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(71) **Applicant**: **FRAUNHOFER-GESELLSCHAFT ZUR FÖRDERUNG DER ANGEWANDTEN FORSCHUNG E.V.** [DE/DE]; Hansastrasse 27c, 80686 München (DE).

(72) **Inventors**: **MÖHRLE, Martin**; Bültenring 7, 12683 Berlin (DE). **THEURER, Michael**; Proskauer Strasse 31, 10247 Berlin (DE). **SIGMUND, Ariane**; Marchlewski Straße 100, 10243 Berlin (DE). **TROPPENZ, Ute**; Müngersdorfer Strasse 39 E, 12524 Berlin (DE).

(74) **Agent**: **MAIKOWSKI & NINNEMANN**; 15 09 20, 10671 Berlin (DE).

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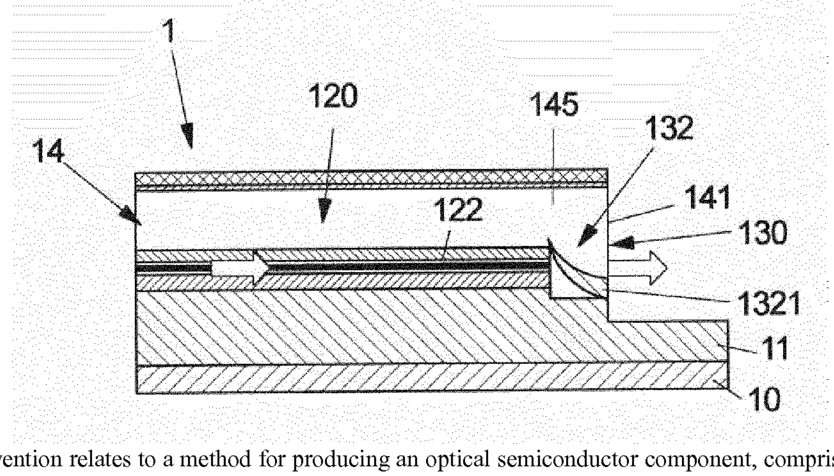
(54) **Title**: METHOD FOR PRODUCING AN OPTICAL SEMICONDUCTOR COMPONENT AND OPTICAL SEMICONDUCTOR COMPONENT

FIG 4



(57) **Abstract**: The invention relates to a method for producing an optical semiconductor component, comprising the steps of fabricating an optical waveguide strip (12) of an optical waveguide (120), the waveguide strip (12) comprising at least one aluminium-containing active layer (122); generating at least one aluminium-free optically and/or electrically functional layer (13) in such a way that it comprises a first and a second portion (131, 132), wherein the first portion (131) extends laterally along and/or above the waveguide strip (14) and the second portion (132) covers at least one face (140) of the waveguide strip (12) at least in the region of the active layer (122); completing the optical waveguide (120); and generating at least one optical facet (130) for injecting light into or emitting light from the optical waveguide (120). The invention also relates to an optical semiconductor component.

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Method for producing an optical semiconductor component and optical semiconductor component

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Description

The invention relates to a method for producing an optical semiconductor component according to claim 1 and optical semiconductor component according to claim 12.

It is known to use aluminium-containing semiconductor layers (e.g. multi-quantum well – MQW layers such as InGaAlAs-MQW layers) as active material of semiconductor lasers or amplifiers. These components have the potential for an improved high temperature behavior because of the larger discontinuities of the conduction band and therefore may be operated under less power consumption and may not require an active cooling device.

However, the active layers may oxidize because of their aluminum content; for example, during a cleaving or etching step for generating optical input and/or output facets. An oxide layer on the optical facets absorbs light which increases the temperature such that during the operation of the component the optical facets may be damaged or even destroyed. The oxide layer on the laser facets may be removed and the facets may be covered by passivating layers. Further, if the optical facets are generated by means of an etching process, a protective material may be grown for protecting the facets as disclosed in DE 101 57 233 A1. However, this method of protecting the optical facets requires at least one additional epitaxy step, thereby e.g. increasing the fabrication costs.

It is an object of the invention to protect the optical facets while keeping the fabrication process as simple as possible.

According to the invention, a method for producing a optical semiconductor component is provided, comprising the steps of:
- fabricating an optical waveguide strip of an optical waveguide (e.g. an optical waveguide layer stack), the waveguide strip comprising at least one aluminium-containing active layer;
- generating at least one aluminium-free optically and/or electrically functional layer in such a way that it comprises a first and a second portion, wherein the first portion extends laterally along and/or above the waveguide strip and the second portion covers at least one face (front and/or rear face) of the waveguide strip at least in the region of the active layer;
- completing the optical waveguide; and
- generating at least one optical facet for injecting light into or emitting light from the optical waveguide.

The second portion of the functional layer protects the face of the waveguide strip against oxidization and thus e.g. avoids aging problems due to an oxidation of waveguide facets. The functional layer in particular is a layer that has an electrical and/or optical function in the completed optical semiconductor component, i.e. a layer which has not only been provided for protecting the face of the of the waveguide strip. That is, instead of generating an additional layer or an additional material region for the only purpose of protecting the face of the waveguide strip, at least one of the component's functional layers, which in any case has to be generated, is modified such as to also cover at least one of the waveguide strip's faces (i.e. the front and/or rear face). Thus, no additional production step is needed for the protection of the active layer of the waveguide strip.

The “face” of the waveguide strip is a face that extends with an angle (e.g. perpendicular) with respect to the longitudinal direction of the waveguide strip (at least with respect to the longitudinal direction of the corresponding waveguide strip ending). If the optical waveguide comprises two light coupling endings (as e.g. in an optical amplifier) such that the waveguide strip has a front and a rear face, the functional layer (i.e. its second portion) can be formed in such a way that it covers both the front and the rear face of the waveguide strip as mentioned above.

The optical facet provides an optical interface of the completed optical semiconductor component via which light is coupled into the optical waveguide and/or light is decoupled from the optical waveguide. In particular, the optical facet is created in such a way that the face of the waveguide strip remains covered by the second portion of the functional layer. Accordingly, the second portion of the functional layer may not be removed before generating the optical facet.

For example, the optical facet is created in such a way that it is at least partially formed by a face of an aluminum-free material region adjacent the face of the waveguide strip, the material region comprising at least a section of the second portion of the functional layer of the optical semiconductor component. For example, the material region comprises the second portion of the functional layer and/or a portion of another layer (e.g. of an upper cladding layer) of the optical semiconductor component. According to another embodiment of the invention, the optical facet is generated using an etching (wet or dry etching) or a cleaving method.

The method according to the invention may be used for fabricating a buried heterostructure component such as a buried heterostructure laser (e.g. a DFB laser, a DBR laser, a horizontal cavity surface-emitting laser - HCSEL or a broad area laser) or amplifier (i.e. a semiconductor optical amplifier – SOA or a reflective semiconductor optical amplifier – RSOA). The method, however, may also be used for fabricating other devices such as photodiodes or arrays of optical semiconductor components (see below). Further, the component might have different active layers (e.g. different InGaAlAs-MQW layers).

Further, the functional layer may be an epitaxially grown layer. For example, the functional layer is a blocking layer (in particular, of a buried heterostructure component).

Moreover, before generating the optical facet, at least one cladding layer of the optical waveguide may be generated above the functional layer.

For example, the active layer is a layer of a MQW stack such as an InGaAlAs-MQW stack.

The invention also relates to a optical semiconductor component, in particular fabricated using the method as described above, the component comprising

- an optical waveguide that comprises a waveguide strip having at least one aluminium-containing active layer;
- at least one aluminium-free optically and/or electrically functional layer comprising a first and a second portion, wherein the first portion extends laterally to and/or above the active layer and the second portion covers at least one face of the waveguide strip at least in the region of the active layer; and
- at least one optical facet for injecting light into or emitting light from the optical wave-guide.

The optical semiconductor component may be a buried heterostructure component such as a buried heterostructure laser or amplifier. For example, the optical facet is formed by an aluminum-free material region adjacent the face of the waveguide strip, the material region comprising at least a section of the second portion of the functional layer of the optical semiconductor component.

The invention further relates to an array of a plurality of optical semiconductor components according to the invention. For example, at least some of the optical semiconductor components of the array may have different active layers (e.g. different MQWs). However, other layers of the two optical semiconductor components may be identical; e.g. the functional layer and/or an upper cladding layer.

For example, the invention relates to an array comprising optical semiconductor components in the form of SOAs, RSOAs, DFB lasers, DBR lasers and/or HCSELs, wherein the active layers of at least some of the optical semiconductor components might be different (e.g. different InGaAlAs-MQW layers) as already mentioned above. Further, at least some of the components may comprise different active layers (e.g. different InGaAlAs-MQW layers). Of course, the optical semiconductor components of the array may also comprise identical active layers. The array may have optical faces on front and/or rear sides of the individual waveguide strips (generated by e.g. cleaving or etching) providing optical facets of the semiconductor components.

Embodiments of the invention are described hereinafter with reference to the drawings, in which:

Figures 1A to 3B	illustrate steps during the fabrication of an optical semiconductor component using a method according to an embodiment of the invention;
Figure 4	shows a lateral view of an optical semiconductor component according to an embodiment of the invention;
Figure 5	shows a lateral view of an optical semiconductor component according to another embodiment of the invention;
Figure 6	depicts a front view of an array of optical semiconductor components according to an embodiment of the invention;
Figures 7 to 9	depicts top views of arrays of optical semiconductor components.

Figures 1A to 3A each show front views of a semiconductor structure during different steps of a method according to an embodiment of the invention. More particularly, the method is used for the production of a optical semiconductor component in the form of a buried heterostructure (BH) component (e.g. a laser or an optical amplifier). Figures 1B to 3B show the semiconductor structure in corresponding side views.

According to Figure 1A, lower cladding layers 11 (e.g. n-doped Indiumphosphide layers) or a single lower cladding layer are arranged on a substrate 10 (e.g. an Indiumphosphide - InP substrate). Further, a waveguide strip 12 is produced by arranging and structuring a plurality of lower waveguiding layers 121, a plurality of active layers in the form of aluminum-containing multi-quantum well layers 122 and upper waveguiding layers 123. The multi-quantum well layers 122 (forming e.g. an InGaAlAs-MQW stack) form both the active region and, together with the waveguiding layers (121, 123), the core of the optical waveguide of the optical semiconductor component.

The layers 121 – 123 are structured laterally and may also be structured in their front and end regions such that the waveguide strip 12 is formed (which at this stage of the fabrication of the semiconductor component has a ridge shape protruding from the lower cladding layer 11).

In a subsequent production step (Figures 2A and 2B), functional layers in the form of blocking layers 13 are epitaxially grown in such a way that they comprises a first portion 131 having subsections 131a, 131b extending along opposite longitudinal sidewalls of the waveguide strip 12. The first portion 131 of blocking layers 13 is at least partially arranged on the lower cladding layer 11 and also covers the longitudinal sidewalls of the waveguide strip 12. The blocking layers 13 may be formed by p- and n-InP or a semi-insulating material (e.g. semi-insulating InP). If a DFB laser shall be produced, a Bragg grating will be generated before growing the blocking layers 13.

The blocking layers 13 further comprise a second portion 132 which covers a front face 140 of waveguide strip 12 and in particular covers the front face of the active MQW layers 122. The second portion 132 thus prevents oxidization of the front face of the aluminum-containing MQW layers 122. Protecting the face 140 of the waveguide strip 12 e.g. allows to keep the cleaved optical semiconductor component under normal ambient conditions (e.g. in normal ambient air) for a longer period of time.

After growing the blocking layers 13, upper (e.g. p-doped) cladding layers 14 (or a single upper cladding layer) are grown such that an optical waveguide 120 is realized comprising at least the lower cladding layer 11, the waveguide strip 12 and at least portions of the upper cladding layers 14. The upper cladding layers 14 comprise a section 145 extending adjacent the second portion 132 of the blocking layers 13. The section 145 of the upper cladding layers 14 and the second portion 132 of the blocking layers 13 thus form an aluminum free material region protecting the front face 140 of waveguide strip 12. Figures 3A and 3B show the completed BH structure. The blocking layers 13 and the upper cladding layers 14 together at least essentially hermitically cover the entire active layers 122 such that a laser 1 (or any other optical semiconductor component produced by means of the method according to the invention) is e.g. suited for an airtight packaging of the optical semiconductor component.

For generating an optical facet of the optical waveguide 120 permitting light produced by the laser 1 to be coupled out of its optical waveguide 120, an etching process (such as a wet etching process or dry etching process) is used. The etching process is carried out in such a way that an optical facet 130 is formed in the aluminum-free material region provided by section 145 of the upper cladding layers 14 and the second portion 132 of the blocking layers 13. More particularly, the optical facet 130 is formed by a face 1321 of the second portion 132 of the blocking layers 13 and a face 141 of the upper cladding layer 14.

For example, the optical facet 130 extends vertically, i.e. perpendicular to the optical waveguide 120, through the upper cladding layer 14 and the second portion 132 of the blocking layers 13 (Figures 2B and 4) or the optical facet 130 extends obliquely (with respect to the optical waveguide 120) through the upper cladding layer 14 and the second portion 132 of the blocking layers 13 (Figures 2B and 5). It is also possible that only section 145 of the upper cladding layers 14 (which also can be regarded as “functional layer”) covers the front face 140 of waveguide strip 12 such that the entire optical facet 130 is formed in the cladding layer section 145. The optical facet 130 may be coated, e.g. using a high reflection or anti-reflection coating.

Figure 6 relates to an array 200 comprising a plurality of optical semiconductor components 100a – 100e according to the invention, wherein each of the components 100a – 100e is a buried heterostructure component such as a laser or an amplifier. It is possible that at least some of the components have different active layers such that components with different properties are realized. For example, components 100a and 100b comprise different multi-quantum well layers 122a, 122b. However, the optical semiconductor components 100a – 100e are arranged on a common substrate 10 and may share some functional layers such as the lower and the upper cladding layers 11, 14. Further, the blocking layers 13a – 13e may be grown simultaneously (i.e. using the same processing step).

Figure 7 depicts a top view of an array 200 of optical semiconductor components 100a – 100e (e.g. configured similarly or identically to the array shown in Fig. 6). Each one of the components comprises a front optical facet 130a – 130e and a rear optical facet 1300a – 1300e. The optical facets are created by cleaving the substrate 10 (and the layers arranged on the substrate) perpendicular to the direction of the optical semiconductor strip 100a – 100e (i.e. perpendicular to their optical waveguides).

According to the embodiment of Fig. 8, the front and rear optical facets 130a – 130e, 1300a – 1300e are generated by means of an etching process (e.g. a wet etching process). The resulting optical facets 130a – 130e, 1300a – 1300b are orientated perpendicular (Fig. 8) or inclined (Fig. 9) with respect to the optical waveguides of the optical semiconductor components 100a – 100e. It is also possible that each one of the components 100a – 100e comprises individual front and/or rear facets.

Claims

1. A method for producing an optical semiconductor component, comprising the steps of:
   - fabricating an optical waveguide strip (12) of an optical waveguide (120), the waveguide strip (12) comprising at least one aluminium-containing active layer (122);
   - generating at least one aluminium-free optically and/or electrically functional layer (13) in such a way that it comprises a first and a second portion (131, 132), wherein the first portion (131) extends laterally along and/or above the waveguide strip (12)and the second portion (132) covers at least one face (140) of the waveguide strip (12) at least in the region of the active layer (122);
   - completing the optical waveguide (120); and
   - generating at least one optical facet (130) for injecting light into or emitting light from the optical waveguide (120).

2. The method as claimed in claim 1, wherein the optical facet (130) is created in such a way that the face (140) of the waveguide strip (12) remains covered by the second portion (132) of the functional layer (13).

3. The method as claimed in claim 1 or 2, wherein the optical facet (130) is created in such a way that it is formed by an aluminum-free material region adjacent the face (140) of the waveguide strip (12), the material region comprising at least a section of the second portion of the functional layer (13) of the optical semiconductor component.

4. The method as claimed in any of the preceding claims, wherein the optical facet (130) is created in such a way that it is at least partially formed by a face (1321) of the second portion (132) of the functional layer (13).

5. The method as claimed in any of the preceding claims, wherein the optical facet (130) is generated using an etching or cleaving method.

6. The method as claimed in any of the preceding claims, wherein the method is used for fabricating a buried heterostructure component.

7. The method as claimed in claim 6, wherein the method is used for fabricating at least one buried heterostructure laser or amplifier.

8. The method as claimed in any of the preceding claims, wherein the functional layer (13) is an epitaxially grown layer.

9. The method as claimed in any of the preceding claims, wherein the functional layer (13) is a blocking layer.

10. The method as claimed in any of the preceding claims, wherein before generating the optical facet (130), at least one cladding layer (14) of the optical waveguide (120) is generated above the functional layer (13).

11. The method as claimed in any of the preceding claims, wherein the active layer (122) is a layer of MQWs formed by InGaAsP, InGaAlAs and/or InGaAsP/InGaAlAs.

12. Optical semiconductor component, in particular fabricated using the method as claimed in any of the preceding claims, comprising
    - an optical waveguide (120) that comprises a waveguide strip (12) having at least one aluminium-containing active layer (122);
    - at least one aluminium-free optically and/or electrically functional layer (13) comprising a first and a second portion (131, 132), wherein the first portion (131) extends laterally to and/or above the active layer (122) and the second portion (132) covers at least one face (140) of the waveguide strip (12) at least in the region of the active layer (122); and
    - at least one optical facet (130) for injecting light into or emitting light from the optical waveguide (120).

13. Optical semiconductor component as claimed in claim 12, wherein the optical facet (130) is formed by an aluminum-free material region adjacent the face (140) of the waveguide strip (12), the material region comprising at least a section of the second portion of the functional layer (13) of the optical semiconductor component.

14. Array comprising a plurality of optical semiconductor components (100a – 100e) as claimed in claim 12.

15. Array as claimed in claim 14, wherein at least two of the optical semiconductor components (100a – 100e) have different active layers (122a – 122e).

FIG 1A

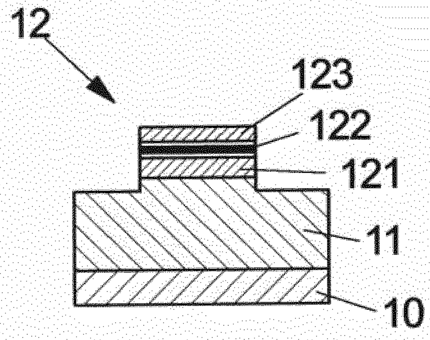


FIG 1B

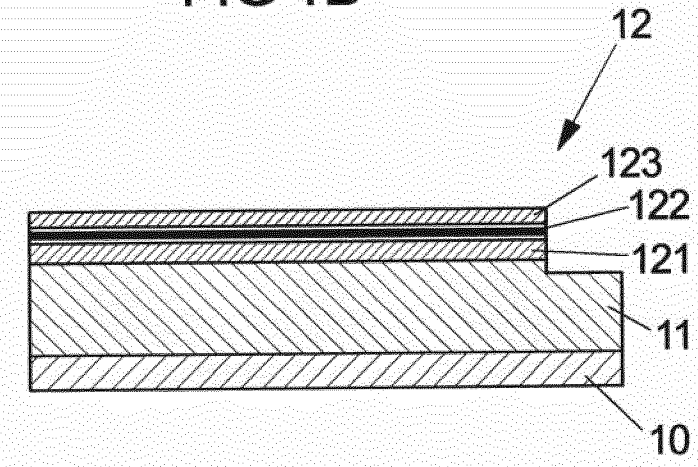


FIG 2A

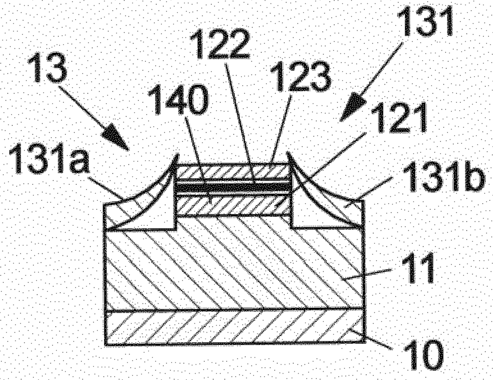


FIG 2B

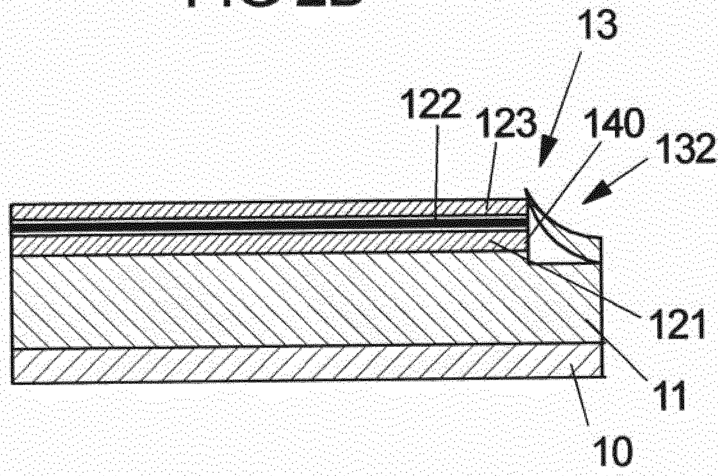


FIG 3A

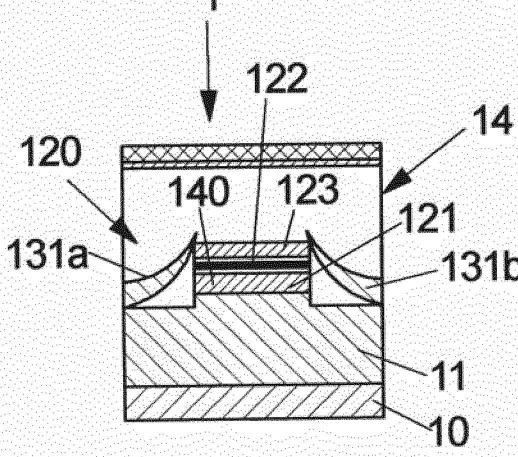


FIG 3B

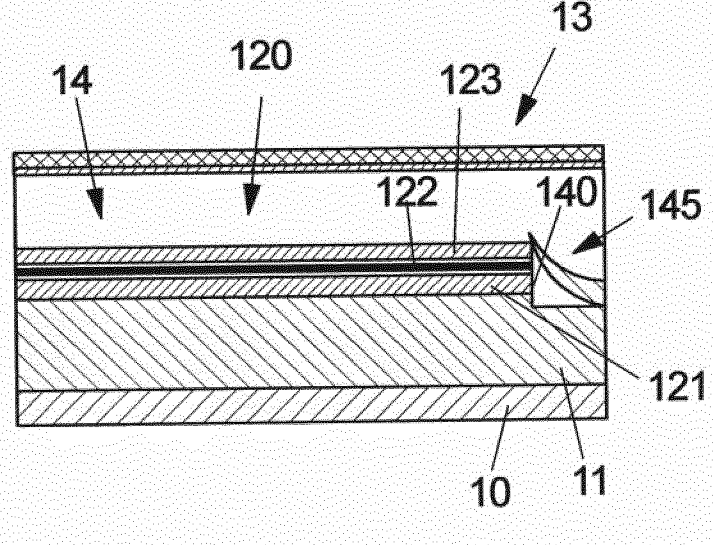
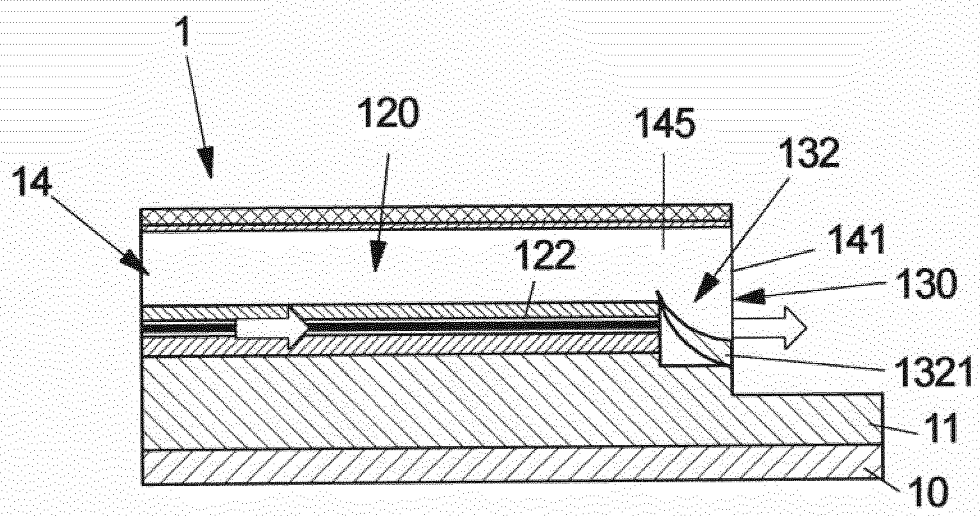


FIG 4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120
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141
122
130
1321
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10

FIG 5

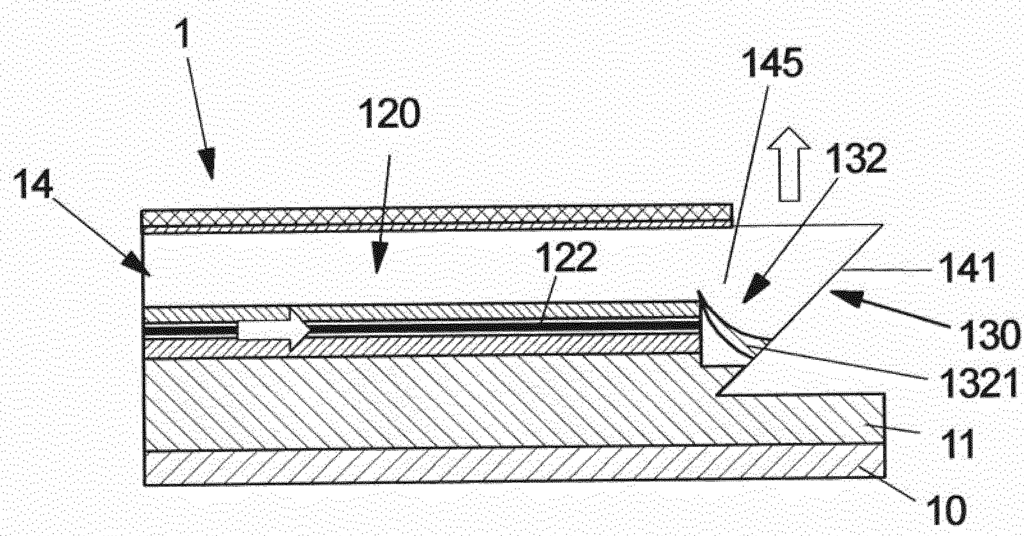
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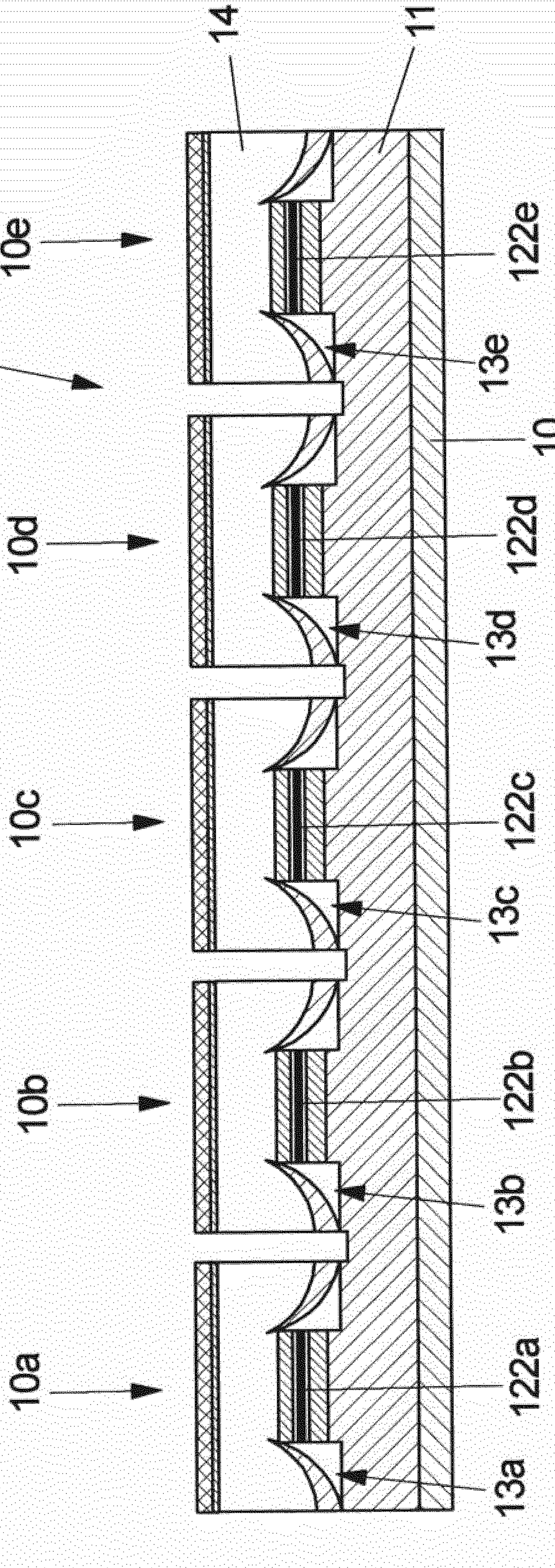
FIG 6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10e
122e
200
13e
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122d
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10c
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10b
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10a
122a
13a

FIG 7

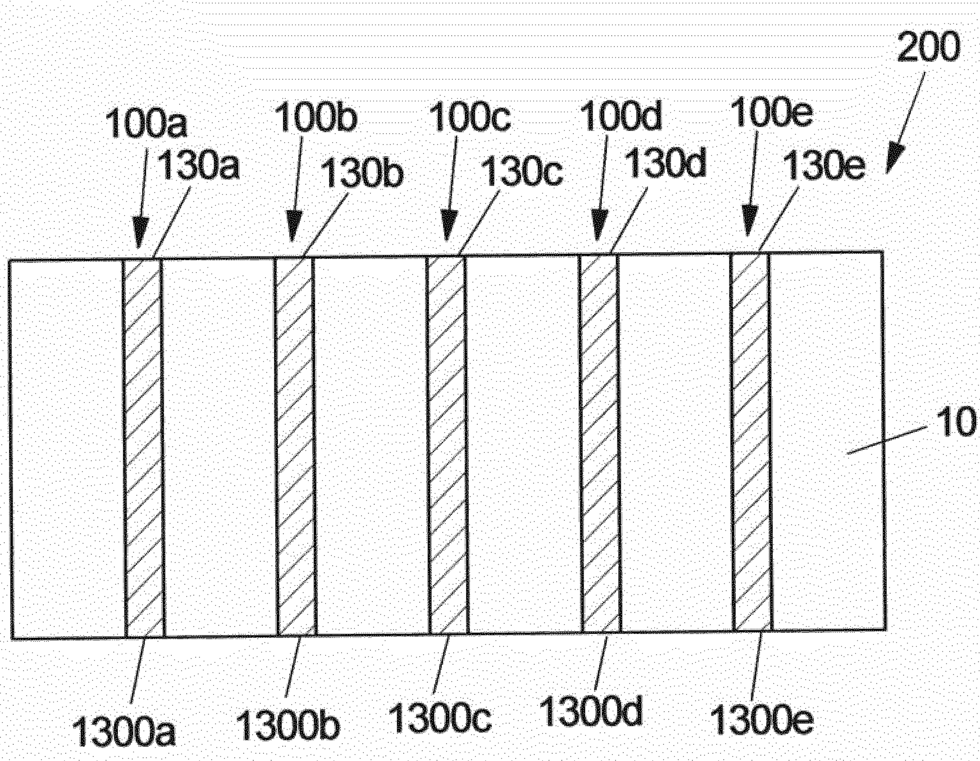
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FIG 8

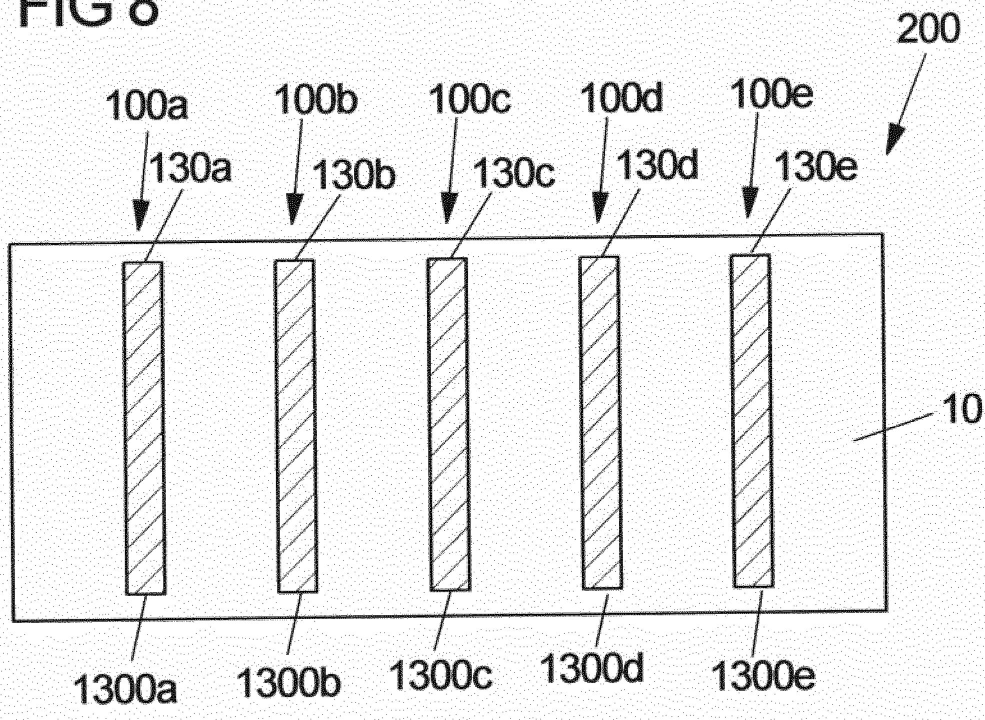
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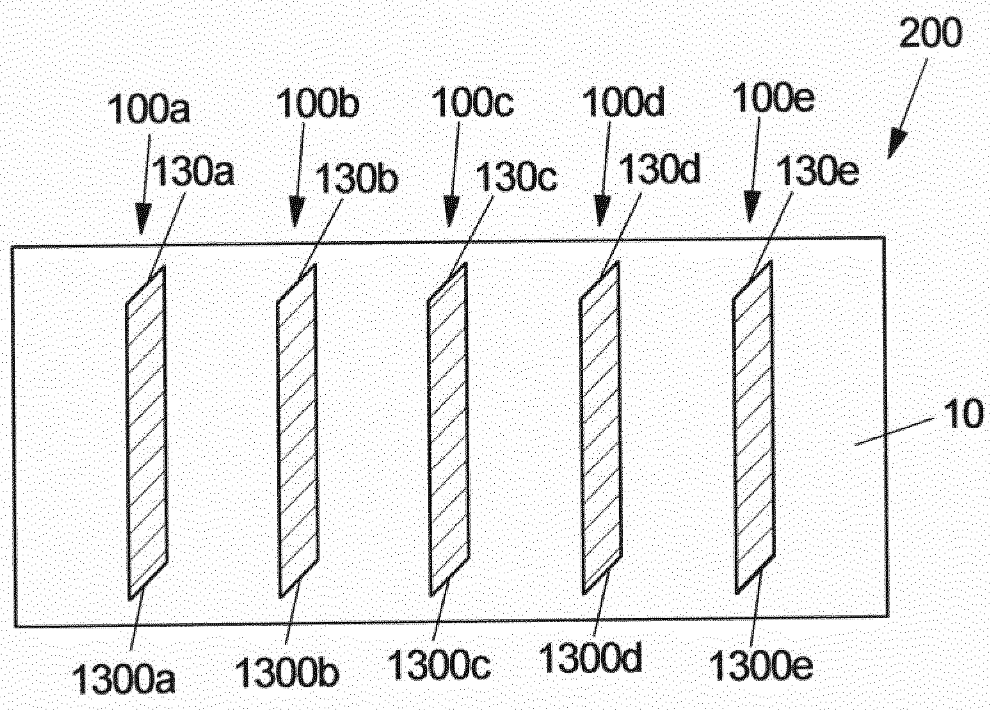
FIG 9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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/051441

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01S5/16 H01S5/227
ADD. H01S5/02 H01S5/10 H01S5/18 H01S5/22 H01S5/40
H01S5/343

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)
H01S

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 practicable, search terms used)

EPO-Internal, 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 2008/175549 A1 (UETAKE AYAHITO [JP] ET AL) 24 July 2008 (2008-07-24) abstract paragraphs [0049], [0053], [0055], [0078], [0086]; figures 3,4,5 -----	1-9, 11-15
X	JP 2004 341092 A (FURUKAWA ELECTRIC CO LTD) 2 December 2004 (2004-12-02) abstract paragraphs [0058], [0067]; figures 1,4,8 -----	1-15
X	US 5 430 751 A (WETERINGS JOSEPHUS P [NL]) 4 July 1995 (1995-07-04) abstract column 5, lines 42-47; figures 1,2 column 6, lines 7-9 column 8, lines 3-5 -----	1-9, 11-15

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 September 2016	23/09/2016

Name and mailing address of the ISA/	Authorized officer
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3

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2016/051441

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2008175549 A1	24-07-2008	EP 1947747 A1	23-07-2008
		JP 5185537 B2	17-04-2013
		JP 2008177405 A	31-07-2008
		US 2008175549 A1	24-07-2008
JP 2004341092 A	02-12-2004	JP 4550371 B2	22-09-2010
		JP 2004341092 A	02-12-2004
US 5430751 A	04-07-1995	DE 69400237 D1	18-07-1996
		DE 69400237 T2	05-12-1996
		EP 0613222 A1	31-08-1994
		JP H06252511 A	09-09-1994
		US 5430751 A	04-07-1995