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(71) Applicant: **CORNING INCORPORATED** [US/US]; 1 Riverfront Plaza, Corning, NY 14831 (US).

(72) Inventors: **GREGORSKI, Steven, J.**; 10791 Hidden Meadow Trail, Corning, NY 14831 (US). **THOMAS, Leo, C.**; 10645 West Caton Road, Corning, NY 14830 (US).

(74) Agent: **SMITH, Eric M**; Corning Incorporated, SP TI 3 1, Corning, NY 14831 (US).

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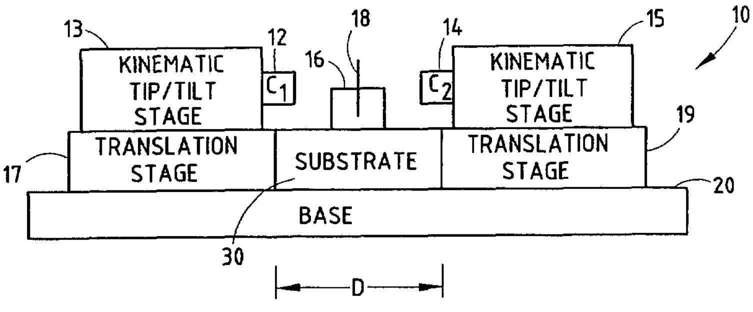
**(54) Title:** SYSTEM AND METHOD OF ALIGNING TWO OPTICAL AXIS TOWARDS EACH OTHER




**(57) Abstract:** A system (10) for precisely aligning the optical axis of an optical component (12, 14) with respect to its surroundings first positions the optical axis of a component in perpendicular relationship to a flat reflective surface (18) by adjusting the angular position of the optical device. Subsequently, the flat reflective surface is replaced by a sphere (18') and the optical device is translated relative to this sphere until the beam is directed to the center of the sphere. Two collimators can be aligned with one another using such a process.

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SYSTEM AND METHOD OF ALIGNING TWO OPTICAL AXIS TOWARDS EACH OTHER

## BACKGROUND OF THE INVENTION

### Field of the Invention

The present invention relates to a system for the precise positioning of an optical beam with respect to a reference location.

### Technical Background

Fiber optic based circuits frequently require free-space optics such that light in an optical fiber must exit the fiber for filtering, coupling, or other functions after which it is subsequently reinjected into a second fiber. Such free-space optics require the use of collimators since light exiting the end of a fiber tends to divert spacially. Collimators coupled to optical fibers, therefore, are employed to maintain a focused beam of light which is filtered or otherwise the subject of optical processing in free space. Subsequently, the processed signal is introduced into another fiber utilizing a mating collimator.

The use of collimators in such applications requires the alignment of the optical axis of the collimator to minimize insertion loss. Collimators typically have a mechanical axis which can be as much as two degrees or more offset from their optical axis, resulting in a pointing error for the collimator. Thus, it is not possible to merely align the mechanical axes of two collimators and expect signal communication between them. In order to align the optical axes of collimators, in the past, one of the collimators has been clamped on an optical bench and the second collimator spaced anywhere from 3 to 100 mm from the first collimator, placed on a staging system which allows full axes of movement of translation and rotation such that a signal injected from a light source is coupled to the first collimator and the second collimator is coupled to a power meter. The second collimator is translated and rotated until the power meter indicates a peak. With such a system which is manually accomplished through an operator requiring a certain amount of skill, if not luck, the alignment process does not typically result in an optimal alignment of the optical axes inasmuch as several false peaks can be detected by the power meter. The process can take significantly longer than 5 minutes even for an operator with significant skill and experience. Unfortunately, the alignment utilizing such mechanical techniques is not particularly accurate and the rate of device rejections using such alignment techniques result in an unacceptable yield rate for optical circuits manufactured utilizing such mechanical alignment techniques.

In order to overcome these difficulties, a computer controlled stage for moving a second collimator with respect to the first collimator has been employed, which maps and stores all possible peaks detected by a power meter coupled to the second movable collimator. Although the most accurate alignment peak is detected and can be selected, the mapping process involving moving the stage throughout a plane in which the movable collimator is mounted can take up to one hour, thereby greatly increasing the cost of optical devices utilizing collimators aligned in such a manner.

There exists, therefore, a need for precisely positioning an optical light beam with respect to its surroundings and which eliminates the guess work required by mechanical alignment or the tedious and expensive utilization of computerized mapping.

## SUMMARY OF THE INVENTION

The system of the present invention provides an accurate, quick and relatively inexpensive system for precisely aligning a light beam with respect to its surroundings and, in one application, for the alignment of one collimator with respect to a second collimator. The concept of the system and method of the present invention is to first position the optical axis of a light beam in a known orientation with respect to a flat reflective surface of, for example, a precision gauge block by adjusting the angular position of the optical device and subsequently substituting the gauge block with a precision reflective sphere and translating the optical device until the reflected beam is precisely positioned and detected. Two collimators can be aligned to a parallel opposed flat reflective surface, such as provided by a gauge block positioned in a location where, for example, a filter may then be inserted to form an optical component. Each collimator is initially aligned with emitted beams of optical energy aligned normally with each of the associated surfaces of the gauge block, such that the beams are then parallel to one another and perpendicular to the gauge block. Subsequently, the gauge block is replaced with a reflective precision sphere and the collimators translated until the beams intercept the center of the sphere and are not only parallel to one another but perfectly aligned with one another within arc seconds of the optical axes of the devices.

The process of precisely aligning, for example, two collimators by an operator, once trained, can be accomplished in from one to two minutes and results in the alignment of the optical axes of the collimators within tenths of microns, thereby greatly reducing insertion loss in optical components having their optical axes aligned in such manner. The system and method of aligning, for example, two collimators utilizes relatively inexpensive commercially available gauge blocks and precision spheres and alignment techniques which can be easily learned and quickly applied to provide precise alignment of the optical axes of two devices or the precise positioning of one device with respect to its surrounding environment.

The systems and methods of the present invention can be employed not only for the manufacturing of optical circuits, it can also be used in the testing of optical components prior to their subsequent assembly with other components. Such testing, for example, may be used for determining the center wavelength of filters.

Additional features and advantages of the invention will be set forth in the detailed description which follows and will be apparent to those skilled in the art from the description or recognized by practicing the invention as described in the description which follows together with the claims and appended drawings.

It is to be understood that the foregoing description is exemplary of the invention only and is intended to provide an overview for the understanding of the nature and character of the invention as it is defined by the claims. The accompanying drawings are included to provide a further understanding of the invention and are incorporated and constitute part of this specification. The drawings illustrate various features and embodiments of the invention which, together with their description serve to explain the principals and operation of the invention.

## BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a side elevational schematic view of the apparatus employed for aligning the optical axes of two optical devices embodying the system of the present invention;

Fig. 2 is a schematic optical diagram of the equipment employed in connection with the apparatus shown in Fig. 1 for the practice of the present invention;

Fig. 3 is a schematic diagram illustrating a first step in a first stage in the alignment of the optical axes of two collimators embodying the system and method of the present invention;

Fig., 4 is a schematic diagram illustrating the completion of the first step of alignment of the pair of collimators embodying the system and method of the present invention;

Fig. 5 is a schematic view illustrating a first step in a second stage of the alignment of two collimators by the system and method of the present invention;

Fig. 6 illustrates a second step completing the second stage of the alignment of two collimators in the alignment system and method of the present invention; and

Fig. 7 is a schematic view of an optical component manufactured according to the system of the present invention.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring initially to Fig. 1, there is shown an apparatus 10 for the alignment of the optical axis of two optical components, such as a first collimator 12 and a second collimator 14 which are employed in a free-space optics application such as placing a filter between the two collimators (as seen in Fig. 7) which requires the precise alignment of the optical axes of the collimators. The collimators 12 and 14 may be spaced a distance D from one another which, depending upon the application and device, can range anywhere from 3 mm to 100 mm. The collimators are each held by a kinematic tip/tilt stage 13 and 15, respectively, which, in turn, are mounted to translation stages 17 and 19, respectively. The coupled stages are then mounted to a stable base 20, such as an optical bench. The kinematic tip/tilt stages and the translation stages are commercially available from sources such as Newport Equipment and are in common use in the manufacture of optical components.

Additionally, the apparatus 10 of Fig. 1 includes a substrate 30 which is employed for the final supporting of an optical component which includes collimators 12 and 14 and a filter positioned therebetween. Mounted to the substrate 30 is a holding clamp 16 which is interposed between and generally in alignment with the collimators 12 and 14 for holding a target device 18 which, as described below, is employed for alignment of the optical axes and subsequently is replaced by an optical component, such as a filter, to be positioned between the collimators.

The system and method of the present invention involves a two-stage alignment process with both stages employing the optical components for providing a source of light either visible or at signal wavelengths and detectors for detecting such light, as shown in Fig. 2. In Fig. 2, the alignment target device 18 is shown schematically positioned between collimator 12 and 14. Each of the collimators have an input optical fiber 22 and 24, respectively, coupled by a Y-splitter 26 and 28, respectively, to couple a light source 32 and 34, respectively, to input optical fiber 22 and 24 and, therefore, collimators 12 and 14. Power meters 36 and 38 receive optical signals received by collimators 12 and 14 through fibers 22 and 24, splitter 26, and detect the optical signal impinging upon the ends of collimators 12, 14.

In the schematic diagram of Fig. 3, there is schematically illustrated the collimators 12 and 14, each of which having a mechanical axis, such as axis 40 for collimator 12 and axis 42 for collimator 14. They also have an optical axis, such as axis 41 for collimator 12 and axis 43 for collimator 14, which are illustrated as being offset from the respective optical axis 40 and 42. The physical alignment, therefore, of devices 12 and 14 does not optically align the devices due to the pointing error which can be as much as two degrees or more for each component.

The first step in the first stage of alignment of collimators 12 and 14 is accomplished by injecting a visible optical signal from light source 32, such as by the use of a helium neon laser, to project a light beam represented by beam 50 in Fig. 2 onto a surface 52 of the alignment device 18 which, in this step, is a gauge block having opposed, polished, parallel surfaces 52 and 53 which are flat and parallel to within as little as .03 microns. Such gauge blocks are relatively inexpensive commercially available devices which are typically used for the alignment of mechanical machinery.

The visible light beam 50 is directed to surface 52 and reflected, as indicated by beam 54, back toward collimator 12. At this point in time, although the initial set up generally positions the mechanical axis perpendicular to surface 52, the reflected beam may be as much as an inch or more off of the end of the collimator. A temporary target, such as a card or the like, can be placed in front of collimator 12 and stage 13 adjusted to walk the beam onto the end of collimator 12 by adjustment of stage 13 which is visually confirmed by the operator due to the use of a visible light spectrum. Next, light source 32 is switched to a wavelength signal, such as a 1550 nm, for the final adjustment, and power meter 36 (Fig. 2) detects the signal wavelength while the tip/tilt stage 13 is adjusted by rotating the collimator 12 on two orthogonal axes (X, Y) until, as seen in Fig. 4, beams 50 and 54 are coincident and the beam is perpendicular to surface 52 of gauge block 18 for collimator 12.

The next step in the stage one alignment of collimators 12 and 14 is to repeat the process on the opposite side or surface 53 of gauge block 18 in the same sequence to align the optical axis of collimator 14 represented by incident and reflective beams 60 and 64 to surface 54 such that the optical axis represented by these beams 60, 64 is also coincident and aligned perpendicularly to the surface 53 of gauge block 18. As seen in Fig. 4, although the optical axis represented by beams 50, 54 and 60, 64 of collimators 12 and 14, respectively, are perpendicular to the opposed surfaces of gauge block 18 and, therefore, parallel to one another, they are offset from one another after the completion of the first stage of alignment. Accordingly, the system and method of the present invention provides for the subsequent translation of the parallel optical axes of devices 12 and 14 as represented by the steps shown in Figs. 5 and 6.

In Fig. 5, the gauge block 18 held by clamp 16 is replaced by a precision reflective sphere 18′, which can be from ¼" to ¾" in diameter, however, it is typically ½" in diameter and has a roundness of about .1 micrometers. Such spheres are commercially available and used in the coordinate positioning of mechanical machining equipment and are relatively inexpensive. Sphere 18′ is positioned at the same location as gauge block 18 and, as seen in Fig. 5, the beams of light 50, 60 from collimators 12, 14 are offset from one another and from the center 21 of sphere 18′, resulting in reflected beams 54, 64.

The next step in the alignment process is to inject a helium neon signal from light source 32 to collimator 12 while again watching the beam 53 reflected off the spherical surface 55 of sphere 18′. Collimator 12 is then translated only along two orthogonal axes (X, Y) until, as represented in Fig. 6, the incident and reflective rays 50 and 54 coincide and correspond to the optical axes 40 of collimator 12. Thus, by translating the collimator 12 utilizing the translation stage 17 shown in Fig. 1, with respect to sphere 18′, the optical axis is now aligned and its extension passes through the center 21 of sphere 18′.

Subsequent to the visual alignment, again the helium neon visible light source from source 32 is replaced by a signal frequency lightwave, and the power meter 36 (Fig. 2) is employed to assure the reflected beam 54 is at the peak detected power, resulting in the optical alignment of the optical axis 40 of collimator 12 with the center of sphere 18′, as shown in Fig. 6. Subsequently and employing the same sequence of steps, collimator 14 is also aligned with the center 21 of sphere 18′ utilizing first the visible light source for general positioning and subsequently the signal frequency light source for detecting the precise alignment of the optical axes with the center of sphere 18′. This, as seen in Fig. 6, perfectly aligns the optical axes 40 and 42 of the collimators 12 and 14 with respect to one another. The sphere 18′ is subsequently removed and an optical component, such as a filter 62 including the newer smaller 1.4 $mm^3$ filter is positioned by clamp 16 onto the substrate 30 and subsequently a bonding epoxy or other suitable material is employed for fixing the relative position of collimator 12, filter 62 and collimator 14 in precise optical alignment. It is noted that the distance D is preselected for the component to be manufactured and, therefore, the kinematic stage and translation stage 13 and 17, 15 and 19, respectively, need not move in a Z axis direction to move the collimators toward and away from one another nor rotate them on a roll axis Z.

Although the preferred embodiment of the invention is employed for aligning collimators and/or providing an alignment process for an optical component resulting from the affixing of two collimators and a third optical component to a substrate, the alignment system of the present invention, as best seen in Fig. 6, can also be employed for precisely aligning the optical axis, such as axis 40 of collimator 12, with respect to a fixed point in space, namely, the center 62 of sphere 18′. Thus, the system can be used for aligning the optical axis of a single component, such as a collimator, with respect to a fixed known reference position. The technique also can be employed for the precise testing of filters by assuring the optical pathway between a transmitting collimator 12 and a receiving collimator 14, for example, precisely aligned orthogonally to the opposed surfaces of the filter, such as element 60, either to be tested or to be inserted into the optical component.

It will become apparent to those skilled in the art that various modifications to the preferred embodiment of the invention as described herein can be made without departing from the spirit or scope of the invention as defined by the appended claims.

The invention claimed is:

1. A method of aligning an optical element comprising the steps of:
providing an optical element having an optical axis extending from an end;
providing a planar reflective surface in spaced facing relationship to the end of the optical element;
emitting a beam of light from the optical element, wherein the beam of light is coincident with the optical axis; and
positioning the optical element so that the beam of light strikes and is normal to the planar reflective surface.

2. The method of claim one and including the additional steps of:
removing the planar reflective surface from the beam of light;
providing a reflective sphere;
positioning the reflective sphere at the previous location of the planar reflective surface; and
positioning the optical element until the beam of light is normal to the surface of the reflective sphere.

3. The method of claim 2 wherein the first named positioning step comprises rotating the optical element along mutually orthogonal axes.

4. The method of claim 3 wherein the second named positioning step comprises translating the optical element along mutually orthogonal axes.

5. The method of claim 4 wherein the first named providing step provides a gauge block as the reflective surface.

6. The method of claim 6 wherein said beam of light is in the visible spectrum.

7. The method of claim 5 wherein said beam of light is in the spectrum of optical communication wavelengths.

8. A method of aligning the optical axes of a pair of collimators comprising the steps of:

providing a first reflective surface, wherein the first reflective surface is parallel to a reference plane;

providing a second reflective surface parallel to the first reflective surface;

positioning a first collimator in a facing relationship to the first reflective surface;

positioning a second collimator in a facing relationship with the second reflective surface;

coupling a source of optical energy to the first collimator, such that the first collimator emits a first collimated beam of light;

coupling a source of optical energy to the second collimator, such that the second collimator emits a second collimated beam of light;

positioning the first collimator so that the first collimated beam of light is substantially perpendicular to the first reflective surface; and

positioning the second collimator so that the second collimated beam of light is substantially perpendicular to the second reflective surface.

9. The method of claim 8 and further including the steps of:

removing the first and second reflective surfaces from the path of the first and second collimated beams of light;

providing a reflective sphere; and

positioning the first and second collimators so that the first and second collimated beams of light are directed toward the center of the reflective sphere.

10. The method of claim 9 wherein the step of positioning the first and second collimators comprises rotating the first and second collimators in planes orthogonal to the reference plane.

11. The method of claim 10 wherein the step of positioning the first and second collimators further comprises translating the first and second collimators with respect to the sphere.

12. A method of aligning the optical axes of a first and second optical element comprising the steps of:

providing a first reference surface parallel to a reference plane;

providing a second reference surface parallel to said first reference surface;

positioning a first optical element in a facing relationship to said first reference surface;

positioning a second optical element in a facing relationship to said second reference surface;

coupling a source of optical energy to the first optical element such that the first optical element emits a first beam of light;

coupling a source of optical energy to the second optical element such that the second optical element emits a second beam of light;

positioning the first optical element so that the first beam of light is substantially perpendicular to the first reference surface;

positioning the second optical element so that the second beam of light is substantially perpendicular to the second reference surface;

removing the first reference surface from the path of the first beam of light;

removing the second reference surface from the path of the second beam of light;

providing a sphere;

disposing the sphere between the first and second optical elements; and

positioning the first and second optical elements so that the first and second beams of light are directed toward the center of the sphere.

13. The method of claim 12 wherein the step of positioning the first and second optical elements includes rotating the first and second optical elements along orthogonal axes until the light is normal to the reference plane.

14. The method of claim 13 wherein the step of positioning the first and second optical elements further includes translating the first and second optical elements until the first and second beams of light are directed toward the center of the sphere.

15. The method of claim 14 wherein the reference planes are defined by a reflective gauge block.

16. The method of claim 15 wherein the sphere is reflective.

17. The method of claim 16 and further including detecting light reflected onto the optical elements from the gauge block and the sphere and positioning the optical elements to maximize the level of light detected.

18. The method of claim 17 wherein the light is within the visible spectrum.

19. The method of claim 17 wherein the light falls within the optical communications signal spectrum.

20. A method of positioning the optical axis of a collimator with respect to a reference location comprising the steps of:

positioning the collimator in facing relationship to a reflective surface of a gauge block positioned at a reference location;

coupling a source of optical energy to the collimator;

rotating the collimator along at least one of two mutually orthogonal axes until optical energy supplied to the collimator is reflected from the gauge block onto the collimator;

replacing the gauge block with a reflective sphere; and

translating the collimator along at least one of two mutually orthogonal axes until optical energy supplied to the collimator is reflected from the sphere onto the collimator.

21. The method of claim 20 wherein the coupling step comprises coupling a source of visible optical energy to the collimator.

22. The method of claim 21 wherein the rotating step comprises rotating the collimator along two mutually orthogonal axes until a spot of visible light reflected from the gauge block impinges upon the collimator.

23. The method of claim 22 and further including providing a splitter at the input of the collimator and coupling one leg of the splitter to the source of optical energy and the other leg to a power meter.

24. The method of claim 23 wherein the coupling step comprises coupling a source of signal wavelength energy to the one leg of the splitter.

25. The method of claim 24 wherein the rotating step further comprises rotating the collimator along the mutually orthogonal axes until the power meter detects a signal peak.

26. The method of claim 25 wherein the coupling step includes replacing the source of signal wavelength energy with a visible energy source.

27. The method of claim 26 wherein the translating step comprises translating the collimator along mutually orthogonal axis until the visible light impinges upon the collimator.

28. The method of claim 27 wherein the coupling step replaces the source of visible energy with signal wavelength energy.

29. The method of claim 28 wherein the translating step comprises translating the collimator along mutually orthogonal axis until the power meter detects a peak signal.

30. A method of positioning the optical axis of a light emitting component with respect to a reference location comprising the steps of:

positioning the light emitting component in facing relationship to a reflective surface of a gauge block positioned at a reference location;

activating the light emitting component to emit optical energy therefrom;

rotating the light emitting component along at least one of two mutually orthogonal axes until optical energy is reflected from the gauge block onto the light emitting component;

replacing the gauge block with a reflective sphere; and

translating the light emitting component along at least one of two mutually orthogonal axes until optical energy is reflected from the sphere onto the light emitting component.

31. The method of claim 30 wherein the rotating step comprises rotating the light emitting component along two mutually orthogonal axes until a spot of visible light reflected from the gauge block impinges upon the light emitting component.

32. The method of claim 31 wherein the translating step comprises translating the light emitting component along mutually orthogonal axis until the visible light impinges upon the light emitting component.

33. An apparatus for the precise alignment of a pair of collimators comprising:

a base;

first and second translation stages positioned on the base in spaced opposed relationship;

first and second kinematic stages positioned on the translation stages in spaced facing relationship for holding a first and second collimator in spaced facing relationship; and

a clamp for holding a target between the collimators.

34. The apparatus of claim 33 wherein the target comprises a gauge block having opposed parallel reflective surfaces

35. The apparatus of claim 34 wherein the target comprises a reflective sphere.

36. The apparatus of claim 35 and further including sources of optical energy for coupling to inputs of the collimators.

37. The apparatus of claim 36 and further including a splitter having one leg coupled between each source and each collimator and a power meter coupled to each other leg of each splitter.

38. The apparatus of claim 37 wherein the sources of optical energy include visible optical energy and signal wavelength energy.

39. A method of aligning the optical axes of a pair of collimators comprising the steps of:

positioning a first collimator in facing relationship to a first reflective surface of a gauge block positioned at a reference location;

positioning a second collimator in facing relationship to a second and opposed reflective surface of the gauge block;

coupling a source of optical energy to each of the collimators;

rotating the collimators along at least one of two mutually orthogonal axes until optical energy supplied to the collimators is reflected from the surfaces of the gauge block onto the collimators;

replacing the gauge block with a reflective sphere; and

translating the collimators along at least one of two mutually orthogonal axes until optical energy supplied to the collimators is reflected from the sphere onto the collimators.

40. The method of claim 39 wherein the coupling step comprises coupling a source of visible optical energy to the collimators.

41. The method of claim 40 wherein the rotating step comprises rotating the collimators along two mutually orthogonal axes until a spot of visible light reflected from opposite surfaces of the gauge block impinges upon the collimators.

42. The method of claim 41 and further including providing a splitter at an input of the collimators and coupling one leg of each of the splitters to a source of optical energy and the other leg to a power meter.

43. The method of claim 42 wherein the coupling step comprises coupling a source of signal wavelength energy to the one leg of the splitter.

44. The method of claim 43 wherein the rotating step further comprises rotating the collimators along the mutually orthogonal axes until the power meter detects a signal peak.

45. The method of claim 44 wherein the coupling step includes replacing the source of signal wavelength energy with a visible energy source.

46. The method of claim 44 wherein the translating step comprises translating the collimators along mutually orthogonal axes until the visible light impinges upon the collimators.

47. The method of claim 46 wherein the coupling step replaces the source of visible energy with signal wavelength energy.

48. The method of claim 47 wherein the translating step comprises translating the collimators along mutually orthogonal axes until the associated power meters detect a peak signal.

49. An optical component including facing collimators aligned by the steps of:
positioning a first collimator in facing relationship to a first reflective surface of a gauge block positioned at a reference location;

positioning a second collimator in facing relationship to a second reflective surface of a gauge block positioned at a reference location;

coupling a source of optical energy to each of the collimators;

rotating the collimators along at least one of two mutually orthogonal axes until optical energy supplied to the collimators is reflected from the gauge block onto the collimators;

replacing the gauge block with a reflective sphere; and

translating the collimators along at least one of two mutually orthogonal axes until optical energy supplied to the collimators is reflected from the sphere onto the collimators.

50. The component of claim 49 and including a filter positioned between the collimators at the location of the gauge block.

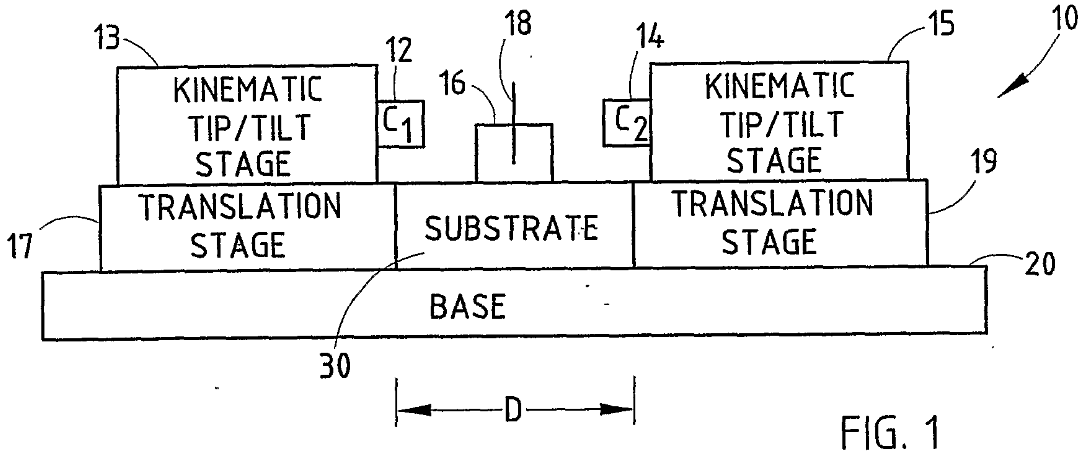


FIG. 1

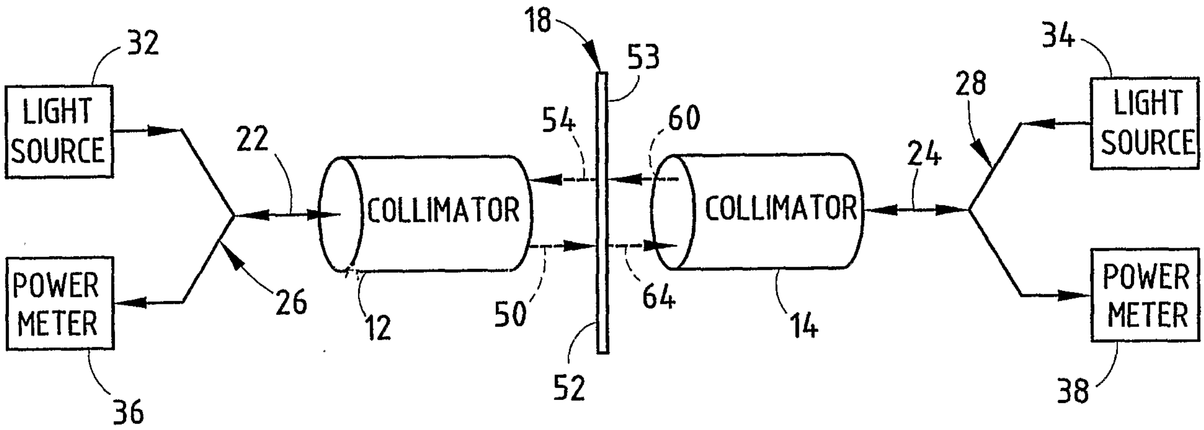


FIG. 2

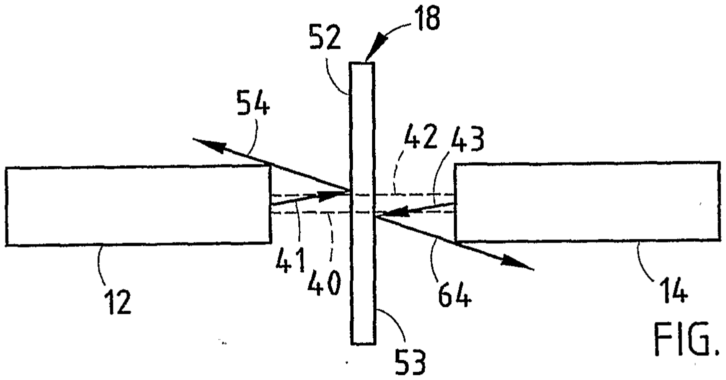


FIG. 3

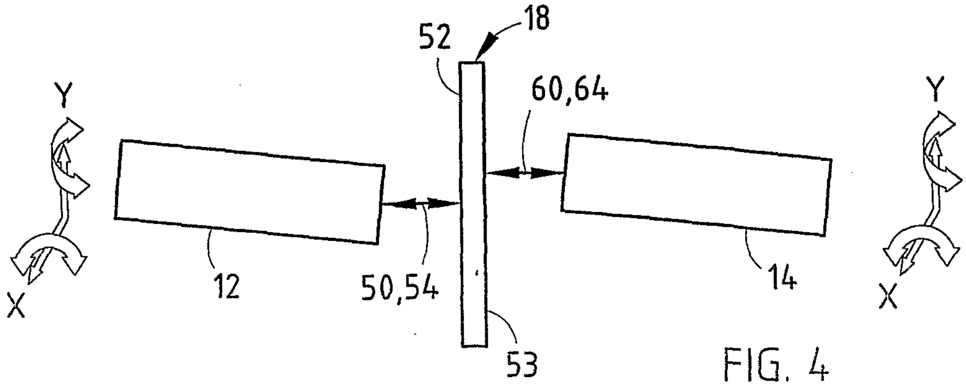


FIG. 4

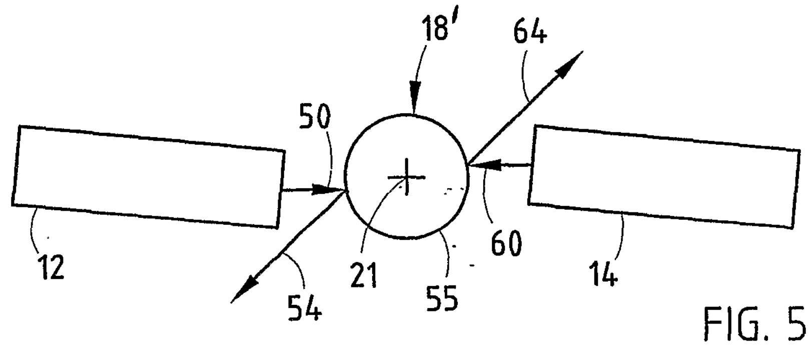


FIG. 5

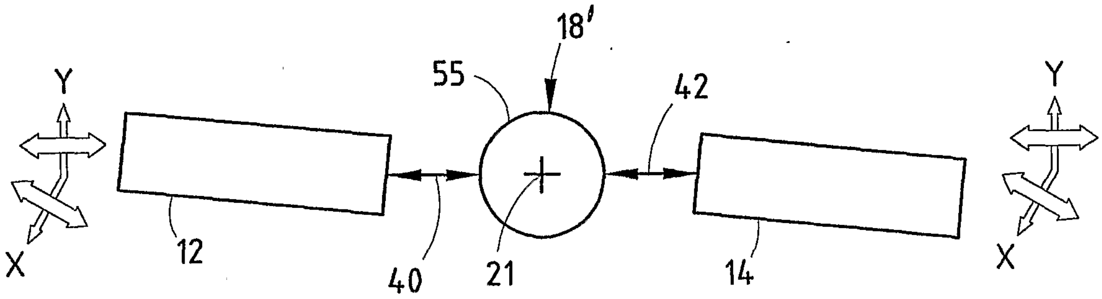


FIG. 6

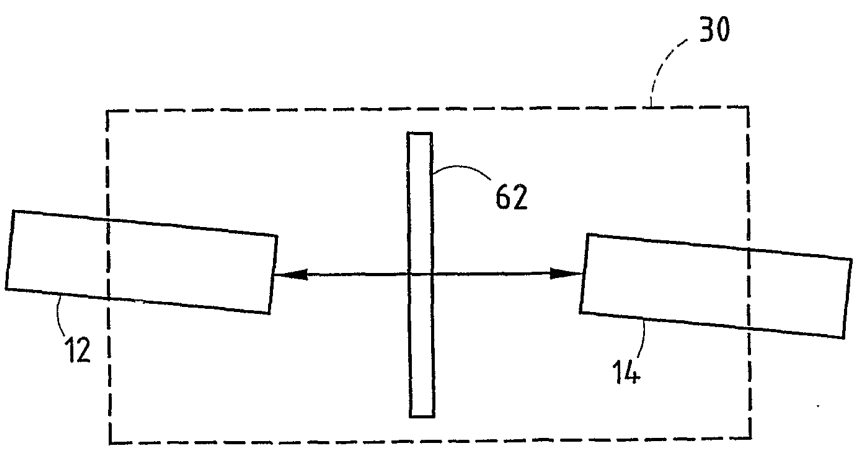


FIG. 7

# INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 02/04611

**A. CLASSIFICATION OF SUBJECT MATTER**
IPC 7 G01B11/27 G02B27/62

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 G01B 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)

EPO-Internal, WPI Data, PAJ

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category ° | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
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[X] Further documents are listed in the continuation of box C.

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° Special categories of cited documents :

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

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| European Patent Office, P.B. 5818 Patentlaan 2<br>NL – 2280 HV Rijswijk<br>Tel. (+31–70) 340–2040, Tx. 31 651 epo nl,<br>Fax: (+31–70) 340–3016 | Frisch, A |

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