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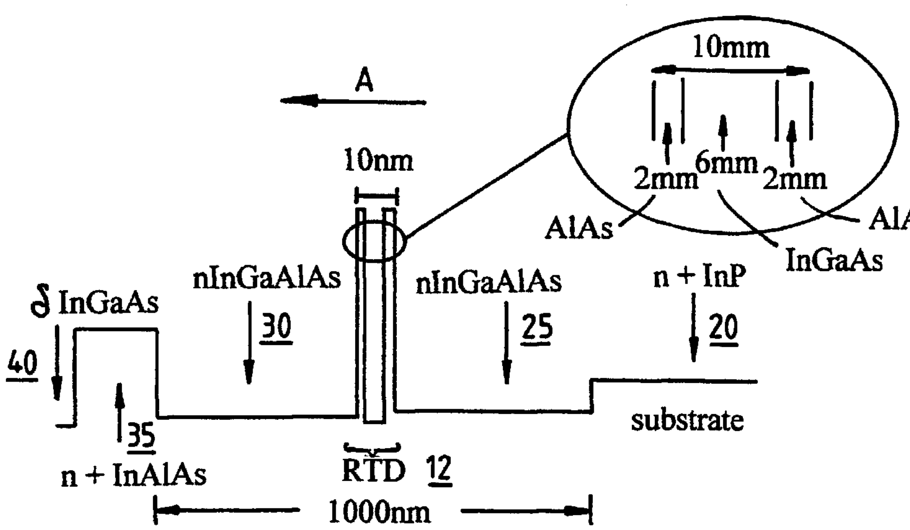
(54) Title: IMPROVED OPTOELECTRONIC DEVICE



(57) Abstract: There is disclosed an optoelectronic device (5) at least partially made from a quaternary III - V semiconductor alloy, the device (5) including at least one resonant tunnelling diode (RTD) (12). In a preferred embodiment the quaternary alloy is Indium Gallium Aluminium Arsenide (InGaAlAs). There is also disclosed an optical modulator (10) for modulation of electro-magnetic radiation in the wavelength region 1000 to 1600 nm, wherein the modulator (10) includes an RTD (12) for modulating the radiation.

WO 00/72383 A1

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IMPROVED OPTOELECTRONIC DEVICE

Background of the Invention

This invention relates generally to optoelectronic devices.

One aspect of the present invention relates to the use of quaternary III-V semiconductor alloys in the fabrication of optoelectronic devices, and in particular - though not exclusively - to the use of quaternary III-V semiconductor alloys in optoelectronic components integrated with resonant tunnelling divides (RTDs).

Another aspect of the present invention relates to optical modulators, and in particular - though not exclusively - to an optical modulator controlled or switched by a resonant tunnelling diode.

Regarding the aforementioned one aspect, it is among the objects of one or more embodiments of the one aspect of the present invention to provide an optoelectronic device which:

(a) uses a quaternary III-V semiconductor alloy (compound) which does not include Phosphorous (P) and is, therefore, particularly suitable for fabrication by Molecular Beam Epitaxy (MBE);

(b) provides for band-gap tuning and lattice matching to substrate;

(c) which at least when used as an optical detector provides for built-in amplification.

Regarding the aforementioned another aspect, modulators such as Electro Absorption modulators are employed in optical communication systems where they switch light from a laser source on and off according to an applied electrical signal, i.e. they convert information from electrical to optical form. Key performance factors are the power used by the device and the speed of the device.

It is an object of the another aspect of the present invention to obviate or mitigate one or more problems/disadvantages in known modulators.

It is a further object of at least one embodiment of the another aspect of the present invention to provide an optical modulator which uses less electrical power and/or operates at a higher speed than known modulators.

It is a yet further object of at least one embodiment of the another aspect of the present invention to provide an optical modulator which operates at a very low voltage, e.g. which can be switched on and off with an applied signal of less than 1 volt.

A device according to another aspect of the present invention may be used in telecommunications.

With the expansion of mobile communications, an optical fibre connection is required to each base station in a mobile network, and in future generations of mobile network there may be many more base stations; the next generation is the picocell network with a base only covering a range of a few tens of meters. The information from each of these stations may be encoded on to optical fibres, e.g. using electro absorption modulators.

A device according to the another aspect of the present invention may also be used in Wavelength Division Multiplexing (WDM), wherein separate wavelengths are used for each channel, and a modulator is required for each channel.

Summary of Invention

According to a first aspect of the present invention there is provided an optoelectronic device at least partially made from a quaternary III-V semiconductor alloy, the device including at least one resonant tunnelling diode (RTD).

The quaternary III-V semiconductor alloy may advantageously be Indium Gallium Aluminium Arsenide (InGaAsAs). Alternatively, the quaternary III-V semiconductor alloy may be Indium Gallium Arsenide Phosphide (InGaAsP).

A quaternary III-V semiconductor alloy layer may be provided on at least one side, and preferably both sides of the RTD.

In one embodiment the RTD may act as an electrically controlled optical device, eg. an optical modulator or alternatively as an optical switch. In another embodiment the RTD may act as an optically controlled electrical device, eg. an optical detector.

According to a second aspect of the present invention there is provided a base station of a communication network, the station including at least one optoelectronic device according to the first aspect.

According to a third aspect of the present invention there is provided a communication network including at least one optoelectronic device according to the first aspect.

According to a fourth aspect of the present invention there is provided use of a quaternary III-V semiconductor alloy in the fabrication of an optoelectronic device, the optoelectronic device including a resonant tunnelling diode (RTD).

According to a fifth aspect of the present invention there is provided an optical modulator for modulation of electro-magnetic radiation in a wavelength region 1000 to 1600 nanometres (nm), wherein the modulator includes a resonant tunnelling diode (RTD) for modulating the radiation.

Advantageously, the modulator may include means for guiding the radiation, e.g. a waveguide.

Advantageously, the modulator is fabricated at least partially from Indium Gallium Aluminium Arsenide (InGaAlAs).

Advantageously, the RTD is fabricated at least partially from InGaAlAs.

In one embodiment of the fifth aspect of the present invention there is provided a unipolar electro-optical and/or electro-absorption modulator for operation in a wavelength region 1000-1600nm, the modulator being made at least partly from InGaAlAs, modulation being based on electric fields switched by an RTD.

According to a preferred form of the fifth aspect of the present invention there is provided an electro-absorption modulator of light at around 1550nm in wavelength in a unipolar InGaAlAs optical waveguide containing an InGaAs/AlAs double-barrier resonant tunnelling diode (DB-RTD). The RTD peak to valley transition may increase the electric field across the waveguide, which shifts the core material absorption band-edge to longer wavelengths via the Franz-Keldysh effect thus changing the light guiding characteristics of the waveguide. Low-frequency characterisation of a device has shown modulation up to 28 dB at 1565nm. When DC biased close to the negative differential resistance (NDR) region, the RTD optical waveguide behaves as an electro-absorption modulator integrated with a wide bandwidth electrical amplifier, offering a potential advantage over conventional pn modulators.

According to a sixth aspect of the present invention there is provided a base station of a communication network, the station including at least one optical modulator according to the fifth aspect.

According to a seventh aspect of the present invention there is provided a communication network including at least one optical modulator according to the first aspect.

Brief Description of the Drawings

An embodiment of the present invention will now be described, by way of example only, with reference to the accompanying drawings, which are:

Figure 1(A) a schematic diagram of a wafer structure for use in fabrication of a device according to an embodiment of the present invention;

Figure 1(B) a perspective view of a resonant tunnelling diode (RTD) optical modulator according to an embodiment of the present invention made from the wafer of Figure 1 (A);

Figure 2 an experimental I-V characteristic of a 2μm active area RTD optical waveguide, showing a PVCR around 7 and a peak current density of 17.5kA/cm^2; and

Figure 3 modulation depth enhancement as a function of wavelength, induced by the RTD peak-to-valley transition.

Detailed Description of Drawings

Referring to Figures 1(A) and (B), there is shown an optoelectronic device 5 comprising part of an optical modulator, generally designed 10, according to an embodiment of the present invention. The modulator 10 is intended to modulate light in the wavelength region 1000-1600nm, and preferably at around 1550nm, by use of a resonant tunnelling diode (RTD) 12 formed in the modulator 10. The modulator 10 includes a waveguide 15 operatively associated with the RTD 12. The modulator 10 according to this embodiment of the invention may, therefore, be termed a resonant tunnelling diode electro-absorption modulator (RTD-EAM). RTD's are advantageous due to their high speed response and potential for electrical gain over a wide bandwidth.

The operation of the device 5 is based on the RTD 12 within the optical waveguide 15 which introduces a non-uniform electric field distribution across a core of the waveguide 15. The electric field becomes strongly dependent on the bias voltage due to accumulation and depletion of electrons in the emitter and collector sides of the RTD 12, respectively. Depending on the DC bias operating point, a small high frequency AC signal (<1V) can induce high-speed switching. This produces substantial high-speed modulation of the waveguide optical absorption coefficient at a given wavelength near the material band-edge via the Franz-Keldysh effect and, therefore, modulates light at photon energies lower than the waveguide core band-gap energy. The modulation depth can be considered because, under certain conditions, the RTD operation point switches well into the two positive differential resistance portions of the current-voltage I-V characteristic, with a substantial part of the terminal voltage dropped across the depleted region in the collector side. The advantage of RTD-EAM compared to the conventional pn modulators is that, when DC biased close to the negative differential resistance (NDR) region, the device 5 behaves as an optical waveguide electro-absorption modulator integrated with a wide bandwidth electrical amplifier.

The high-frequency and large modulation depth characteristics of the RTD-EAM are a direct consequence of the carrier transport mechanisms across the RTD 12 and a depletion region of the waveguide 15. They are closely related to the material system and the specific device structure. High-speed performance can be improved by increasing the differential negative resistance (NDR), R_n, or decreasing the series resistance, R_s. The velocity of the carriers, v, and hence the carriers transit time across the whole structure are material and structure dependent. To obtain a larger value of R_n, it is necessary to achieve a high peak current density, J_p, and a low valley current, J_v.

The demonstration and development of this new modulator concept in the InGaAs-InAlAs material system lattice matched to InP appear to be a promising route towards high speed, low radio frequency (rf) power consumption, optoelectronic converters (rf-optical and optical-rf), because it can cover the waveguide range 1.0 to 1.6 μm where optical fibres have the lowest loss and chromatic dispersion. This disclosure teaches modulation of light at wavelengths around 1550nm in a unipolar InGaAIAs optical waveguide containing a InGaAs/AIAs double-barrier resonant tunnelling diode (RTD). Furthermore, due to a smaller effective mass for the electrons in InGaAs (0.045m_o compared to 0.067m_o for GaAs), and a larger Γ_{InGaAs}

$-X_{alAs}$ barrier height (0.65 eV compared to 0.20 eV GaAs/AlAs) which will reduce the parasitic Γ-X mediated transport, the InGaAs-InAlAs material system has improved tunnelling characteristics with a superior peak-to-valley current ratio evident in the dc current-voltage characteristics. In addition, by changing the material to InGaAs/AlAs, a specific contact resistivity less than 10^{-7} Ωcm^2 and a saturation velocity higher than 10^7 cm/s can be achieved. For GaAs/AlGaAs, typical metal to n^+- GaAs contacts have a specific contact resistivity of about 10^{-6} Ωcm^2, and the saturation velocity of electrons in GaAs layers is less than 10^7 cm/s. In GaAs/AlAs RTDs can present higher peak current density and smaller valley current density, higher-speed operation can be expected.

The use of the InGaAs/AlAs system shifts the wavelengths of operation to optical communication wavelengths, and also gives a significant improvement in the electrical characteristics of the devices compared to the GaAs/AlAs system.

The InGaAlAs RTD optical waveguide structure may be grown by Molecular Beam Epitaxy (MBE) in a Varian Gen II system, on a n^+ InP substrate 20 (see Fig. 1(A)). It consists of two 2 nm thick AlAs barriers separated by a 6nm wide InGaAs quantum well, sandwiched between two 500nm thick moderately doped (Si: $5x10^{16}$ cm^{-3}) InGaAs spacer layers 25,30 which form the waveguide core. The InP substrate and a top heavily doped (Si: $2x10^{18}$ cm^{-3}) InAlAs region 35 provide the waveguide cladding layers, which confine the light in a direction parallel to the double barrier plane, thus increasing the interaction length between the electric and the optical fields. A δ-doped InGaAs cap layer 40 is provided for formation of Au-Ge-Ni ohmic contacts.

Ridge waveguides (2 to 6 μm wide) and large-area mesas in each side of the ridges may be fabricated by wet-etching. Ohmic contacts (100 to 400 μm long) may then be deposited on top of the ridges and mesas. The waveguide width and the ohmic contact length define the device 5 active area. A SiO_2 layer may be deposited, and access contact windows etched on the ridge and the mesa electrodes [Fig. 1(B)], allowing contact to be made to high frequency bonding pads (coplanar waveguide transmission line, CPW 45). After cleaving, the device 5 may be die bonded on packages allowing light coupling into the waveguide 15 by a microscope objective end-fire arrangement.

The DC I-V characteristics of packaged devices 5 have been measured using a HP 4145 parametric analyser and show typical RTD behaviour. From the I-V characteristics one can estimate the electric field change across the depleted portion of the waveguide core due to RTD peak-to-valley switching. Figure 2 shows the I-V characteristic of a 2μm x 100μm active area RTD 12. Typical devices 5 have peak current density around 20 kA/cm^2, with a peak-to-valley current ratio (PVCR) of 4. The difference between the valley and peak voltages, ΔV, is around 0.8V, and the difference between the peak and valley current densities, $\Delta J = J_p(1 - PVCR^{-1})$, is about 15kA/cm^2. (Typical GaAs/AlAs devices show a PVCR around 1.5, J_p ~ 13 kA/cm^2, ΔV ~ 0.4V, and ΔJ ~ 5 kA/cm^2).

Two important figures of merit of the modulator 10 can be estimated from the RTD DC characteristics, and for a given material system they can be tailored by structural design. They are the modulator bandwidth, which is related to the 10%-90% switching time, t_R, of the RTD 12 between the peak and valley points, and the modulation depth, which is related to the peak-to-valley current ratio. The switching time of the RTD 12 can be estimated from $t_R = 4.4\ (\Delta V/\Delta J)\ C_v$, where C_v is the capacitance at the valley point per unit area ($C_v = \varepsilon/W$, where ε is the dielectric constant, and W is the depletion region width). For the present device 5 $W = 0.5\ \mu m$ and $\varepsilon = 13\varepsilon_0$, $t_R = 5$ ps. From this switching time, one can expect devices 5 with a bandwidth larger than 60 GHz.

Experimental optical characterisation of the modulator 10 employed light from a Tunics diode laser, tuneable in the wavelength region around the absorption edge of the

InGaAlAs waveguide (1480-1580nm). The laser light was coupled into the waveguide 15 by a microscope objective end-fire arrangement. To measure the change in the optical absorption spectrum induced by the peak-to-valley transition, a low frequency rf signal was injected to switch the RTD 12 between the extremes of the NDR region, and a photodetector was used to measure the transmitted light. The applied electric field enhancement is given by:

$$\Delta E \sim \frac{\Delta V}{W} + \frac{W}{2\varepsilon v_{sat}} \Delta J$$

Taking $\varepsilon=13\varepsilon_0$ and $v=1x10^7$ cm/s (electron saturation velocity in the depletion region), and assuming the depletion region to be 500nm wide, we have ΔE=47 kV/cm (for the GaAs based device we obtained ΔE=20kV/cm). The shift in the transmission spectrum due to electric field enhancement in the InGaAlAs depletion region, as a result of the Franz-Keldysh effect, is given approximately by:

$$\Delta\lambda_g \sim \frac{\lambda_{2g}}{hc} \sqrt{\frac{e^2h^2}{2m_r} \Delta E^2}$$

where m_r is the electron-hole system reduced effective mass, *h* is Planck's constant, *c* is the light velocity, *e* is the electron charge, and λ_g is the wavelength corresponding to the waveguide transmission edge at zero bias, which is around 1520nm. The observed band edge shift associated with peak-to-valley switching is approximately $\Delta\lambda_g$ = 30nm, which agrees with the expression above and confirms that ΔE is approximately 47kV/cm.

Figure 3 shows modulation depth as a function of the wavelength for peak-to-valley switching induced by a low-frequency, i.e. < 10kHz square wave signal with 1V amplitude for a 4μm x 200μm active area. A maximum modulation depth of 28 dB was obtained at 1565nm.

In conclusion, optical modulation up to 28 dB has been demonstrated in InGaAlAs optical waveguides containing an

InGaAs/AlAs double-barrier resonant tunnelling diode (RTD), due to peak-to-valley switching. Integration of a RTD with an optical waveguide, which combines a wide bandwidth electrical amplifier with an electro-absorption modulator, opens up the possibility for a variety of operation modes (such as modulation due to self-oscillation and relaxation oscillation).

It will be appreciated that the embodiment of the present invention hereinbefore described is given by way of example only, and is not meant to limit the scope thereof in any way.

Particularly, it will be appreciated that the device disclosed may have an operational speed limited by its packaging of around 8GHz bandwidth. However, it will be understood that a device according to the invention may have a much large bandwidth, e.g. it is envisaged that up to 60 Ghz is possible.

It will further be appreciated that although the optoelectronic device 5 has hereinbefore been described as an electrically controlled optical device, eg. an optical modulator 10 or switch, wherein an input signal in the form of an applied electrical signal modulates an output signal in the form of an optical signal, the device 5 may also be used in reverse, ie. as an optically controlled electrical device eg. as an optical detector wherein the input signal is in the form of an applied optical signal which controls an output signal in the form of an electrical signal. It will be appreciated that such an optical detector will act, in use, as if it were provided with a built-in amplifier.

CLAIMS

1. An optoelectronic device at least partially made from a quaternary III - V semiconductor alloy, the device including at last one resonant tunnelling diode.

2. An optoelectronic device as claimed in claim 1, wherein the quaternary III - V semiconductor alloy is Indium Gallium Aluminium Arsenide (InGaAlAs).

3. An optoelectronic device as claimed in claim 1, wherein the quaternary III - V semiconductor alloy is Indium Gallium Arsenide Phosphide (InGaAsP).

4. An optoelectronic diode as claimed in any of claims 1 to 3, wherein a quaternary III - V semiconductor alloy layer is provided on at least one side of the at least one resonant tunnelling diode.

5. An optoelectronic device as claimed in claim 4, wherein quaternary III - V semiconductor layers are provided on both sides of the at least one resonant tunnelling diode.

6. An optoelectronic device as claimed any of claims 1 to 5, wherein the resonant tunnelling diode acts as an optical modulator or switch.

7. An optoelectronic device as claimed in any of claims 1 to 5, wherein the resonant tunnelling diode acts as an optical detector.

8. A base station of a communication network, the station including at least one optoelectronic device according to any of claims 1 to 7.

9. A communication network including at least one optoelectronic device according to any of claims 1 to 7.

10. An optical modulator for modulation of electromagnetic radiation in a wavelength region 1000 to 1600 nanometres (nm), wherein the modulator includes a resonant tunnelling diode for modulating the radiation.

11. An optical modulator as claimed in claim 10, wherein the modulator includes means for guiding the radiation.

12. An optical modulator as claimed in either of claims 10 or 11, wherein the modulator is fabricated at least partially from Indium Gallium Aluminium Arsenide (InGaAlAs).

13. An optical modulator as claimed in either of claims 10 or 11, wherein the resonant tunnelling diode is fabricated at least partially from Indium Gallium Aluminium Arsenide (InGaAlAs).

14. An optical modulator comprising a unipolar electro-optical and/or electro-absorption modulator for operation in a wavelength region 1000-1600 nm, the modulator being made at least partly from Indium Gallium Aluminium Arsenide (InGaAlAs), modulation being based on electric fields switched by a resonant tunnelling diode (RTD).

15. A modulator as claimed in claim 14, wherein the modulator is an electro-absorption modulator of radiation at around 1550 nm in wavelength the modulator including a unipolar InGaAlAs optical waveguide containing an Indium Gallium Arsenide/Aluminium Arsenide (InGaAs/AlAs) double-barrier resonant tunnelling diode (DB-RTD).

16. A modulator as claimed in claim 15, wherein in use, the resonant tunnelling diode peak to valley transition increases an electric field across the waveguide thereby shifting a core material absorption band-edge to longer wavelengths via the Franz-Keldysh effect thus changing radiation guiding characteristics of the waveguide.

17. A modulator as claimed in either of claims 15 or 16, wherein, in use, when DC biassed close to a negative differential resistance (NDR) region the waveguide and resonant tunnelling diode act as an electro-absorption modulator integrated with a wide band electrical amplifier.

18. A base station of a communication network, the station including at least one optical modulator according to any of claims 10 to 17.

19. A communication network including at least one optical modulator according to any of claims 10 to 17.

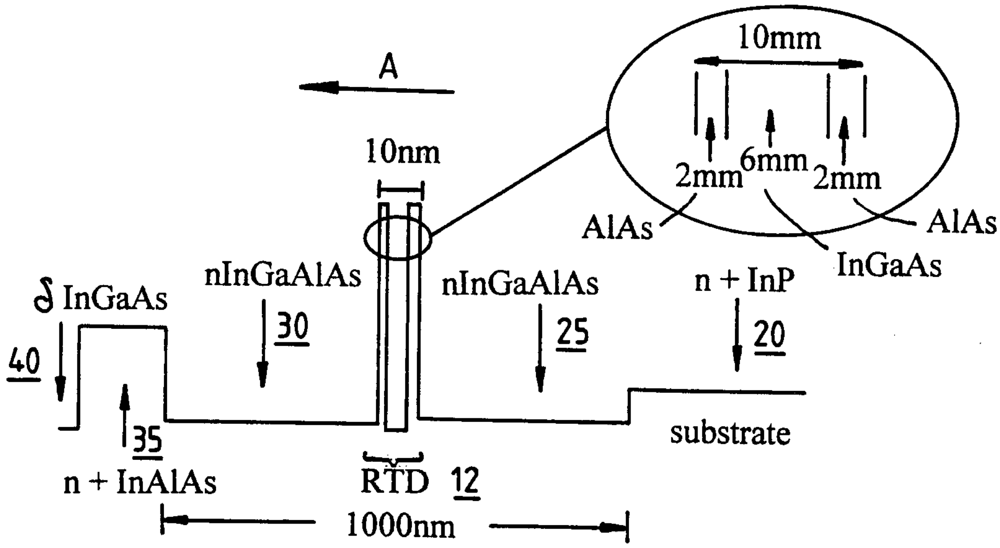
A
10mm
2mm
6mm
2mm
AlAs
InGaAs
AlAs
10nm
δ InGaAs
nInGaAlAs
nInGaAlAs
n + InP
40
30
25
20
35
substrate
n + InAlAs
RTD 12
1000nm

Fig. 1(A)

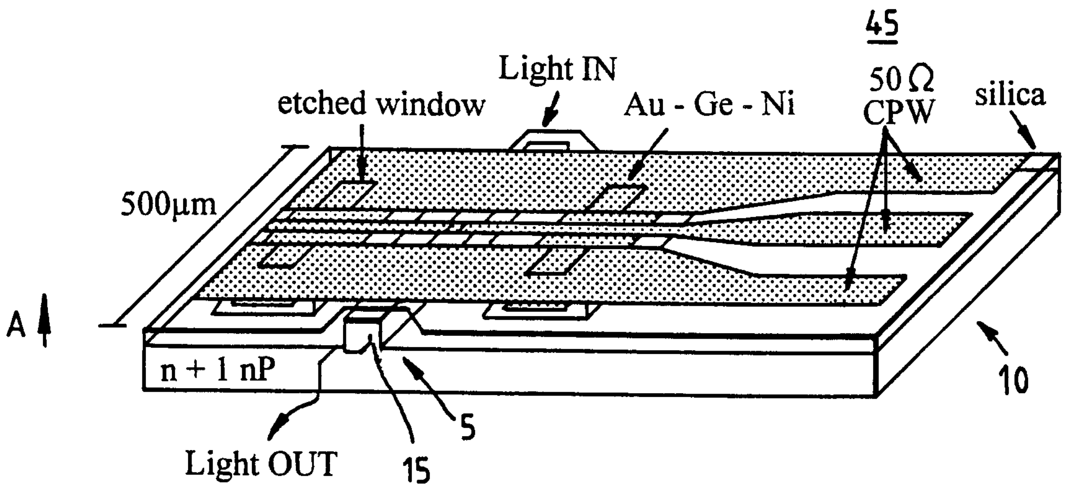
45
Light IN
50 Ω
CPW
silica
etched window
Au - Ge - Ni
500μm
A
n + 1 nP
10
5
Light OUT
15

Fig. 1(B)

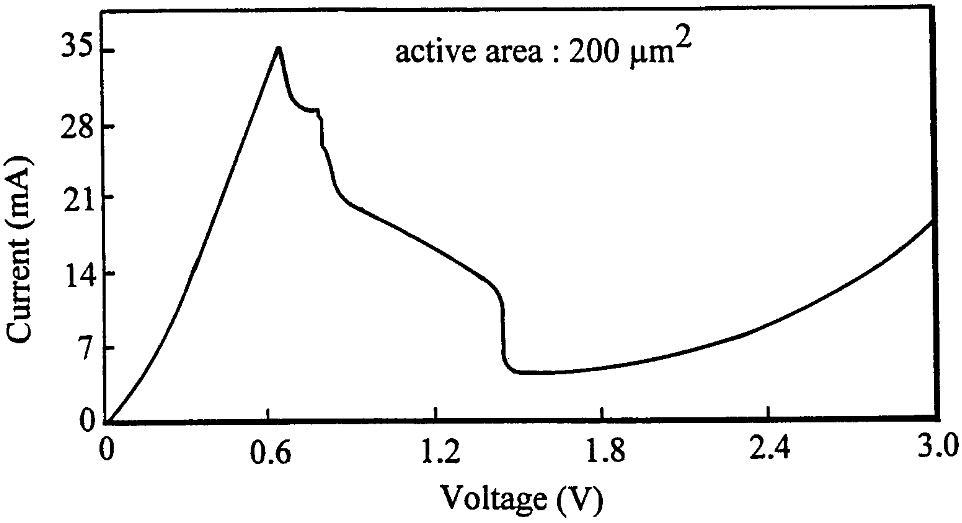
active area : 200 μm2
Current (mA)
35
28
21
14
7
0
0
0.6
1.2
1.8
2.4
3.0
Voltage (V)

Fig. 2

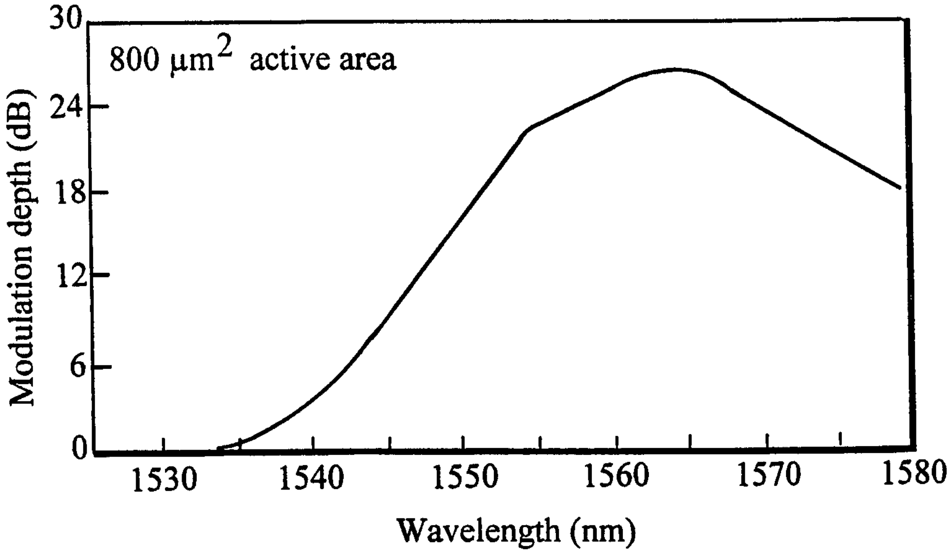
800 μm2 active area
Modulation depth (dB)
30
24
18
12
6
0
1530
1540
1550
1560
1570
1580
Wavelength (nm)

Fig. 3

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 00/02112

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01L29/88 G02F1/017 H01L31/0352

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 H01L G02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 689 250 A (KOKUSAI DENSHIN DENWA CO LTD) 27 December 1995 (1995-12-27) column 9, line 46 -column 12, line 13 figures 16-19	1-7, 10-15,17
Y		16,18,19

X	EP 0 706 225 A (TEXAS INSTRUMENTS INC) 10 April 1996 (1996-04-10)	1,2,4, 7-9
Y	page 4, line 25 -page 5, line 36 page 9, line 10 -page 10, line 6 figures 3,14,17,18	18,19

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

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

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"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

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Date of the actual completion of the international search	Date of mailing of the international search report
27 October 2000	15/11/2000

Name and mailing address of the ISA	Authorized officer
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	Visscher, E

Form PCT/ISA/210 (second sheet) (July 1992)

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	FIGUEIREDO J M L ET AL: "Integration of a RTD with an optical waveguide to form a high speed electroabsorption modulator" IEE COLLOQUIUM ON OPTOELECTRONIC INTEGRATION AND SWITCHING (REF. NO.1997/372), IEE COLLOQUIUM ON OPTOELECTRONIC INTEGRATION AND SWITCHING (REF. NO.1997/372), GLASGOW, UK, 13 NOV. 1997, pages 6/1-6, XP002151207 1997, London, UK, IEE, UK See sections: Introduction Device preparation Operation principle Conclusion ---	16
X	PATENT ABSTRACTS OF JAPAN vol. 017, no. 338 (P-1564), 25 June 1993 (1993-06-25) -& JP 05 045692 A (KOKUSAI DENSHIN DENWA CO LTD), 26 February 1993 (1993-02-26) abstract ---	1-7, 10-14
X,P	FIGUEIREDO J M L ET AL: "Self-oscillation in a resonant tunnelling diode electroabsorption modulator" TECHNICAL DIGEST. SUMMARIES OF PAPERS PRESENTED AT THE CONFERENCE ON LASERS AND ELECTRO-OPTICS. POSTCONFERENCE EDITION. CLEO '99. CONFERENCE ON LASERS AND ELECTRO-OPTICS (IEEE CAT. NO.99CH37013), TECHNICAL DIGEST. SUMMARIES OF PAPERS PRESENTED AT THE, pages 125-126, XP002151208 1999, Washington, DC, USA, Opt. Soc. America, USA ISBN: 1-55752-595-1 the whole document -----	1,2,6,7, 10-17

INTERNATIONAL SEARCH REPORT

..iformation on patent family members

International Application No
PCT/GB 00/02112

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0689250 A	27-12-1995	JP 8008443 A	12-01-1996
		US 5952683 A	14-09-1999
EP 0706225 A	10-04-1996	JP 8111540 A	30-04-1996
JP 05045692 A	26-02-1993	JP 2678698 B	17-11-1997