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(74) Agents: UNWIN, Stephen, Geoffrey et al.; Fry Heath &
Spence LLP, The Gables, Massetts Road, Horley, Surrey
RH6 7DQ (GB).

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(71) Applicant (*for all designated States except US*):
BOOKHAM TECHNOLOGY PLC [GB/GB]; 90
Milton Park, Abingdon, Oxon OX14 4RY (GB).

(72) Inventors; and

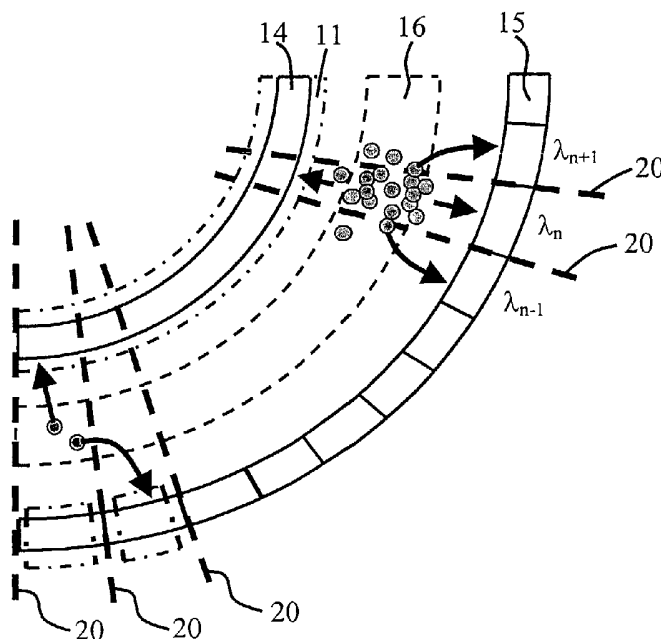
(75) Inventors/Applicants (*for US only*): **ASGHARI, Mehdi**
[GB/GB]; 29 Westlecot Road, Old Town, Swindon SN1
4EZ (GB). **HOUSE, Andrew, Alan** [GB/GB]; 8 Black-
stock Close, Headington, Oxford OX3 7JR (GB).

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(54) Title: WAVELENGTH-DEMULPLEXER WITH INTEGRATED MONOLITHIC PHOTODIODES



(57) Abstract: A monolithic photodetector array comprising a plurality of monolithic photodiodes formed in a light conducting substrate and positioned in an array (10, 11, 12) across the substrate so that each photodiode receives a different light signal or different portion of a light signal propagating through the substrate.

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WAVELENGTH-DEMULTIPLEXER WITH INTEGRATED MONOLITHIC PHOTODIODES

TECHNICAL FIELD

This invention relates to a monolithic photodetector.

BACKGROUND ART

This invention represents an extension of other proposals made by the applicant as described, for example, in GB0131001.0 and GB013003.6 and in GB0218843.1. The disclosure of these specifications is incorporated herein. In each of these cases, a photodiode is provided in which light of one or more selected wavelengths is absorbed so as to generate free charge carriers and these are then detected to provide a signal indicative of the wavelength being sensed.

SUMMARY OF THE INVENTION

According to a first aspect of the invention, there is provided a monolithic photodetector array comprising a plurality of monolithic photodiodes formed in a light conducting substrate and positioned in an array across the substrate so that each photodiode receives a different light signal or different portion of a light signal propagating through the substrate.

The invention thus provides an adaptation of the other proposals referred to above for use as a photodetector array.

Preferred and optional features of the invention will be apparent from the following description and from the subsidiary claims of the specification.

BRIEF DESCRIPTION OF DRAWINGS

The invention will now be further described, merely by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a schematic diagram of a typical, known configuration of an optical channel monitor (OCM);

Figure 2 is a schematic diagram of a first embodiment of the invention arranged as an OCM;

Figure 3 is a more detailed schematic diagram of part of Figure 2;

Figures 4, 5, 6 and 7 are detailed schematic diagrams of the part shown in Figure 3 illustrating various possible arrangements; and

Figure 8 is a cross-sectional view taken along line X-X' of Figure 3 of another embodiment of a photodetector array according to the invention.

BEST MODE OF INVENTION

The photodetector array will be described with particular reference to its use within an OCM although it will have a wide variety of other applications.

A typical configuration of a known OCM formed on an optical chip is shown in Figure 1. Figure 1 shows an OCM 1 comprising an input waveguide 2, an arrayed waveguide grating (AWG) 3, a plurality of output waveguides 4A, 4B, 4C....., a hybridised photodiode array 5 and free propagation slab regions 6 and 7 at either end of the AWG 3. The AWG 3 may, for example, comprise an array of rib waveguides monolithically formed in the optical chip.

In Figure 1 light enters the OCM device 1 via the input waveguide 2. The OCM may be part of a dense wavelength division multiplexed (DWDM) optical network and so typically the input light will be made up of a spectrum of different wavelengths: $\lambda_1, \dots, \lambda_N$. Often, the OCM input is preceded by a tap coupler (not shown) that has been used to sample a small fraction of the optical power at a point in the network.

The input waveguide 1 delivers the light into the AWG 3 which disperses the light into its component wavelengths (in other implementations of the device, an alternative dispersive element, such as a reflection grating, might be used). The light emerges from the AWG 3 onto an arc A-A'. The point on A-A' at which the light is focused is dependent upon its wavelength. The array of output waveguides 4A, 4B, 4C.... are placed along arc A-A' and these waveguides transport the light to the edge of the optical chip. Each output waveguide carries a different wavelength of light. For simplicity, only 5 waveguides are shown in Figure 1 although a typical OCM will have many more output waveguides than this.

The photodiode array 5 is located at the edge of the chip where the output waveguides 4A, 4B, 4C... terminate. Typically, this photodiode array 5 is made from a different material to the optical chip; for example, the optical chip may be a silicon wafer, e.g. a silicon-on-insulator (SOI) wafer, while the photodiode array 5 may be a III-V semiconductor. The photodiode array 5 must be carefully optically aligned to the output waveguide facets and then bonded in place by a suitable epoxy adhesive; a process known as hybridisation. Each pixel of the photodiode array 5 is used to detect the light from one of the output waveguides thus providing a measure of the optical power at a particular wavelength.

Figure 2 shows an OCM of similar configuration but with a monolithic photodiode array 10 according to one form of the present invention in place of the output waveguides 4A, 4B, 4C... and the hybridised photodiode array 5. A major advantage of this implementation of an OCM is that there is no need to hybridise the photodiode array as it is now realised monolithically in the optical chip. Whereas in Figure 1 the output from the AWG 3 had been collected by an array of output waveguides 4A, 4B, 4C.... placed along the arc A-A' , it is now detected immediately by a monolithic photodiode array 10. Both the AWG 3 and the photodiode array 10 may thus be monolithically formed in the optical chip.

Figure 3 shows a more detailed view of part of the photodiode array 10 according to a first embodiment of the invention.

The monolithic array 10 comprises an array of PIN diodes each comprising p- and n- doped regions 11, 12 either side of a nominally intrinsic region 13. In the illustrated configuration, the diode anodes (the p-doped regions) are commoned together into a single region 11 while the cathodes (n-doped regions) are separated into discrete regions 12A, 12B.... (the reverse of this, i.e. a common cathode configuration, is also possible). Metal contact vias connect electrode pads 14, 15 to the p-doped region 11 and the n-doped regions 12A, 12B..... respectively. As with the regions of n-type doping, the electrode pads 15A, 15B are discrete from one another (in Figure 3, for clarity, only the n-type doped regions 12A, 12B for the first two cathodes are depicted). A space (not shown) of intrinsic silicon is left between adjacent electrodes. In this embodiment a region 16 of a light absorbing dopant is implanted into the intrinsic region 13. The dopant could be any one of a number of suitable atoms such as gold, indium or even silicon itself (as described in GB0131001.0). Various other dopants may also be used including chalcogens (Group VI elements) and germanium. The role of the dopant is to introduce deep bandgap impurity states into the silicon. Pure intrinsic silicon is transparent to light at conventional telecoms wavelengths (1.3-1.6 μ m) but the dopant allows absorptive transitions to occur via the deep band gap states thus making photodetection possible. In the case of implantation of silicon atoms, the implanted silicon creates deep bandgap defect levels due to the damage created by the implantation process. Proton implantation may also be used.

The principle of operation is that light passes from an external source (in the case of Figure 2 an AWG) into the doped region 16 where it is photoabsorbed creating free charge carriers. The array of PIN diodes is reverse biased or unbiased so that the photogenerated carriers are swept to the electrodes 14,

15 by the imposed electric field. This produces a photocurrent to flow in each cathode 15A, 15B, which is proportional to the optical power of the incident light. As the AWG 3 has dispersed the multi-wavelength spectrum across the full extent of the monolithic photodiode array 10 then each cathode 15A, 15B.... will detect a signal proportional to the wavelength that focuses in the region where it is located. Each cathode 15A, 15B... thus constitutes one pixel in the detector array 10 and if these pixels are of sufficiently small width then, a quasi-continuous measure of the output spectrum can be recorded. This is not the case for the original waveguide-based implementation of Figure 1 in which parts of the spectrum are omitted from detection due to the overlap of the output waveguide modes with the slab mode being less than 100%. Capture of the full spectrum and a narrow spectral resolution is especially important for accurately determining the power in high bit rate signals where much of the optical power may be concentrated in narrow sidelobes.

Some practical limitations inhibit the operation of such a monolithic photodiode array. A photodetector formed in a rib waveguide to monitor an optical signal therein as described in GB0131001.0, only needs to absorb a small amount of the optical power therein, typically as little as 1% and, if the PIN diode detector is located laterally around a rib waveguide, a long interaction length between the dopant and the optical excitation, typically thousands of microns, can be used to increase the sensitivity of the device.

In contrast, a monolithic array such as that of Figures 2-3 is located in a slab waveguide and the PIN diode is placed in a direction coincident with the direction of propagation of the light, rather than perpendicular to it. Since it is expected that the PIN diode will typically have a p-to-n type dopant separation of the order of $\sim 10\mu\text{m}$ then this reduces the interaction length of the light with the dopant by a factor of ~ 100 in comparison to a rib waveguide monitor. Furthermore, an OCM ideally requires 100% of the incident light to be detected, unlike the 1% tap-monitor application. Thus, the photoabsorption in

the monolithic array may need to be $\sim 10^4$ times greater than the tap-monitor application.

A second problem that can occur in the monolithic array of Figure 3 is that of electrical crosstalk. With the layout of the array as depicted in Figure 3, there is nothing to prevent light photoabsorbed in the doped region adjacent to a particular pixel being detected inadvertently by a neighbouring pixel as indicated in Figure 4. This occurs due to the scattering of free charge carriers and variations in their initial momentum. If the number of photogenerated carriers is large and the optical spectrum has a fairly uniform power distribution across the wavelengths, then the averaging effect of the lateral motions of the carriers will help minimise the error due to electrical crosstalk. However, in situations such as when the λ_n DWDM wavelength has a large optical power and at least one of its immediate neighbours, λ_{n+1} or λ_{n-1} , has close to zero power, then the electrical nearest-neighbour crosstalk may be significant and may compromise the accuracy of the array for the detection of low-optical powers. Also, where a gradient in the free carrier density exists, such as for a high optical power channel next to a zero optical power channel, then diffusion currents will be set up that will lead to crosstalk as also shown in figure 4.

There are a number of ways in which such electrical crosstalk problems can be addressed. Electrical isolation measures can be located between the pixels of the photodiode array so as to prevent lateral motion of the free charge carriers. For example, trenches may be etched through to the SOI buried oxide layer or dopants implanted in an npn or n-i-p-i-n configuration as described in WO02/025334. The isolation features are located so as to run between pixels parallel to the direction of light propagation, as indicated by the thick dashed lines 20 in Figure 4. Such isolation features typically have a width of around $50\mu\text{m}$ for n-i-p-i-n type isolation or $\sim 10\mu\text{m}$ for etched-trench isolation.

The introduction of such isolation features will potentially lead to the removal of part of the optical spectrum. In the OCM of Figure 1, the output waveguide array typically has each waveguide 4 covering about $9\mu\text{m}$ of the slab waveguide width when there are ~ 40 output waveguides in total. Thus, if the monolithic photodiode array pixels are $\sim 9\mu\text{m}$ across, and if located along the same arc A-A' as the ends of the waveguides 4, there would be insufficient space to include such isolation features. However, if the location of the monolithic array 10 is moved further from the output side of the AWG 3, so that the free propagation region 7 of the AWG 3 is increased, then the optical spectrum is dispersed across a greater lateral extent and so allows such isolation features to be introduced. Such an arrangement may be sufficient to allow $10\mu\text{m}$ wide trench isolation features to be interspersed between $\sim 10\mu\text{m}$ wide pixels.

An alternative approach to reducing electrical crosstalk in the monolithic array 10 is to adopt a revised contact configuration such as illustrated in Figure 5. In this case, the doped regions of the cathodes have been formed into a cusp-like shapes 30A, 30B, so as to capture free carriers that are moving in a lateral direction. As with the isolation features described above, there will be a finite width to the doped cathode regions 30 which may impact upon the total spectral coverage of the photodiode array. Individual regions 31A, 31B, of absorbent doping are provided in such an arrangement as shown in Figure 5.

As well as electrical crosstalk, the photodiode array may suffer from optical crosstalk. A disadvantage of not using output waveguides is that the mode filtering that they contribute is lost. This means that high order slab modes may propagate to the detection region and cause optical crosstalk. For this reason, and also if a longer interaction length is required in the detectors, it may be preferred in some circumstances to use a configuration similar to that of Figure 1 but with a monolithic detector formed within each of the output

waveguides 4A, 4B, 4C...., e.g. as described in GB013003.6. The need to hybridise a photodiode array to the outputs of the waveguides is thus avoided.

As already mentioned, it may be desirable to increase the interaction length of the light with the light absorbent dopant. This can be done by increasing the optical path length about which a PIN diode is located. A simple way of doing this in the absence of a rib waveguide is to repeat the configuration of Figure 3 a number of times as illustrated in Figure 6. Figure 6 shows a common anode electrode 40 as intersecting successive arrays of cathode electrodes 41, 42.... Only two cathode arrays 41, 42 are shown but this pattern could be extended indefinitely as far as space on the chip permits.

Another alternative, is to surround the photodiode pixels of Figure 3 with mirrors 50, 51, or other reflective devices so as to form a Fabry-Perot cavity therebetween as shown in Figure 7. Such an arrangement extends the interaction length of the detector by making it a multi-pass device. Some wavelength selectivity may also be introduced by using different cavity lengths for individual pixels as indicated by the steps in mirror 51. Mirrors can be implemented in silicon by means of etched trenches. Mirror 50 is a one-way mirror to allow light into the cavity but reflect light within the cavity. Bragg gratings may also be used to provide wavelength selective reflection.

GB..... entitled "A Light Sensor" filed on the same day as the present application by the same applicant discloses a light sensor with wavelength selective reflector means and an arrangement comprising a plurality of such sensors in series, and the disclosure thereof is incorporated herein.

Another point that must be considered in a monolithic photodiode array as shown in Figure 3, compared to a waveguide tap-monitor, is how the light traverses the doped regions of the PIN diodes. In the arrangement shown in Figure 3, it is seen that the light that is incident upon the photodiode array must pass through the region of p-type doping that forms the common anode.

This static doping is strongly optically absorbing and may impede the operation of the detector unless an appropriate countermeasure is included. Instead of providing the doping 61 on the input side of the device directly within the slab waveguide it can be formed within a ridge 62 provided above the slab region as shown in Figure 8 which is a longitudinal cross-section through the device that corresponds to the line X-X' shown in Figure 3.

Figure 8 shows a device formed in a silicon-on-insulator chip comprising a silicon layer 65 separated from a substrate 66, typically also of silicon, by an insulating layer 67 of silicon dioxide. An absorbent doped region 68 is formed in a slab waveguide formed by the silicon layer 65. A passivating oxide layer 69 is formed over the silicon layer 65.

In Figure 8 the doping 63 forming the cathode has also been shown positioned in a ridge 64. This would be necessary for a detector arrangement such as that of Figure 7 where the light must bypass the dopant in the cathode as well as the dopant in the anode contact. The ridges 62, 64 need not be large and a width of $\sim 5\mu\text{m}$ is sufficient to allow electrical interconnection with minimal impact upon the optical properties of the chip. Preferably, the ridges have sufficient height such that the dopant therein does not overlap to a significant extent with the slab waveguide optical mode. Typically, the ridges 62, 64 may have a height of a few microns. The ridges extend laterally across the upper surface of the slab region and, in the application described, are preferably curved so as to extend parallel to the arc A-A' shown in Figures 1 and 2. Figure 8 also shows metal electrodes 70, 71 and contact vias 72, 73 providing electrical contact to the doped regions 61, 63 respectively.

In a simple, single-cathode-row array such as that of Figure 3, it would not be necessary to place the doping forming the cathode in a ridge and so, in this case, the ridge 64 could be omitted and the cathode contact formed directly in the slab as previously described. Indeed, if it is undesirable for the light to

propagate beyond the photodiode array then it may be advantageous to locate the rearmost doped region the detection array within the slab. As stated previously, the cathode doping is strongly optically absorbing and so placing this in the slab will reduce or prevent further propagation of the light beyond the device. This will help limit stray light in the optical chip and hence avoid crosstalk with other optical components that may be fabricated on the same optical chip. It may also help to prevent optical crosstalk within the monolithic photodiode array itself by suppressing spurious back-reflections into other detector channels, for example reflections from the edge of the chip.

Other arrangements in which the p- and n- doped regions are located adjacent the light absorbent region so as to collect free charge carriers generated therein may be used, the doped regions either being within the optical path or adjacent thereto.

Where it is sufficient to tap-off a proportion of the optical signal in order to monitor it, the light absorbent region may be located adjacent the optical pathway, for example as described in GB..... entitled "A Tap-Off Light Sensor" filed on the same day as this application. In this case, the light absorbent regions either spoils the guidance conditions of part of the waveguide so a proportion of the light is diverted thereto or it senses an evanescent portion of the optical signal. Charge carriers generated therein are detected by a diode formed across the absorbent region in the manner described above.

The above arrangements are particularly suited to the fabrication of a monolithic photodiode array within a silicon device, e.g. formed on a silicon-on-insulator (SOI) chip but may also be used on substrates formed of other materials.

CLAIMS

1. A monolithic photodetector array comprising a plurality of monolithic photodiodes formed in a light conducting substrate and positioned in an array across the substrate so that each photodiode receives a different light signal or different portion of a light signal propagating through the substrate.
2. An array as claimed in claim 1 formed across a slab waveguide.
3. An array as claimed in claim 2 comprising optical isolation features which divide the slab waveguide into a plurality of quasi-waveguides each having a monolithic photodiode formed therein.
4. An array as claimed in claim 1 formed across an array of discrete waveguides, each waveguide having a monolithic photodiode formed therein.
5. An array as claimed in claim 4 in which the discrete waveguides are rib waveguides.
6. An array as claimed in any preceding claim in which each photodiode comprises a light absorbing region that generates free charge carriers when light of a selected wavelength or wavelengths is received thereby.
7. An array as claimed in claim 6 in which each photodiode comprises a p-doped region and an n-doped region located adjacent the light absorbing region for detecting the presence of free-charge carriers generated therein.

8. An array as claimed in claim 7 in which one of the p-doped region and the n-doped region is common to each or at least a plurality of said photodiodes.
9. An array as claimed in claim 8 in which the other of the p-doped region and the n-doped region of each photodiode is discrete from that of each adjacent photodiode.
10. An array as claimed in claim 7, 8 or 9 in which at least one of the doped regions of each photodiode is formed within the light conducting substrate so as to be within the path of at least part of a light signal propagating through the substrate.
11. An array as claimed in any of claims 7-10 in which at least one of the doped regions of each photodiode is formed adjacent said path.
12. An array as claimed in claim 11 in which at least one of the doped regions of each photodiode is formed within a ridge provided on the light conducting substrate.
13. An array as claimed in claim 12 in which the ridge extends laterally across the substrate relative to the direction of a propagation of light within the substrate.
14. An array as claimed in any of claims 7-13 in which at least one of the doped regions of each photodiode is positioned and/or shaped so as to reduce electrical cross-talk between adjacent photodiodes.
15. An array as claimed in claim 6 or any claim dependent thereon in which the light absorbent region is located within the pathway of light propagating through the substrate.

16. An array as claimed in claim 15 arranged to absorb substantially all of the light received thereby.
17. An array as claimed in claim 6 or any of claims 8-14 when dependent thereon in which the light absorbent region is located adjacent said substrate so as to tap-off a proportion of the light propagating through said substrate.
18. An array as claimed in claim 15, 16 or 17 in which the light absorbing region is a region of said substrate modified so as to introduce deep band gap states therein so as to enable the absorption of one or more wavelengths not absorbed by the unmodified substrate.
19. An array as claimed in any preceding claim in which each photodiode has reflector means associated therewith so light received thereby passes repeatedly through the photodiode.
20. An array as claimed in claim 19 in which the reflector means is wavelength selective.
21. An array as claimed in any preceding claim in which each photodiode has one or more further photodiodes associated with it arranged in series therewith.
22. An array as claimed in claim 2 or 3 in which each photodiode is sensitive to a different wavelength or band of wavelengths than the photodiodes adjacent thereto.
23. An array as claimed in claim 22 arranged to receive a dispersed, multi-wavelength light signal.

24. An array as claimed in any preceding claim arranged as an optical channel monitor.
25. An array as claimed in claims 23 and 24 arranged to receive the output of a diffraction grating.
26. An array as claimed in claim 25 in which the diffraction grating is an arrayed waveguide grating.
27. A monolithic photodetector array substantially as hereinbefore described with reference to and/or shown in one or more of Figures 2-8 of the accompanying drawings.

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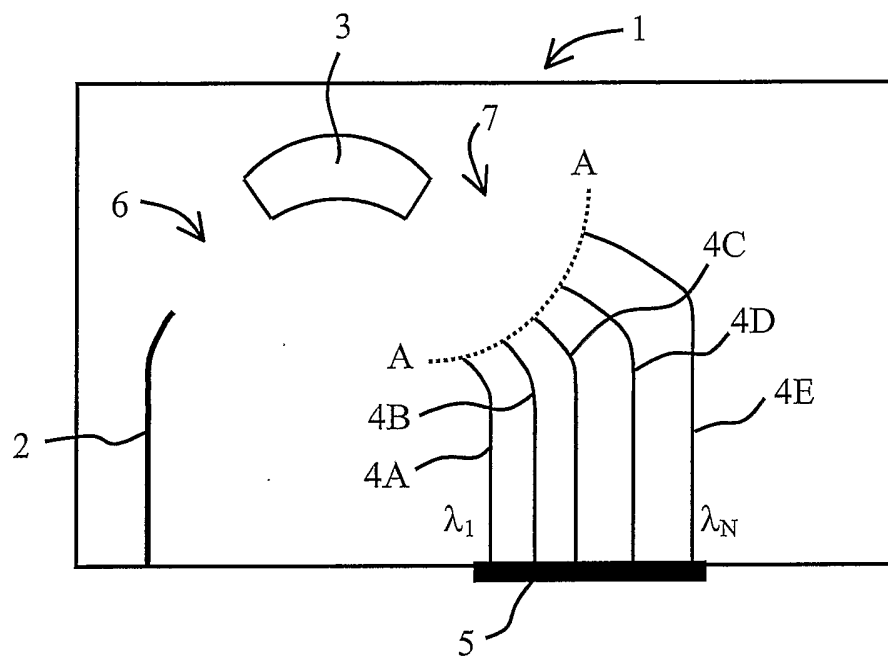


Figure 1

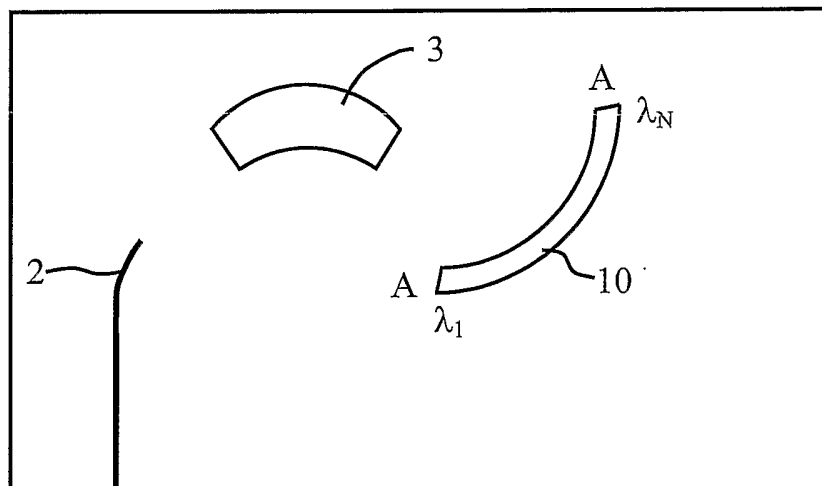


Figure 2

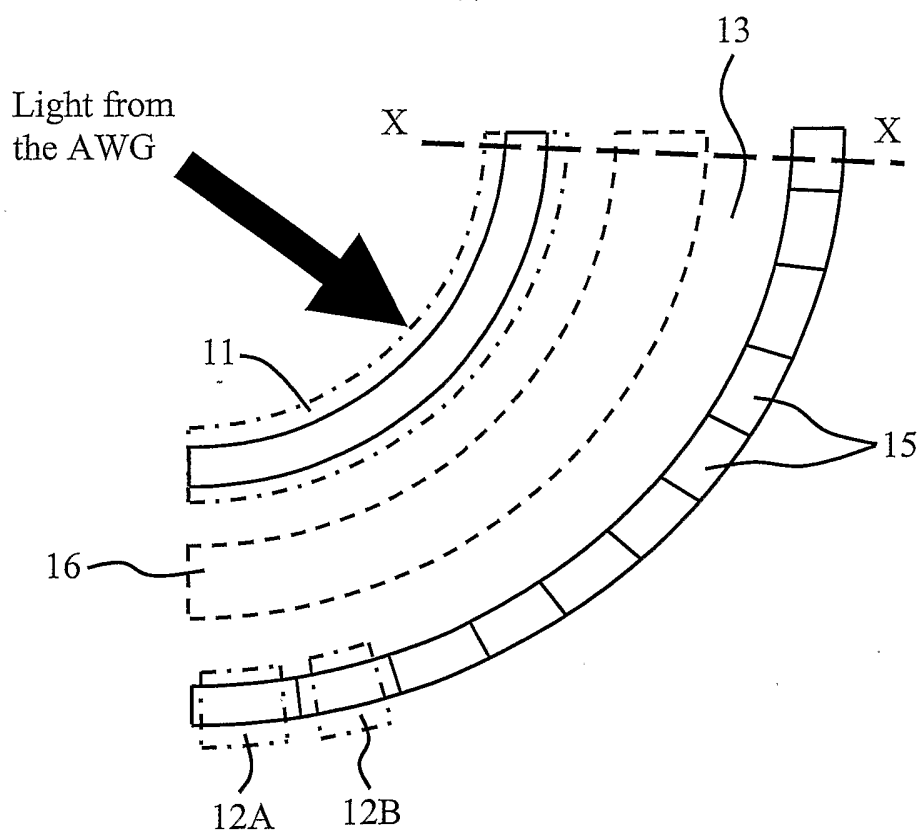


Figure 3

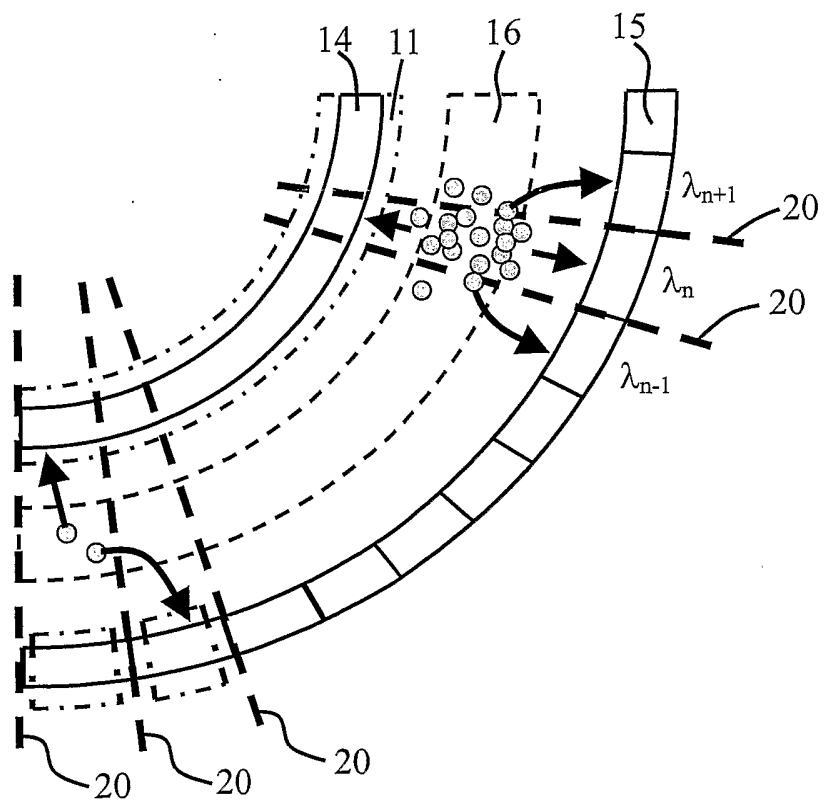


Figure 4

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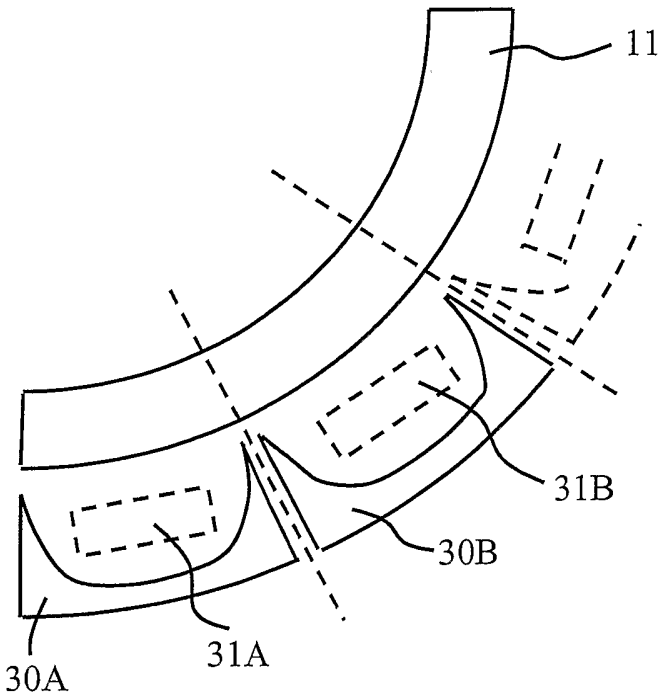


Figure 5

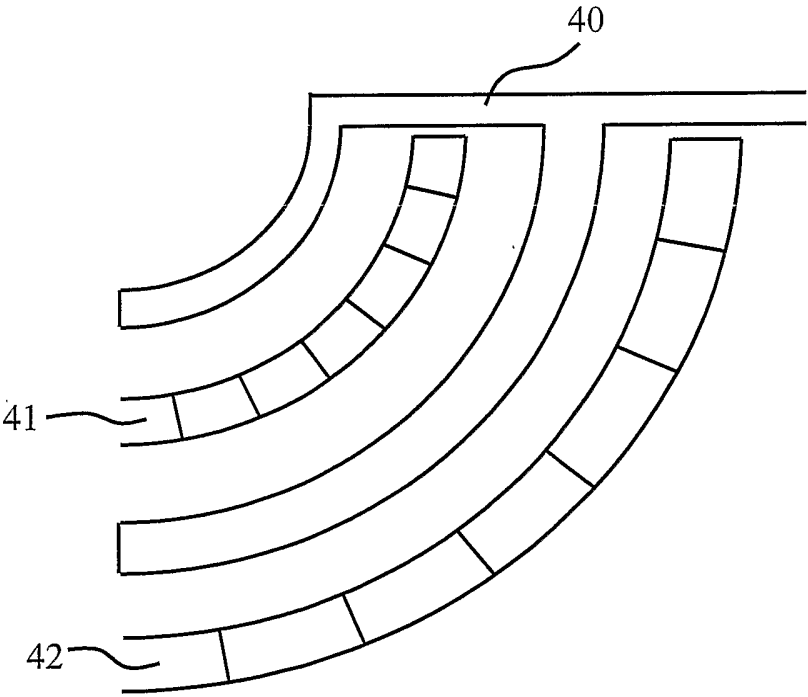


Figure 6

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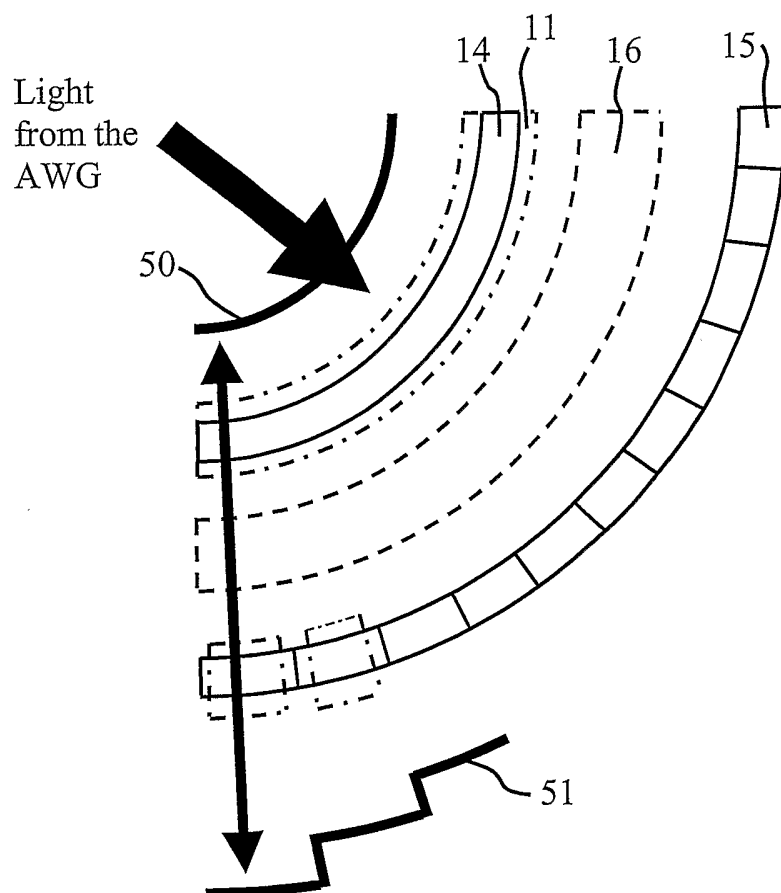


Figure 7

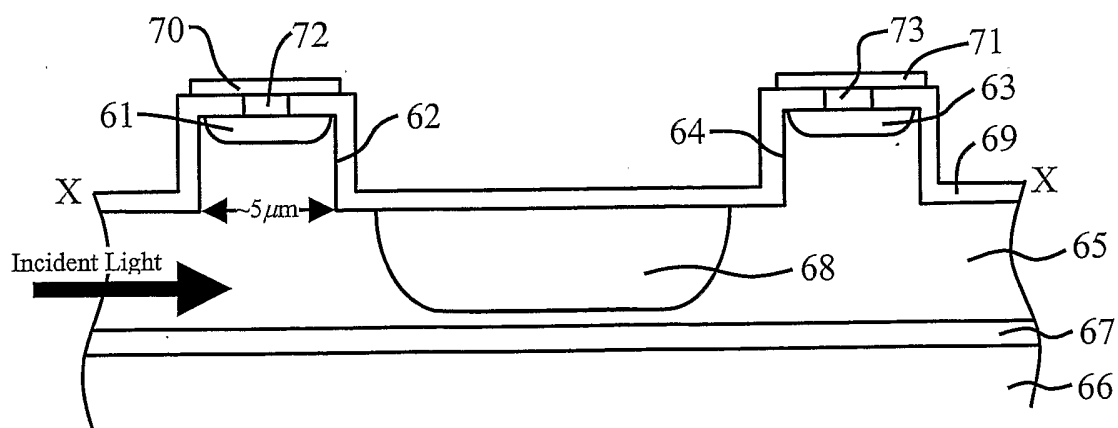


Figure 8

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 03/03181

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 H01L31/105 H01L27/146 H01L31/0232 G02B27/10

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 G02B H01L

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, INSPEC, PAJ, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 773 063 A (HUNSPERGER ROBERT G ET AL) 20 September 1988 (1988-09-20) column 7, line 10 - line 45; figure 2 column 9, line 28 - column 10, line 2 column 10, line 3 - line 24	1-11, 14-18, 21-27
X	KOHTOKU M ET AL: "POLARIZATION INDEPENDENT SEMICONDUCTOR ARRAYED WAVEGUIDE GRATINGS USING A DEEP-RIDGE WAVEGUIDE STRUCTURE" IEICE TRANSACTIONS ON ELECTRONICS, INSTITUTE OF ELECTRONICS INFORMATION AND COMM. ENG. TOKYO, JP, vol. E81-C, no. 8, August 1998 (1998-08), pages 1195-1204, XP000848521 ISSN: 0916-8524 page 1202 - page 1203; figures 19,20 ----- -/-	1-18, 22-27

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

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Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Agne, M

INTERNATIONAL SEARCH REPORT

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 822 428 A (HITACHI CABLE) 4 February 1998 (1998-02-04) abstract; figure 8 -----	

INTERNATIONAL SEARCH REPORT

Information on patent family members

Internati Application No

PCT/GB 03/03181

Patent document cited in search report		Publication date		Patent family member(s)	Publication date
US 4773063	A	20-09-1988	JP	61121007 A	09-06-1986
EP 0822428	A	04-02-1998	JP	2870499 B2	17-03-1999
			JP	10048440 A	20-02-1998
			CA	2198836 A1	03-02-1998
			DE	69704642 D1	31-05-2001
			DE	69704642 T2	29-05-2002
			EP	0822428 A1	04-02-1998
			US	5841919 A	24-11-1998