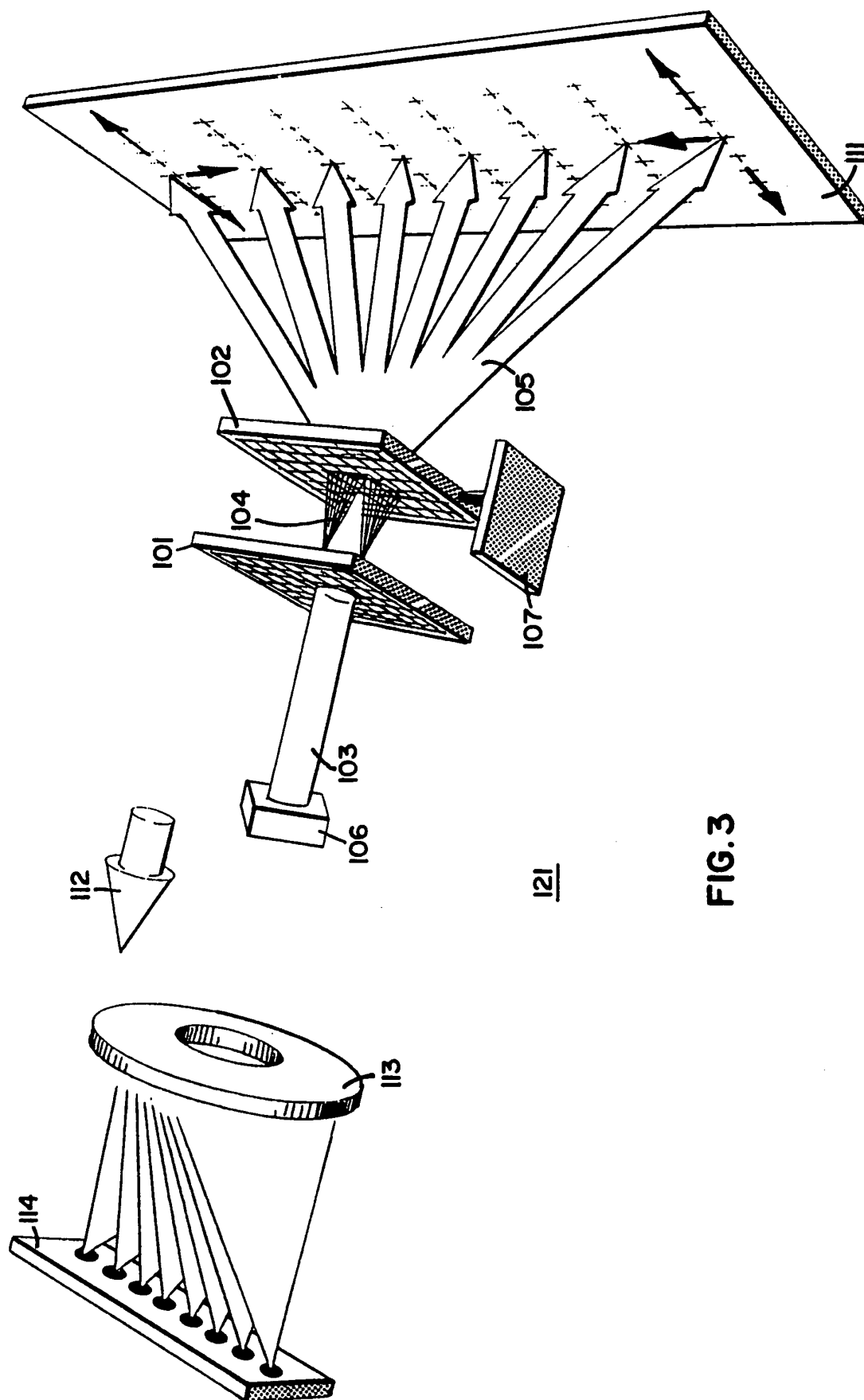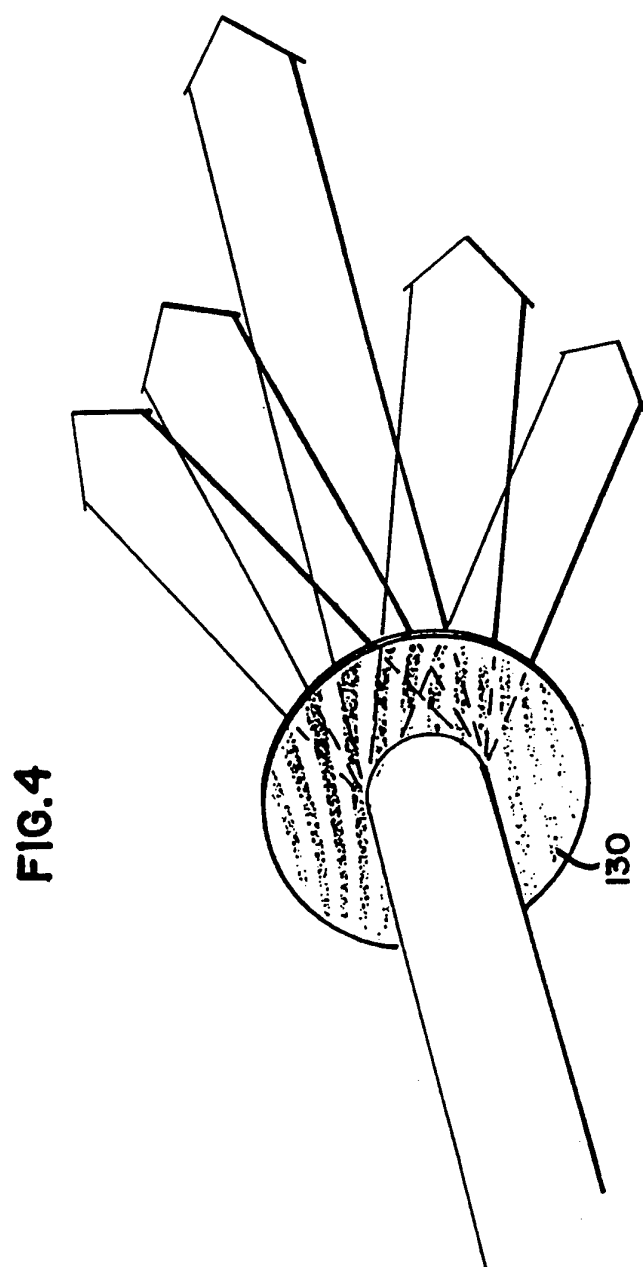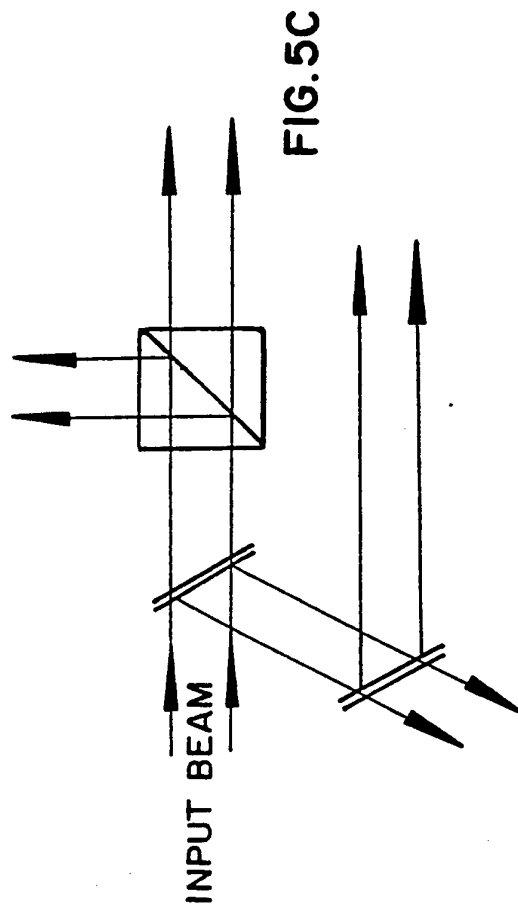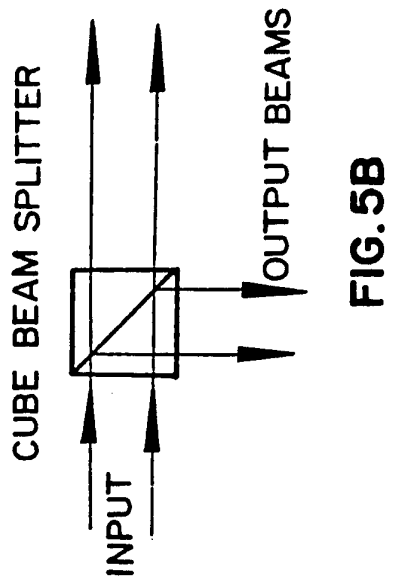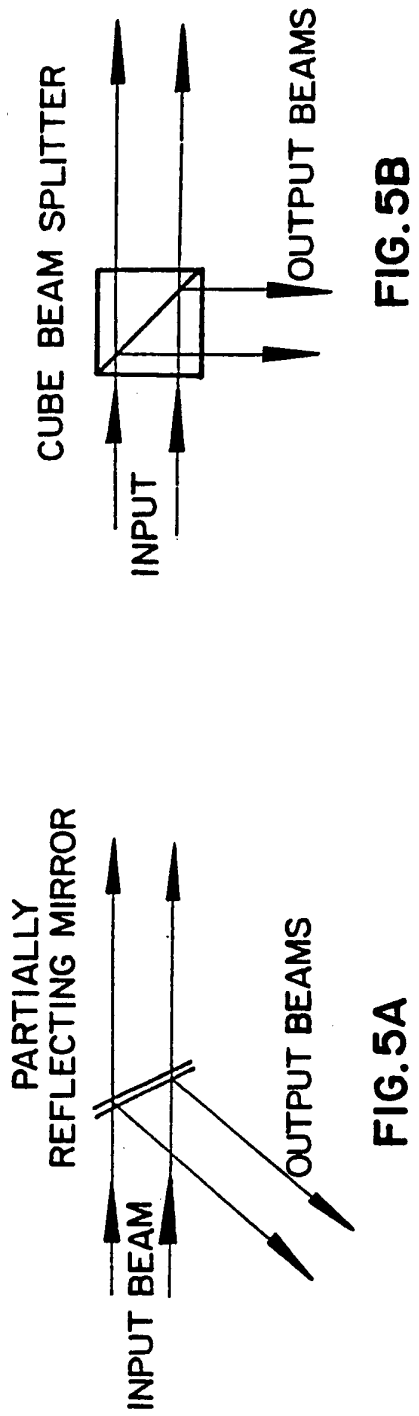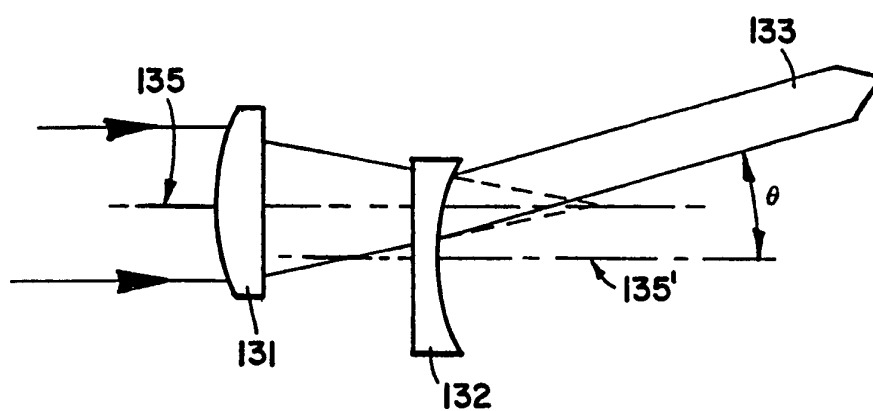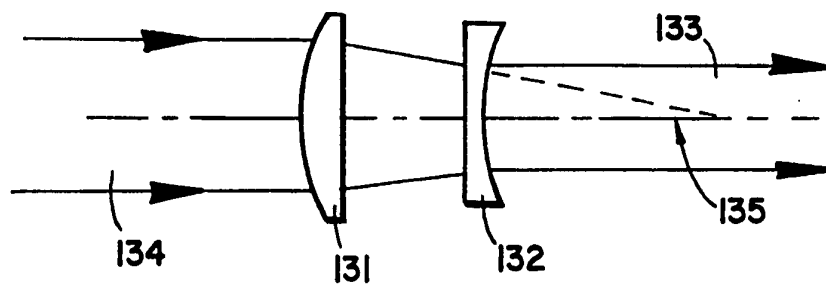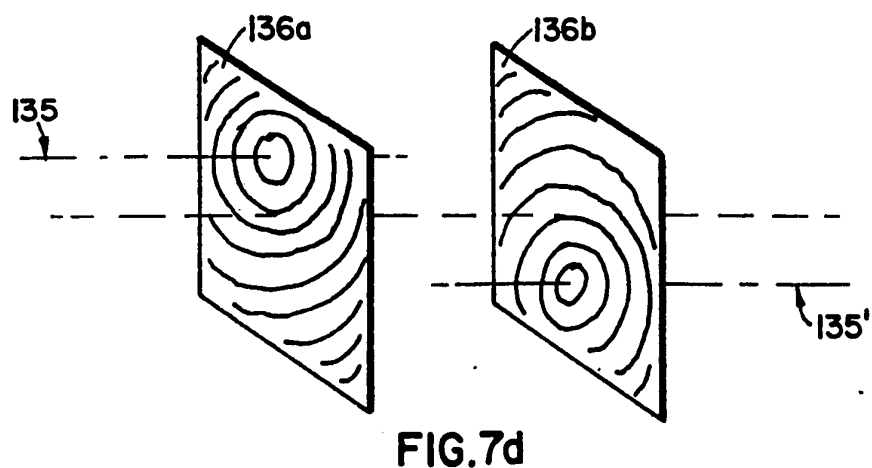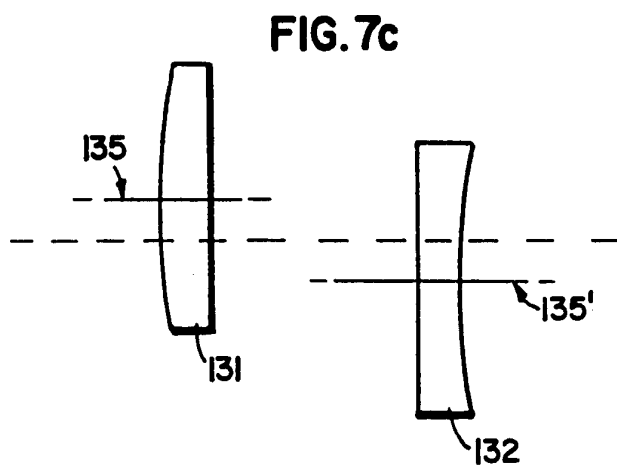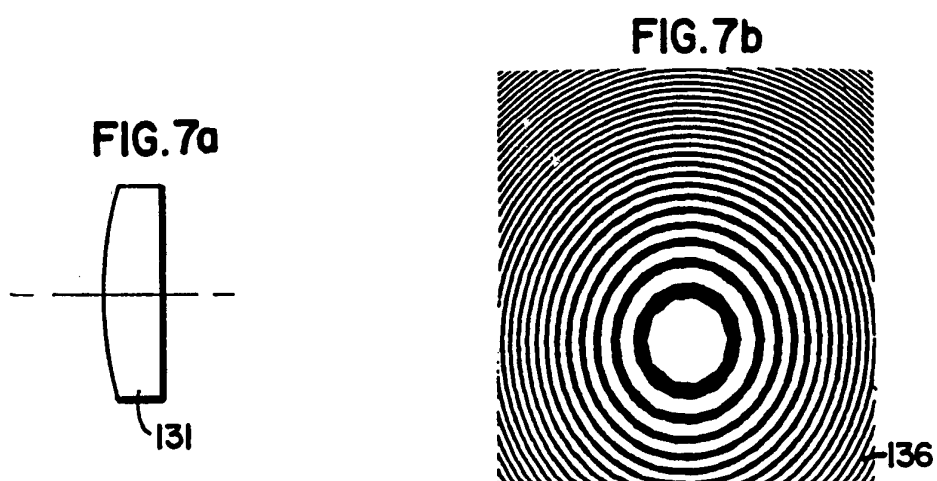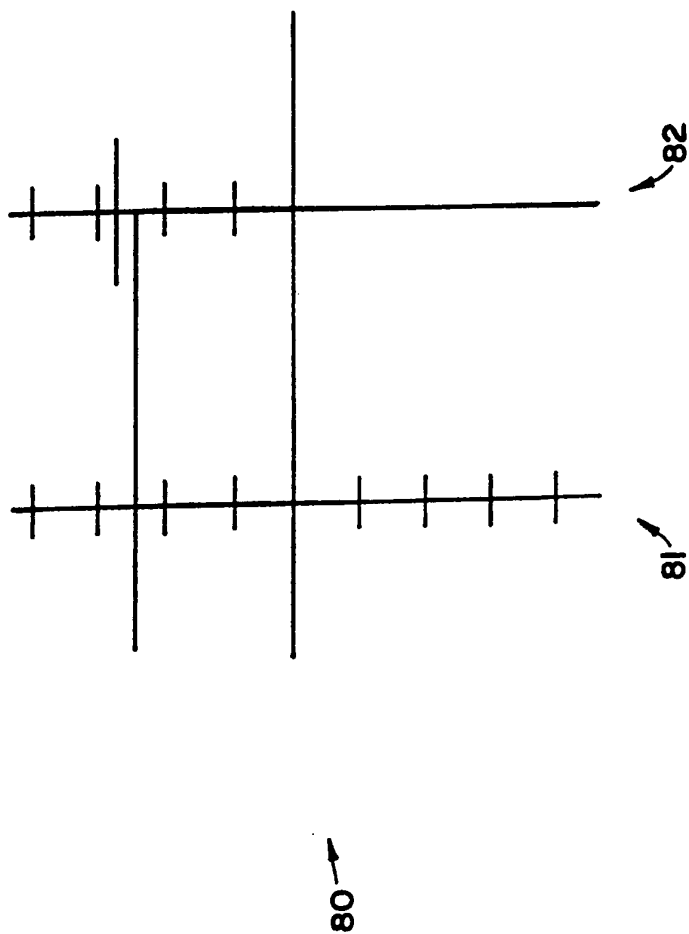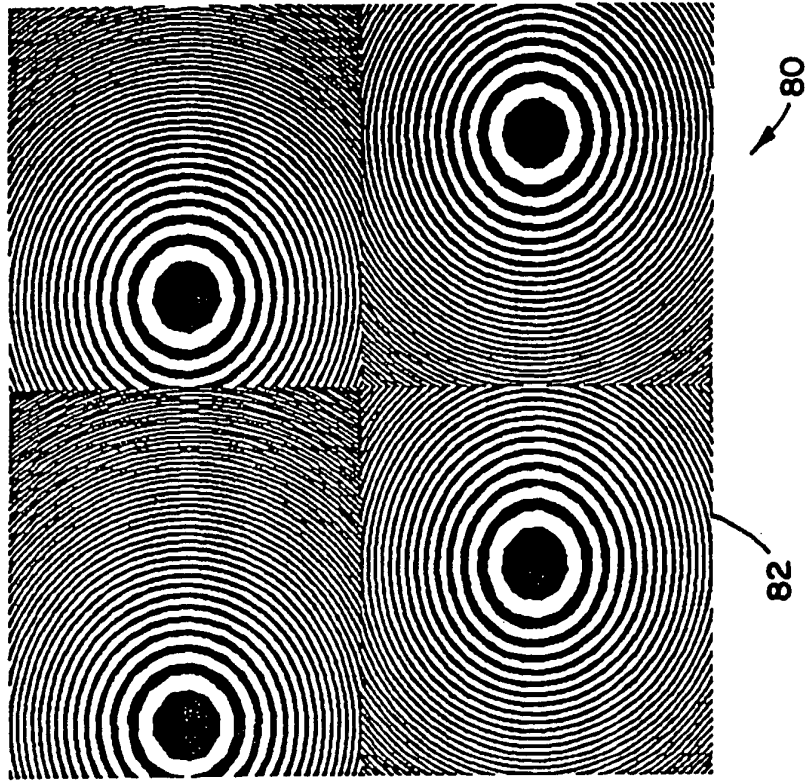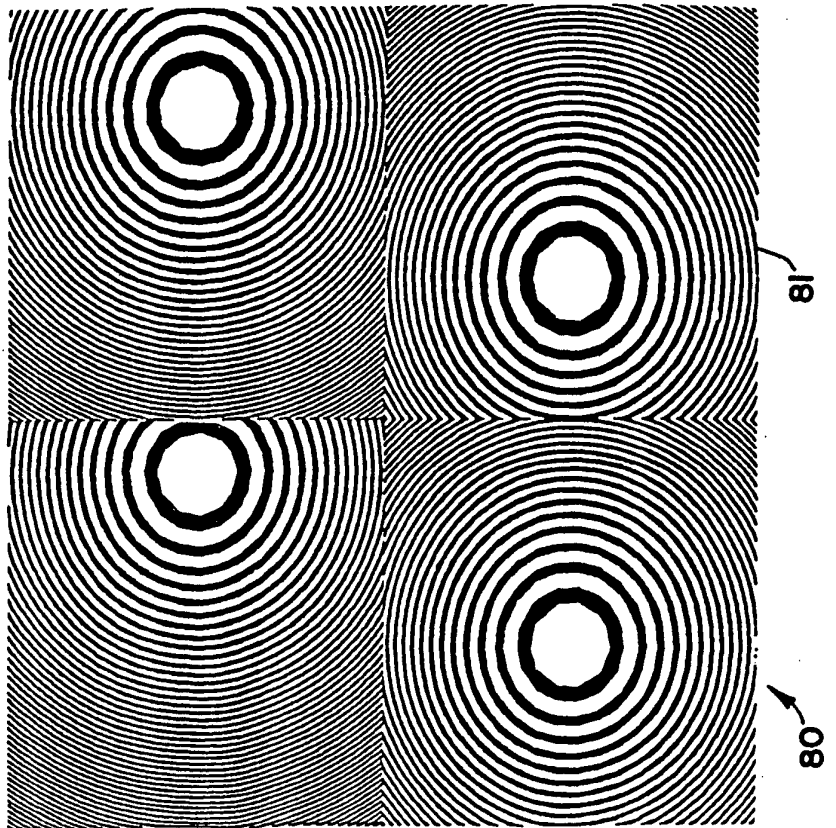
FIG. 2A

Y axis

X axis

120

102

103

104

101

107

105

111

$$\Theta = \arctan [\,X/D\,(f/\#)\,]$$
$$= \arcsin [\,m\lambda/D\,]$$

x

105

D

FIG. 2B

FIG. 3

FIG.4

130

CUBE BEAM SPLITTER

INPUT

OUTPUT BEAMS

FIG.5B

PARTIALLY REFLECTING MIRROR

INPUT BEAM

OUTPUT BEAMS

FIG.5A

FIG.5C

INPUT BEAM

FIG.6a

FIG.6b

FIG.7b

136

FIG.7a

131

FIG.7c

135

131

135'

132

136a   136b

135

135'

FIG.7d

FIG.8

FIG.9b

FIG.9a

FIG.10b

FIG.10a

FIG.11

FIG.12

FIG. 13

FIG.14a

FIG.14b

FIG. 15a

FIG. 15b

FIG.16

FIG.17C

81%

TWO MASK
LEVELS FOUR
PHASE

FIG.17B

40%

40%

ION ETCHED
BINARY PHASE

FIG.17A

25%   10%

10%

10%

25%

10%
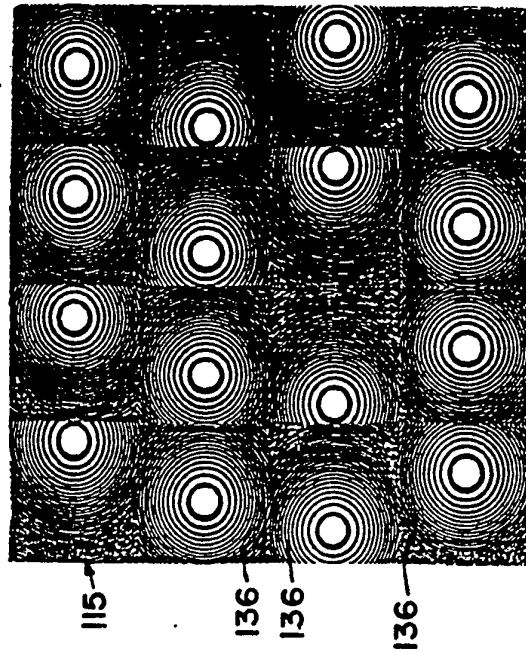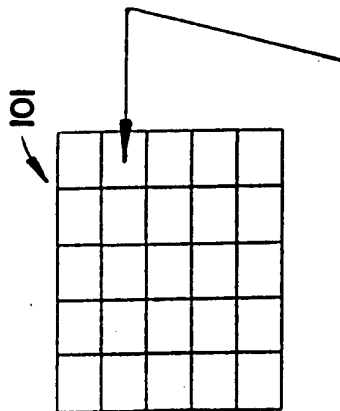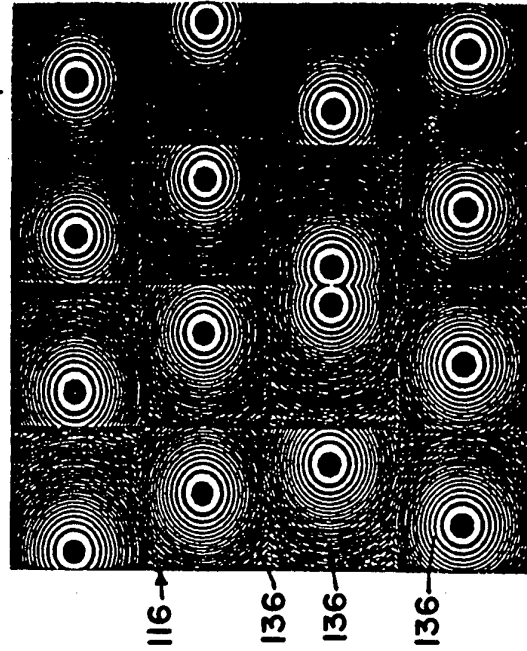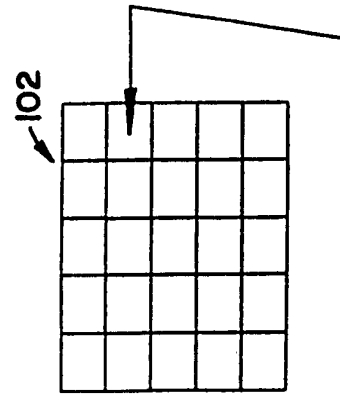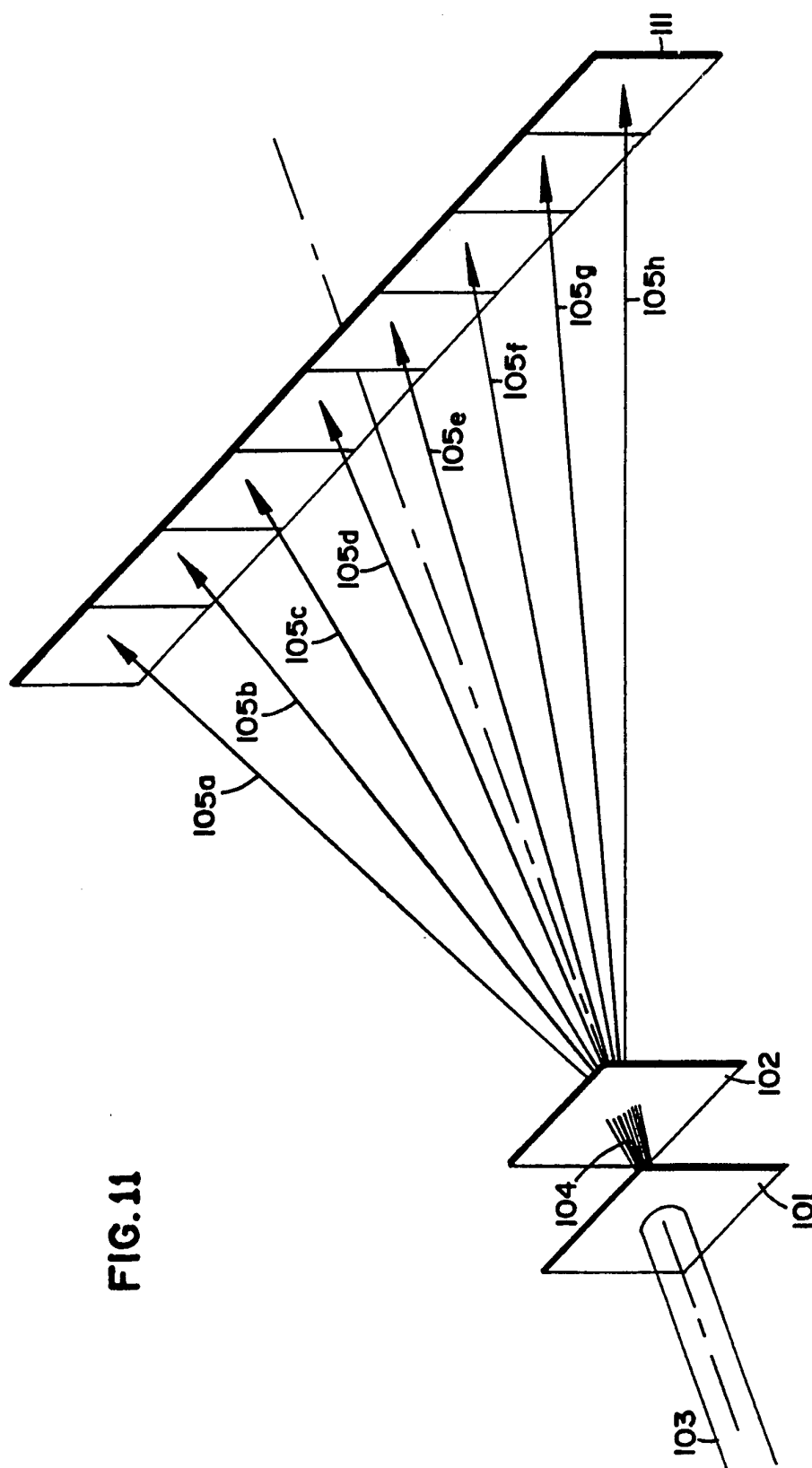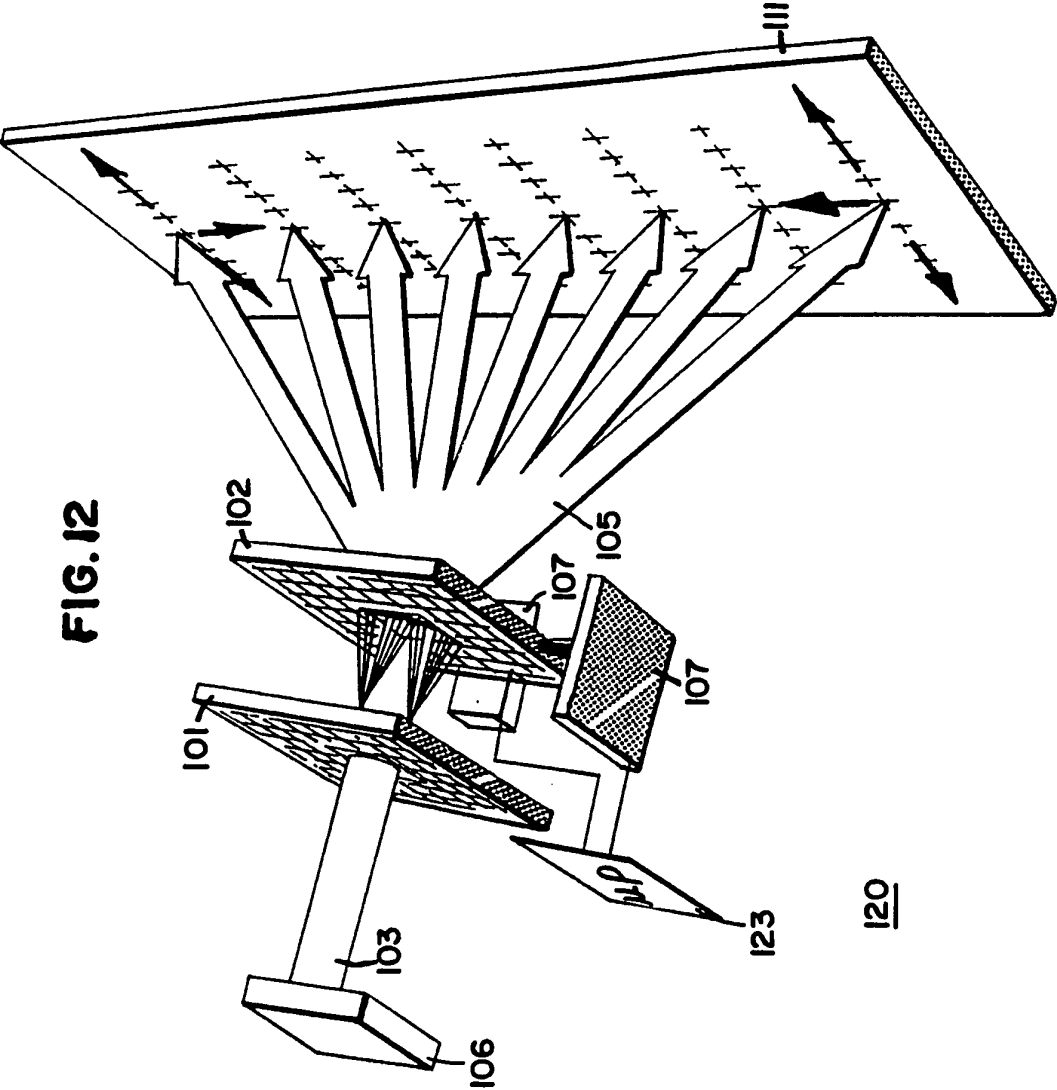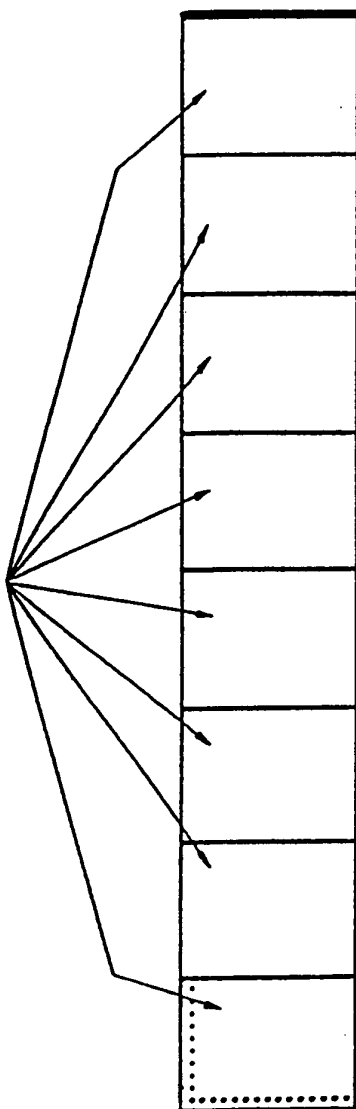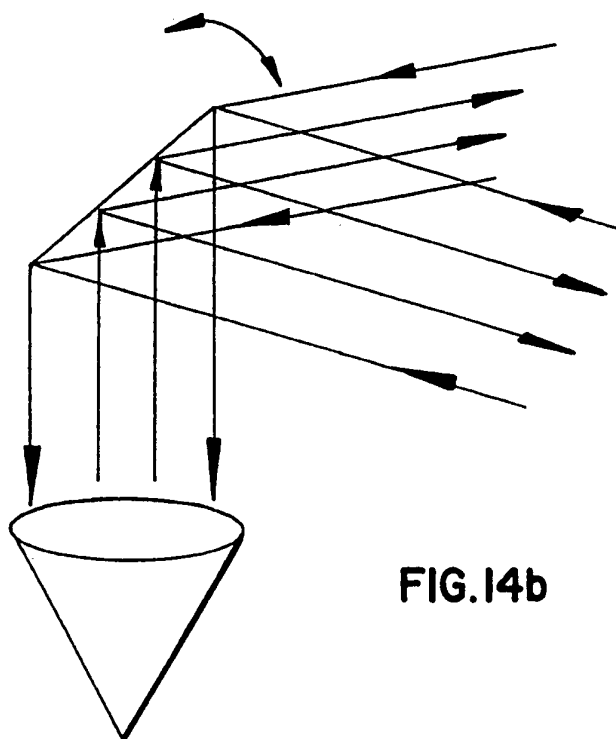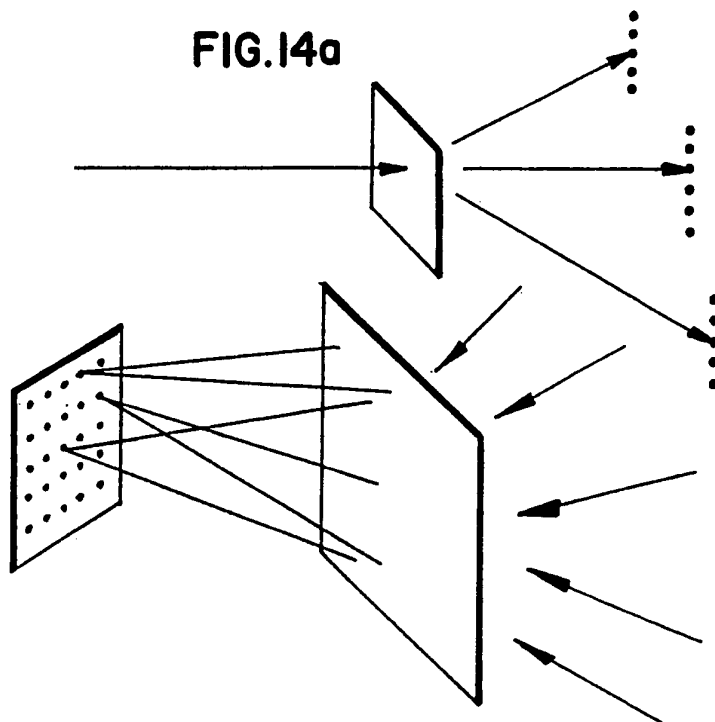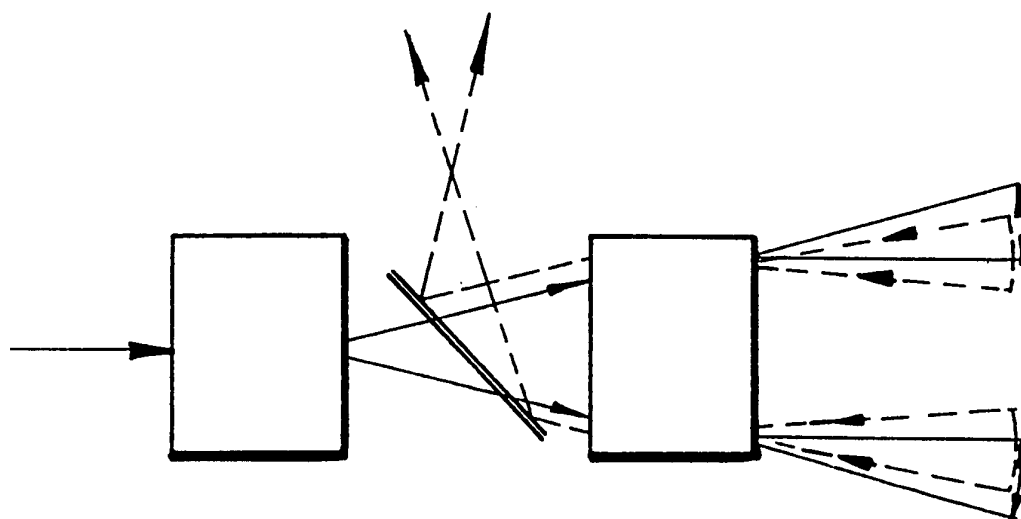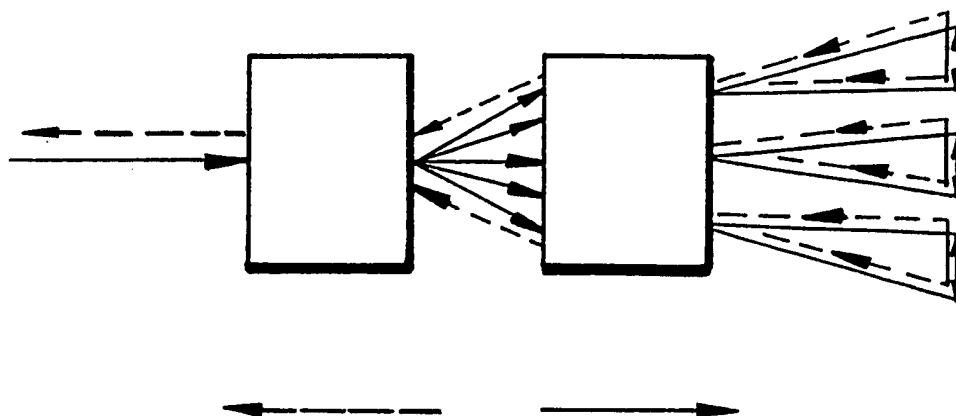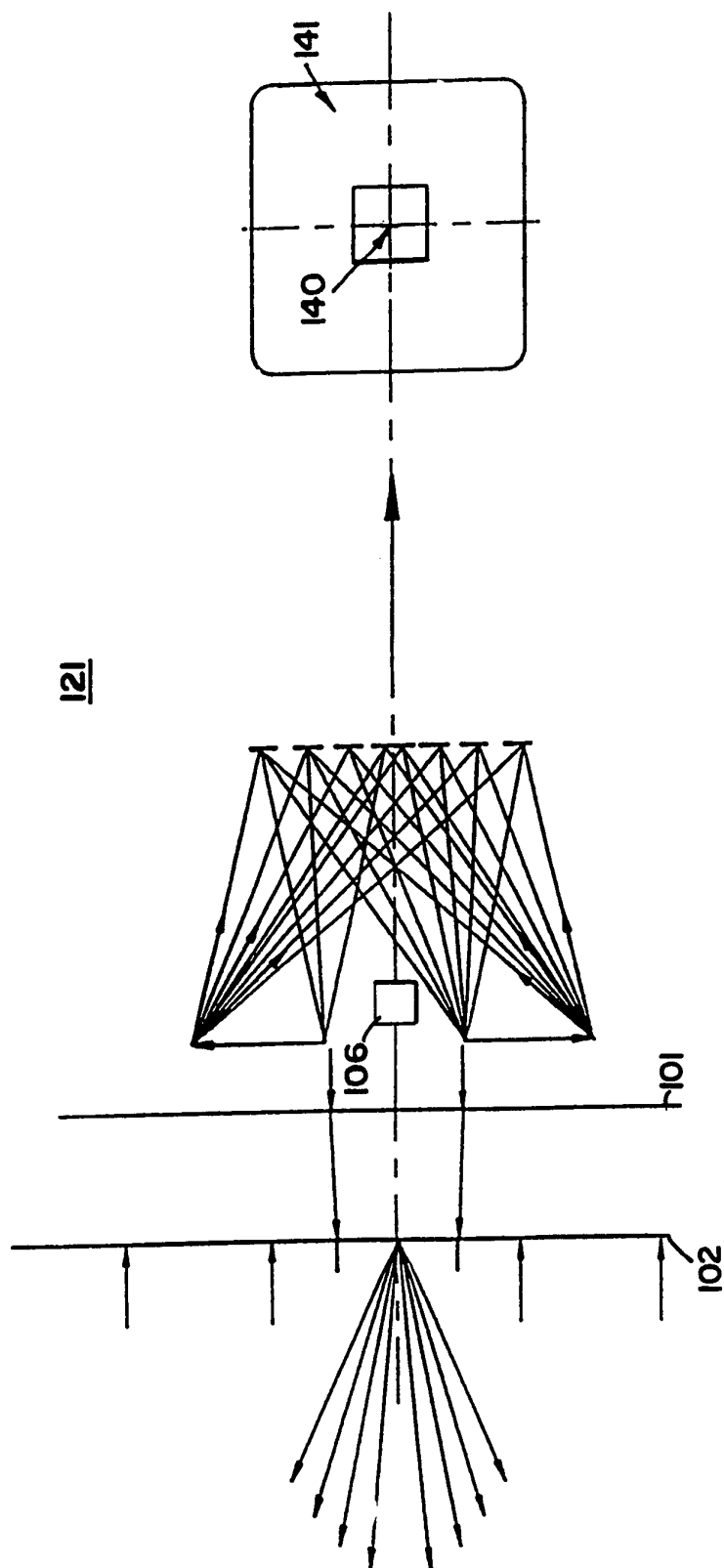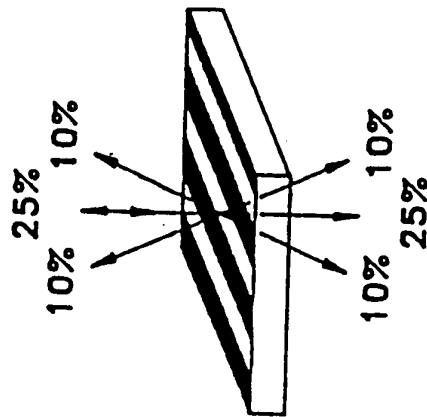
CHROME ON
GLASS BINARY
ABSORPTION

MULTI-LEVEL CGH

(1)

— PHOTORESIST
— CHROME
— 2-LEVEL CGH

Λ

(2)

MASK ALIGN
VACUUM CONTACT
UV EXPOSE

(3)

SOLVENT DEVELOP

(4)

CHROME ETCH
RESIST STRIP

(5)

ION ETCH (λ /2)

(6)

CHROME ETCH

FIG. 18

FIG.19a

ETCH PROFILE FOR 1% MISALIGNMENT

Etch depth (waves)

Mask 1
Mask 2
Mask 3

FIG. 19b
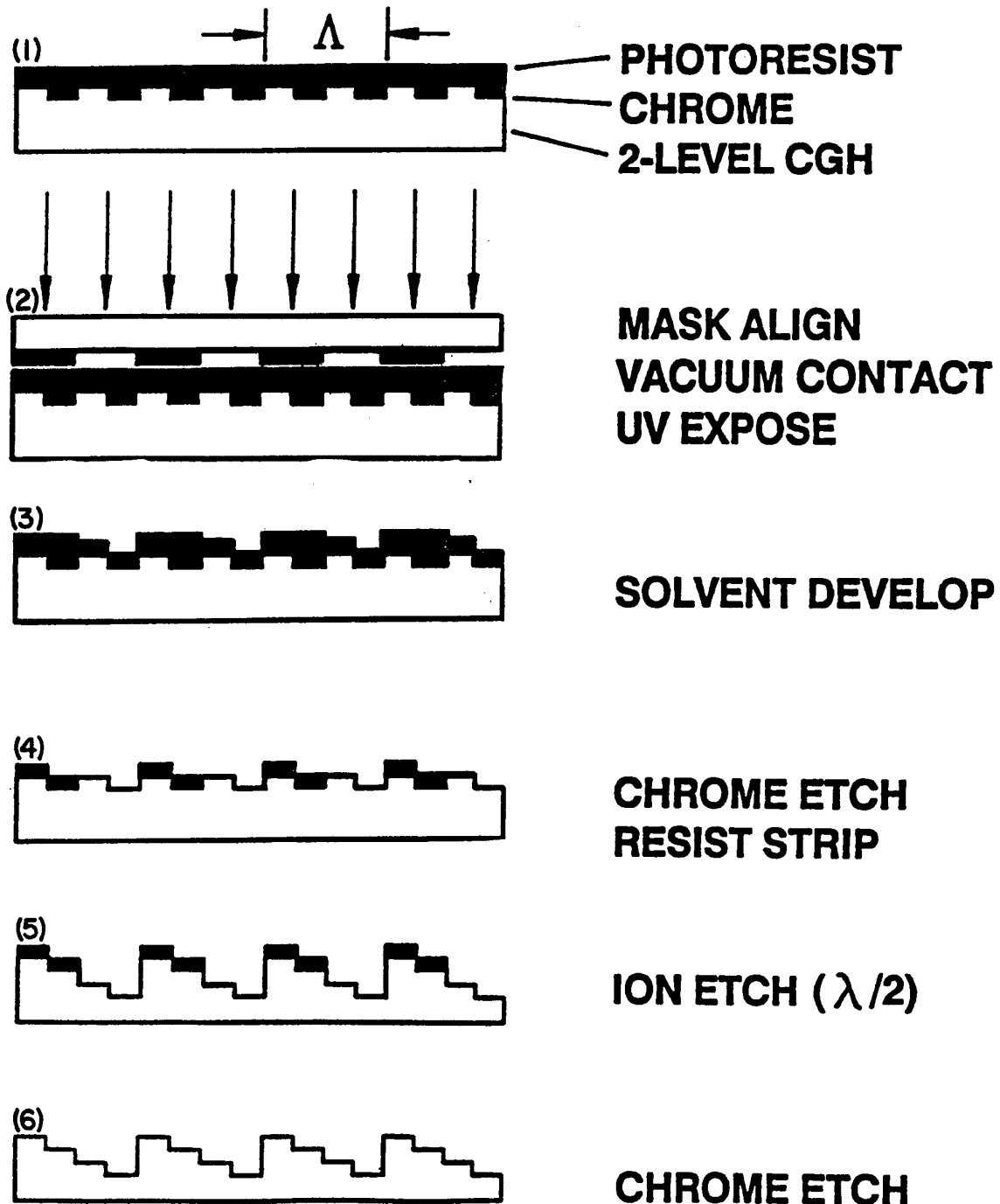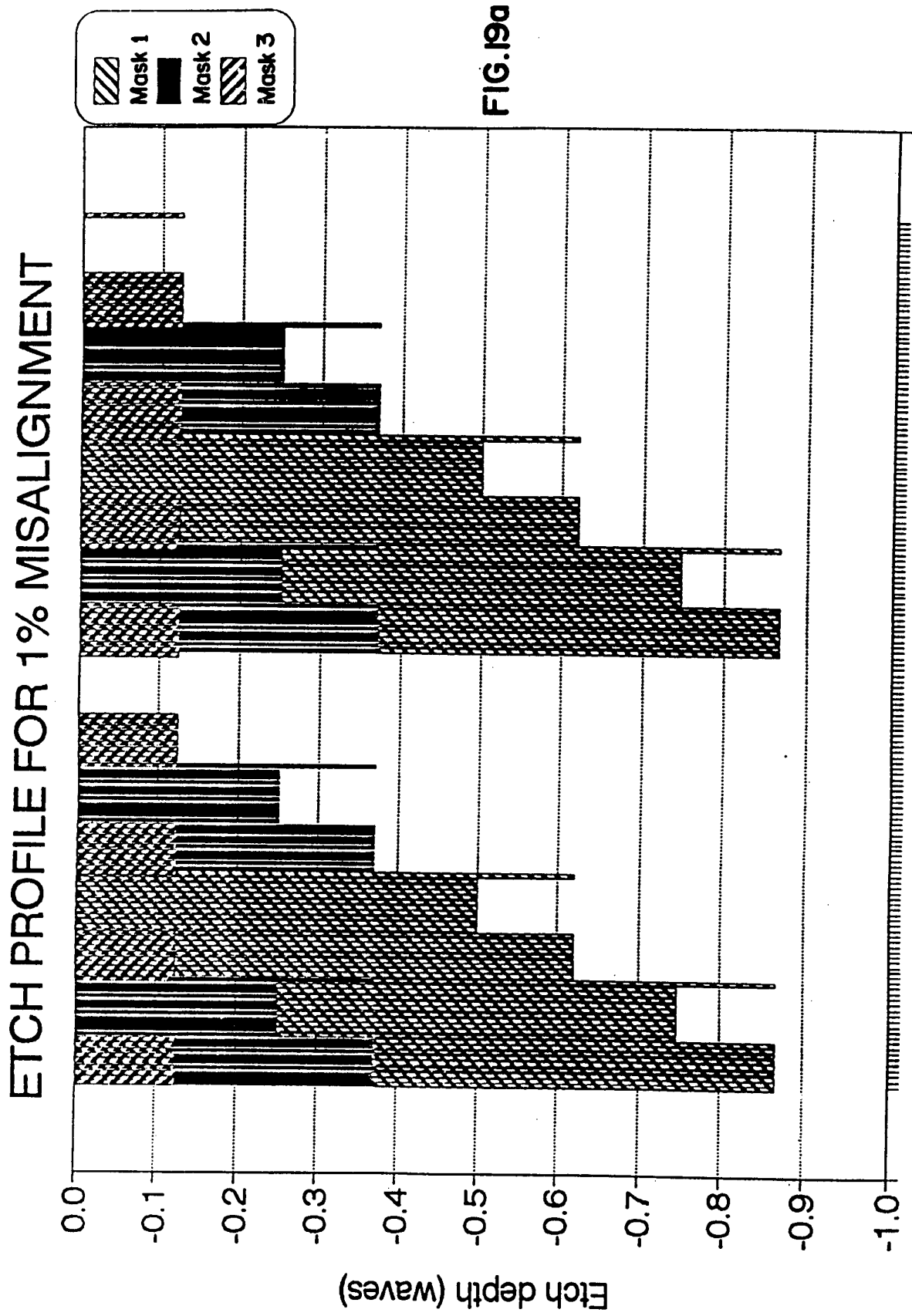
ETCH PROFILE FOR PERFECT ALIGNMENT

Etch depth (waves)

Mask 1
Mask 2
Mask 3
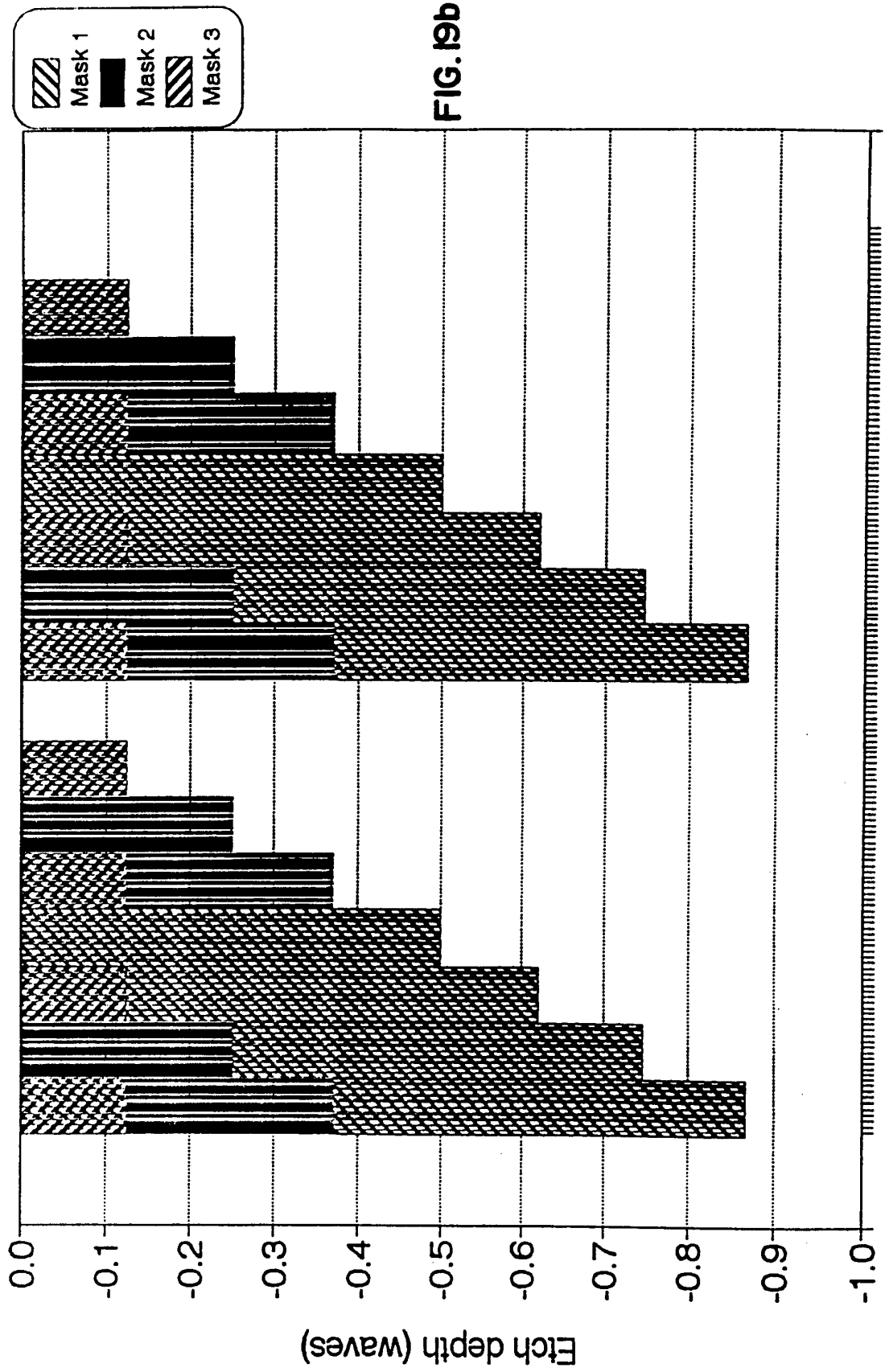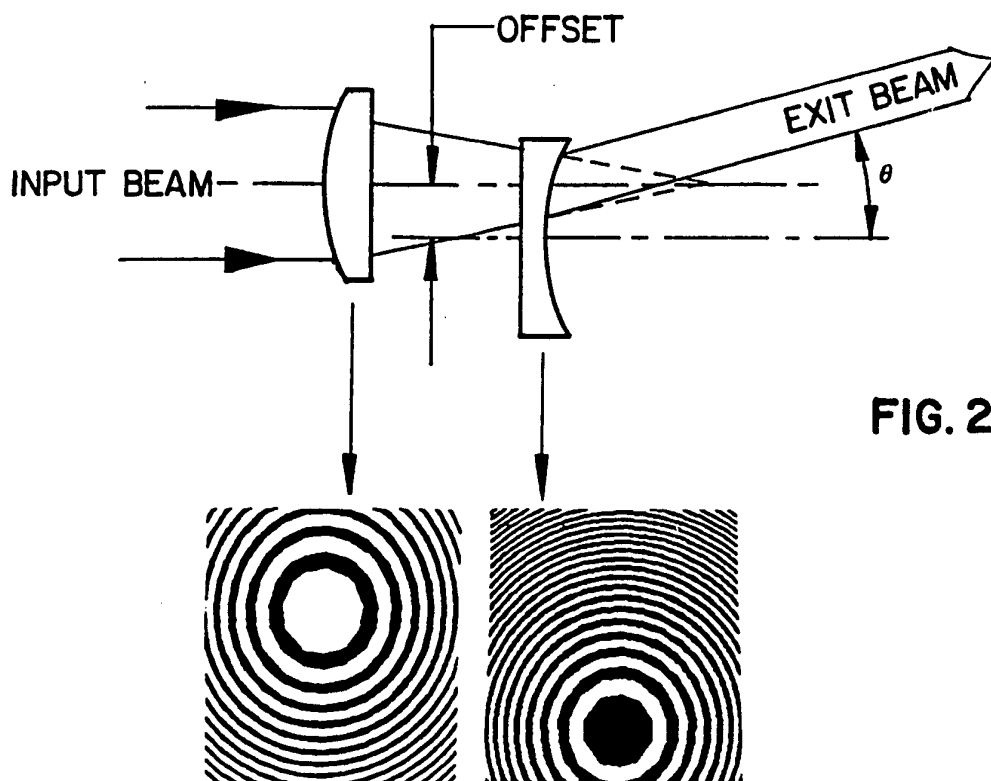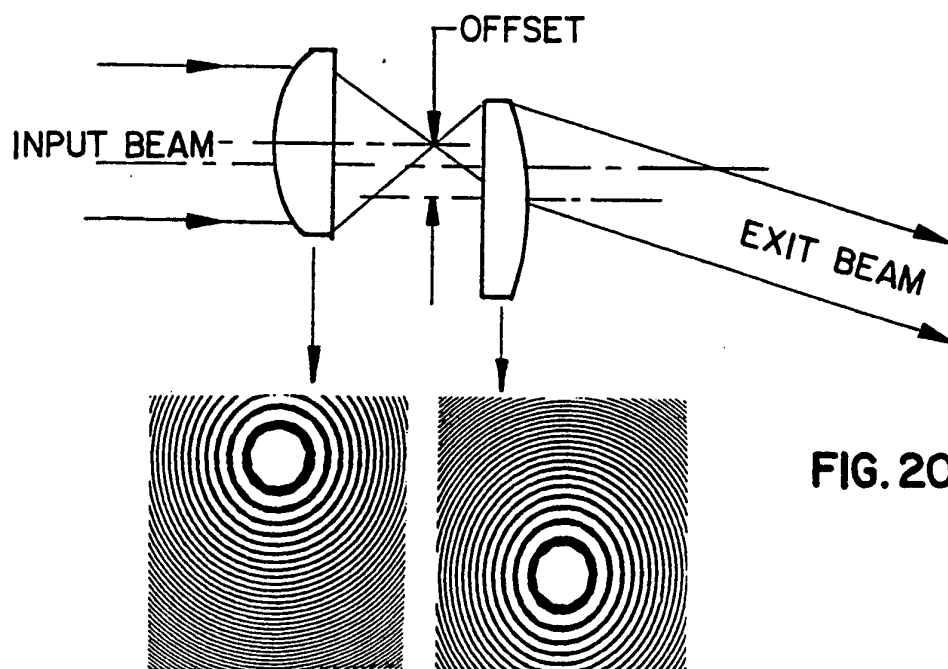
FIG. 20A

FIG. 20B

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 5   G02B5/18   G02B3/00   G02B27/10   G02B26/08   G02B27/42

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 5   G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category°	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	PROCEEDINGS OF THE SPIE - HOLOGRAPHIC OPTICS: OPTICALLY AND COMPUTER GENERATED, vol.1052, 19 January 1989, LOS ANGELES, CALIFORNIA, US pages 131 - 141 GOLTSOS ET AL 'Binary Micro Optics: An Application to Beam Steering' cited in the application see the whole document	1,3-6, 11, 13-15, 20,26, 30,31,33
A	US,A,4 867 514 (WALDRON) 19 September 1989 see figure 2	1,2,11, 20,26,30
A	US,A,5 059 008 (FLOOD ET AL) 22 October 1991 see the whole document	1,11,20, 26,30

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 May 1994	01 JUIN 1994

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+ 31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+ 31-70) 340-3016	Ward, S

Form PCT/ISA/210 (second sheet) (July 1992)

	Intern' nal Application No
	PCT/US 94/01153

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A-4867514	19-09-89	US-A- 5016980	21-05-91
US-A-5059008	22-10-91	NONE	