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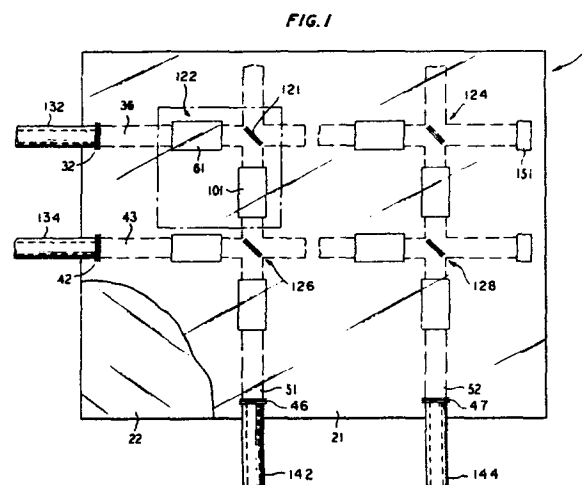
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54 **Optical crosspoint switch.**

57 An optical crosspoint switch has a mode-sensitive reflector (121) at the crosspoint of two crossed optical waveguide channels (36, 51). Mode switches (61, 101) are coupled to the channels, one (61) in one channel upstream of the reflector and the other (101) in the other channel downstream of the reflector. With the mode switches in a non-converting state optical energy passes through the crosspoint without being redirected. With the mode switches in a converting state the optical energy is changed in mode by one of the mode switches, reflected into the other channel, and then changed back again in mode by the other mode switch.

Switches according to the invention can be used in a switching array suitable for use in telecommunications switching.



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Optical Crosspoint Switch

The invention relates to optical crosspoint switches for selectively redirecting optical wave energy from a first one to a second one of a pair of optical waveguiding channels.

Several proposals have been made in the past involving an optical crosspoint array which employs acoustic-optic interaction for selectively deflecting an input beam of light energy propagating along the axis of an optical channel. Such channel is conventionally defined, e.g., on a substrate-supported film.

Each of such proposed acoustic-optic arrangements has one or more disadvantages. In one technique, for example, separate piezoelectric transducers must be affixed to the lateral edges of the substrate at each of the crosspoints; this leads to a complicated and bulky assembly.

In another of such arrangements, the input and output channels are individually defined in parallel fashion on opposite surfaces of a common substrate. In addition to the complex processing steps necessary for this, such design requires for its switching operation the physical movement of a pair of beam-guide couplers that are disposed at the opposite surfaces of the substrate.

Optical crosspoint matrix designs using magneto-optic conversion have also been proposed. These designs have contemplated the use, at each crosspoint, of at least one directional coupler to extract only a portion of the incident energy for processing through the array. The insertion loss exhibited by such scheme is relatively

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large and cumulative over the path of propagation of an optical beam through the device.

In the invention as claimed a signal propagating in the second mode in the first channel and incident on the switch will, if the mode-switching means are inoperative, pass through the switch and continue propagating in the second mode in the first channel. If the mode-switching means are operative the signal will be converted to the first mode by the first mode-switching means, redirected to the second channel by the mode-sensitive means, and then be reconverted to the second mode by the second mode-switching means.

The invention is particularly suited to fabrication by thin-film techniques and can be made inexpensively and with low insertion loss.

An embodiment of the invention will now be described by way of example with reference to the accompanying drawings of which:-

FIG. 1 is a plan view of an optical crosspoint array employing thin-film light guiding paths therein and incorporating crosspoint switches according to the invention,

FIG. 2 is a fragmentary elevation view of a portion of the array of FIG. 1, illustrating a technique for coupling incident light energy onto a guided-wave mode for propagation along one of the thin-film paths of FIG. 1,

FIG. 3 is an enlarged fragmentary plan view of a typical crosspoint switch of the array of FIG. 1, and

FIG. 4 is a plan view similar to FIG. 1, illustrating a system of pulse-operated "X" and "Y" leads threaded through the array for selectively operating the crosspoint switches.

Referring to the drawings, FIG. 1 depicts generally an optical crosspoint switching array 11 including crosspoint switches in accordance with the invention. For simplicity, only four crosspoints (designated 122-128) of the array 11 are illustrated for coupling one of a pair

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of input optical waveguides 132 and 134 to one of a pair of output optical waveguides 142 and 144. In general, of course, any desired number $M \times N$ of crosspoints may be provided in the array 11 for coupling one of M input
5 waveguides to one of N output waveguides.

The array 11 may illustratively form a part of an optical telephone communications system. Thus, for example, the array 11 may be situated in a central office, while a unique input waveguide 132, 134 and a
10 corresponding unique output waveguide 142, 144 may be assigned to one of the subscribers to such central office. For local-to-local subscriber communications through such central office, the operation of one of the crosspoints 12 within the matrix 11 (e.g., by magneto-optic interaction
15 in the manner to be described) will connect two local subscribers at the array 11. In such contemplated application, the waveguides 132, 142 may take the form of optical fibre transmission lines, and will be referred to as fibres in the following description.

20 The crosspoints 122-124 are disposed at the intersections of discrete light paths through the array 11. In the particular arrangement of FIG. 1 and 2 such light paths are established as guided-mode channels through a thin planar optical film 21 disposed on a substrate 22.

25 Illustratively, the film 21 is a magnetic single-crystal iron-garnet layer that is epitaxially grown on a chemically processed $[1,1,1]\text{Gd}_3\text{Ga}_5\text{O}_{12}$ substrate. By proper choice of the lattice constants of the substrate and the magnetic thin-film, a magnetic
30 anisotropy can be induced, with the easy axis thereof parallel to the plane of the film 21. In addition, by proper choice of the film thickness and proper selection of the relative refractive indices of the film 21 and the substrate 22, the guided modes in the film may be
35 restricted to the lowest-order TE and TM modes (designated TE_0 and TM_0). Such expedients are well known to those skilled in the art.

38 Such arrangement of the film and substrate not

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only yields a large difference in refractive index therebetween relative to that which would normally be obtained if both the film and the substrate were isotropix, but also provides a large difference, within
5 the film 21 itself, between the effective refractive indices respectively presented to the TE_0 and TM_0 modes.

Optical energy from the output end of the fibre 132 is coupled, via a thin-film grating 32 fabricated on the surface of the film 21, onto a first
10 guided-mode optical path 36. As best shown in FIG. 2, the optical wave energy from the fibre 132 impinges obliquely downwardly onto the grating 32, which converts a portion of the incident rays into the desired film-guided wave propagating along the path 36. By suitable
15 choice of the polarization of the

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incident beam from the fibre 132, a desired one of the TE and TM modes can be selected by the grating 32 as the polarization for the film-guided waves propagating along the light channel 36; and it will be assumed that the polarization of the beam in the fiber 132 and the characteristics of the grating 32 are so chosen, in a conventional manner, that the TE_0 mode is selected for propagation along the path 36.

The grating 32 may be constructed as described, e.g., in an article by M. L. Dackss et al, "Grating Coupler for Efficient Excitation of Optical Guided Waves in Thin-Films", Applied Physics Letters, Vol. 16, No. 12, pages 523-525 (June 15, 1970). In particular, the fabrication of the grating 32 may be accomplished by conventional holographic techniques, e.g., by exposing a photoresist layer on top of the film 21 to the interference of a collimated laser beam and a cylindrically focused beam. The photoresist grating which remains after development serves as a mask through which the grating may be replicated, by ion etching, onto the surface of the film.

By analogy to the above, a thin-film grating 42 (FIG. 1) identical to the grating 32 may be defined on the film 21 for coupling light energy from the other illustrated input fiber 134 onto a second guided-mode light path 43 on the film 21. Again, the polarization of the beam from the fiber 134, and the characteristics of the grating 42, are suitably chosen such that a TE_0 film-guided wave is launched in the light channel 43.

A pair of output thin-film gratings 46, 47, identical to the gratings 32 and 42, are also fabricated in the film 21 for coupling light energy selectively routed through the array 11 to one of the output fibres 142 and 144 via light channels 51, 52. In particular, the grating 46 is effective to couple light energy, propagating in the TE_0 mode on the light channel 51, onto the output fibre 142, while the grating 47 is effective to couple

light energy, propagating in the TE_0 mode on the channel 52, onto the output fibre 144.

The output light channel 51 intersects the input light channels 36, 43 at the crosspoints 122 and 126, respectively. Similarly, the output light channel 52 intersects the input light channels 36, 43 at the crosspoints 124 and 128, respectively.

The TE_0 mode launched onto the light path 36 from the input optical fibre 132 passes through a first magneto-optic selection switch 61 associated with the crosspoint 122. The switch 61 includes a photolithographically patterned, serpentine current conductor 62 (FIG. 3) which may be excited by current pulses as indicated below to produce a pulsed RF magnetic field that is directed along the path 36; such RF field is periodically reversed in direction as a result of the depicted geometry.

Suitable DC biasing facilities (not shown) may also be associated with the conductor 62 for establishing a steady magnetic field in the plane of the film 21 and directed at an acute angle (illustratively 45 degrees) to the axis of the light path 36. Because of the magnetic anisotropy caused, e.g., by the mismatch in lattice constant between the epitaxially grown iron-garnet film 21 and the underlying crystalline substrate 22, the total magnetization vector in the plane of the path 36 in the region encompassed by the conductor 62 may be rotated by the application of a relatively small magnetizing RF field in the conductor 62. Thus, by suitably pulsing the conductor 62, such magnetization vector (which is normally oriented at 45 degrees to the path 36) can be periodically switched into a direction along the axis of the path 36. Also, with a suitable choice of the periodic constants of the conductor 62 and the strength of the total magnetization vector along the path 36 when the conductor 62 is pulsed, a significant portion of the TE_0 mode energy normally propagating in the path 36 is converted into the TM_0 mode.

A discussion of the above-mentioned magneto-optic effect, together with design considerations for the switch 61, is set forth in an article by K. Tien, et al, "Switching and Modulation of Light in Magneto-Optic Waveguides of Garnet Films", Applied Physics Letters, Vol. 21, No. 8, pages 394-396 (October 15, 1972).

The current pulses for exciting the conductor 62 may illustratively be derived from a time-division switching pulse generator of the above-mentioned telephone communications system. Such pulses are preferably selectively applied via parallel pulse inputs on an "X" lead 91 and a "Y" lead 92. Under non-coincident pulse conditions, the incoming TE_0 mode is not significantly affected, and proceeds unconverted through the switch 61 toward the intersection of the light paths 36 and 51.

A second magneto-optic switch 101, identical to the switch 61, is associated with the crosspoint 122 and is positioned in the output light path 51 of the crosspoint. The switches 61 and 101 are arranged for joint excitation, and for this purpose the switch 101 is connected in series with the switch 61 by both the "X" lead 91 and the "Y" lead 92 as shown.

Since the magneto-optic effect provided by the switches 61 and 101 is reciprocal, a TM_0 mode propagating downwardly (as shown in the figure) from the intersection of the paths 36 and 51 through the switch 101 will be reconverted to the TE_0 mode by such switch when a serpentine conductor 102 thereof is simultaneously pulsed by the conductors 91 and 92.

A grating 121 is disposed at the intersection of the paths 36 and 51 in mode coupling relation to the associated magneto-optic switches 61 and 101. The grating 121 is preferably positioned at 45 degrees to the axes of each of the paths 36 and 51. The grating 121 may be fabricated holographically on the film 21 in a manner similar to that of the above-described input and output gratings 32, 42, 46 and 47 of the array 11.

By suitable choice of the periodicity of the grating 121, the attenuation constants presented thereby to incident TE_0 and TM_0 modes, respectively, can be made to differ significantly; this effect is discussed, e.g.,
5 in Abstract F3 on page 21 of the Digest of Technical Papers for the 1972 International Quantum Electronics Conference. In this way, the grating 121 functions as an effective polarization mode filter, which presents a relatively low insertion loss to an incoming TE_0 wave
10 while presenting a substantially totally reflecting interface to an incoming TM_0 wave. Since it is oriented at 45 degrees to the paths 36 and 57 as shown, the grating 121 will cause wave energy in the TM_0 mode to be directed from the incoming light path 36 into the
15 intersecting light path 51.

The transparency of such a 45 degree grating to the TE_0 mode is substantially independent of the direction of incidence of the wave energy; that is, the desired low insertion loss will be exhibited whether the wave energy
20 is propagating toward the crosspoint in one of the input waveguides 132, 134 or in one of the output waveguides 142, 144. Moreover, the grating 121 will effect no significant interaction between optical beams simultaneously propagating toward the associated crosspoint in each of the
25 constituent crossed optical paths.

Further details of the design of such grating-type mode filters are presented, e.g., in U.S. Patent 3,891,302 and in an article by T.P. Sosnowski, "Polarization Mode Filters for Integrated Optics", Optical Communications, Vol.
30 4, No. 6, pages 408-412 (February/March 1972).

In the operation of the crosspoint 122 as described above (e.g., consisting of a pair of magneto-optic switches 61 and 101 mode-coupled to the 45 degree grating 121 at the intersection of the paths 36 and 51),
35 the functioning of such crosspoints in the absence of coincidence of current pulses on the leads 91 and 92 will

first be described. Under such conditions, a guided TE_0 wave launched on the light path 36 from the fiber 132 will pass essentially unimpeded and unconverted through the magneto-optic switch 61 and will impinge on the grating 121 at the intersection. Because of the low insertion loss of the grating to the TE_0 mode, such impinging wave energy will pass through the intersection and thereafter through the remaining unoperated crosspoints in the path 36 (e.g., the crosspoint 124 in FIG. 1) to be absorbed in a conventional reflectionless termination 151.

Upon a simultaneous excitation of the "X" and "Y" leads 91 and 92 at the crosspoint 122, both of the serially-connected switches 61 and 101 at the crosspoint will be operated to convert optical wave energy incident thereon in one of the TE_0 and TM_0 modes into the other of such modes. In particular, wave energy in the TE_0 mode entering the crosspoint 122 on the path 36 will be initially converted, by the switch 61, into the TM_0 mode. When the so-converted mode reaches the 45 degree grating 121 at the intersection of the paths 36 and 51, such mode will be reflected by the grating toward the other magneto-optic switch 101 in the path 51. Such switch reconverts the reflected TM_0 mode to the TE_0 mode, which in turn will pass freely through the remaining unoperated crosspoints (e.g., the crosspoint 126) disposed in the path 51 to be coupled onto the output fibre 142.

It will be evident to those skilled in the art that "X" and "Y" current excitation leads corresponding to the leads 91 and 92 can be threaded in coordinate fashion through the various crosspoints of the array 11 so that a desired one of the crosspoints can be operated to the exclusion of all others. For example, as shown in FIG. 4, the "X" lead 91 extending through the crosspoint 122 also extends through all of the other remaining crosspoints in the light path 36, while the "Y" lead 92 extends through all of the remaining crosspoints in the light path 51.

In like manner, an additional "X" lead 201

extends through all of the crosspoints in the light path 43, while an auxiliary "Y" lead 202 extends through all of the crosspoints in the light path 52. It will be understood that the coincident excitation of a desired pair of the 5 illustrated leads "X", "Y" will operate only the associated crosspoint.

Because of the magnetic nature of the thin-film 21 and the magneto-optic operation of the switches 61 and 101 at each crosspoint, it is convenient to provide suitable 10 retentive memory in each of the switches 61 and 101. In this way, current pulses of one polarity coincidentally applied to a crosspoint with an appropriate amplitude from the related X-Y leads will establish one of two bistable 15 one of such states can be suitably arranged to direct a mode-converting magnetic excitation along the direction of propagation of optical energy in the associated light path for the purpose described. Once such state is selected, excitation of the X-Y leads may be removed 20 without de-energizing the crosspoint. Therefore, when the array 11 forms a switching matrix in a central office, a speech path may be maintained through such crosspoint from an input subscriber's fiber 132,134 to an output subscriber's fiber 142,144 until the state of the associated magneto-optic 25 switches is changed. Such change may be accomplished, e.g., by suitably pulsing the associated X-Y leads with the opposite polarity.

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CLAIMS

1. An optical crosspoint switch for selectively redirecting optical wave energy from a first one (36) to a second one (51) of a pair of optical wave-guiding channels, characterised in that the optical waveguiding channels are each supportive of optical wave energy in at least a first mode and a second mode, mode-sensitive means (121) are arranged to redirect optical wave energy in the first mode from the first channel to the second channel and to pass optical wave energy in the second mode without substantial redirection, and the switch includes optical mode-conversion means including first mode-switching means (61) coupled to the first channel upstream of the mode-sensitive means selectively operable to convert optical wave energy from the second mode to the first mode and second mode-switching means (101) coupled to the second channel downstream of the mode-sensitive means selectively operable to convert optical wave energy from the first mode to the second mode.

2. Apparatus for controlling the direction of wave energy through a crosspoint (122) of a pair of crossed optical wave guiding channels (35, 51), each channel being supportive of optical wave energy in at least first and second modes, the apparatus comprising switching means (61, 101) associated with the crosspoint and operable for converting wave energy, incident thereon in one of the first and second modes, into the other of the first and second modes, characterised in that the apparatus is provided with mode-sensitive means (121) associated with the crosspoint (122) and responsive to the incidence thereon of optical wave energy from one of the channels (36) in the first mode for directing such wave energy into the other of the channels (51); and that mode switching means (61, 101) are individually disposed in jointly operable relation in each of the channels (36, 51) in mode coupling relation with the directing means (121).

3. Apparatus as claimed in claim 2. wherein the directing means (121) is substantially transparent to

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optical wave energy incident thereon from said one channel (36) in the second mode.

4. Apparatus as claimed in claim 2 or claim 3 wherein means (91, 92) are provided for operating the mode switching means (61, 101) associated with the selected crosspoint (122).

5. A switch or apparatus as claimed in any of the preceding claims wherein one of the first and second modes is the TE_0 mode and the other of the first and second modes is the TM_0 mode.

6. A switch or apparatus as claimed in any of the preceding claims wherein the mode-switching means are connected together for joint operation.

7. A switch or apparatus as claimed in any of the preceding claims wherein the mode-switching means are magneto-optic and are switchable between a stable non-mode-converting state and a stable mode-converting state.

8. A switch or apparatus as claimed in any of the preceding claims wherein at least the portions of the channels associated with the mode switching means (61, 101) are formed from a magnetic thin-film material having a lattice constant related to that of a substrate (22) on which the channels are disposed, producing a magnetic anisotropy having an easy axis parallel to the plane of the channel.

9. A switch or apparatus as claimed in any of the preceding claims wherein the mode-sensitive means comprises a reflection-type mode filter (121) at the crosspoint.

10. A switch or apparatus as claimed in any of the preceding claims wherein each mode-switching means (61, 101) comprises a magneto-optic switch which includes parallel pulse input means (19, 92) magnetically coupled to means (62, 102) for periodically varying the magnetization of the channel within the switch in the direction of wave propagation, for selectively establishing a magnetic field along associated channel.

11. An optical crosspoint switching array

characterised by a switch or apparatus as claimed in any of the preceding claims associated with each crosspoint, the switches being disposed on a common substrate (22).

12. An array as claimed in claim 11 wherein
5 optical coupling means (32, 42, 46, 47) are individually disposed on the substrate (22) at input ends of the first channels (36, 43) and at output ends of the second channels (51, 52) for providing external coupling access to and from the associated channels.

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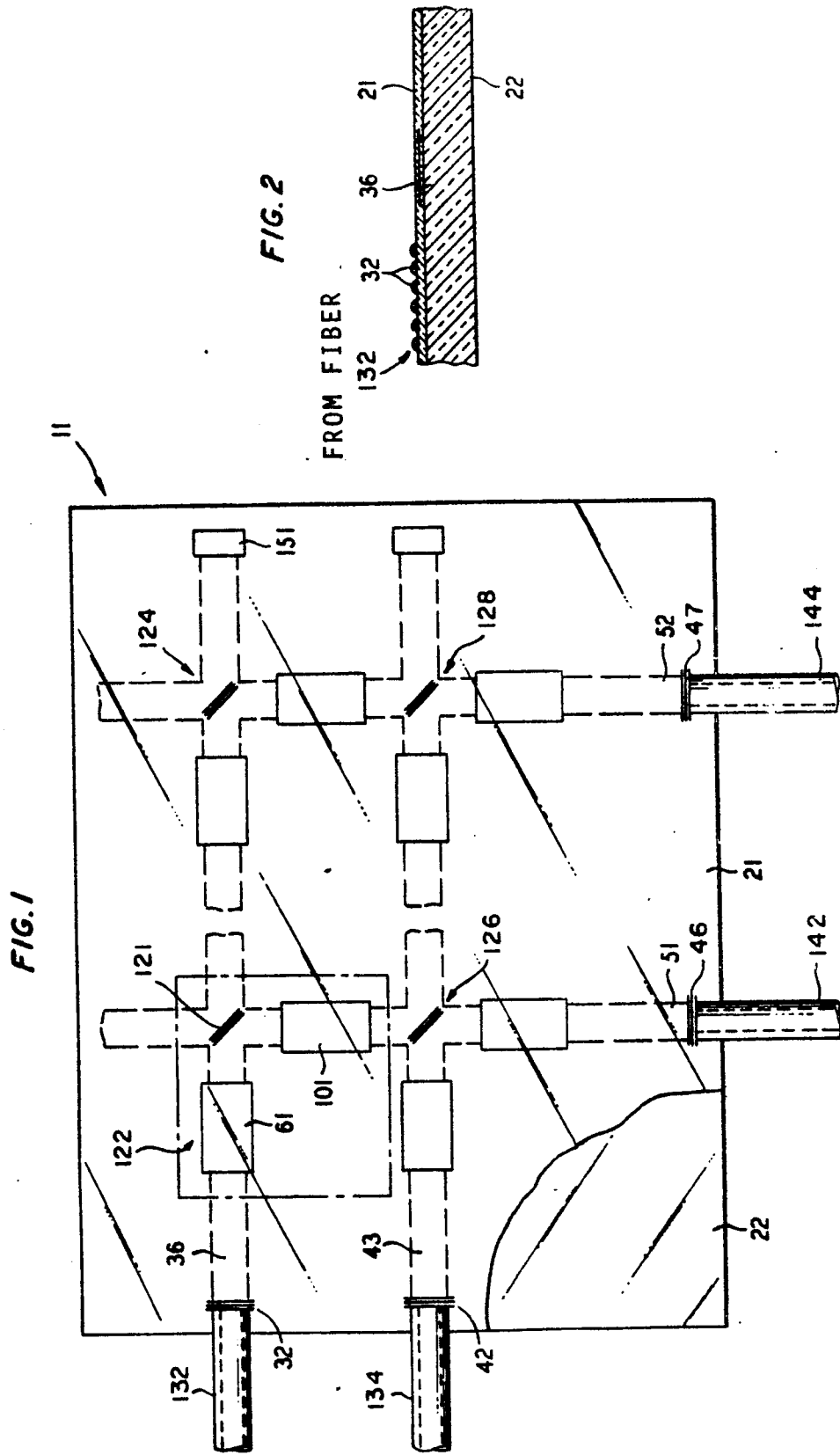
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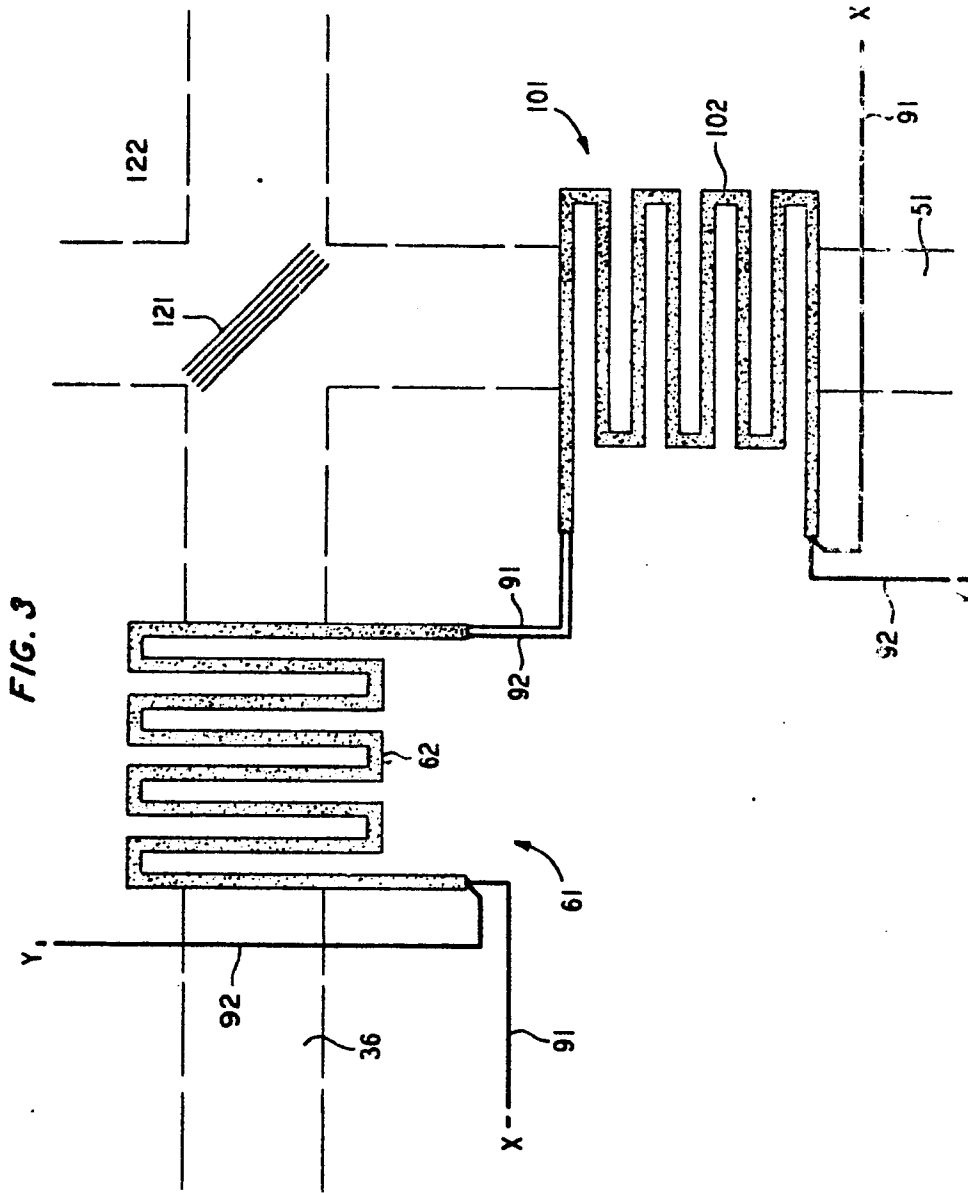
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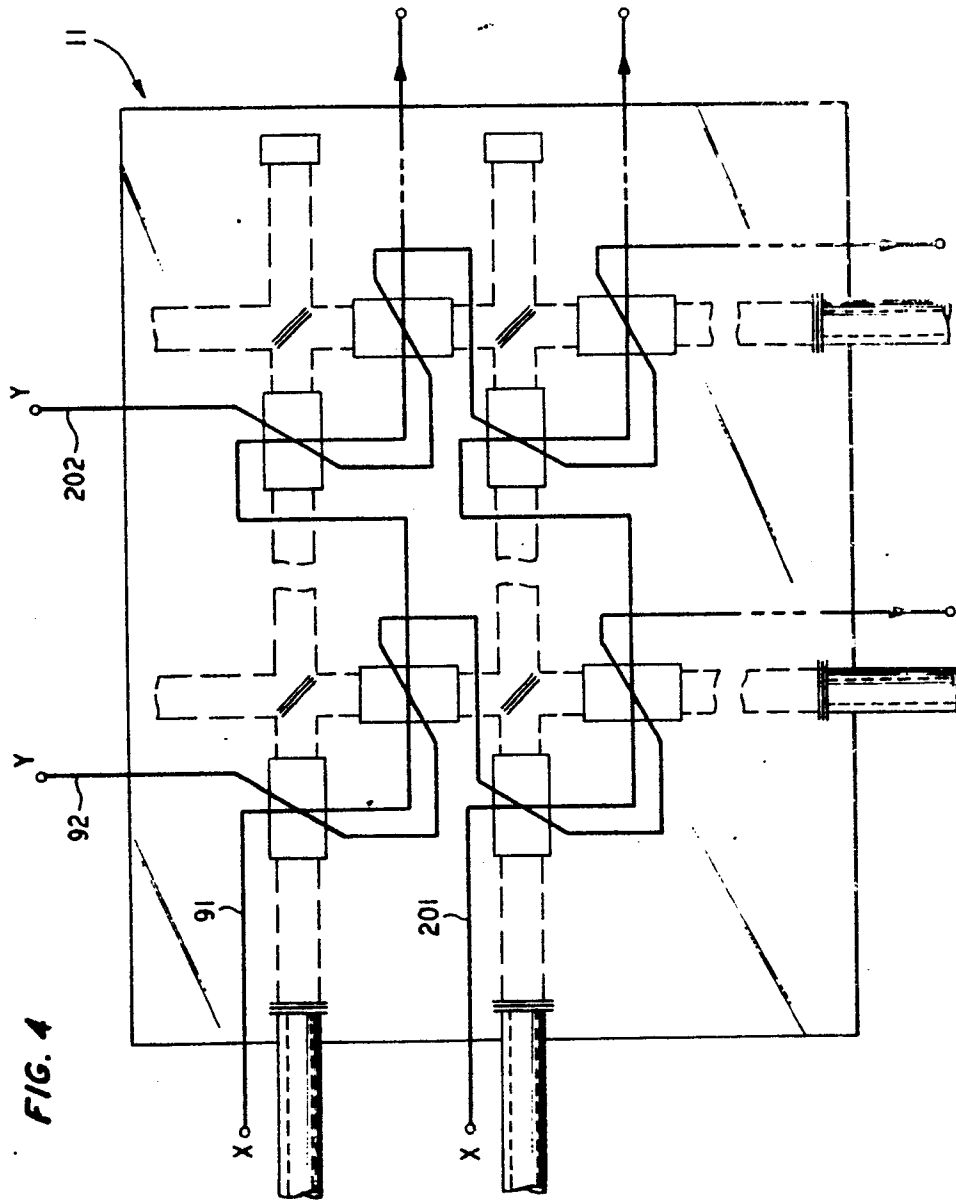


FIG. 4



DOCUMENTS CONSIDERED TO BE RELEVANT		CLASSIFICATION OF THE APPLICATION (Int. Cl. 2)	
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	
	<p><u>US - A - 3 990 776</u> (S.C.C.TSENG et al.)</p> <p>* Column 1, lines 6-10; column 2, line 1 - column 3, line 8; column 4, lines 1-60; column 7, lines 19-48; figure 3 *</p> <p>---</p> <p>JOURNAL OF APPLIED PHYSICS, vol. 45, no. 2, February 1974. New York US</p> <p>S.YAMAMOTO et al. "Circuit theory for a class of anisotropic and gyrotropic thin-film optical waveguides and design of nonreciprocal devices for integrated optics", pages 882-888.</p> <p>* Page 887, paragraphs B and E; figure 6 *</p> <p>---</p> <p>A <u>US - A - 3 764 195</u> (S.L.BLANK et al.)</p> <p>* Claims 1,4-8; figure 3 *</p> <p>---</p> <p>A <u>US - A - 4 011 543</u> (R.A.SOREF et al.)</p> <p>* Column 1, lines 14-31; column 3, lines 28-40; claim 1, figures 1 and 4 *</p> <p>----</p>	<p>1-5, 7-12</p> <p>1-2, 5,7,8</p> <p>5,7-8, 10,12</p> <p>1,11- 12</p>	<p>G 02 F 1/29// G 02 F 1/09 H 04 B 9/00 G 02 B 5/14</p> <p>TECHNICAL FIELDS SEARCHED (Int.Cl.2)</p> <p>G 02 F 1/29 G 02 F 1/09 H 04 B 9/00</p> <p>CATEGORY OF CITED DOCUMENTS</p> <p>X: particularly relevant A: technological background O: non-written disclosure P: intermediate document T: theory or principle underlying the invention E: conflicting application D: document cited in the application L: citation for other reasons</p> <p>&: member of the same patent family, corresponding document</p>
<p><input checked="" type="checkbox"/> The present search report has been drawn up for all claims</p>			
Place of search	Date of completion of the search	Examiner	
The Hague	31-10-1978	BORMS	