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(54) **Title:** GHOST IMAGE ELIMINATION OF DOE USING FOURIER OPTICS METHOD

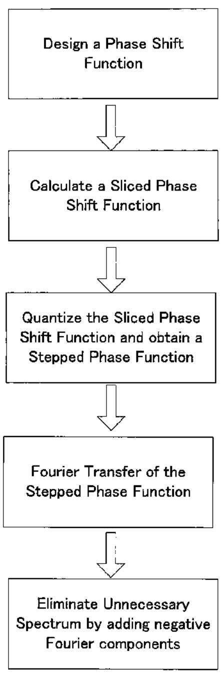

Fig-11

(57) **Abstract:** A see-through image display system having a DOE often has undesirable light or so called ghost images due to the quantization of saw tooth shape of DOE surface. This invention provides ways to eliminate ghost images.

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[Continued on next page]

Declarations under Rule 4.17:

— *of inventorship (Rule 4.17(iv))*

Published:

— *with international search report (Art. 21(3))*

— *with information concerning one or more priority claims considered void (Rule 26bis.2(d))*

Ghost image elimination of DOE using Fourier optics method

Cross Reference to Related Applications

[0001] This application is a Non-Provisional Application that claims a Priority Date of a previously filed Provisional Application 62/498,144 filed on December 15, 2016. This Application and Provisional Application 62.498,140 are a Continuation in Part (CIP) of Patent Application PCT/US2014//000153 filed on June 27, 2014, which is a Non-Provisional filing of a Provisional Application 61/957,258 filed on June 27, 2013.

Technical Field

[0002] This invention relates to a display system for projecting an image to a diffractive optical element enabling a see-through display with high resolution and wide field of view. More particularly, this invention relates to a display suitable for wearable displays with very small form factor.

Background Art

[0003] Wearable displays get attention in recent years after smart phones are well accepted by the market. Wearable displays provide hands free operation as well as showing image in the distance same as regular sight. There are tremendous needs for wearable displays. However in the past, near eye displays such as Head Mount Display, Head up Display and Eye Glass Type Display not necessarily satisfied viewers, because they were often too heavy, too large, too dark, low resolution, not see through, expensive and small size of image. There are needs for light, small, bright, high resolution, see-through, stealth, inexpensive and large image. This invention provides a new display system which satisfies all of these needs.

[0004] As shown in Fig-1 and Fig-1A, Kasai et al. disclosed in Patent US7460286 an eye glass type display system that implements see-through capability with a holographic optical element. This display system projects images in the normal direction from display device, more particularly perpendicular direction for a surface of LCD display, and projected light containing an image is led into optical wave guide and reflected toward the eye of viewer. Because of waveguide, the field of view and resolution are very limited.

[0005] As shown in Fig-2 and Fig-2A, Mukawa et al. in SID 2008 Digest, ISSN/008-0966X/08/3901-0089, "A Full Color Eyewear Display using Holographic Planar Waveguides", disclose an eye glass type display system that implements see-through capability with two plates of holographic optical elements. This system also uses a waveguide which limits resolution and field of view.

[0006] As shown in Fig-3, Levola in SID 2006 Digest, ISSN0006-64 • SID 06 DIGEST 0966X/06/3701-0064, Novel Diffractive Optical Components for Near to Eye Displays discloses another implementation locating LCD device in the middle of two eyes, but still it requires large protruded space which enlarge the form factor. The above three types of displays are using either holographic optical element (HOE) or diffractive optical element (DOE) and all of these have some fundamental difficulties of large chroma aberration, cross talk of colors, large field curvature aberration and distortion aberration. Mukawa et al. explained how to reduce cross talk of colors using multiple wave guides, which makes the system heavier and thicker and the efficiency of utilization of light will be lower. Kasai et al. used a single HOE which helped to improve the efficiency of light utilization, although the other aberrations remained and the FOB (field of view) has to be small so that these aberrations will not be conspicuous. This invention will show how these difficulties will be removed.

[0007] As shown in Fig-4 and Fig-4A, Li et al. disclosed in Patent US7369317 a compact display and camera module attachable to eye glasses. This also requires a thick PBS (polarized beam splitter) and the FOB (field of view) is rather small and this is not stealth and the presence of display is very obvious.

[0008] The examples such as Fig-1 and Fig-2 successfully demonstrated to public that a wearable display with see-through image is possible using holograms and wave guides. However making an accurate hologram is not an easy task which requires precise alignment of light beams and setting up of optical elements in a severe accuracy and it not easy to repeat same results consistently. On the other hand, a new method is gaining popularity utilizing a DOE (Diffractive Optical Element) which can be produced by semiconductor tools with a very repeatable way in a digital patterning technique. Digitizing the pattern of diffractive optical element often creates unnecessary ghost image because the frequency of quantization and that of DOE are not necessarily same and the difference creates a “Ghost image”. This invention will show some ways to eliminate “Ghost Images” coming from DOE.

Summary of the Invention

[0009] The objective of this invention is to create a see-through display using a DOE whose Fourier Transfer Function is close to zero except the intended image and other high order peaks which are out of sight.

[00010] Fig-11 shows an example of embodiment of this invention. To create an image in good focus, a phase shift function must be designed with an optical design tool such as Code-V or Zemax, so that the reflected light focuses at a right location. Then slice the function for every 2*pi and it will generate a function as a saw tooth, a sliced phase shift function. It is possible to make the exact shape with a certain tool, but it will require a very specialized tool which is not common for a typical semiconductor fab. Then quantization method is often used so that a common semiconductor fab can handle with common tools. However this quantization will creates unnecessary Fourier peaks within the viewing angle of viewer. Then the phase shift function has to be modified by adding a negative phase in a certain manner including randomized phase addition or distorting the phase shift function so that the Fourier Transfer Function becomes almost zero.

BRIEF DESCRIPTION OF THE DRAWINGS

[00011] Fig-1 is a cross sectional view of an image display system of prior art shown by Kasai in his published technical report related to US7460286. Fig-1A is a photo of the actual sample which successfully demonstrated see-though capability. This was very successful to demonstrate the possibility of see-through-display, but it does not provide enough viewing angle or resolution.

[00012] Fig-2 and Fig-2A are shown by Mukawa et al. in SID 2008 Digest, ISSN/008-0966X/08/3901-0089, "A Full Color Eyewear Display using Holographic Planar

Waveguides". The sample of wearable display in Fig-2A successfully demonstrated see-through capability. However, there is a need of higher resolution and wider viewing angle.

[00013] Fig-3 is another example of prior art and reported by Levola at SID 2006 Digest, ISSN0006-64 • SID 06 DIGEST 0966X/06/3701-0064, Novel Diffractive Optical Components for Near to Eye Displays. This display has not demonstrated samples.

[00014] Fig-4 shows another prior art of wearable display with see-through capability having both a display and a camera described in Patent US7369317. Fig-4A is an example using a similar configuration of optics. However the size of viewing angle is not large enough.

[00015] Fig-5 and Fig-6 are example eyeglasses having temples large enough to embed all optics and electronics of this invention, so that the existence of display is not noticeable.

[00016] Fig-7 is an example of this invention using a DOE as a see-through lens(702).

[00017] Fig-8 shows the light paths from a display to an eye after reflection by a DOE (802).

[00018] Fig-9 shows an example of a high resolution see-through eye-glass display as an Auxiliary Reality display and its optical structure. A DOE (902) provides a see-through lens.

[00019] Fig-10 shows an example of the light path.

[00020] Fig-11 illustrates a procedure to make a DOE to eliminate ghost images.

[00021] Fig-12 illustrates a structure of a phase function which reflects projected light toward an eye.

[00022] Fig-13 shows a process to convert the phase function to a sliced phase function whose pattern will be made on a wafer by semiconductor processes.

[00023] Fig-14 shows the structure of the sliced phase function and the direction of light reflection. The distance marked as 1404 is the pitch of saw tooth of DEO.

[00024] Fig-15 shows the pitch of quantization, "q" 1507 and 1509, which is not necessarily integral ratio to the pitch of saw tooth of DOE. This non-integral ratio creates a long period and low frequency of cycle and it will be converted to a short spatial frequency (length and spatial frequency are inverse proportional). This short spatial frequency generates so called "Ghost Image", because it will reflect in a small angle from the main image.

[00025] Fig-16 shows the Fourier Transfer function of the quantized sliced phase function and contains many peaks close to the main peak marked as "1" which creates the main image.

[00026] Fig-17 shows an experimental result showing many light spots corresponding to the peaks of the Fourier Transfer function, whose peaks showed good match with the measured spots.

[00027] Fig-18 shows an example of this invention, eliminating the undesirable spots or "Ghost Images" close to the main image (1801 and 1803) with the second peak (1802 and 1804) which is far enough to be non-visible for a human eye.

[00028] Fig-19 shows the phase function used for the above test having the total summation of phases close to zero.

Detail Descriptions of the Preferred Embodiments

[00029] The objective of this invention is to create a see-through display using a DOE wherein the Fourier Transfer Function is close to zero except the intended image and other high order peaks which are out of the viewing sight.

[00030] Fig-11 shows an example of embodiment of this invention. To create an image in good focus, a phase shift function must be designed with an optical design tool such as Code-V or Zemax, so that the reflected light focuses at a right location. Then slice the function for every 2*pi and it will generate a function as a saw tooth, a sliced phase shift function. It is possible to make the exact shape with a certain tool, but it will require a very specialized tool which is not common for a typical semiconductor fab. Then quantization method is often used so that a common semiconductor fab can handle with common tools. However this quantization will creates unnecessary Fourier peaks within the viewing angle of viewer as the example shown in Fig-16 (calculated Fourier Transfer) and Fig-17 (actual experimental result). Then the phase shift function has to be modified by adding a negative phase in a certain manner including randomized phase addition or modifying the phase shift function so that the Fourier Transfer Function becomes almost zero.

[00031] The addition of negative Fourier Transfer function can be done as the following steps. 1) Design an optics system including lens and mirrors to project image to a DOE. 2) Follow the steps in Fig-11 to obtain the Fourier Transfer Function of the quantized phase shift function as Fig-16. 2) Identify which peaks are undesirable peaks within the viewing angle. 3) Extract the undesirable peaks and apply Fourier Inverse Transfer of the extracted peaks and add this inverse transfer

function to the original phase shift function and recalculate the process until the undesirable peaks disappear.

[00032] Another example of embodiments is to randomize the phase shift function so that the undesirable peaks will be diluted into noises. The pitch marked as “p” in Fig-14 can be randomized to eliminate ghost peaks. Calculate P’=P+ (random number) using a normal distribution having zero average and standard variance is about 10% of P for example. This randomization will reduce the peaks of undesirable ghost images.

[00033] Another example is embodiments is to modify the original optics design as shown in Fig-18 (Fourier Transfer Distribution) and Fig-19 (Phase shift function shown in equiheight lines), where the pitches of saw tooth varies for every line and Fourier Transform (Fig-18) has very little undesirable peaks.

[00034] Though the invention has been described with respect to specific preferred and alternative embodiments, many additional variations and modifications will become apparent to those skilled in the art upon reading the present application. Thus it is the intention that the appended claims be interpreted as broadly as possible in view of the prior art to include all such variations and modifications.

Claims

We claim:

1. A see-through display system comprising:

   A display device from a group of LCD, LCOS, Micromirror, Microshutter, OLED and laser beam scanner and

   A circuit to drive said display device and

   Light Source(s) having light emitting device(s) from a group of Laser, LED and OLED and

   An Eyeglass lens and temple and

   A see-through optical element using a diffractive optical element (DOE) attached to the eyeglass wherein the peaks of spectrum of Fourier Transfer of the surface shape of said DOE are close to zero within the viewing angle except the peak of intended image.

2. The see-through display system of claim 1 wherein:

   The pitch of saw tooth of DOE is randomized to reduce undesirable peaks of Fourier Spectrum of the shape of DEO surface.

3. The display system of claim 1 wherein:

   A negative Fourier Transform spectrum is added to reduce undesirable peaks of Fourier Spectrum.

4. The display system of claim 1 wherein:

   The phase shift function of DOE is designed so that undesirable peaks within the viewing angle will be minimized.

5. A display system comprising:

A display device from a group of LCD, LCOS, Micromirror, Microshutter, OLED and laser beam scanner and

A circuit to drive said display device and

Light Source(s) having light emitting device(s) from a group of Laser, LED and OLED and

A DOE to focus light beams, wherein the peaks of spectrum of Fourier Transfer of the surface shape of said DOE are close to zero within the viewing angle except the peak of intended image.

6. The display system of claim 5 wherein:

The pitch of saw tooth of DOE is randomized to reduce undesirable peaks of Fourier Spectrum of the shape of DEO surface.

7. The display system of claim 5 wherein:

A negative Fourier Transform spectrum is added to reduce undesirable peaks of Fourier Spectrum.

8. The display system of claim 5 wherein:

The phase shift function of DOE is designed so that undesirable peaks within the viewing angle will be minimized.

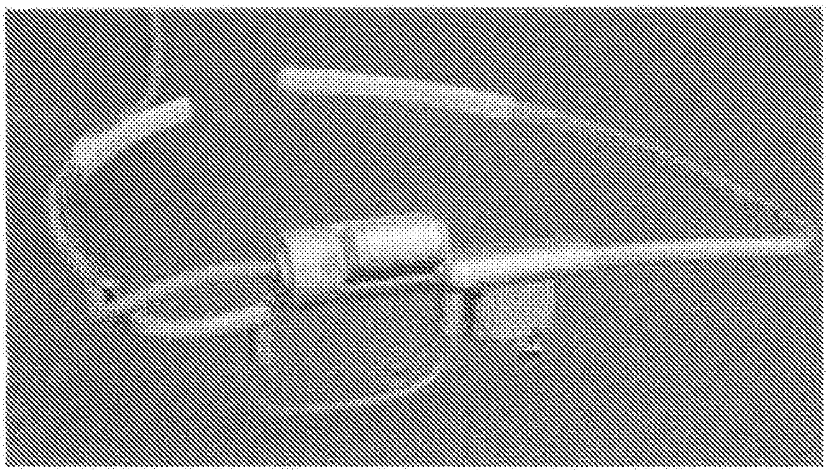


Fig-1(Prior Art)

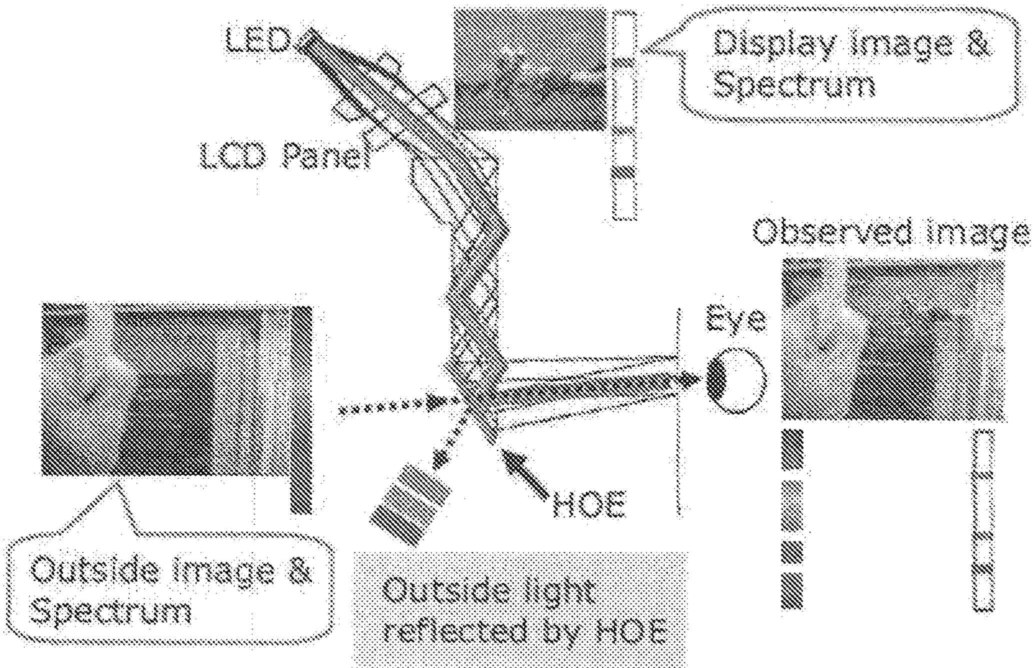


Fig-1A (Prior Art)

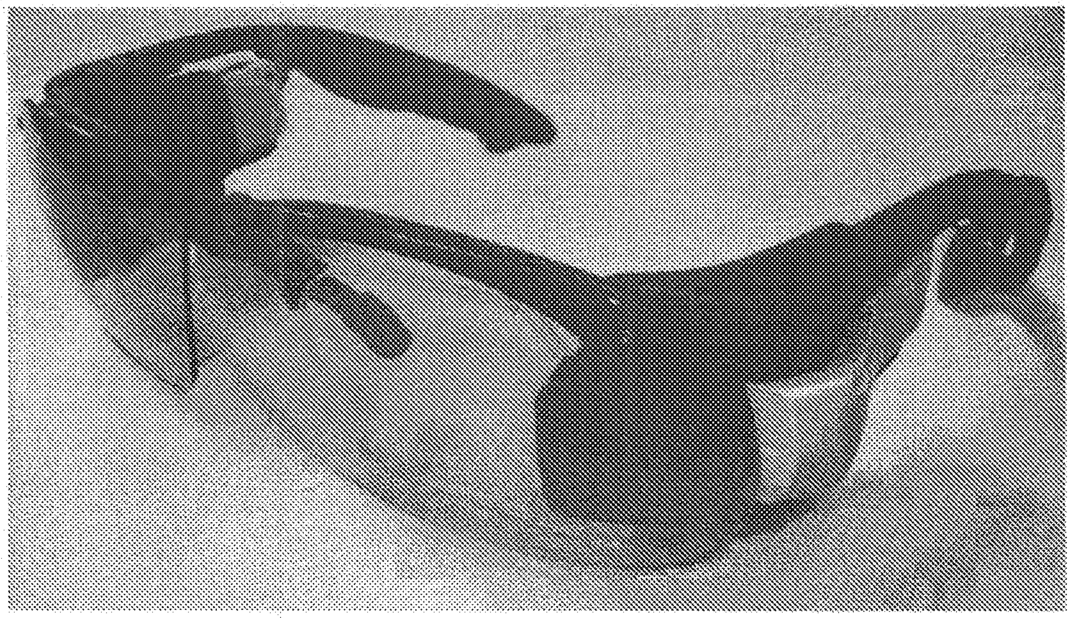


Fig-2(Prior Art)

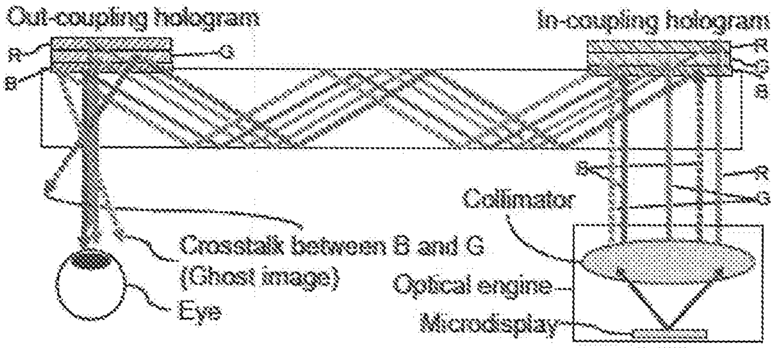


Fig-2A (Prior Art)

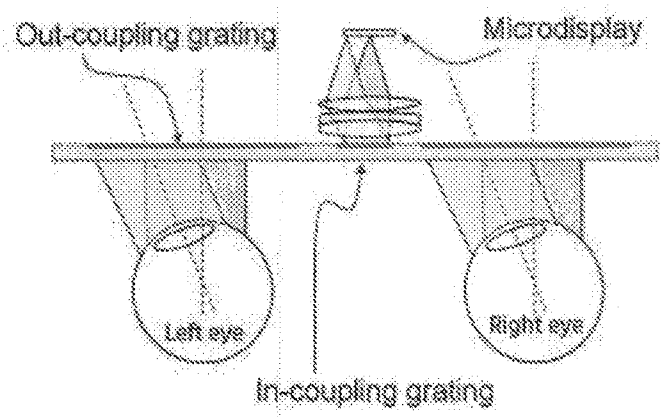


Fig-3 (Prior Art)

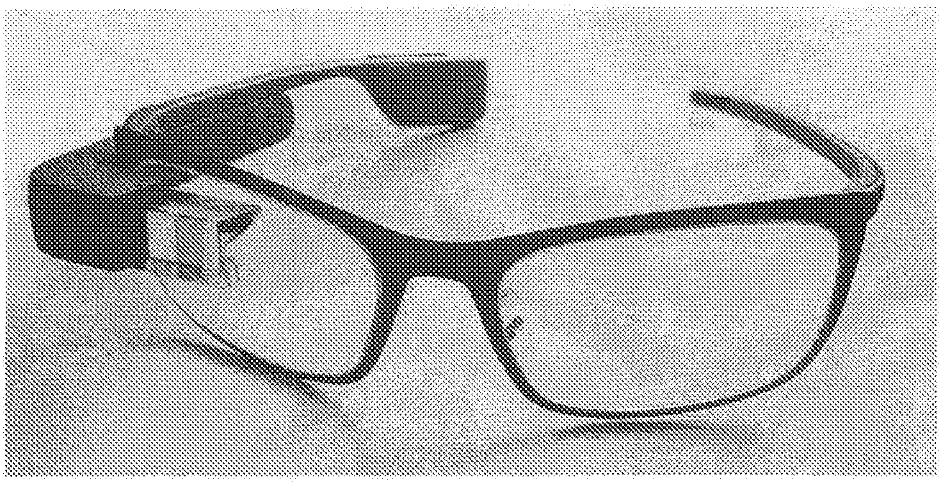


Fig-4 (Prior Art)

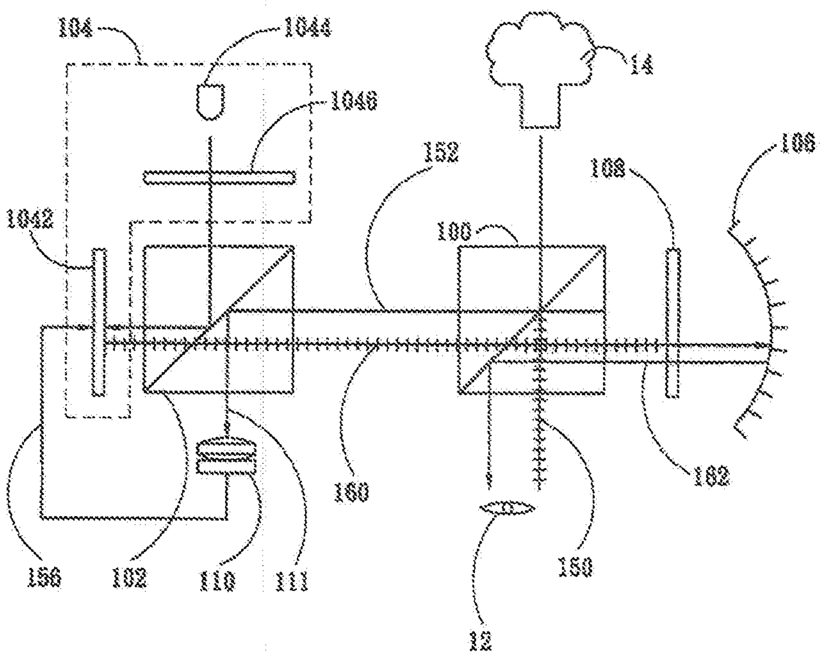


Fig-4A (Prior Art)

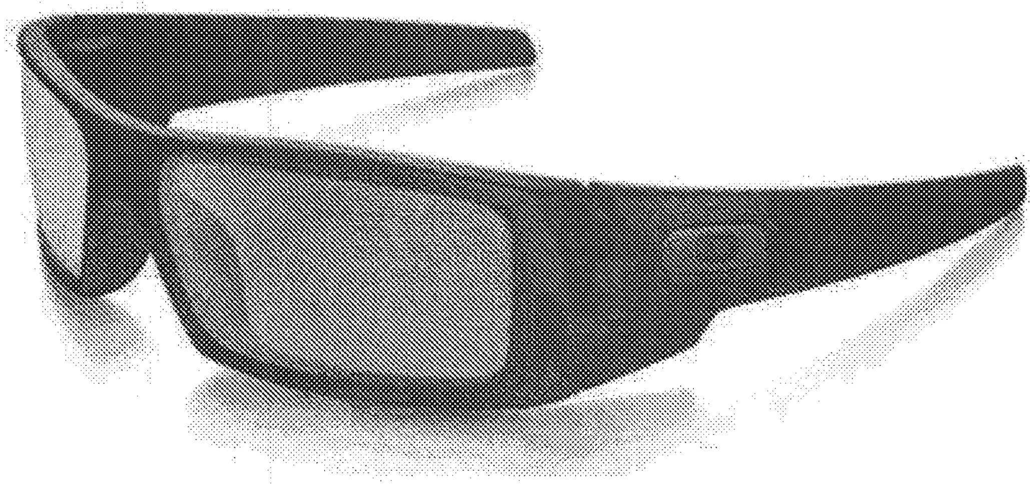


Fig-5

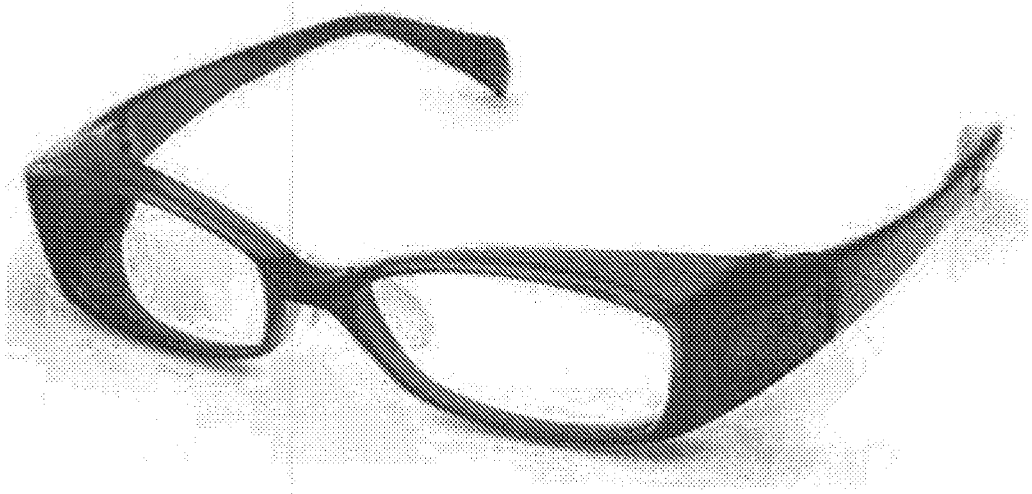


Fig-6

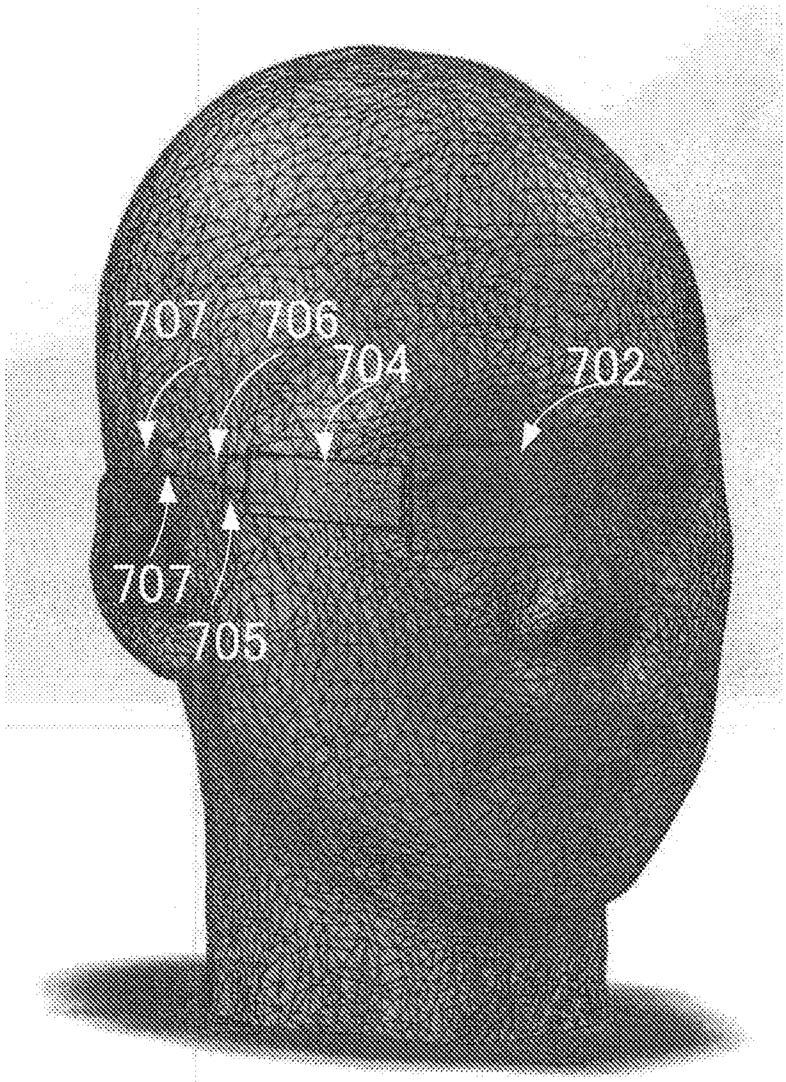


Fig-7

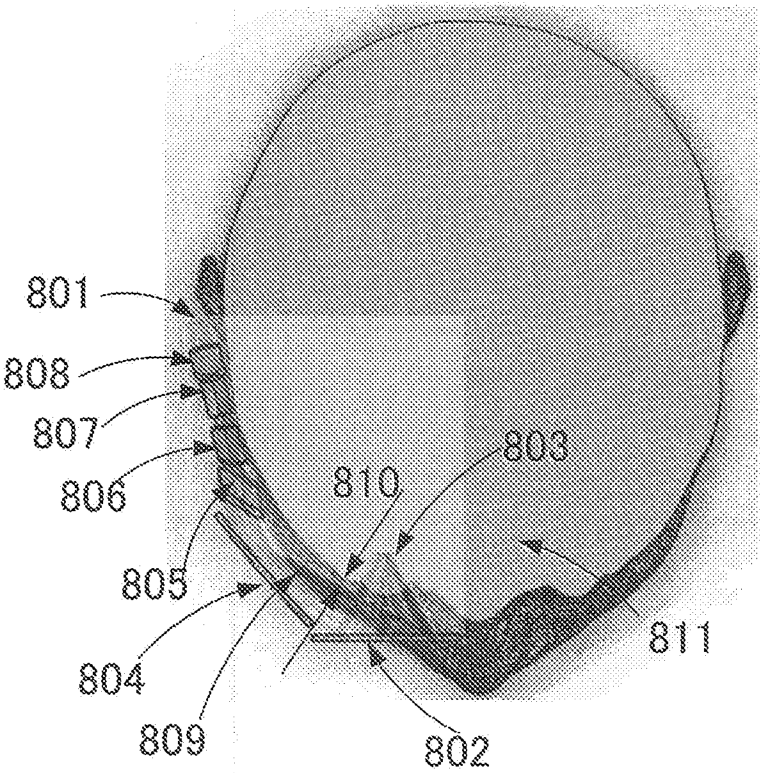


Fig-8

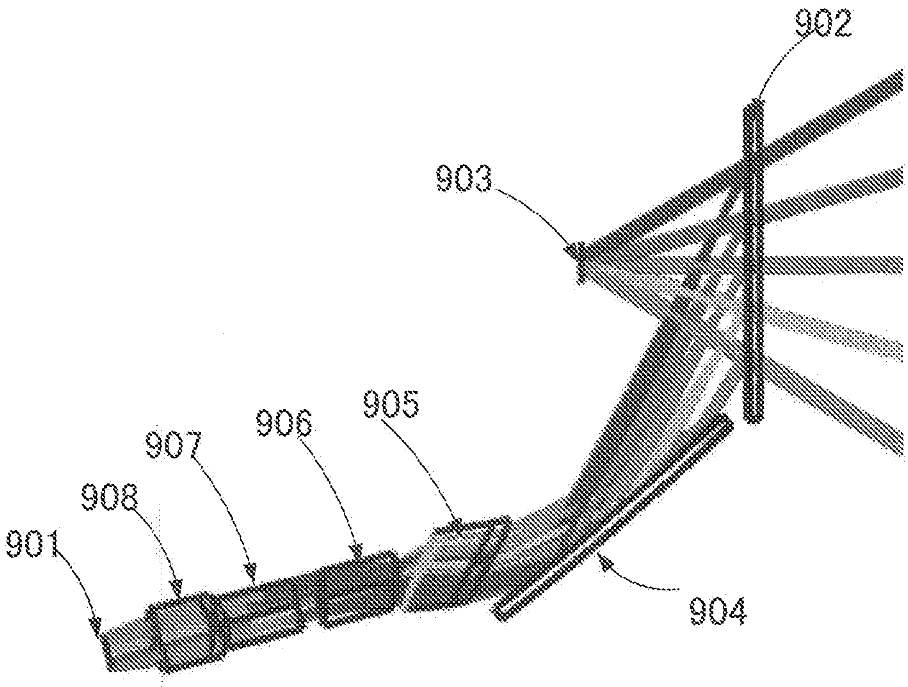


Fig-9

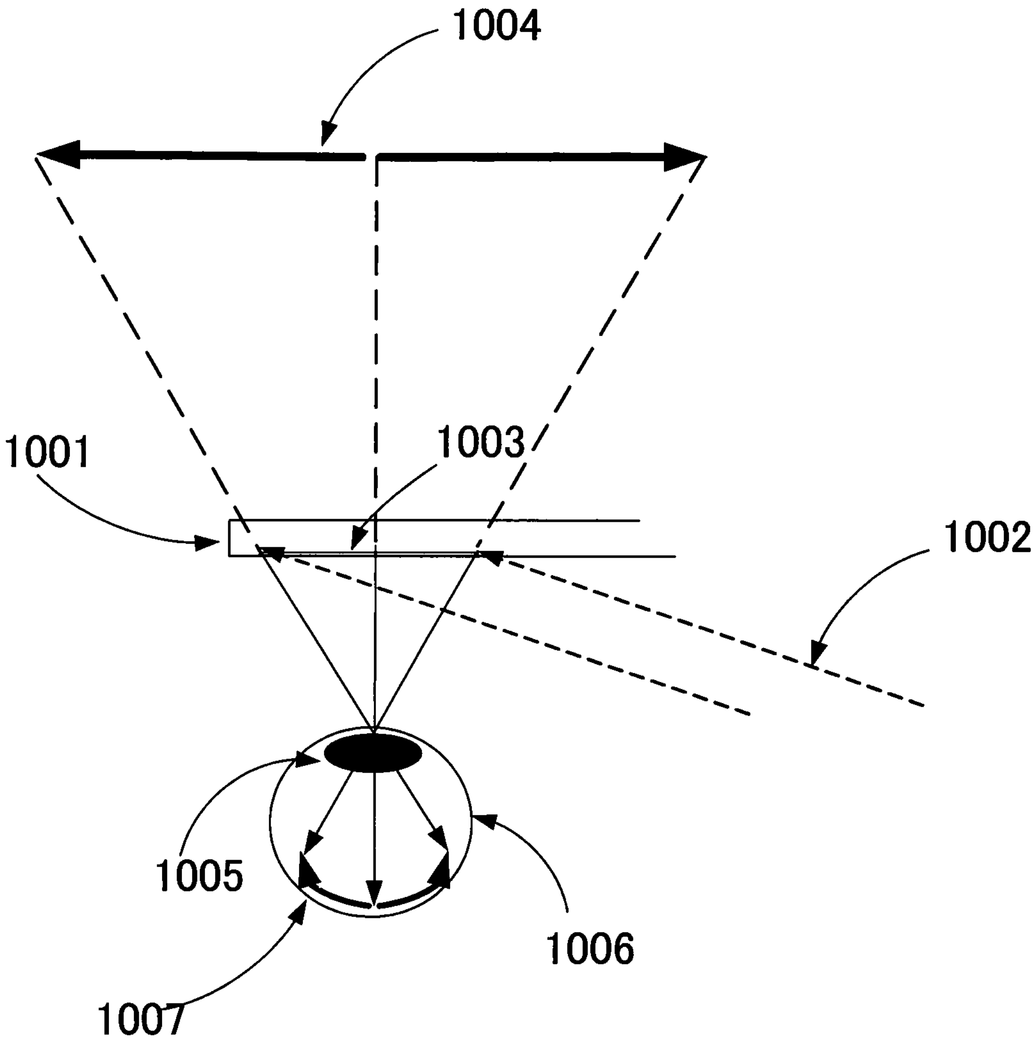


Fig-10

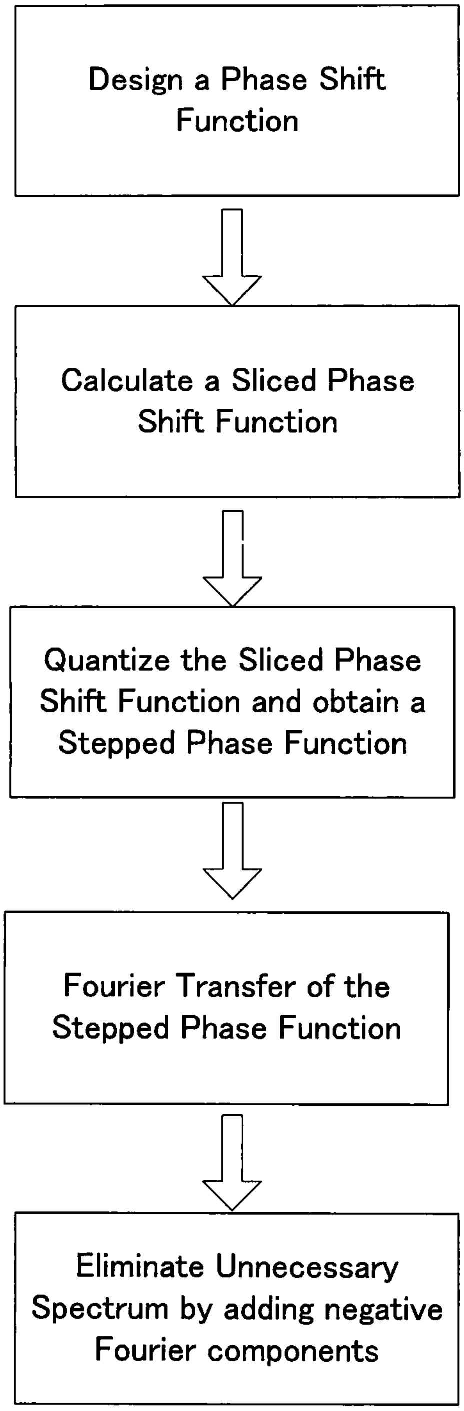

Design a Phase Shift Function
Calculate a Sliced Phase Shift Function
Quantize the Sliced Phase Shift Function and obtain a Stepped Phase Function
Fourier Transfer of the Stepped Phase Function
Eliminate Unnecessary Spectrum by adding negative Fourier components

Fig-11

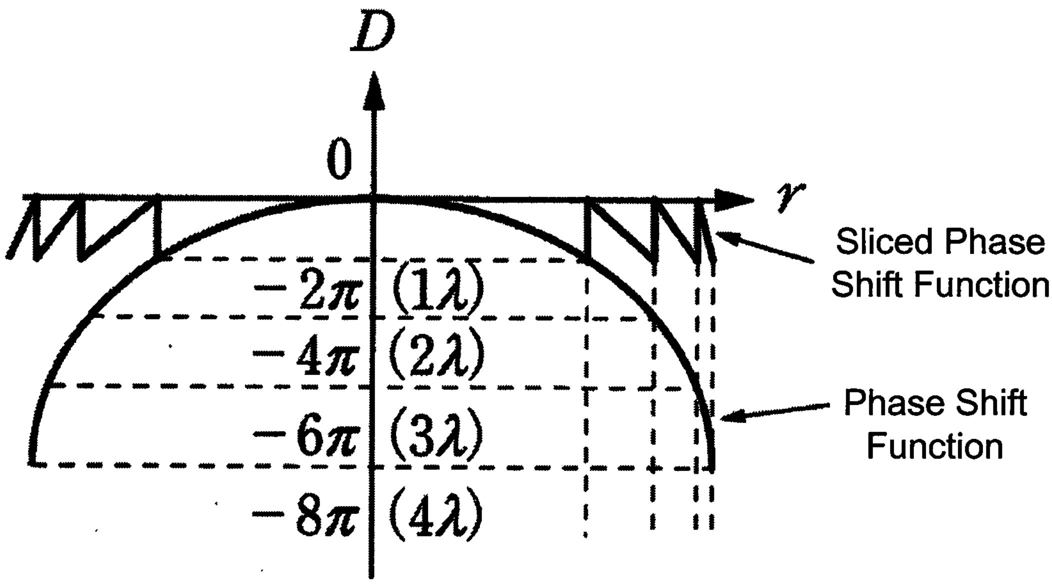

D
0
r
Sliced Phase Shift Function
−2π (1λ)
−4π (2λ)
−6π (3λ)
−8π (4λ)
Phase Shift Function

Fig-12

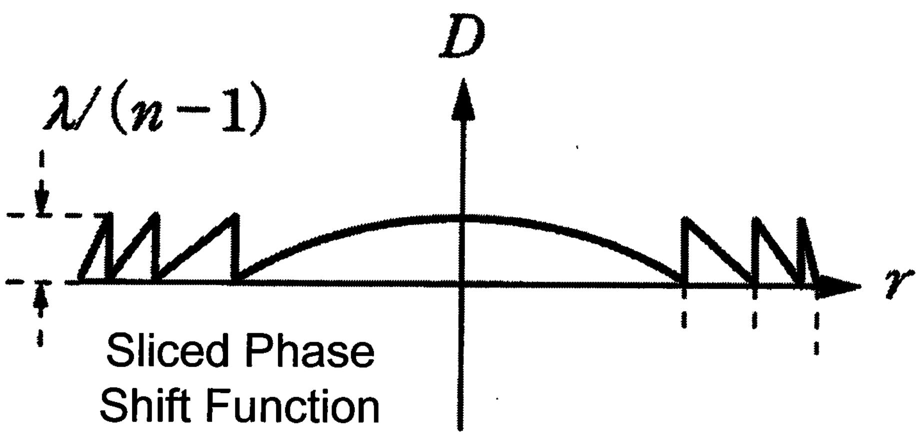

D
λ/(n−1)
r
Sliced Phase Shift Function

Fig-13

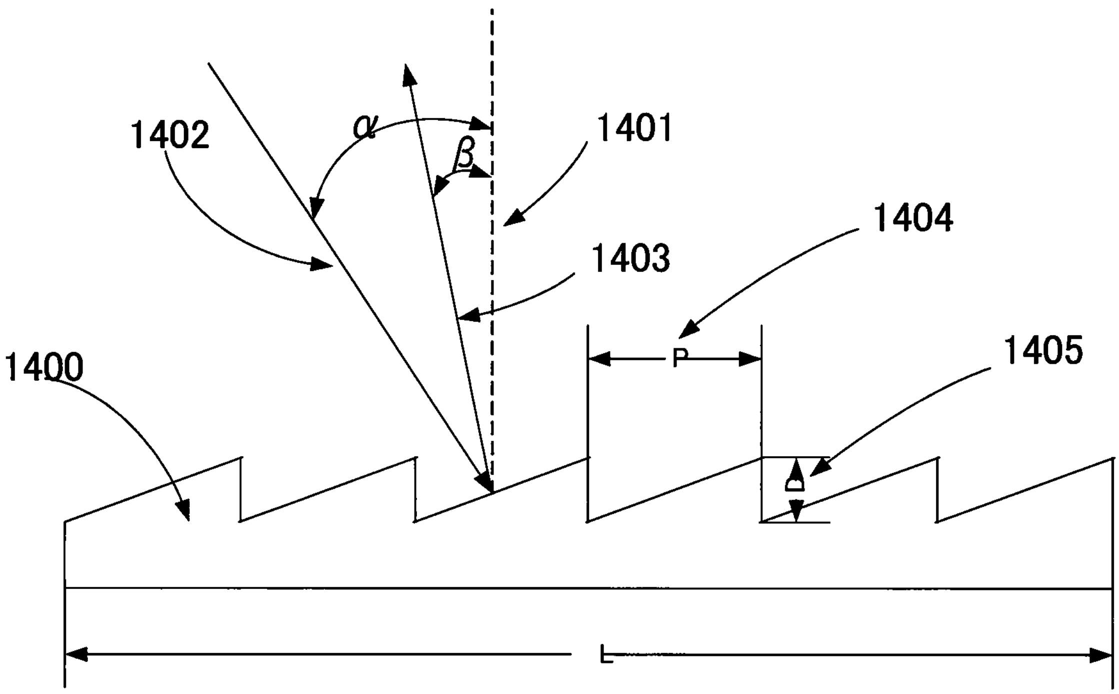


Fig-14

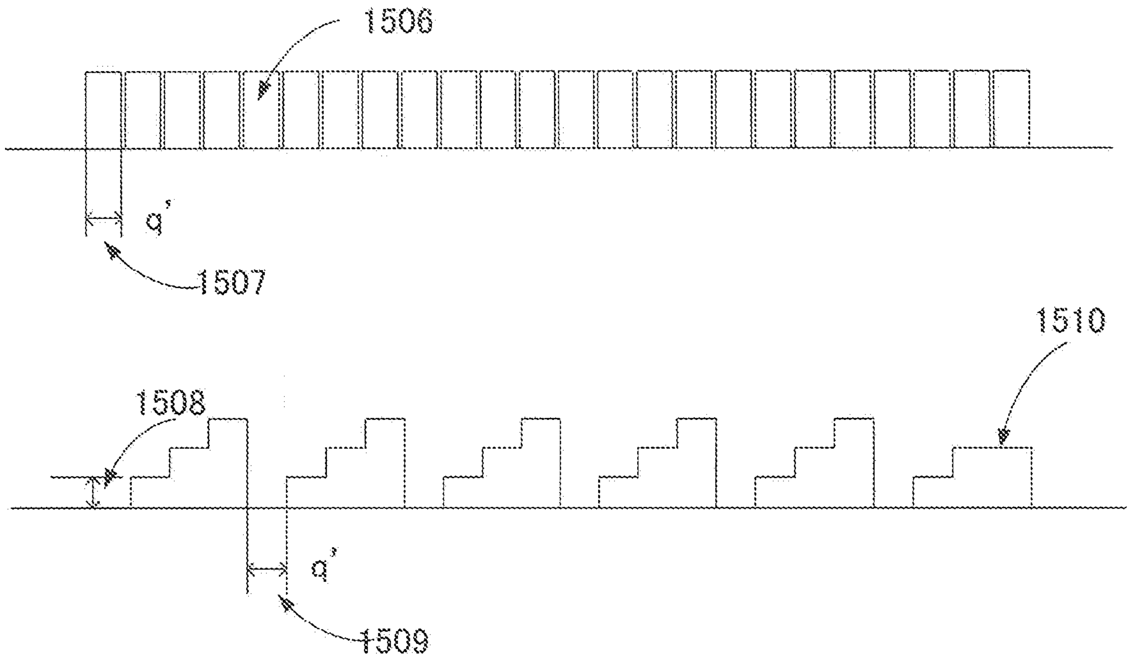
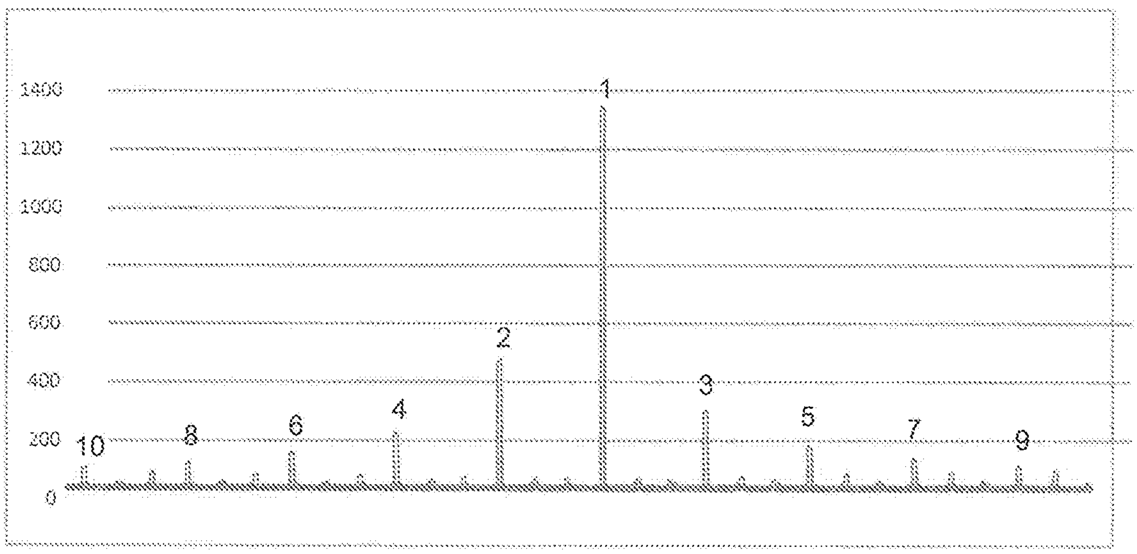

1506
q'
1507
1510
1508
q'
1509

Fig-15


1400
1200
1000
800
600
400
200
0
1
2
3
4
5
6
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8
9
10

Fig-16

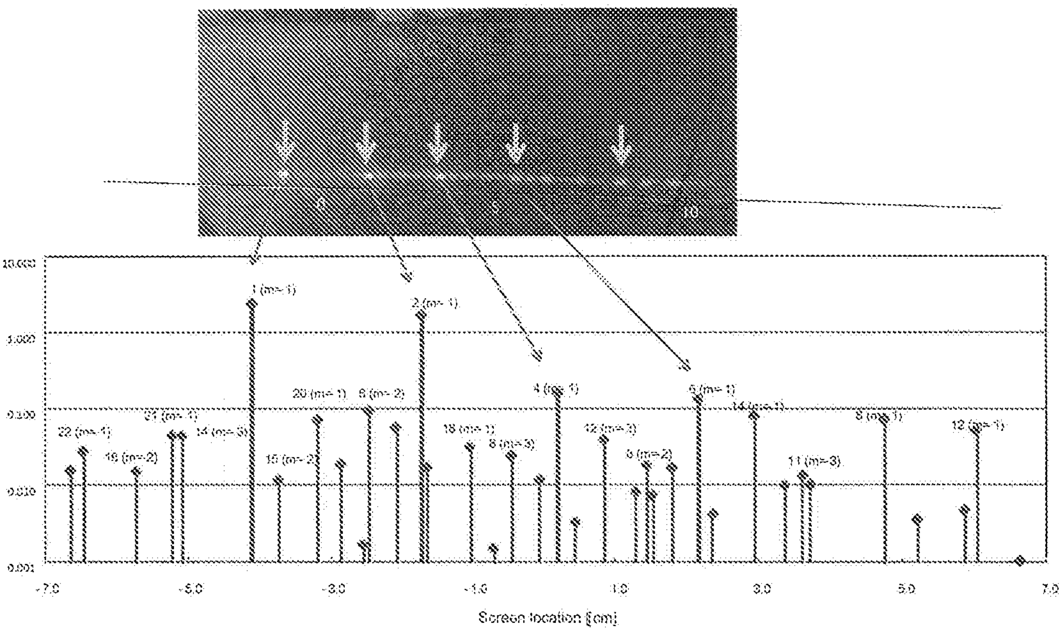

Fig-17

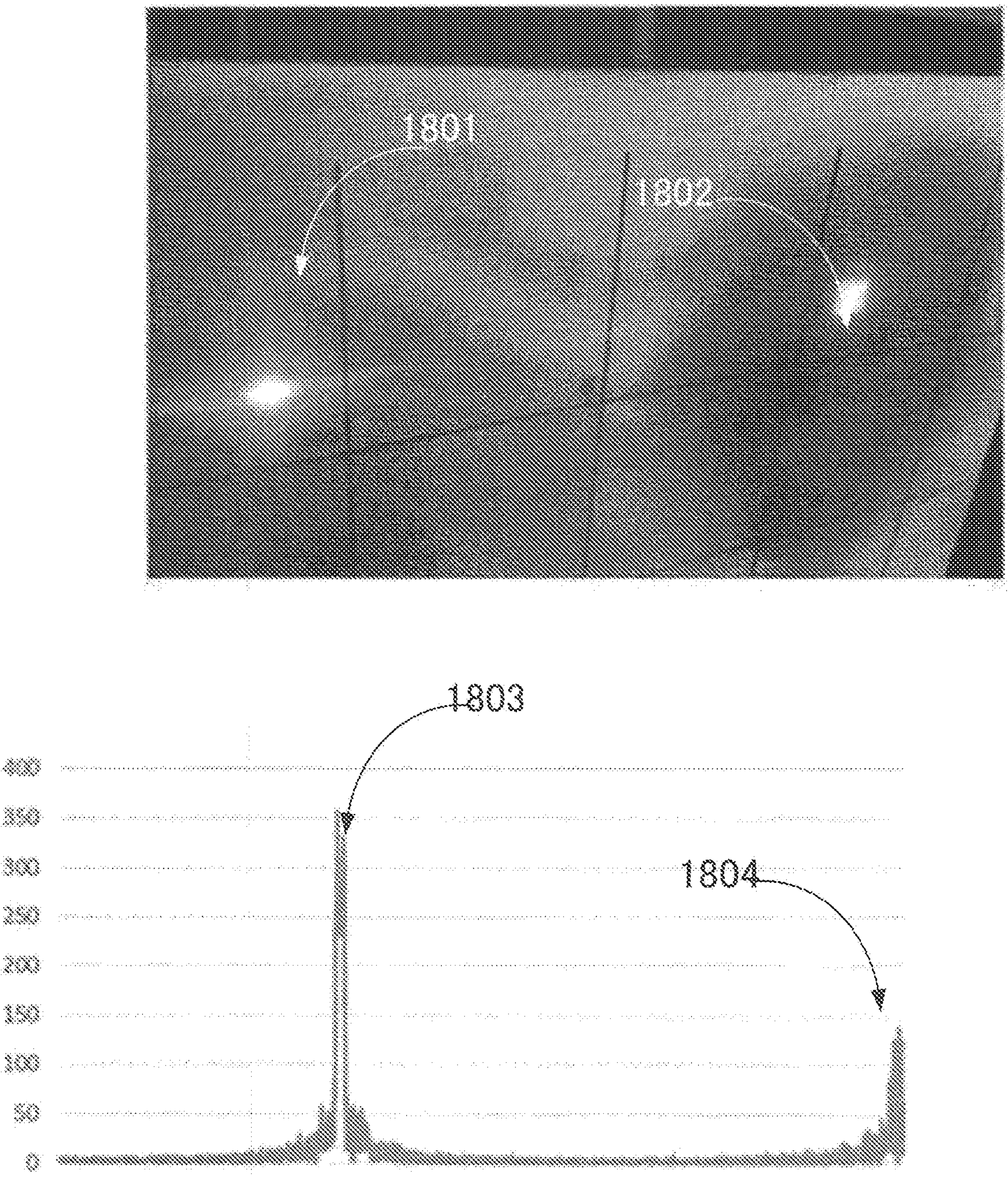

Fig-18

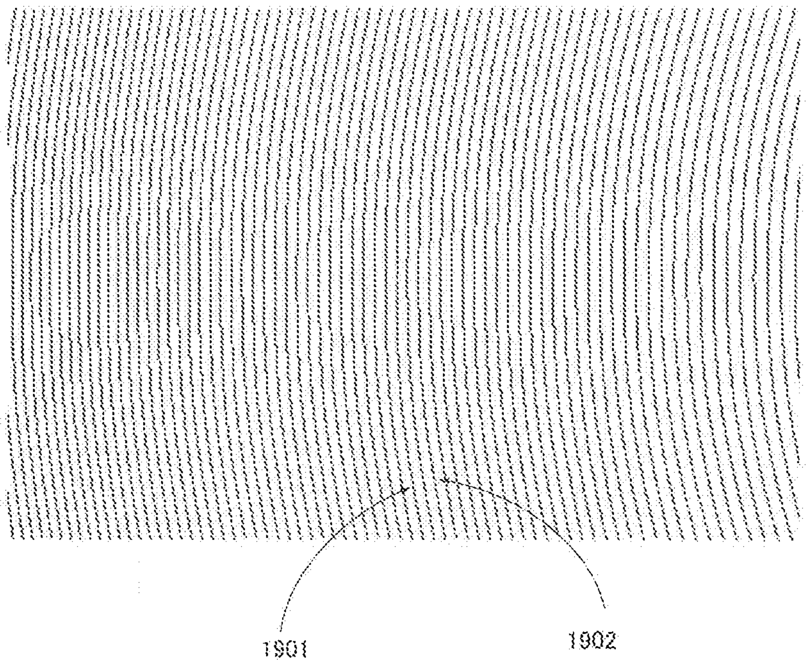

Fig-19

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 17/66858

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - G02B 27/01; G02B 27/42 (2018.01)
CPC - G02B 27/0018; G02B 27/0037; G02B 27/0172; G02B 27/4205

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)
See Search History Document

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
See Search History Document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 8,467,133 B2 (MILLER) 18 June 2013 (18.06.2013), Fig 1, 123A, 123B, abstract, col 11, ln 3 -col 13, ln 28	1-8
Y	US 5,742,262 A (TABATA et al.) 21 April 1998 (21.04.1998), Fig 3, 21a, 21b, 22, 23, 24, 29, 31, abstract, col 5, ln 30-38, col 9, ln 15-col 10, ln 12, col 11, ln 11-27	1-8
Y	US 7,418,202 B2 (BIERNATH et al.) 26 August 2008 (26.08.2008), Fig 2E, abstract, col 7, ln 52 -54	2, 6
Y	US 5,161,027 A (LIU) 03 November 1992 (03.11.1992), abstract	3, 7
Y	US 5,847,877 A (IMAMURA et al.) 08 December 1998 (08.12.1998), Fig 3, abstract, col 1, ln 5-12, col 4, ln 3-42	4, 8
A	US 6,185,043 B1 (IMAMURA) 06 February 2001 (06.02.2001), Fig 23, 25, abstract, col 29, ln 15 -50	1, 5

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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"A" document defining the general state of the art which is not considered to be of particular relevance
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"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
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"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
01 March 2018	26 MAR 2018
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774