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(54) **Title**: DEVICES AND METHODS FOR SPATIAL FILTERING

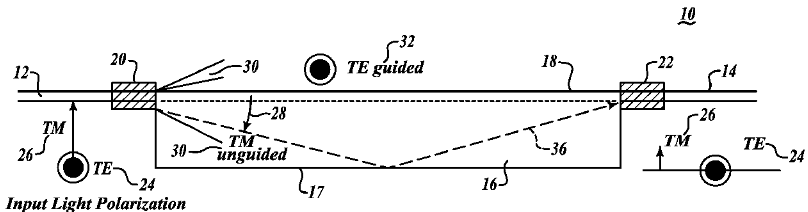

FIG.1A *(PRIOR ART)*

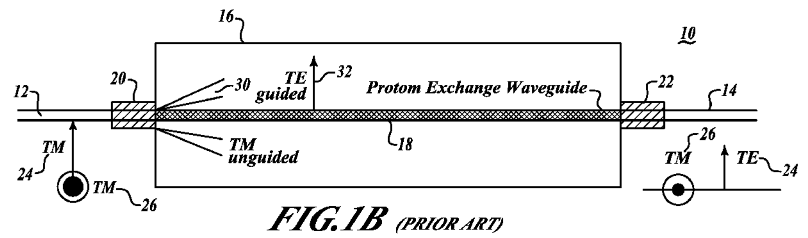

FIG.1B *(PRIOR ART)*

(57) **Abstract**: Methods and devices for polarizing light in a proton exchange polarizer where cross-coupling of unwanted modes of light is reduced with an integrated spatial filter. An optically transmissive substrate such as a substrate (16a) created from LiNbO3 or LiTaO3 has side surfaces, which reflect unguided TM mode light. The light originates from an input fiber (12). The input fiber is connected to the substrate at one end and an output fiber is connected to receive guided TE mode light at the opposite end. The spatial filter (34, 38a-c, 42, 44) is positioned at the primary reflection position of the light with respect to the sides of the polarizer. To improve extinction further, the spatial filter can also be located at secondary reflection points in another alternate embodiment.

DEVICES AND METHODS FOR SPATIAL FILTERING

BACKGROUND OF THE INVENTION

[0001] Optical wave guide devices fabricated by the Proton Exchange (PE) method provide some unique qualities. The process of proton exchange increases the refractive index only in extraordinary axis and thus will only guide one polarization state. The other polarization state is unguided and is eventually eliminated. This quality of Proton Exchange devices makes them naturally very high performance polarizers (60 dB or more). In addition, this quality makes them very attractive for use in Multiple Function Chips (MFCs) used in construction of fiber optic gyros (FOGs).

[0002] Now refer to FIGURE 1A which shows a schematic diagram of a proton exchange polarizer with crosstalk. A proton exchange polarizer 10 includes a $LiNbO_3$ or $LiTaO_3$ material forming an optically transmissive substrate 16. The proton exchange polarizer 10 further includes a glass ferrule 20 as an input coupling for an optical fiber 12 and a glass ferrule 22 coupled to an output fiber 14. The optical fiber 12 receives light comprised of both a TE mode 24 and a TM mode 26. The TE mode 24 includes the solutions of Maxwell's equations with symmetric boundary conditions for an optical wave propagating within the waveguide (i.e. LiNbO3 at both sides of the waveguide) and the TM mode 26 includes the solutions of Maxwell's equations with non-symmetric boundary conditions for an optical wave propagating within the waveguide (i.e. LiNbO3 at one side of the waveguide and air at the opposing side of the waveguide). TE mode light 32 is substantially guided by a proton exchange wave guide 18 through the optically transmissive substrate 16. When light exits the fiber 12 the TM mode 26 becomes unguided TM mode light 30. The TE mode 24 becomes guided TE mode light 32 by the proton exchange wave guide 18.

[0003] Unguided TM mode light 30 propagates through the optically transmissive substrate 16. A portion of the unguided TM mode light 30 from the polarizer escapes. An angle of reflection 28 may be determined by the dimensions of the particular embodiment, specifically the distance between the glass ferrules 20 and 22.

[0004] The TM mode unguided light 30 is reflected as indicated by light 36 from a bottom 17 and sides of the substrate 16 and exits the substrate through fiber 14. The reflected unguided TM mode light 36 is unwanted in various applications such as fiber-optic gyros.

[0005] During the development of proton exchange devices it was discovered that some devices do not have very high extinction ratios (more than 60 dB) as expected. It was also found that the polarizer extinction ratio decreased with device length. After studying different devices, it was concluded that the crosstalk/modulator mechanism had TM light 30 that was unguided by the wave guide 18 and reflected from the bottom 17 and sides of the substrate 16. The reflected TM light 36 was then collected by the output fiber 14. It was believed that longer polarizer length results in a smaller angle of reflection, which increases this pickup. Several polarizers of different lengths were measured to confirm this theory.

SUMMARY OF THE INVENTION

[0006] The invention provides a proton exchange polarizer where cross-coupling of unwanted modes of light is reduced with an integrated spatial filter. An optically transmissive substrate such as a substrate created from $LiNbO_3$ or $LiTaO_3$ has side surfaces which reflect unguided TM mode light. The light originates from an input fiber. The input fiber is connected to the substrate at one end and an output fiber is connected to receive guided TE mode light at the opposite end. The sides of the substrate couple the unguided TM mode light to the output fiber. This coupling is undesirable in various polarizer applications such as those used in fiber-optic gyros. The extinction ratio of the substrate is improved by the incorporation of a spatial filter. The spatial filter is positioned at the primary reflection position of the light with respect to the sides of the polarizer. To improve extinction further, the spatial filter can also be located at secondary reflection points in another alternate embodiment. The spatial filter is positioned within the substrate or at the sides of the substrate, depending on whether the barrier was created by physical or chemical methods such as saw cutting, etching, diamond machining, micro-machining, or laser-machining. The spatial filter acts to block the propagation of the unguided TM light.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] Preferred and alternative embodiments of the present invention are described in detail below with reference to the following drawings:

[0008] FIGURE 1A schematically shows a proton exchange polarizer side view illustrating a crosstalk/modulator mechanism formed in accordance with the prior art;

[0009] FIGURE 1B schematically shows a proton exchange polarizer top view illustrating the crosstalk/modulator mechanism; formed in accordance with the prior art;

[0010] FIGURES 2A, B show side and top views of a filter formed in accordance with an embodiment of the present invention;

[0011] FIGURE 3A shows a perspective view of a spatial filter created by cutting a slot in the sides of the substrate;

[0012] FIGURE 3B shows a side view of the spatial filter of FIGURE 3A;

[0013] FIGURE 4 shows a isometric view of the substrate with grooves in the side wall of the substrate; and

[0014] FIGURE 5 shows an anti-reflective coating on the sides of a substrate used to absorb unguided TM or light in the anti-reflective layer.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0015] FIGURES 2A, B show a proton exchange polarizer 11 with an integrated spatial filter 34 located in the substrate 16a. The substrate 16a couples a fiber 12 with ferrule 20 to fiber 14 to ferrule 22. The substrate 16a incorporates a proton exchange wave guide 18. The TM mode unguided light 30 propagates through the light conducting substrate 16a but is blocked by spatial filter 34 incorporated into the substrate 16a. The spatial filter 34 prevents reflected light from coupling back into the output fiber 14 by blocking the propagation of the light wave. The barrier, or the spatial filter 34, may be advantageously made by a number of processes including physically depositing the spatial filter 34 into the substrate 16a. The substrate may be saw-cut to create a void in the substrate 16a impeding the propagation of the unguided TM mode light 30. The side may be diamond machined, etched, micro-machined or laser-machined. Alternatively, the surface may simply be scratched or similarly damaged to provide spatial filters in the propagation path of the TM mode unguided light 30.

[0016] The reflected TM mode light 30 is thus substantially removed by creating a spatial filter 34 in the sides 39 of the substrate 16a. With the spatial filter 34 or barrier incorporated into the substrate 16a, any reflected TM light 30 will be substantially blocked. However, there are multiple paths at which reflections may occur. In order to achieve high performance, both primary and secondary reflections must be substantially removed. Experimentally, it was found that three equally spaced spatial filters are required to satisfactorily remove the primary and secondary reflections.

[0017] FIGURES 3A, B shows a spatial filter created by a dicing saw. FIGURE 3A shows an isometric view of the substrate 16 with three slots 38a, 38b and 38c. Slots 38a and 38c are used to attenuate the secondary reflections and 38b is intended to remove the primary reflection. The side of the substrate 16 is shown with cuts made across the entire height of the substrate 16. The side view shows the slots 38a, 38b, and 38c cut into the side of the substrate 16 attenuating the primary and secondary reflections.

[0018] FIGURE 4 shows micro-etched grooves 42 in a substrate 76. The micro-etched groves 42 are formed on vertical sides 78 of the substrate 76 substantially at about a 45° angle as referenced to an incoming beam of light. In this way, reflected light is rejected at an angle of about 90° off the incident beam. The grooves may be formed by chemical etching or by mechanical abrasion (saw cuts, grinding, etc.).

[0019] FIGURE 5 shows an alternate embodiment of the present invention using an antireflection and absorbing layer 44 at the sides of a substrate 86 so that there are no reflections from the sides of substrate 86. Antireflection layers may be formed by deposition of dielectric materials such as Magnesium Fluoride, silicon, or polymers.

[0020] The present invention may be combined with a spatial filter located on the bottom surface of the substrate, such as that shown and described in U.S. Patent No. 5,475,772, which is hereby incorporated by reference.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A proton exchange polarizer device (11) comprising:
   an optically transmissive substrate (16a) having a first surface, and second and third surfaces approximately perpendicular to the first surface, the surface having an extraordinary axis with an increased refractive index for guiding only one polarization state of light;
   a proton exchange waveguide (18) formed on the first surface of the optically transmissive substrate, having an extraordinary axis with an increased refractive index for guiding only one polarization state and having an input coupling on a first end and an output coupling on a second end; and
   an antireflection component (34, 38a-c, 42, 44) formed in relation to the second and third surfaces of the optically transmissive substrate;
   wherein:
      light entering the input coupling has a TE mode and a TM mode;
      light having the TE mode is substantially guided by the proton exchange waveguide;
      light having the TM mode is substantially unguided; and
      a portion of the light having the TM mode propagates through the optically transmissive substrate, and almost all of the portion of the light is unreflected because of the antireflection component.

2. The device of Claim 1, wherein the substrate comprises $LiNbO_3$.

3. The device of Claim 1, wherein the substrate comprises $LiTaO_3$.

4. The device of Claim 1, wherein the antireflection component comprises an array of micro-grooves formed on the second and third surfaces, wherein the array of micro-grooves has a direction of approximately 45 degrees relative to a direction from the first end to the second end of the proton exchange waveguide.

5. The device of Claim 1, wherein the antireflection component comprises one or more deformations formed on the second and third surfaces, wherein one of the deformations is a slot having a longitudinal direction approximately perpendicular to the extraordinary axis of the substrate, and wherein the one or more slots includes first, second and third slots, the second slot is approximately equidistant from the first and second ends of the optically transmissive substrate, the first slot is approximately equidistant from the second slot and the first end of the optically transmissive substrate, and the third slot is approximately equidistant from the second slot and the second end of the optically transmissive substrate.

6. A method for polarizing light comprising:

receiving light at a proton exchange waveguide formed on a first surface of an optically transmissive substrate, the waveguide having an extraordinary axis with an increased refractive index for guiding only one polarization state of the light and having an input coupling on a first end and an output coupling on a second end, wherein the light entering the input coupling has a TE mode and a TM mode, light having the TE mode is substantially guided by the proton exchange waveguide and light having the TM mode is substantially unguided; and

blocking at least a portion of the light having the TM mode by an antireflection component formed in relation to second and third surfaces of the optically transmissive substrate, wherein the second and third surfaces are approximately perpendicular to the first surface.

7. The method of Claim 6, wherein the antireflection component comprises an array of micro grooves formed on the second and third surfaces.

8. The method of Claim 6, wherein the array of micro-grooves has a direction of approximately 45 degrees relative to a direction from the first end to the second end of the proton exchange waveguide.

9. The method of Claim 6, wherein the antireflection component comprises one or more deformations formed on the second and third surfaces.

10. The method of Claim 9, wherein one of the deformations is a slot having a longitudinal direction approximately perpendicular to the extraordinary axis of the substrate, wherein the deformations include first, second and third slots, the second slot is approximately equidistant from the first and second ends of the substrate, the first slot is approximately equidistant from the second slot and the first end of the substrate, and the third slot is approximately equidistant from the second slot and the second end of the substrate.

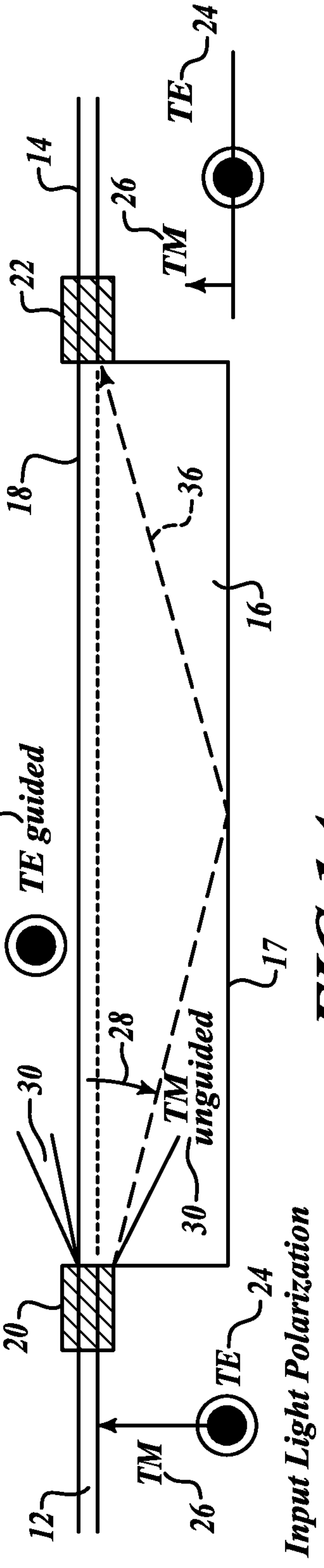

FIG.1A (PRIOR ART)

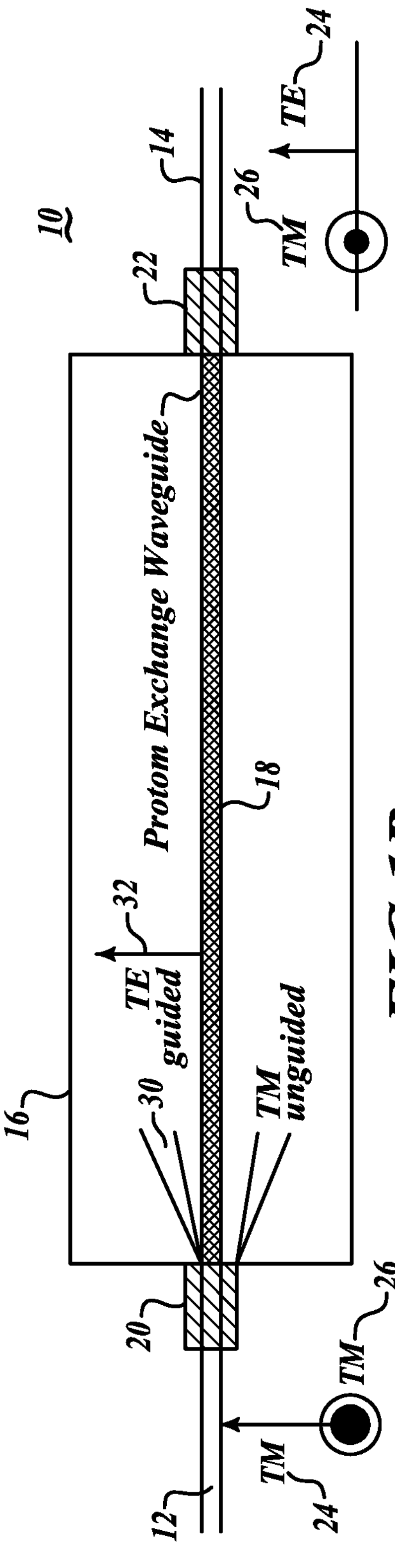

FIG.1B (PRIOR ART)

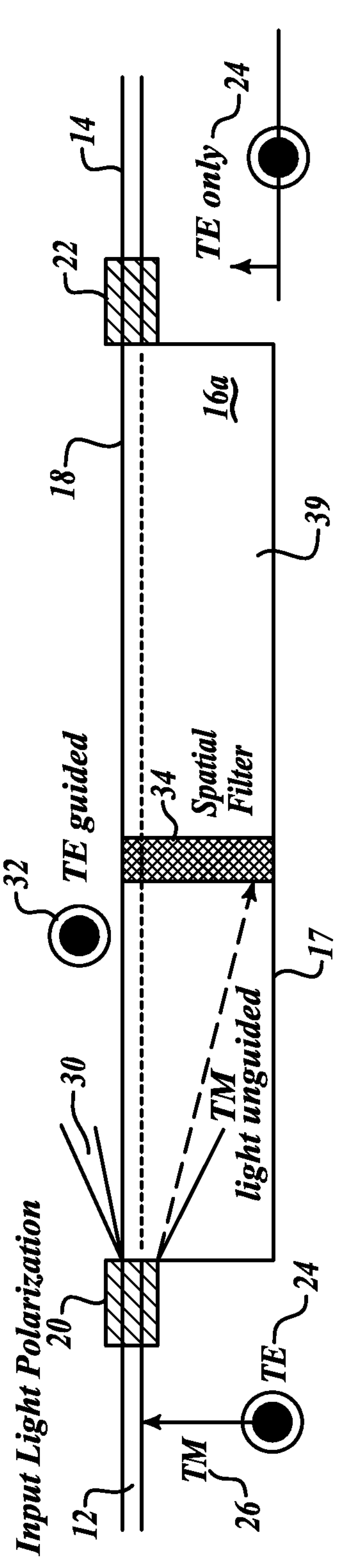
11
Input Light Polarization
12
TM
26
TE
24
20
30
TM
light unguided
32
TE guided
34
Spatial
Filter
17
18
39
16a
22
14
TE only
24

FIG.2A

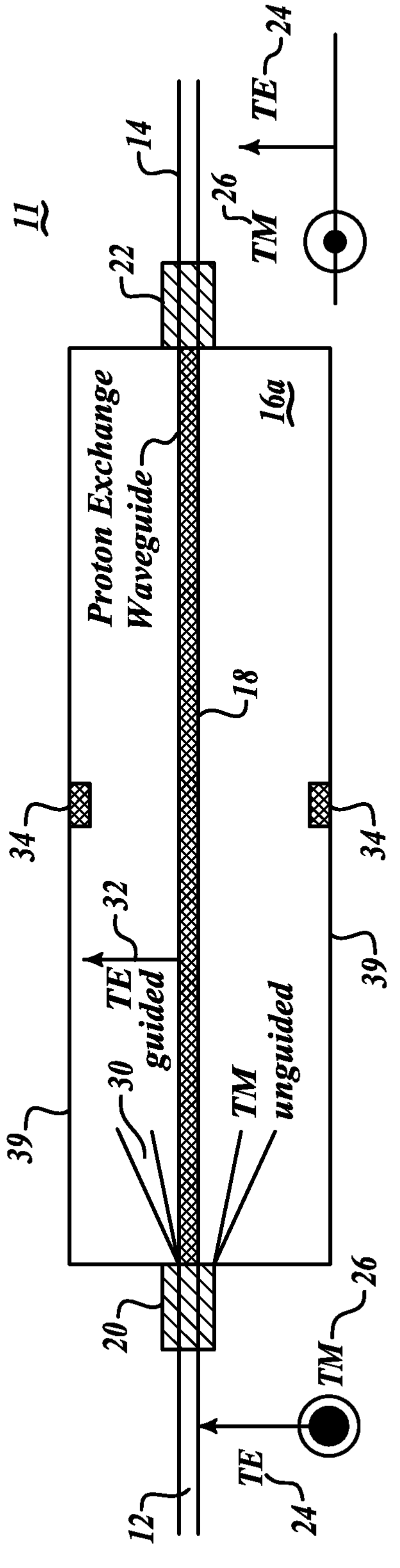
11
12
TE
24
TM
26
20
39
30
TE
guided
32
TM
unguided
34
18
Proton Exchange
Waveguide
16a
22
14
TM
26
TE
24

FIG.2B

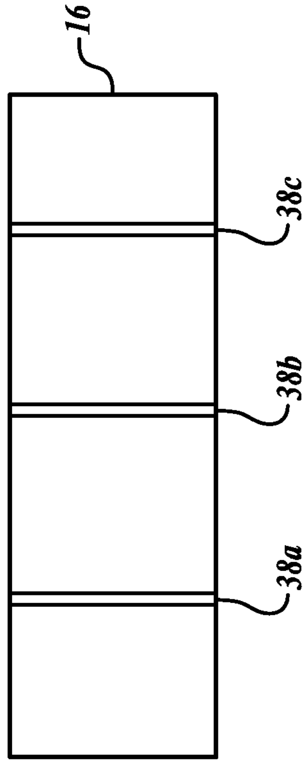

FIG.3B

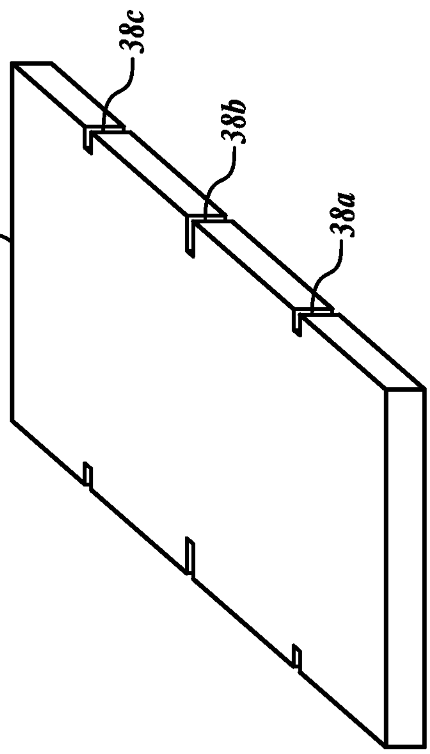

FIG.3A

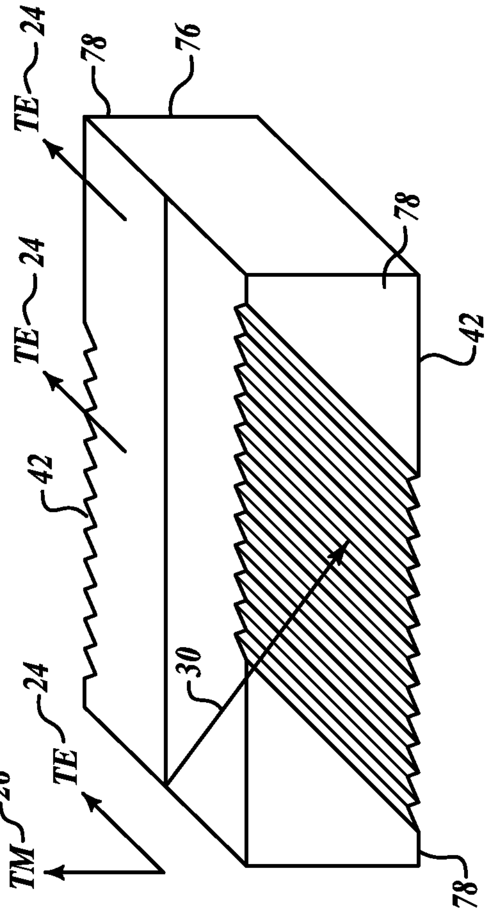

FIG.4

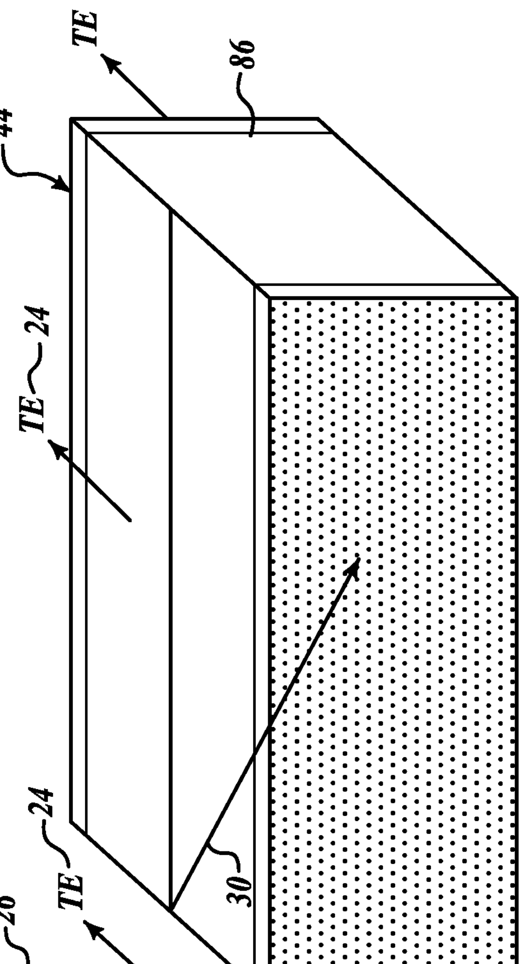

FIG.5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2008/003891

A. CLASSIFICATION OF SUBJECT MATTER

G02B 6/12(2006.01)i, G02B 27/46(2006.01)i

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 8:G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean Utility models and applications for Utility models since 1975
Japanese Utility models and applications for Utility models since 1975

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal), IEEExplore

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5475772 A (HUNG ET AL.) 12 December 1995 See abstract; Figure. 3; Column. 3	1-10
A	US 4984861 A (SUCHOSKI, JR. ET AL.) 15 January 1991 See abstract; Figure. 1; Columns. 3-4	1-10
A	US 5521750 A (ONOE ET AL.) 28 May 1996 See abstract; Figures. 3-4; Columns. 4-6	1-10

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
31 JULY 2009 (31.07.2009)	**03 AUGUST 2009 (03.08.2009)**

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/IB2008/003891

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 05475772 A	12.12.1995	EP 0763212 A1	19.03.1997
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