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(54) **Fabrication of optical isolators**

Herstellung optischer Isolatoren

Procédé de fabrication d'isolateurs optiques

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Description

[0001] The invention relates to light transmission systems, more particularly, to an optical isolator.

[0002] The use of fiber optics in communications has developed rapidly in recent years and, with such progress, new problems have arisen. For example, when a light source transmits light through an optical fiber to another optical device, the light transmitted through the optical fiber is reflected by an end face of a fiber, or by other part of the optical device at the other end, such that reflected light returns to the light source. Multiple reflections at the end faces of optical fibers or other optical devices can cause echoes. These effects adversely affect the performance of the source and compromise the information communicated in the fiber.

[0003] Various optical isolators and non-reciprocal devices have been developed to overcome the problem of light reflections and echoes described above. One such device is disclosed by K.W. Chang, *Optical Non-reciprocal Device*, U.S. Patent No. 4,974,944 (4 December 1990), in which walkoff crystals are used for optical isolation. In other optical isolator designs, birefringent wedges are used, such as in U.S. Patent No. 4,548,478, issued to Shirasaki.

[0004] See also K.W. Chang, *Polarization Preserving Optical Isolator*, U.S. Patent No. 5,446,578 (29 August 1995), which discloses an optical non-reciprocal device for passing light of any polarization in a forward direction from a first point to a second point, and for reducing light passing in a reverse direction from the second point to the first point, where the device comprises at least two walkoff crystal members arranged in a linear array for separating light into two rays and at least one non-reciprocal rotation element interposed between two adjacent crystal members.

[0005] Polarization-dependent isolators using linear polarizers together with Faraday rotators are well known. The state of the art for polarization-independent isolators using spatial walkoff polarizers is discussed in K.W. Chang, W. V. Sorin, *Polarization Independent Isolator Using Spatial Walkoff Polarizers*, IEEE Photonics Technology Letters, Vol. 1, No. 3 (March 1989); and in K. W. Chang, W. V. Sorin, *High-Performance Single-Mode Fiber Polarization-Independent Isolators*, Optics Letters, Vol. 15, No. 8 (April 1990). Fig. 1 shows a state of the art isolator 10, in which light from an input single-mode fiber 12 is focused by a first selfoc™ lens 14 to an isolator 11, and thence through a second lens 15 to an output single-mode fiber 13. A magnetic field 18 is associated with the isolator.

[0006] Non-reciprocal Faraday rotation in the isolator 11 is provided by bismuth substituted YIG films (Bi-YIG) which typically operate in the 1.3 and 1.55 μm wavelength range and typically provide 45° of Faraday rotation in thicknesses of less than 500 μm . Birefringent TiO_2 , i.e., rutile, crystals are used to provide a spatial walkoff for extraordinary polarization travelling through

the isolator. The polarizers in the isolator are typically realized by using the spatial walkoff from the birefringent crystals combined with the spatial filtering provided by the single-mode fiber. The crystals may be slightly angled and the fiber end faces may be polished, for example at an angle of 6°, to reduce back reflections from the internal surface of the isolator.

[0007] Such isolators are quite large because the isolator is actually composed of individual pieces. Such structure is sometimes referred to as a "freespace" structure. The various pieces of the isolator are each placed in a separate holder and are then AR-coated to air. Thus, for each isolator it is necessary to assemble each crystal, where each crystal has a different orientation. Examples of such isolators include the Freespace Interfaced Fiber Isolator (package size 3.8 mm \times 13 mm), Laser Interfaced Fiber Isolator (package size 3.5 \times 23.5 mm), Miniature Optic Freespace Isolator (package size 3.0 mm \times 1.5 mm - one stage; 3.0 mm \times 3.0 mm - two stage), and Polarization Insensitive Miniature Optic Freespace Isolator (package size 4.0 mm \times 5.0 mm), each of which is manufactured by E-Tek Dynamics, Inc.

[0008] EP-A-0,512,572 discloses an optical isolator and method for fabricating the same in which a polarizer, a Faraday rotator and an analyzer are fixed by fused glass applied on an outer periphery of the analyzer to be contacted with the Faraday rotator. No adhesive exists between contact planes of the polarizer and the Faraday rotator and those of the Faraday rotator and the analyzer. The assembled isolator structure is cut to form small isolator units. The features of the preamble of claim 1 are known from that document.

[0009] Accordingly, assembly of the prior art isolator requires the steps of arranging the individual crystals in the holder in a specific orientation. It is therefore necessary to have an alignment mark for each crystal. If the isolator is made small in size, then it is very difficult to arrange the individual elements into a complete, properly aligned isolator. Additionally, it is difficult to handle the assembled isolator.

[0010] Thus, while such isolators are promising, the cost of manufacture and critical need for precision alignment provide significant barriers to the widespread acceptance of such isolation technology. Further, the ability to miniaturize such isolators is approaching the physical limits imposed by the need to assemble each individual isolator component mechanically. Thus, such isolators severely limit the development of emerging technologies where such miniaturization is a critical factor. This is especially true where miniature optical isolators may be desirable, e.g., in a micro-optical bench.

[0011] The present invention seeks to provide an improved method of fabricating an optical isolator.

[0012] According to the present invention there is provided a method of fabricating optical isolator chips as specified in claim 1.

[0013] The embodiments described below are em-

bodiments fabricated according to the claimed method.

[0014] The preferred embodiment can provide small, low-cost optical isolators for both polarization-independent and polarization-dependent applications.

[0015] The preferred embodiment provides a preassembled, low-cost optical isolator having the capability of large optical isolators. An optical isolator unit is assembled and subsequently diced into smaller isolator chips for placement in a micro-optical bench, such as a silicon or ceramic bench, along with input and an output fiber coupling AR-coated ball lenses. In polarization-independent applications, larger birefringence walkoff crystals and a 45° Faraday rotator are first aligned and then glued together with an optical-grade epoxy. In polarization-dependent applications, polarizers and a 45° Faraday rotator are first aligned and then glued together with an optical-grade epoxy. Prior to gluing, the surfaces of the components are AR-coated to match the index of the optical epoxy. An optical isolator unit formed in this manner is then diced into smaller isolator chips with a high-speed wafer saw. The optical isolator unit is mounted on any one of its sides in such a way that only a smallest possible cutting depth is required for dicing, i.e., it is mounted such that a thinnest dimension of the isolator is presented for cutting.

[0016] This procedure reduces material loss due to cutting and prevents delamination of the smaller isolator chips. Thus, the preferred embodiment can provide an optical isolator in which the material cost is reduced. As the isolator chips can be very small, it is possible to place them on a micro-optical bench between a pair of coupling AR-coated ball lenses, which further reduces the size requirement of each isolator chip. The use of a micro-optical bench allows precise, passive positioning of the optical components.

[0017] The preferred technique for fabricating the described isolator chips can also reduce the handling costs associated with the assembly of several small isolator components into a completed assembly by aligning and preassembling the isolator components in a large isolator assembly, and by subsequently dicing the large assembly into several small isolator chips. In this way, only a single alignment step and assembly step is required to produce isolator chips. In this way, only a single alignment step and assembly step is required to produce several optical isolators. Thus, the preferred embodiment can allow for a reduction of cost for fiber collimators, as well as providing improved, cost reduced, polarization-dependent/independent isolators for laser diodes and fiber transmission systems.

[0018] An embodiment of the present invention is described below, by way of example only, with reference to the accompanying drawings, in which:

Fig. 1 is a block schematic diagram of a prior art optical isolator;

Fig. 2 is a block schematic diagram of a first preferred embodiment of optical isolator;

Figs. 3a-3c show the dicing steps that are used to produce an embodiment of a polarization-independent optical isolator;

Fig. 4 is a block diagram of a polarization-dependent optical isolator;

Fig. 5 is a block schematic diagram of another embodiment of optical isolator; and

Fig. 6 is a block diagram of an embodiment of single-mode fiber platform.

[0019] The described embodiments provide a low cost optical isolator that exploits to advantage the capability of large, preassembled optical isolators. In accordance with the preferred embodiment an optical isolator unit is aligned, assembled, and subsequently diced into smaller isolator chips for placement in a micro-optical bench, such as a silicon or ceramic bench, along with input and output fiber coupling AR-coated ball lenses. In polarization-independent applications, the optical isolator unit is preferably comprised of one or more larger birefringence walkoff crystals that are first aligned and then glued with an optical-grade adhesive, such as an optical-grade epoxy, to one or more 45° Faraday rotators. In polarization-dependent applications, polarizers and a 45° Faraday rotator are first aligned and then glued together with an optical-grade adhesive.

[0020] For polarization-independent applications, the preferred embodiment may comprise an optical isolator unit, such as that disclosed by K. W. Chang, *Optical Nonreciprocal Device*, U. S. Patent No. 4,974,944 (4 December 1990), although the principles taught herein can be readily applied to other types of optical isolators. See, also K. W. Chang, *Polarization Preserving Optical Isolator*, U.S. Patent No. 5,446,578 (29 August 1995). An optical isolator unit formed in this manner typically exhibits a rectangular cross section when such section is taken along a longitudinal axis of the optical isolator unit.

[0021] The surfaces of the components are preferably antirefraction (AR) coated to match the index of the optical-grade adhesive. Such AR coating provides an index-matching coating that corrects for a refractive index difference between two adjoining mediums. The actual AR coating used depends on the system in which the coating is required. For example, a thin layer of a material such as magnesium oxide, titanium dioxide, and silicon dioxide is deposited on the surface of a high refractive index material to allow a particular wavelength or band of wavelengths to pass without significant reflection. Multiple coatings may be placed onto the surface to match the material to other wavelengths. AR coatings are well known in the art, see for example The Handbook of Optical Coatings for Fiber Optic Devices, Evaporated Coatings, Inc.

[0022] In the preferred embodiments, the AR coating is provided to match the refractive index of each component of the optical isolator unit to that of the optical-grade adhesive that holds the optical isolator unit components together. Therefore, instead of matching the in-

dex of air, which is 1, the AR coating matches the optical-grade adhesive index, which is closer to that of glass, i. e., about 1.52. In other embodiments, the optical-grade adhesive may be replaced by any known optical-grade adhesive material, such as an optical-grade epoxy.

[0023] The optical isolator unit is diced into smaller isolator chips using a high-speed wafer saw or other such dicing devices as may be known in the art. During such dicing operation, the optical isolator unit is mounted on any one of its sides in such a way that only a smallest possible cutting depth is required for dicing, i. e., it is mounted such that a thinnest possible dimension of the isolator is presented for cutting. This procedure reduces material loss due to cutting and prevents delamination of the small isolator chips that are produced by such cutting.

[0024] Fig. 2 is a block schematic diagram of a first preferred embodiment of optical isolator 20. An input single-mode optical fiber 21 provides a light source that is coupled via the optical isolator to an output single-mode optical fiber 22. Thus, this embodiment is useful for a fiber-to-fiber application.

[0025] Since this type of isolator is used in optical systems that only allow light to travel in one direction, light enters the isolator through an AR-coated glass 24 that is secured to the input single-mode fiber 21 by an index-matching adhesive 23, such as an optical grade epoxy. Light enters a first AR-coated ball lens 25 and is focused thereby to an optical isolator chip 26. The AR-coated ball lenses 25, 27 and optical isolator chip 26 are all preferably mounted on a micro-optical bench 29 that is fashioned in such way that the various optical isolator components are securely held in an aligned configuration.

[0026] Once light has passed across the optical isolator chip 26, it is focused through a second AR-coated ball lens 27, and thence through an AR-coated glass 34, to an output single-mode fiber 22. Thus, the optical isolator chip 26 is a one-way light transmitting device, in which any light that is reflected back along the optical path misses the input single-mode fiber. Accordingly, no light is reflected back to the input single-mode fiber.

[0027] The optical isolator chip 26 operates in conjunction with a magnet (not shown) that produces a magnetic field B 28 to provide a non-reciprocal characteristic to the isolator. The preferred embodiment uses either a very small external magnet or the optical isolator may be positioned inside, and surrounded by, a larger magnet, depending on the preferred package design.

[0028] The active area of the optical isolator chip is very small, i. e., $200\ \mu\text{m} \times 200\ \mu\text{m}$. Thus, this embodiment can provide a significant size reduction when compared to conventional optical isolators, which are typically on the order of $2\ \text{mm} \times 2\ \text{mm}$.

[0029] As discussed above, an optical isolator unit is preferably formed by carefully aligning the isolator components, and then joining the isolator components with an index-matching adhesive, where each element so joined is AR-coated to match the index of the element

to the index of the adhesive.

[0030] Figs. 3a-3c show the dicing steps that are used to produce a polarization-independent optical isolator chip from a larger, optical isolator unit. Each component of the optical isolator unit is AR-coated before the various components are aligned and glued together.

[0031] A layer of glass is provided at either end of the optical isolator unit on which the outer-facing side of the glass is AR-coated for air. To this end, the optical isolator unit may also include an AR-coated glass cover slide 37, 38 that has a refractive index that matches that of the optical-grade adhesive which is used to secure the various optical isolator unit components together.

[0032] Initially, the elements of the optical isolator unit 36, i. e., the AR-coated glass cover slides 37, 38, walkoff crystals 35a, 35b, 35c, 35d and Faraday rotator 39a, 39b, discussed above, are aligned and then glued together. The resulting optical isolator unit is typically $2\ \text{mm} \times 2\ \text{mm} \times 7.3\ \text{mm}$ in size.

[0033] The preferred dicing method dices the optical isolator unit 36 into smaller pieces that each ultimately comprise an individual optical isolator chip. During such dicing operation, the optical isolator unit is mounted on any one of its sides in such a way that only a smallest possible cutting depth is required for dicing, i. e., it is mounted such that a thinnest possible dimension of the isolator is presented for cutting. This procedure reduces material loss due to cutting and prevents delamination of the isolator chips that are produced by such cutting.

[0034] A wafer saw is first used to cut the optical isolator unit 36 into four isolator pieces along the lines 31 in the direction shown by the lines 30 (Fig. 3a). Typically, the cutting depth during the first dicing operation is 2 mm, resulting in a cutting loss of about $150\ \mu\text{m}$ of material. Thus, as a result of this operation shown in Fig. 3a, the isolator assembly is cut into four $2\ \text{mm} \times 0.3875\ \text{mm} \times 7.3\ \text{mm}$ isolator pieces.

[0035] The four isolator pieces formed by the first cutting operation are then each cut as shown by the lines 33 in the direction shown by the lines 32 (Fig. 3b). The cutting depth for this operation is 0.4 mm, producing a loss of material of $100\ \mu\text{m}$ due to the cutting operation.

[0036] As a result of the two cutting operations, a total of 16 optical isolator chips 26 (Fig. 3c) are produced, where each optical isolator chip is $0.45\ \text{mm} \times 0.3875\ \text{mm} \times 7.3\ \text{mm}$. It will be appreciated by those skilled in the art that the dimensions described above relate only to the preferred embodiment, and that the teachings herein are readily practiced to produce optical isolators having any desired dimension. The costs associated with producing such optical isolators provide a substantial economy that otherwise are not achieved in the prior art because only one alignment and one assembly operation are required to produce several optical isolators. Additionally, very small optical isolators may be produced without the need for time consuming and therefore expensive micro-manufacturing and alignment operations. Such costs savings are relative to the particu-

lar optical isolator produced.

[0037] The optical isolator chips 26 are placed in an etched portion of a silicon bench 29 or micro-optical bench, as shown in Fig. 2. The silicon bench is also etched to provide a location for placing each of the AR-coated ball lenses 25 and 27, such that the isolator assembly 20 is readily formed with each component thereof in precise alignment, one component to the other. Additionally, the silicon bench is readily batch processed on a silicon wafer by etching appropriate patterns onto the wafer that predefine with precision the location of the lens and the location of the optical isolator chips.

[0038] It is significant to note that using a ball lens allows the fabrication of a smaller isolation assembly 20 because such lens is able to accommodate a smaller optical isolator. The ball lens is preferably made of glass or any other optical material having a high refractive index, e.g., ruby or sapphire.

[0039] Fig. 4 is a block diagram of a polarization-dependent optical isolator unit from which isolator chips can be made. Initially, the elements of an optical isolator unit 46, i.e., the AR-coated cover slides 47, 48, polarizers 49a, 49b, 49c, and Faraday rotator 45a, 45b are aligned and then glued together. The polarizers may be any appropriate polarizers, such as part no. is 1550-HC-0° manufactured by Corning, Inc., Advanced Product Department, Corning, NY. After assembly, the optical isolator unit is then processed as discussed above for the polarization-independent isolator of Figs. 2 and 3a-3c.

[0040] Fig. 5 is a block schematic diagram of a second embodiment of optical isolator assembly 50. This embodiment combines a laser source 51, such as a laser diode, and a ball lens 54, with a polarization-dependent optical isolator chip 56 of the type that is produced from the optical isolator unit 46, as discussed above in connection with Fig. 4. The laser source, ball lens, and optical isolator chip are mounted to a micro-optical bench 59 and coupled to a single-mode fiber 52 by a second ball lens 57. The system also includes an AR-coated glass cover slide 53 that is mounted directly to the single-mode fiber 52.

[0041] Fig. 6 is a block diagram of an embodiment of a single-mode fiber platform. In this embodiment, the optical isolator assembly 60 includes a single-mode fiber 61 to which an optical isolator chip 62 is glued. The optical isolator chip includes a single AR-coated glass cover slide 65. Light produced by a laser diode 64 is coupled through a lens 63 to the optical isolator chip 62.

[0042] Thus, an optical isolator chip can be produced in which the material waste and cost is reduced. As the optical isolator chips are very small, it is possible to place such optical isolators on a micro-optical bench, such as a silicon or ceramic bench, between a coupling AR-coated ball lens, which further reduces the size requirement of each optical isolator chip. The technique for fabricating the herein described optical isolator chips reduces the handling cost associated with the alignment

and assembly of several small optical isolator components into a completed assembly by preassembling the optical isolator components in a large optical isolator unit, and by subsequently dicing the large optical isolator unit into several small optical isolator chips. This can thus allow for a reduction of cost for fiber collimators, as well as providing improved, cost-reduced, polarization-dependent optical isolators for laser diode and semiconductor amplifiers.

Claims

1. A method of fabricating optical isolator chips, including the steps of:

aligning a plurality of components of the optical isolator;
 assembling said components into an optical isolator unit;
 subsequently dicing said optical isolator unit into optical isolator chips (26, 46, 62), wherein said dicing step includes the step of mounting said optical isolator unit on a side thereof **characterized in that** in said step of mounting, said optical isolator unit is mounted in such a way that the smallest cutting depth is required, and **in that** said dicing step further includes the step of cutting said isolator unit such that said cutting proceeds simultaneously across each layer of said laminate.

2. A method as in claim 1, wherein said assembling step comprises gluing one or more polarizers, or one or more birefringence walkoff crystals, and Faraday rotators together with an optical grade adhesive.

3. A method as in claim 2, comprising the step of:

antirefraction coating surfaces of components which comprise said optical isolator to match the index of said optical grade adhesive.

4. A method as in any preceding claim, including the step of dicing the optical isolator into said isolator chips with a high speed wafer saw during at least one dicing operation.

5. A method as in claim 4, wherein optical isolator is subjected to a first dicing operation; and wherein each diced optical isolator part produced as a result of said first dicing operation is subjected to a second, subsequent dicing operation.

6. A method of fabricating an optical isolator including the steps of fabricating an optical isolator chip according to any preceding claim and placing the iso-

lator chip in a micro-optical bench (25, 59), along with an input and an output fiber coupling ball lens (25, 27; 54, 57).

Patentansprüche

1. Ein Verfahren zum Herstellen von Optikisolatorchips, das folgende Schritte umfaßt:

Ausrichten einer Mehrzahl von Komponenten des optischen Isolators;

Zusammensetzen der Komponenten zu einer Optikisolatoreinheit;

darauffolgendes Vereinzeln der Optikisolatoreinheit in Optikisolatorchips (26, 46, 62), wobei der Vereinzlungsschritt den Schritt des Befestigens der Optikisolatoreinheit an einer Seite derselben umfaßt, **dadurch gekennzeichnet, daß** bei dem Schritt des Befestigens die Optikisolatoreinheit derart befestigt wird, daß die kleinste Schnitttiefe erforderlich ist, und dadurch, daß der Vereinzlungsschritt ferner den Schritt des Schneidens der Isolatoreinheit umfaßt, derart, daß das Schneiden gleichzeitig über jeder Schicht des Laminats voranschreitet.

2. Ein Verfahren gemäß Anspruch 1, bei dem der Zusammensetzungsschritt ein Verkleben von einem oder mehreren Polarisatoren oder einem oder mehreren Doppelbrechungs-Walk-Off-Kristallen und Faraday-Drehern mittels eines Haftmittels einer optischen Güte aufweist.

3. Ein Verfahren gemäß Anspruch 2, das folgenden Schritt aufweist:

Antibrechungsbeschichten von Oberflächen von Komponenten, die den optischen Isolator aufweisen, um mit dem Index des Haftmittels einer optischen Güte übereinzustimmen.

4. Ein Verfahren gemäß einem der vorhergehenden Ansprüche, das den Schritt des Vereinzeln des optischen Isolators in die Isolatorchips mit einer Hochgeschwindigkeits-Wafersäge während zumindest einer Vereinzlungsoperation umfaßt.

5. Ein Verfahren gemäß Anspruch 4, bei dem der optische Isolator einer ersten Vereinzlungsoperation unterzogen wird; und wobei jedes vereinzelte Optikisolatorchip, das als Ergebnis der ersten Vereinzlungsoperation erzeugt wurde, einer zweiten, nachfolgenden Vereinzlungsoperation unterzogen wird.

6. Ein Verfahren zum Herstellen eines optischen Isolators, das die Schritte des Herstellens eines Optikisolatorchips gemäß einem der vorhergehenden Ansprüche und des Plazierens des Isolatorchips in eine mikrooptische Bank (25, 59), zusammen mit einer Eingangs- und einer Ausgangsfaser-Kopplungs-Kugellinse (25, 27; 54, 57), umfaßt.

10 Revendications

1. Procédé de fabrication de pastilles d'isolateur optique, comprenant les étapes consistant à :

15 ■ aligner une pluralité de composants de l'isolateur optique ;

■ assembler lesdits composants dans une unité d'isolateur optique ;

20 ■ ensuite couper ladite unité d'isolateur optique en pastilles d'isolateur optique (26, 46, 62), dans lequel ladite étape de découpage comprend l'étape consistant à monter ladite unité d'isolateur optique sur un côté de celui-ci, **caractérisée en ce que** dans ladite étape de montage, ladite unité d'isolateur optique est montée d'une manière telle que la plus petite profondeur de découpage est nécessaire, et **en ce que** ladite étape de découpage comprend en outre l'étape consistant à couper ladite unité d'isolateur d'une manière telle que ledit découpage se poursuit simultanément à travers chaque couche dudit laminé.

2. Procédé selon la revendication 1, dans lequel ladite étape d'assemblage comprend le collage d'un ou de plusieurs polariseurs, ou d'un ou de plusieurs cristaux de sortie de biréfringence, et des rotateurs de Faraday avec un adhésif de qualité optique.

3. Procédé selon la revendication 2, comprenant l'étape consistant à :

45 ■ enduire par anti-réfléchissement les surfaces des composants qui comprennent ledit isolateur optique pour correspondre à l'indice dudit adhésif de qualité optique.

50 4. Procédé selon l'une quelconque des revendications précédentes, comprenant l'étape consistant à couper l'isolateur optique en lesdites pastilles d'isolateur avec une scie de tranche de grande vitesse pendant au moins une opération de découpage.

55 5. Procédé selon la revendication 4, dans lequel l'isolateur optique est soumis à une première opération de découpage ; et dans lequel chaque partie d'iso-

lateur optique découpée produite par ladite première opération de découpage est soumise à une deuxième opération de découpage subséquente.

6. Procédé de fabrication d'un isolateur optique comprenant les étapes consistant à fabriquer une pastille d'isolateur optique selon l'une quelconque des revendications précédentes et à placer la pastille d'isolateur dans un banc micro-optique (25, 59), avec une fibre d'entrée et de sortie couplant la lentille à bille (25, 27 ; 54, 57).

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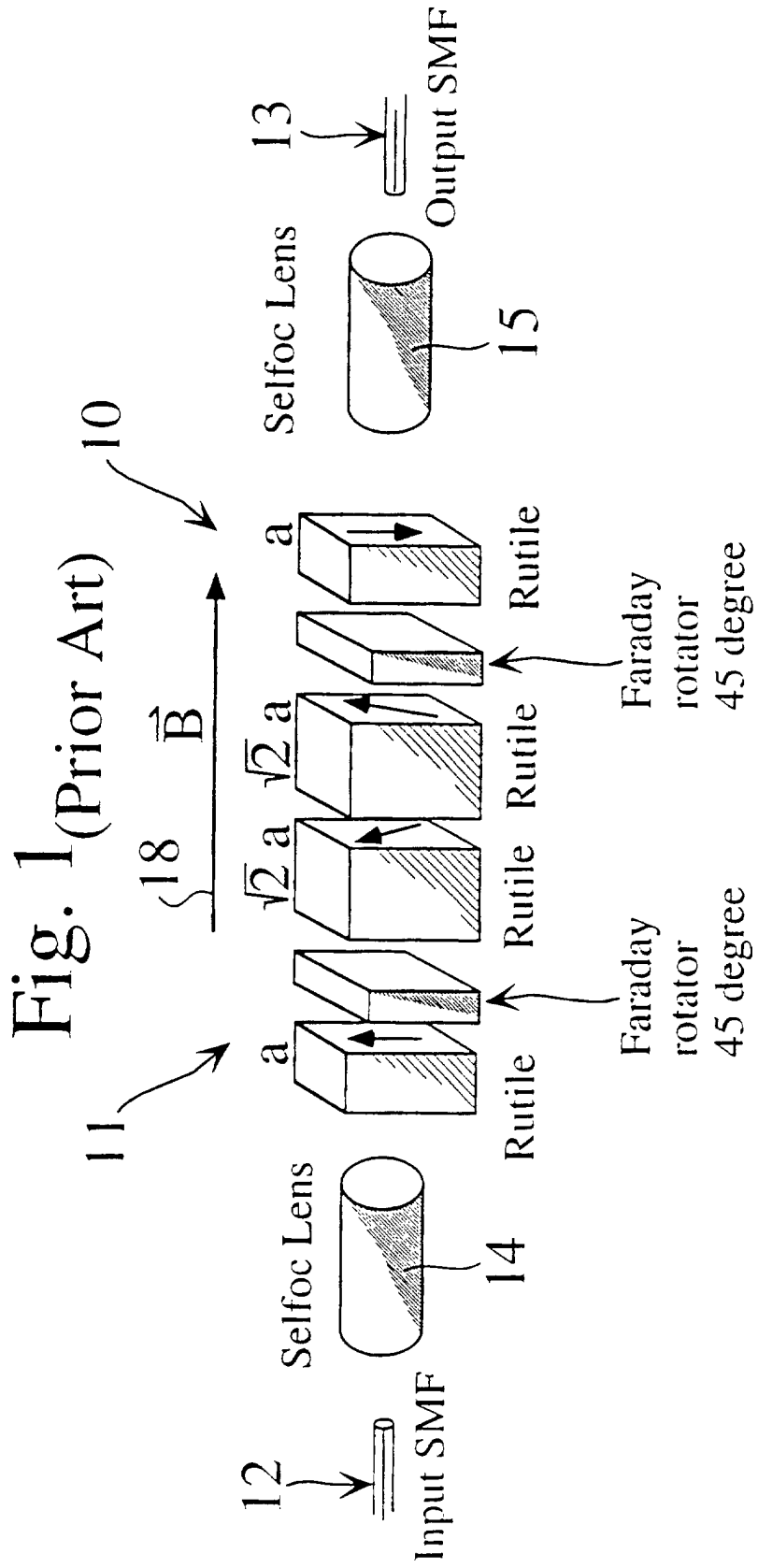
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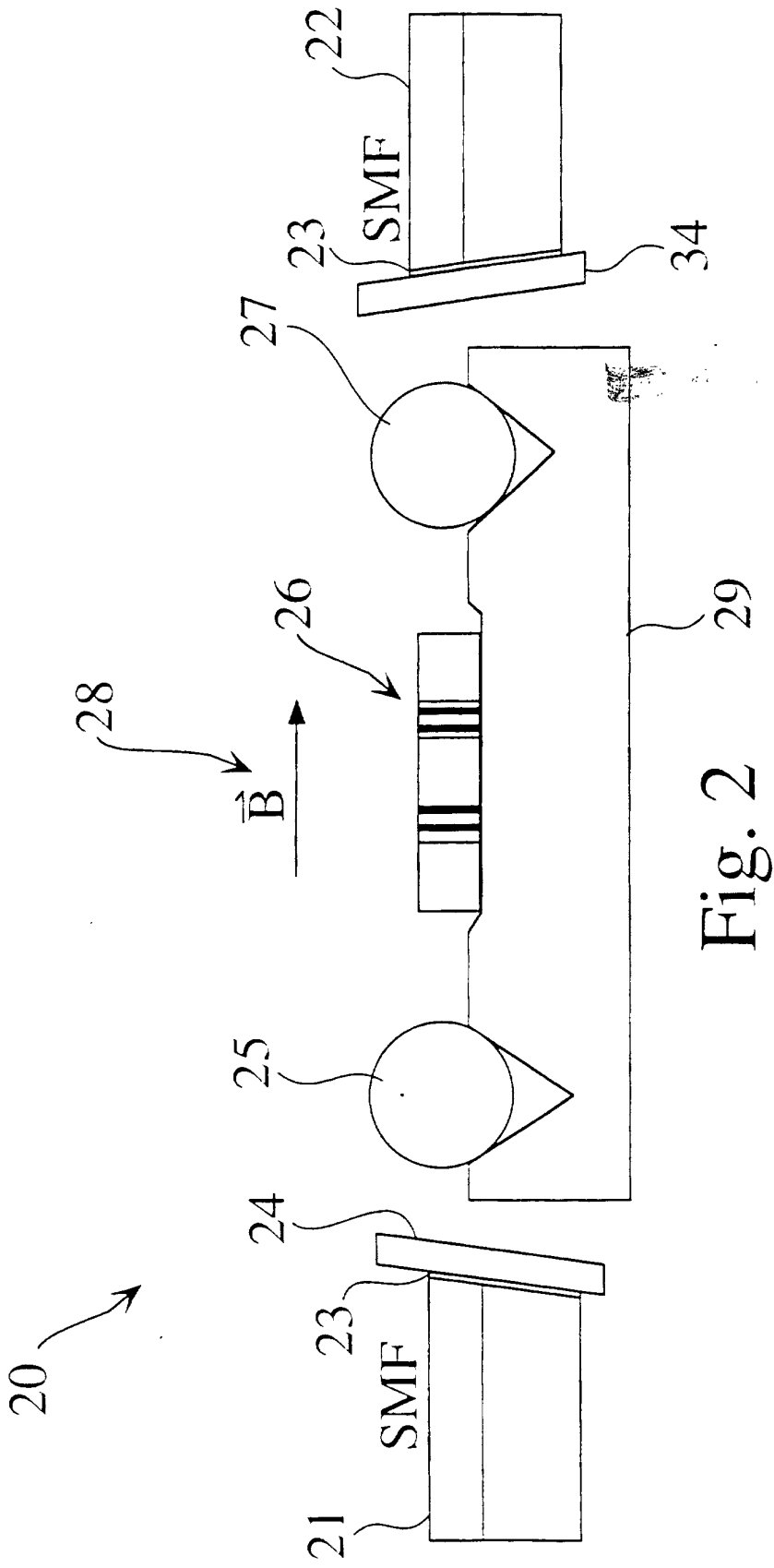


Fig. 2

Fig. 3a

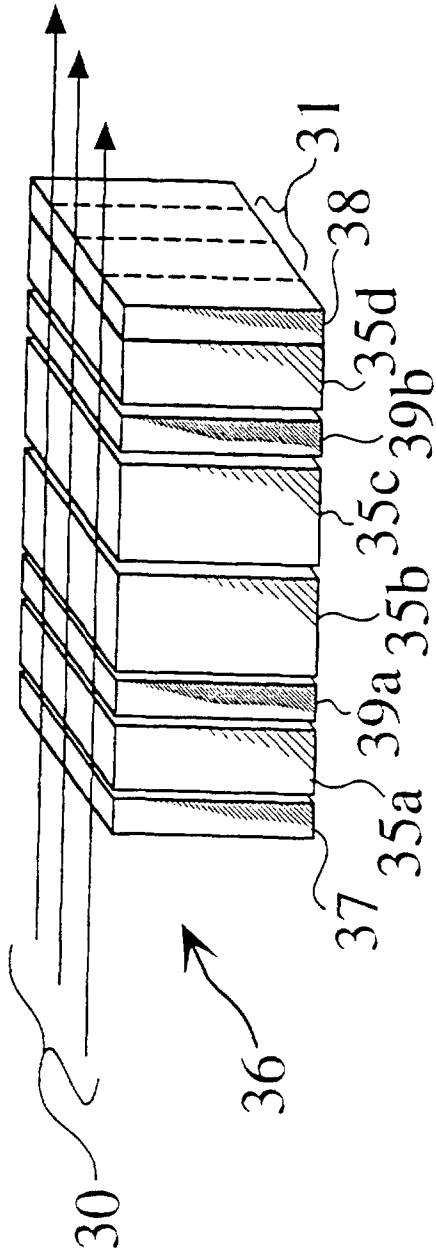


Fig. 3b

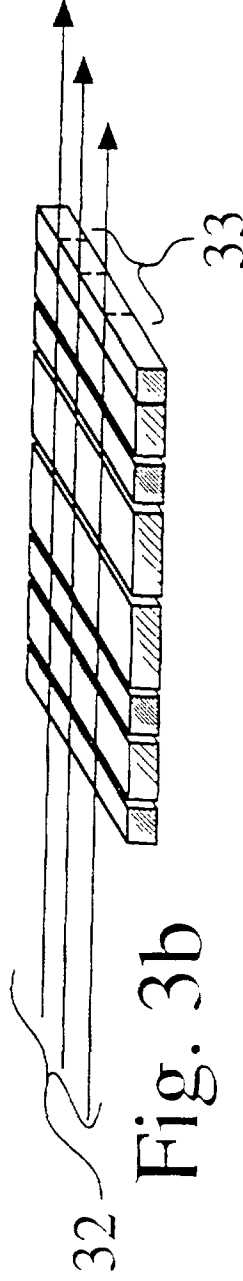
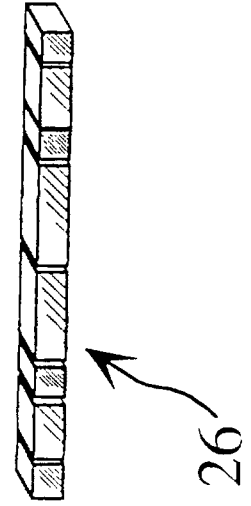


Fig. 3c



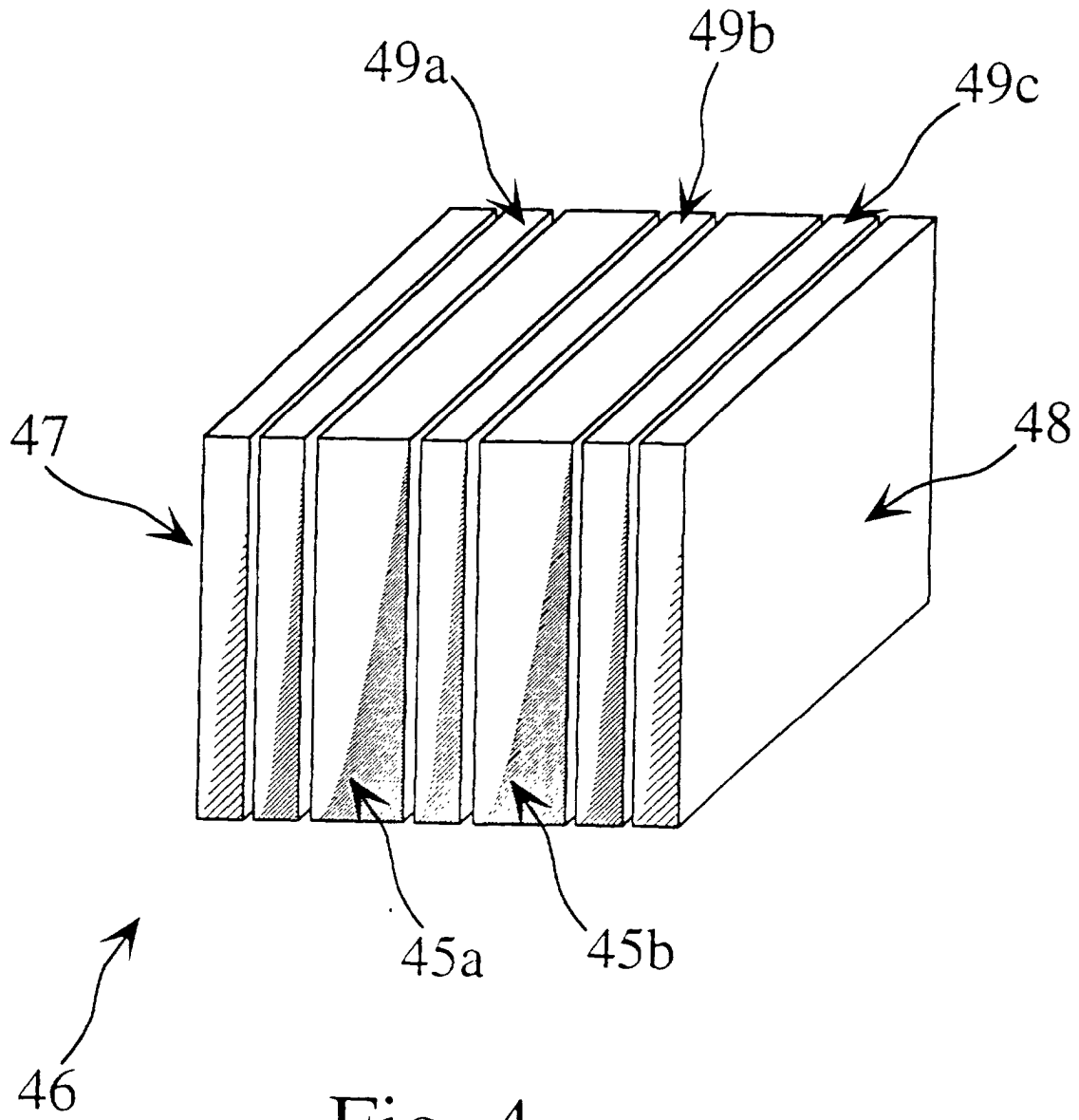


Fig. 4

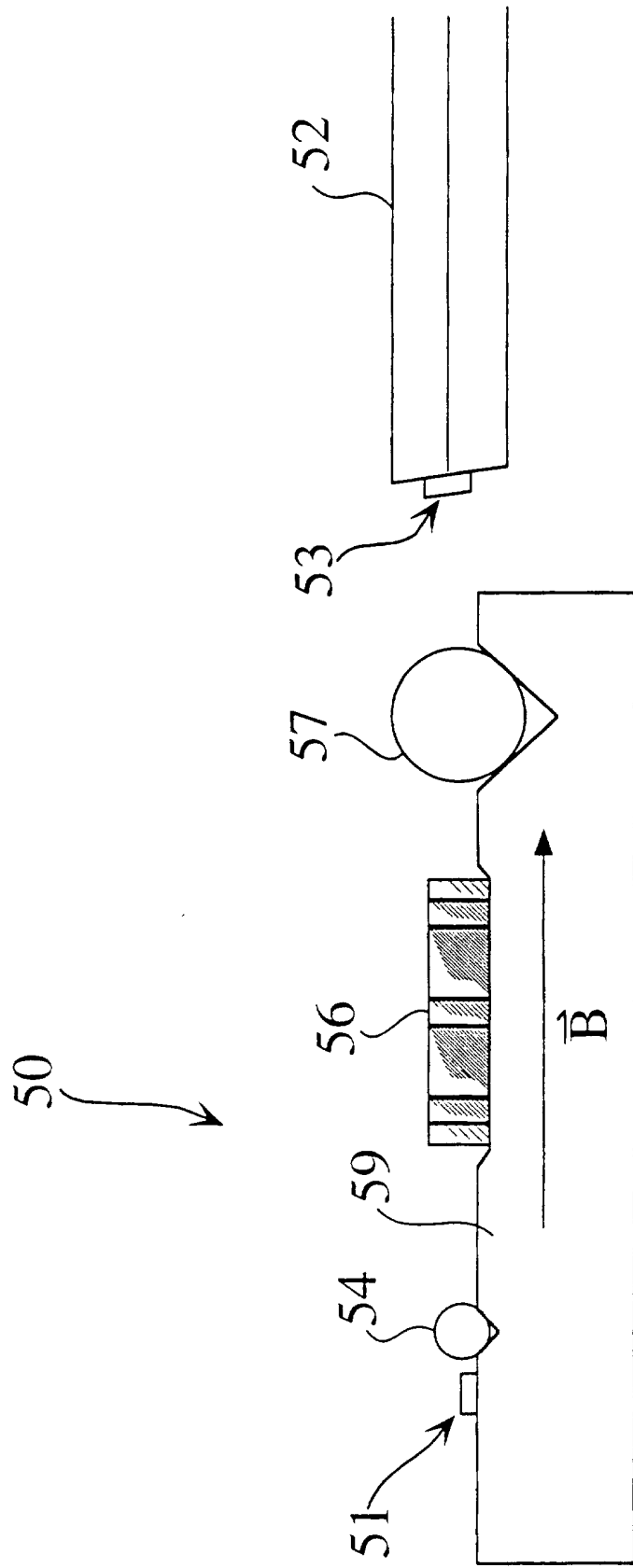


Fig. 5

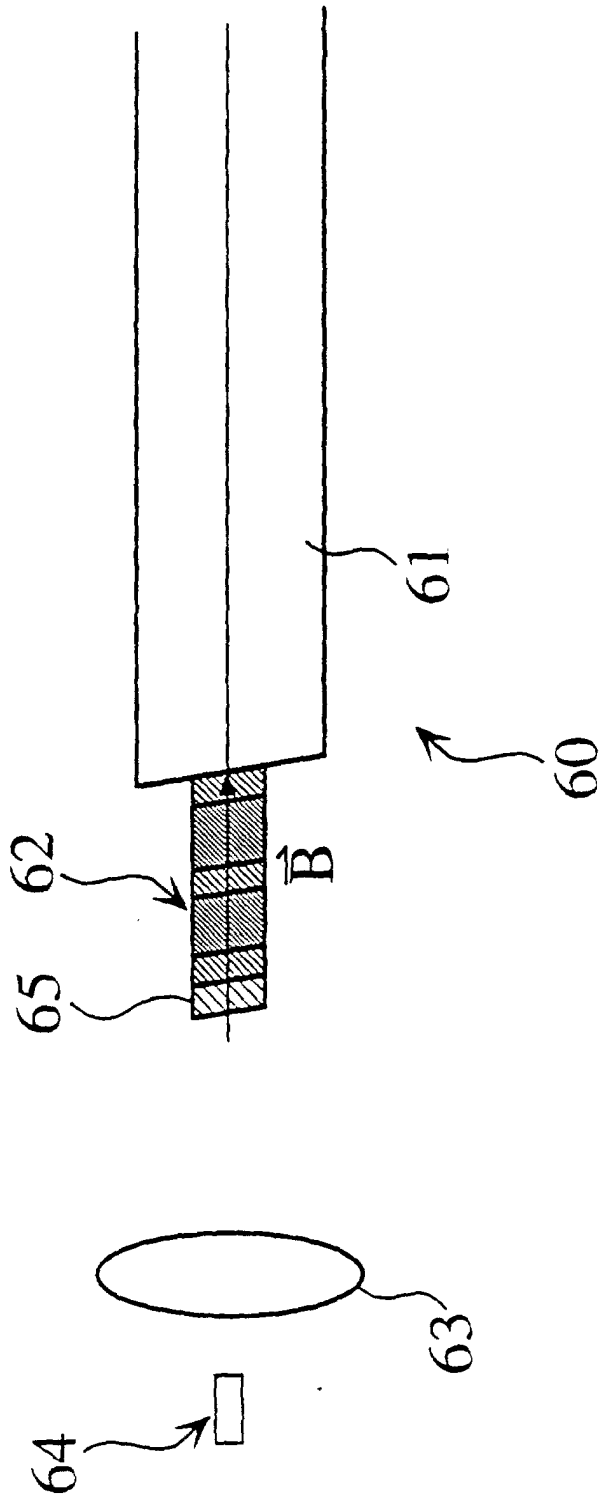


Fig. 6