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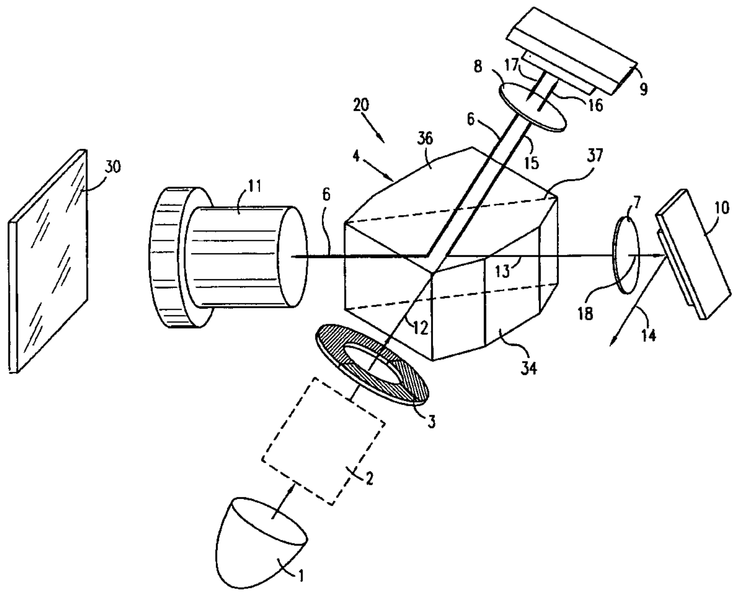
(54) Title: IMAGING SYSTEM



(57) **Abstract:** This invention discloses an imaging system, including a light source, a polarizing beam splitter (PBS) operative to split light impinging thereon from the light source into two generally linearly polarized beams, a pair of optical elements through which pass the linearly polarized beams, the optical elements being operative to change the linearly polarized beams into generally circularly polarized beams, and for each beam, a spatial light modulator (SLM) operative to selectively reflect the generally circularly polarized beam back towards the optical element, the optical element changing the circularly polarized beam into a generally linearly polarized beam with its polarity rotated at an angle to the first-mentioned linearly polarized beam.

WO 01/37029 A1

IMAGING SYSTEM

FIELD OF THE INVENTION

The present invention relates generally to imaging systems, and more particularly to methods and apparatus for obtaining a high quality, correct color, three-dimensional image without flickering using a DMD (digital mirror device).

BACKGROUND OF THE INVENTION

Video and data projection systems generally use spatial light modulators (SLMs) in generating images to be projected on a screen. The broad family of SLMs may be divided into two groups. One group requires that the incoming light be polarized and includes polarizing modulators, such as liquid crystal displays (LCDs), reflective or transmissive, and other devices collectively referred to also as "SLMs". These polarizing modulators modify the polarization of the light impinging thereon, such as by partially rotating the polarization, or by rotating by 90°, or by blocking the polarization altogether, for example.

The other group does not require polarized light and includes mirror devices, such as digital mirror devices (DMDs). DMDs include an array of mirrors which can be tilted (typically ±10°) to reflect light onto or away from a projection screen. DMDs provide significant advantages over the first-mentioned group. First, since non-polarized light may be used, luminance is increased. Second, contrast, such as between shades of gray or between black and white, is improved. In polarizing modulators, the contrast results from an active component (SLM) rotating polarization direction and interacting with passive components (polarizers). The contrast thus depends, *inter alia*, on the efficiency of the blockage of the polarized light. However, in DMD arrays, the black portions of the picture are simply formed by deflecting the light away from the screen, resulting in sharp, high contrasts.

A disadvantage of DMD arrays is that in the prior art it is not possible to obtain a high quality, color, three-dimensional image without "flickering", as is now explained.

Three-dimensional images may be produced by projecting two different images of a scene or object, each image having being filmed from a different view angle, wherein one image is viewed by the left eye of a viewer and the other image viewed by the right eye. In this manner, each eye receives a different perspective of the scene and the viewer's brain combines the viewed information into a 3D picture.

There are three basic methods of producing 3D images in projection systems:

1. The two images are shown in two different colors, e.g., red and green, and the viewer wears special eyeglasses with color filters, such that one eye only sees the red image and the other eye only sees the green image. A disadvantage of this method is that the viewer sees a combined 3D picture which is not in correct color.

2. The two images are projected one after the other rapidly on the screen. The viewer wears *active* eyeglasses that have shutters that can rapidly and sequentially block each eye in synchronization with the color images being projected to the viewer. In this method the viewer does see a 3D color picture, but the method is complicated and expensive, and there is a strong and undesirable effect of "flickering".

3. The two images are projected in different polarizations on the screen, i.e., their polarization fields are rotated 90° from each other. The viewer wears *passive* eyeglasses that have polarizing filters with different polarizations, in accordance with those of the two images. The two differently polarized images are projected simultaneously on the screen, and the filters block each eye in accordance with the particular polarization of the image. This is considered the preferred method of the art, due to its relative simplicity and absence of flickering.

However, current configurations of DMD arrays are not suitable for employing the above preferred method because they do not operate by distinguishing between differently polarized images. It is clear though, that it would be very desirable to achieve a high quality, color, three-dimensional image without flickering with a DMD in order to enjoy the inherent benefits of DMD technology, such as its improved luminance and contrast.

SUMMARY OF THE INVENTION

The present invention seeks to provide a novel method and apparatus for obtaining a high quality, correct color, three-dimensional image without flickering with a DMD.

The present invention employs a polarizing beam splitter/combiner (PBS) to split incoming light into two polarized beams polarized in directions generally orthogonal to each other. The two linearly polarized beams pass through optical elements (preferably quarter-wave plates) which change the linearly polarized beams into generally circularly polarized beams. Each circularly polarized beam preferably reflects off a DMD, the beam being reflected with a reverse circular polarity. If the DMD is arranged to reflect the beam in a direction back towards and through the quarter-wave plate, then the quarter-wave plate changes the circularly polarized beam into a linearly polarized beam with its polarity rotated generally 90° to the *original* linearly polarized beam. In this manner, the reflected linearly polarized beam does not pass back to the light source, but rather is projected to a projection screen.

By means of the PBS and quarter-wave plate, the DMD can be used to correctly direct polarized light beams either to or away from the projection screen. The system can thus be incorporated into the abovementioned method of projecting two images in different polarizations on the screen, wherein a viewer wears eyeglasses that have polarizing filters with different polarizations, in accordance with those of the two images. The two differently polarized images are projected simultaneously on the screen, and the filters block each eye in accordance with the particular polarization of the image, and the viewer's eye perceives a three-dimensional image with no flickering.

There is thus provided in accordance with a preferred embodiment of the present invention an imaging system, including a light source, a polarizing beam splitter (PBS) operative to split light impinging thereon from the light source into two generally linearly polarized beams, a pair of optical elements through which pass the linearly polarized beams, the optical elements being operative to change the linearly polarized beams into generally circularly polarized beams, and for each beam, a spatial light modulator (SLM) operative to selectively reflect the generally circularly polarized beam back towards the optical element, the optical element changing the circularly polarized beam into a generally linearly polarized beam with its polarity rotated at an angle, such as generally 90°, to the first-mentioned linearly polarized beam.

In accordance with a preferred embodiment of the present invention the polarizing beam splitter (PBS) is operative to split the light into two beams linearly polarized in directions generally orthogonal to each other.

Further in accordance with a preferred embodiment of the present invention the spatial light modulator (SLM) is operative to reflect the circularly polarized beam back towards the optical element with a circular polarity of reverse direction to that of the beam before reflecting off the SLM.

The SLMs are preferably digital mirror devices (DMDs), and the optical elements are preferably quarter-wave plates.

Still further in accordance with a preferred embodiment of the present invention a screen is provided, and one or more of the reflected linearly polarized beams passes through the PBS towards the screen. Alternatively, the beams can be deflected away from the screen.

Additionally in accordance with a preferred embodiment of the present invention a color filter element is placed between the light source and the PBS, or alternatively, between the PBS and the optical elements.

In accordance with a preferred embodiment of the present invention a beam shaping element is placed between each of the SLMs and the optical elements, or alternatively, between each of the SLMs and the PBS.

Further in accordance with a preferred embodiment of the present invention the color filter element includes three different color filters of a three primary additive color system, and another color filter of one of the three different color filters.

Still further in accordance with a preferred embodiment of the present invention the color filter element includes a portion which passes white light.

Additionally in accordance with a preferred embodiment of the present invention a color divider splits the light from the light source into three differently colored beams.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be understood and appreciated more fully from the following detailed description, taken in conjunction with the drawings in which:

Fig. 1 is a simplified pictorial illustration of a projection system constructed and operative in accordance with a preferred embodiment of the present invention;

Fig. 2 is a simplified pictorial illustration of a variation of the projection system of Fig. 1, wherein beam shaping elements help direct light beams towards DMDs, constructed and operative in accordance with a preferred embodiment of the present invention;

Fig. 3 is a simplified pictorial illustration of another variation of the projection system of Fig. 1, constructed and operative in accordance with a preferred embodiment of the present invention;

Fig. 4 is a simplified pictorial illustration of a further variation of the projection system of Fig. 1, wherein color filter elements are used to reduce or eliminate color separation, in accordance with a preferred embodiment of the present invention;

Fig. 5 is a simplified pictorial illustration of a variation of the projection system shown in Fig. 4, wherein two color filter elements are placed between a polarizing beam splitter/combiner and two DMDs, in accordance with a preferred embodiment of the present invention;

Fig. 6 is a simplified pictorial illustration of a projection system constructed and operative in accordance with another preferred embodiment of the present invention;

Fig. 7 is a simplified pictorial illustration of a variation of the projection system of Fig. 6, employing a plurality of color light sources and illumination systems, constructed and operative in accordance with another preferred embodiment of the present invention; and

Figs. 8 and 9 are simplified pictorial illustrations of further variations of the projection systems of Figs 6 and 7, respectively, employing color combiners with a dichroic coating, constructed and operative in accordance with another preferred embodiment of the present invention.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

Reference is now made to Fig. 1 which illustrates a projection system 20 constructed and operative in accordance with a preferred embodiment of the present invention. Projector system 20 preferably includes a light source 1, such as an arc lamp based illuminator, which directs a beam of light through an illumination system 2 and a color filter element 3 (such as a color wheel), onto a polarizing beam splitter/combiner 4 (herein referred to as PBS 4).

PBS 4 is preferably constructed as described in applicant/assignee's US Patent 5,946,139 and PCT published patent application WO 99/52269, the disclosures of which are incorporated herein by reference. PBS 4 preferably comprises first and second prisms 34 and 36 separated by a birefringent material 37. Alternatively, PBS 4 may comprise Glen-Thompson or Wollaston prisms which are commercially available from Melles Griot or Spindler & Hoyer. As a further alternative, PBS 4 may be a conventional broad-band polarizing beam splitter comprising plural prisms which are separated by multilayer optical coatings.

PBS 4 preferably splits the light impinging thereon from light source 1 into two generally linearly polarized beams, 13 and 15. Beams 13 and 15 typically, but not necessarily, have different polarizations, such as the p and s components of polarized light, respectively. Beam 13 is reflected in the area of the interface of prisms 34 and 36 towards a first optical element 7 which is operative to change the generally linearly polarized beam 13 into a generally circularly polarized beam 18. Beam 15 passes unreflected to a second optical element 8 which is operative to change the generally linearly polarized beam 15 into a generally circularly polarized beam 16. Preferred optical elements 7 and 8 are quarter-wave plates. Circularly polarized beams 16 and 18 impinge on spatial light modulators 9 and 10, respectively. SLMs 9 and 10 each have two operating orientations, wherein in a first operating orientation the SLM reflects the beam back towards PBS 4, and in the second operating orientation the SLM diverts the beam away from PBS 4. Preferred SLMs are DMDs, and herein SLMs 9 and 10 are referred to as DMDs 9 and 10.

Each DMD can be in either of the two operating orientations. For example, if both DMDs 9 and 10 divert beams 16 and 18, respectively, away from PBS 4, then no light reaches a screen 30. In this situation, both DMDs 9 and 10 are OFF. On the other hand, as shown in Fig. 1, if DMD 9 reflects circularly polarized beam 16 back towards PBS 4 as circularly polarized beam 17 (i.e., DMD 9 is ON), beam 17 having a circular polarity of generally reverse direction to that of beam 16. Beam 17 will pass through second optical element 8 which changes the circularly polarized beam 17 into a generally linearly polarized beam 6 with its polarity rotated 90° to the original linearly polarized beam. In other words, linearly polarized beam 6 has a polarization orthogonal to that of beam 15. For example, beam 6 has p polarization as opposed to beam 15 having s polarization, which means that beam 6 is reflected by PBS 4 through a lens 11 to screen 30.

As a further example, both DMDs 9 and 10 can reflect circularly polarized beams 16 and 18, respectively, back towards PBS 4 (i.e., both DMDs 9 and 10 are ON). As mentioned above, the reflected circularly polarized beams will pass through second optical element 8 which changes the circularly polarized beams into linearly polarized beams with polarity rotated 90° to the original linearly polarized beams. In this manner, beam 15, which had s polarization, is changed to beam 6 which has p polarization, which means that beam 6 is reflected by PBS 4 through lens 11 to screen 30, as mentioned before. Beam 13, which had p polarization, is changed to a beam with s polarization, that beam passing unreflected through PBS 4 through lens 11 to screen 30.

It is noted that screen 30 may be any projection surface, such as a projector screen, a television screen, a printer drum, a piece of photographic film, or any photosensitive media, for example. It is also noted that optical elements 7 and 8 may be provided separately from PBS 4 and DMDs 9 and 10 or may be integrally formed with any of them.

Reference is now made to Fig. 2 which illustrates a variation of projection system 20, wherein beam shaping elements 25 and 26, such as focusing lenses, are respectively placed between DMDs 9, 10 and first and second optical elements 8, 7. Beam shaping elements 25 and 26 help direct the light beam towards the DMD.

Reference is now made to Fig. 3 which illustrates another variation of projection system 20, wherein the beam shaping elements 25 and 26 are placed between first and second optical elements 8, 7 and PBS 4.

Color filter element 3 typically includes three color filters of a three primary additive color system, such as red, green and blue (RGB). Reference is now made to Fig. 4 which illustrates a further variation of projection system 20, wherein color filter element 3 is designed to reduce or eliminate color separation, by including four color filters 3A, 3B, 3C and 3D, such as red, green, blue and green. The double use of one of the color filters, in this example, green, has been shown to reduce or eliminate color separation in sequential color systems, as disclosed in US Patent 5,448,314 to Heimbuch et al., the disclosure of which is incorporated herein by reference. Alternatively, white light may be blended with the three primary additive colors to increase the overall brightness of the image projected on screen 30, as disclosed in US Patent 5,233,385 to Sampsell, the disclosure of which is incorporated herein by reference.

Reference is now made to Fig. 5 which illustrates a variation of the projection system shown and described with reference to Fig. 4, wherein two color filter elements 23 and 24 are placed between PBS 4 and first and second optical elements 8, 7. It is appreciated that other configurations other than those shown in Figs. 1-5 are also within the scope of the present invention.

Reference is now made to Fig. 6 which illustrates a projection system 100 constructed and operative in accordance with another preferred embodiment of the present invention. Projector system 100 preferably includes a light source 50, such as an arc lamp based illuminator, which directs a beam of light through an illumination system 51 to a color divider 52, such as an array of color filters, or a 90° prismatic color divider or a total internal reflectance prism for color division, for example.

Color divider 52 splits the light from light source 50 into three color beams 53, 54 and 55 of a three primary additive color system, such as red, green and blue (RGB). Color beams 53, 54 and 55 are directed to three polarizing beam splitters/combiners (PBSs) 57, 56, and 58, respectively, at the outputs of each of which are two DMDs, 69, 70; 65, 66; and 67, 68, respectively.

The light of each primary color is divided by each PBS into two linear polarized beams, preferably, but not necessarily, polarized in directions generally orthogonal to each other, for example, the p and s components of polarized light, respectively. For example, beam 54 is split into linearly polarized beams 71 and 74. Beams 71 and 74 pass through optical elements (preferably quarter-wave plates) 59 and 60, respectively, which change the linearly polarized beams 71 and 74 into generally circularly polarized beams 72 and 75, respectively. Optical elements 59 and 60 are preferably placed between PBS 56 and DMDs 65 and 66, respectively.

As described hereinabove with reference to Fig. 1, each DMD can be in either of two operating orientations, ON or OFF. For example, if both DMDs 65 and 66 divert beams 72 and 75, respectively, away from PBS 56 (such as beam 73 reflected off DMD 65), then no light associated with color beam 54 reaches a screen 82. On the other hand, as shown in Fig. 6, if DMD 66 reflects circularly polarized beam 75 back towards PBS 56 as generally circularly polarized beam 76 (i.e., DMD 66 is ON), beam 76 will pass through optical element 60 which changes the circularly polarized beam 76 into a linearly polarized beam 77 with its polarity rotated 90° to the original linearly polarized beam. In other words, linearly polarized beam 77 has a polarization orthogonal to that of beam 74. For example, beam 77 has p polarization as opposed to beam 74 having s polarization, which means that beam 77 is reflected by PBS 56 to a color combiner 79 (such as a total internal reflection prism, for example) which combines other reflected beams of the other colors into a combined beam 80. Beam 80 passes through a lens 81 to screen 82.

It is appreciated that the foregoing description applies as well, *mutatis mutandis*, for optical elements (preferably quarter-wave plates) 63 and 64 associated with PBS 57, and optical elements 61 and 62 (preferably quarter-wave plates) associated with PBS 58.

Reference is now made to Fig. 7 which illustrates a variation of projection system 100. The difference here is that instead of a single light source 50 and a single illumination system 51, this variation employs a plurality of color light sources 50', 90 and 92 and a plurality of illumination systems 51', 91 and 93. Thus there is no need for color dividers at the light sources.

Reference is now made to Figs. 8 and 9 which illustrate further variations of the projection systems 100 shown respectively in Figs 6 and 7. In these embodiments, the color combiner is a rectangular prism 179 with a dichroic coating.

It will be appreciated by persons skilled in the art that the present invention is not limited by what has been particularly shown and described hereinabove. Rather the scope of the present invention include both combinations and sub-combinations of the various features described hereinabove as well as variations and modifications of such features as would occur to a person skilled in the art upon reading the description and which are not in the prior art.

CLAIMS

What is claimed is:

1. An imaging system, comprising:

a light source;

a polarizing beam splitter (PBS) operative to split light impinging thereon from said light source into two generally linearly polarized beams;

a pair of optical elements through which pass said linearly polarized beams, said optical elements being operative to change said linearly polarized beams into generally circularly polarized beams; and

for each beam, a spatial light modulator (SLM) operative to selectively reflect said generally circularly polarized beam back towards said optical element, said optical element changing the circularly polarized beam into a generally linearly polarized beam with its polarity rotated at an angle to the first-mentioned linearly polarized beam.

2. The imaging system according to claim 1 wherein said polarizing beam splitter (PBS) is operative to split the light into two beams linearly polarized in directions generally orthogonal to each other.

3. The imaging system according to claim 1 wherein said optical element changes the circularly polarized beam into a generally linearly polarized beam with its polarity rotated generally 90° to the first-mentioned linearly polarized beam.

4. The imaging system according to claim 1 wherein said spatial light modulator (SLM) is operative to reflect said circularly polarized beam back towards said optical element with a circular polarity of reverse direction to that of the beam before reflecting off the SLM.

5. The imaging system according to claim 1 wherein said SLMs are digital mirror devices (DMDs).

6. The imaging system according to claim 1 wherein said optical elements are quarter-wave plates.

7. The imaging system according to claim 1 and further comprising a screen, and wherein at least one of said reflected linearly polarized beams passes through said PBS towards said screen.

8. The imaging system according to claim 1 and further comprising a color filter element placed between said light source and said PBS.

9. The imaging system according to claim 1 and further comprising a color filter element placed between said PBS and said optical elements.

10. The imaging system according to claim 1 and further comprising a beam shaping element placed between each of said SLMs and said optical elements.

11. The imaging system according to claim 1 and further comprising a beam shaping element placed between each of said SLMs and said PBS.

12. The imaging system according to claim 8 wherein said color filter element comprises three different color filters of a three primary additive color system, and another color filter of one of said three different color filters.

13. The imaging system according to claim 8 wherein said color filter element comprises a portion which passes white light.

14. The imaging system according to claim 1 and further comprising a color divider that splits the light from said light source into three differently colored beams.

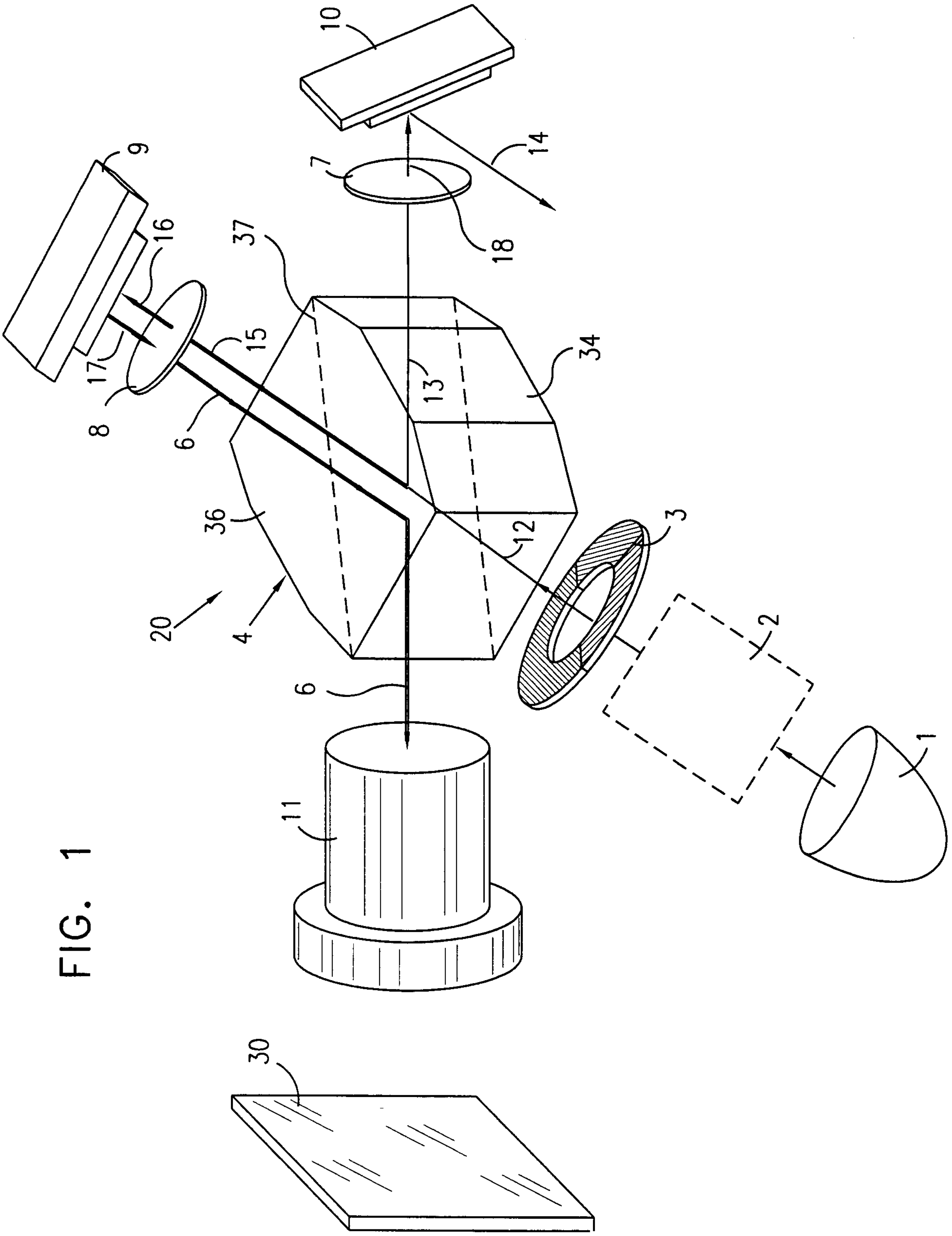


FIG. 1

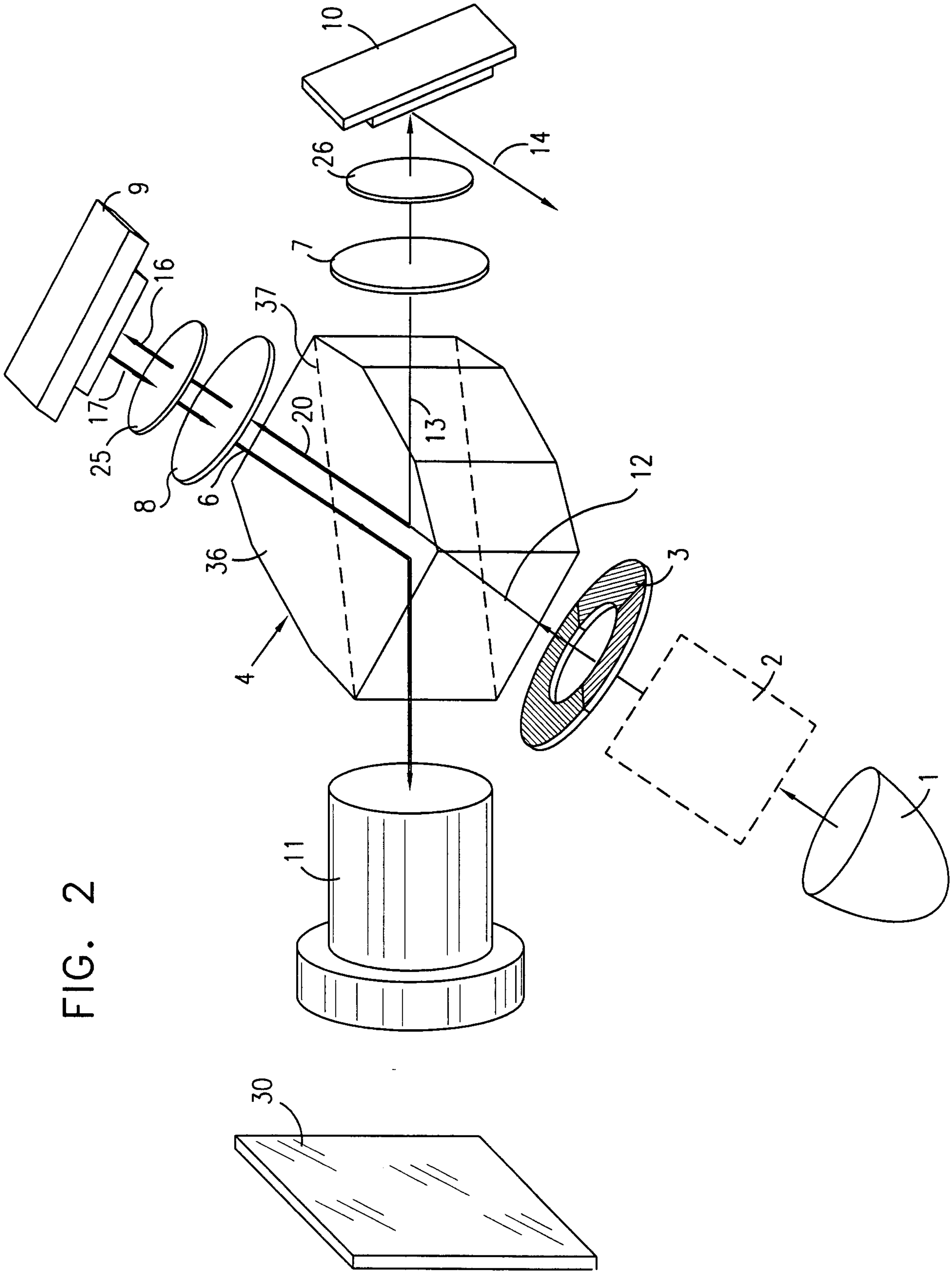


FIG. 2

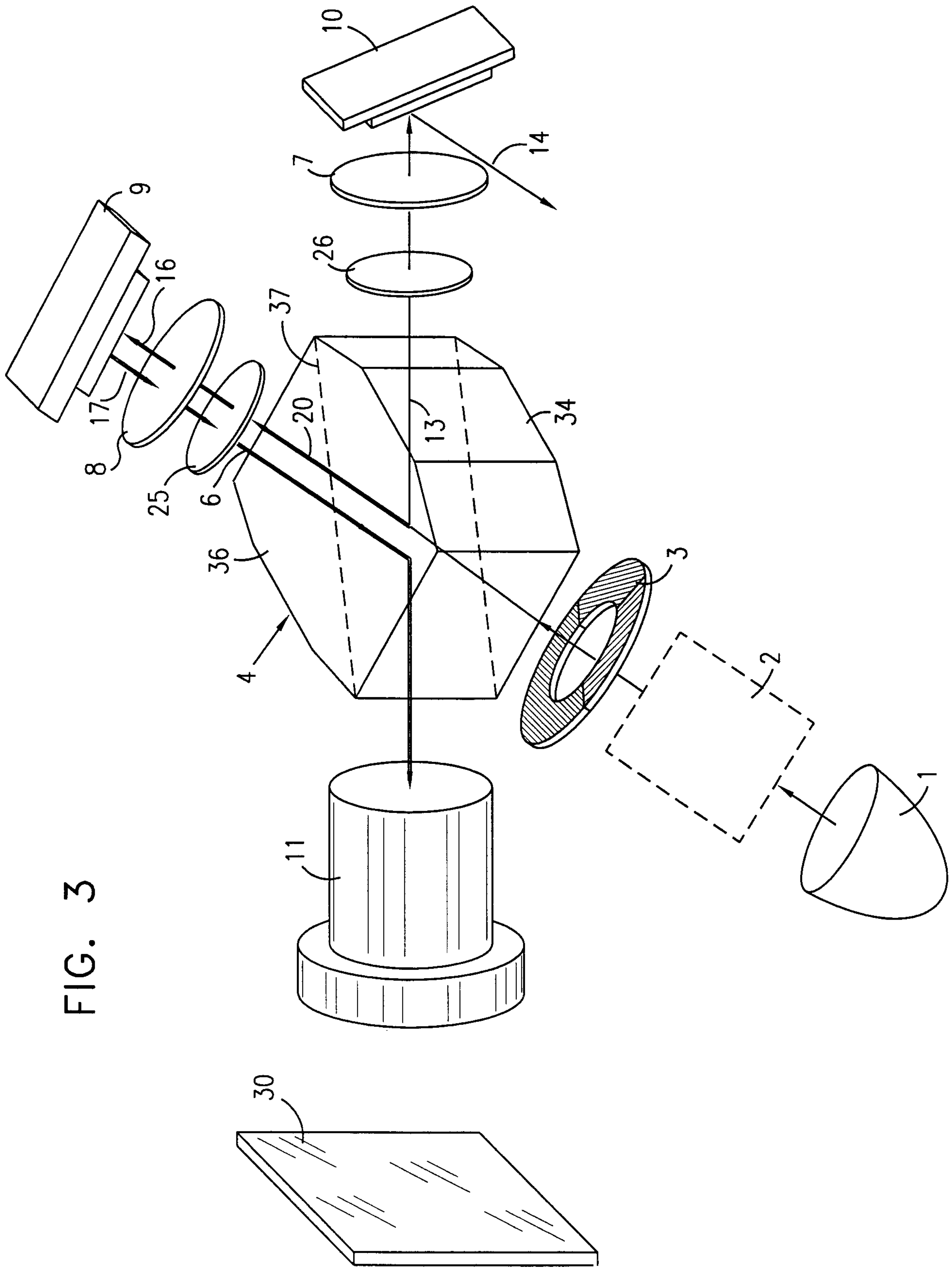


FIG. 3

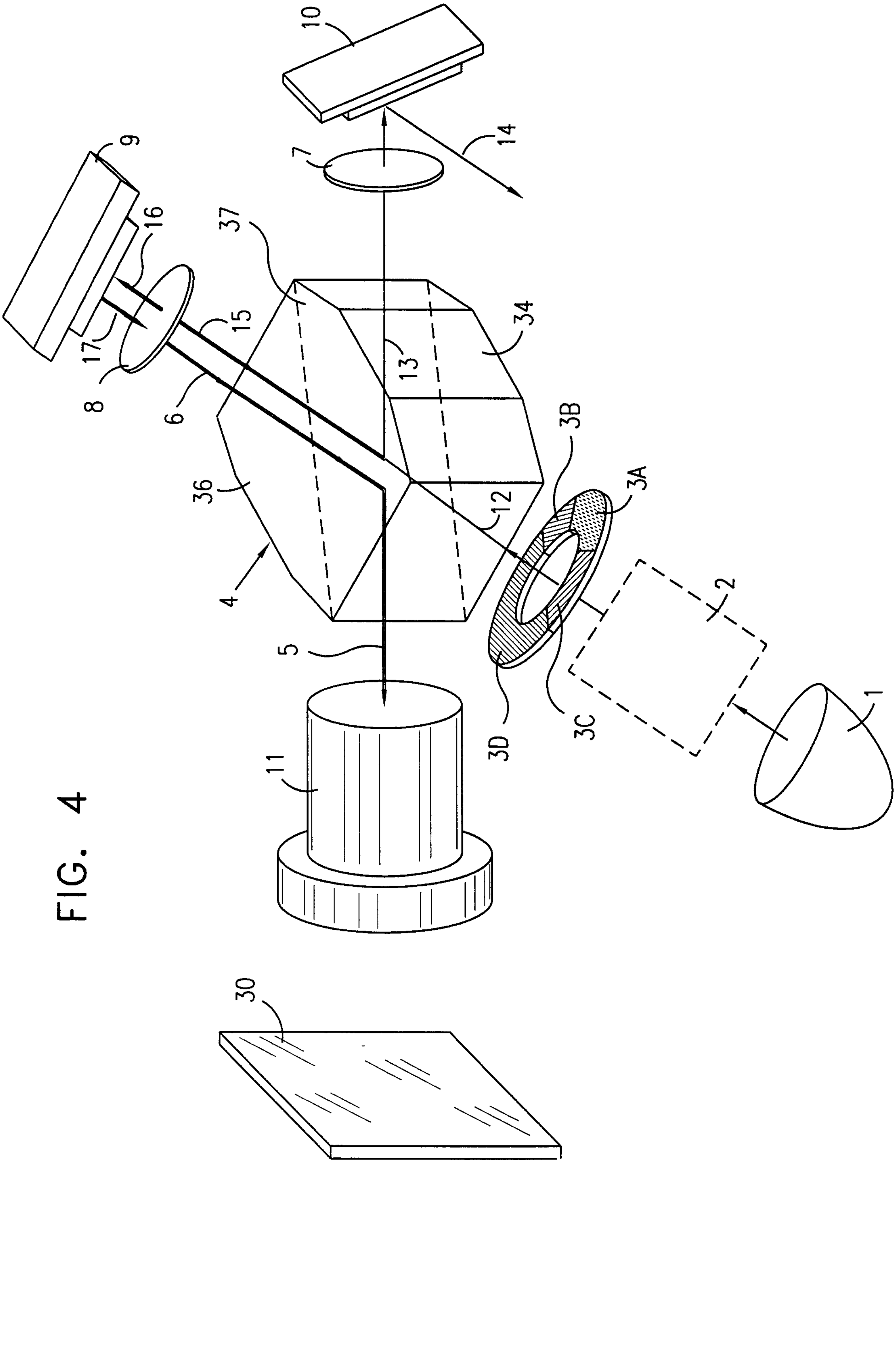


FIG. 4

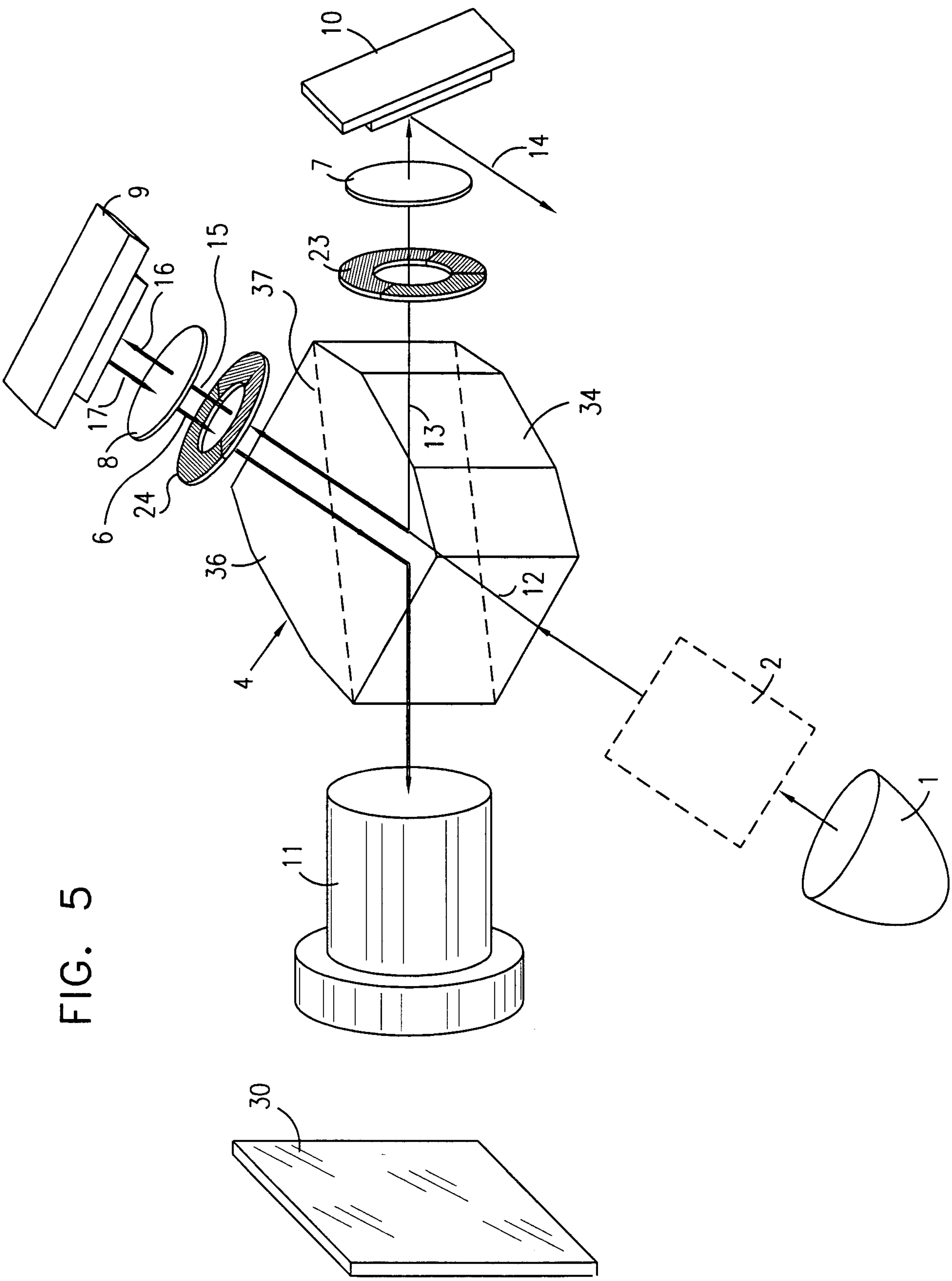


FIG. 5

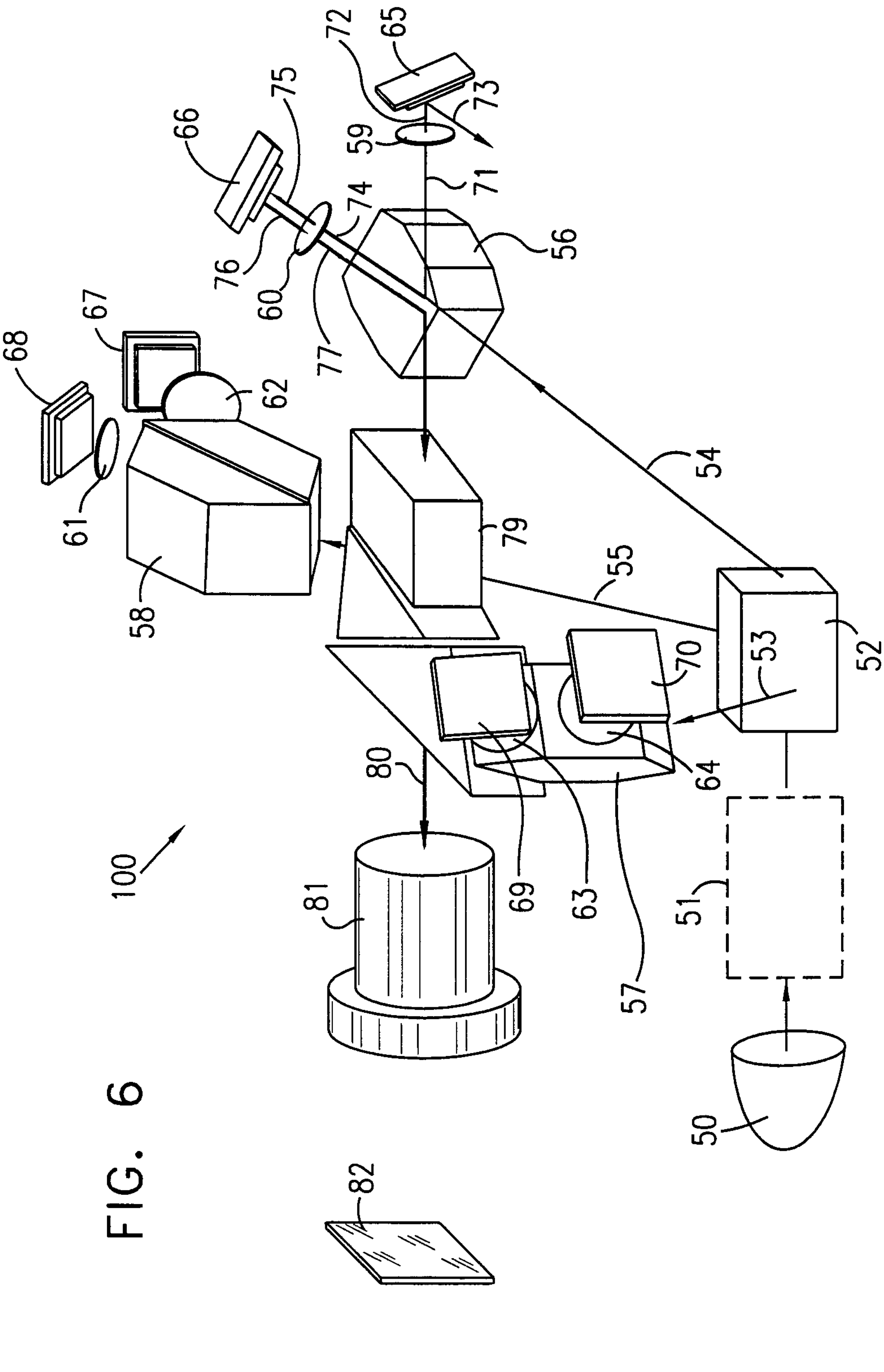

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FIG. 6

FIG. 7

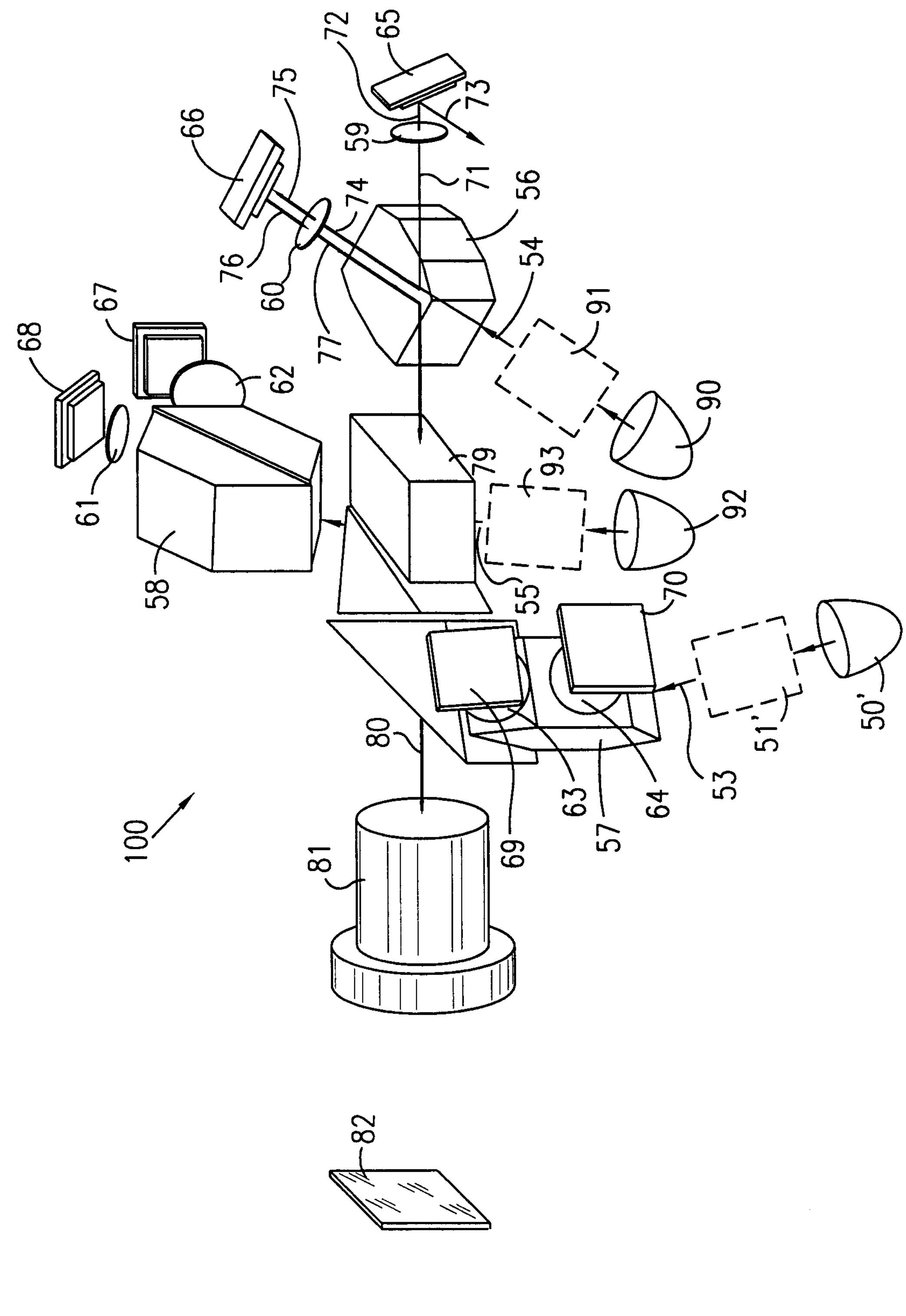
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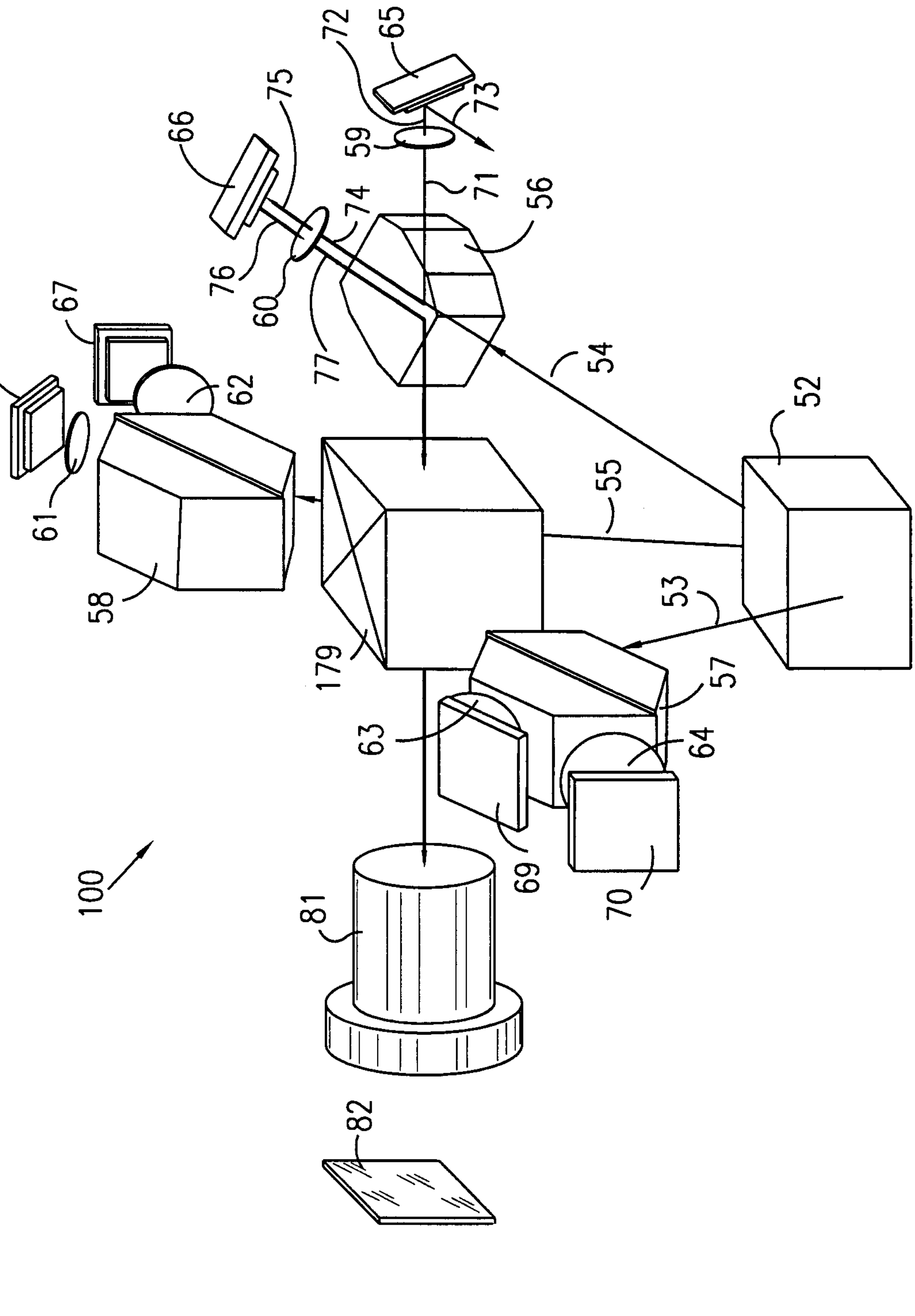
FIG. 8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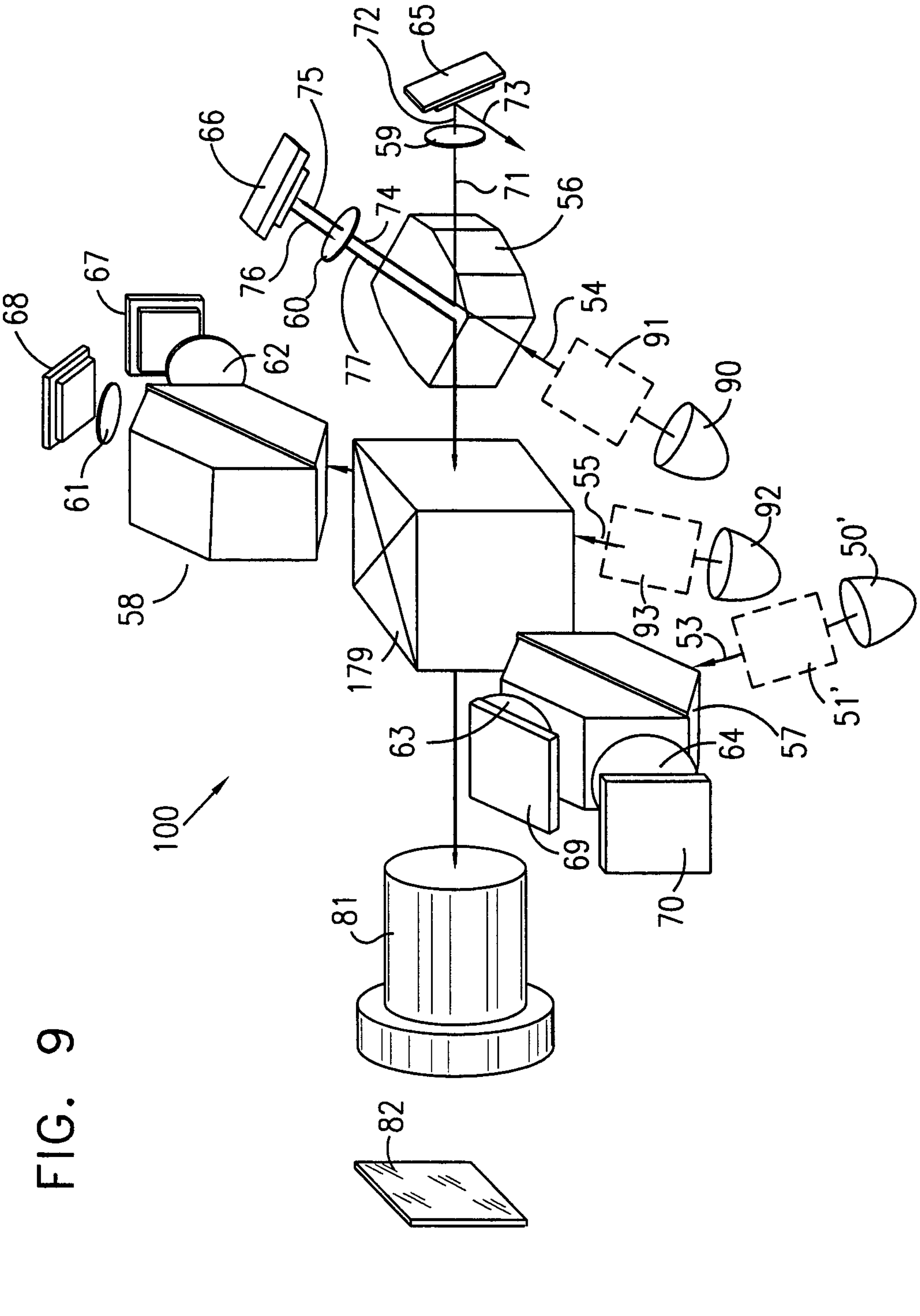
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FIG. 9

INTERNATIONAL SEARCH REPORT

Inter nal Application No
PCT/IL 00/00729

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G02B27/26 G02B27/18 G02B27/28

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 7 G02B H04N

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)

EPO-Internal, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5 701 201 A (OKAZAKI MASAHIDE) 23 December 1997 (1997-12-23) column 7, line 10 - line 23 column 7, line 53 -column 8, line 47; figures 2,7 ---	1-4,6,7, 10,11,14
Y	EP 0 560 636 A (SHARP KK) 15 September 1993 (1993-09-15) the whole document ---	1-4,6,7, 10,11,14
A	US 5 715 084 A (MURAKI MASATO ET AL) 3 February 1998 (1998-02-03) column 2, line 7 - line 45 column 3, line 6 - line 65 ---	1-3,6,7, 10,11
A	US 3 677 621 A (SMITH FRANCIS HUGHES) 18 July 1972 (1972-07-18) column 2, line 1 - line 56 --- -/--	1-3,6,7, 10,11

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
27 March 2001	04/04/2001

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	Mollenhauer, R

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Interr nal Application No
PCT/IL 00/00729

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 771 122 A (SHUMAN CURTIS A) 23 June 1998 (1998-06-23) the whole document ---	1
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