



(51) International Patent Classification:

H01L 27/146 (2006.01) H01L 31/028 (2006.01)

(21) International Application Number:

PCT/EP2018/081086

(22) International Filing Date:

13 November 2018 (13.11.2018)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

17203572.7 24 November 2017 (24.11.2017) EP

(71) Applicant: AMS AG [AT/AT]; Schloss Premstätten, Tobelbader Str. 30, 8141 Premstätten (AT).

(72) Inventors: JONAK-AUER, Ingrid; Haignitzhofweg 17, 8043 Graz (AT). MEINHARDT, Gerald; Haydngasse 1, 8010 Graz (AT). LÖFFLER, Bernhard; Neugasse 17, 8200 Gleisdorf (AT).

(74) Agent: EPPING HERMANN FISCHER PATENTANWALTSGESELLSCHAFT MBH; Schloßschmidstr. 5, 80639 München (DE).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM,

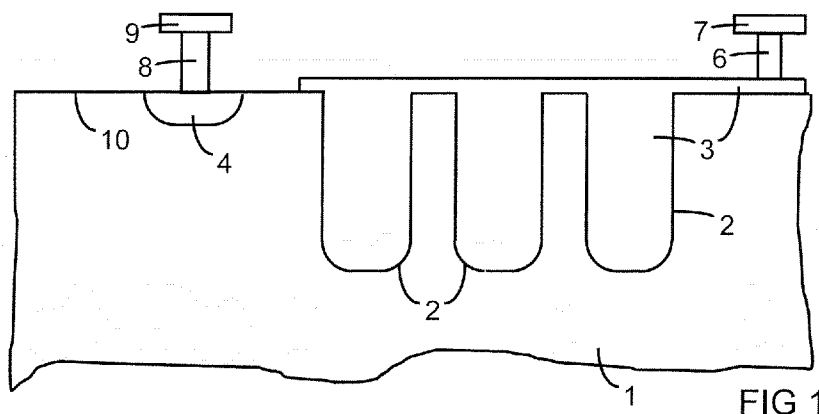
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— with international search report (Art. 21(3))

(54) Title: NEAR-INFRARED PHOTODETECTOR SEMICONDUCTOR DEVICE



(57) Abstract: The near-infrared photodetector semiconductor device comprises a semiconductor layer (1) of a first type of conductivity with a main surface (10), a trench or a plurality of trenches (2) in the semiconductor layer at the main surface, a SiGe alloy layer (3) in the trench or the plurality of trenches, and an electrically conductive filling material of a second type of conductivity in the trench or the plurality of trenches, the second type of conductivity being opposite to the first type of conductivity.



Description

NEAR-INFRARED PHOTODETECTOR SEMICONDUCTOR DEVICE

- 5 The present disclosure applies to the field of integrated near-infrared photodetector semiconductor devices.

Semiconductor photodetector devices for wavelengths in the near infrared (NIR) are applied in optical communication,
10 metrology, imaging and spectroscopy, for instance, and may comprise silicon (Si), germanium (Ge) and SiGe alloys. A monolithic integration of optics and electronics parts is desired in view of system performance and small size.

- 15 It is an object of the present invention to provide a monolithically integrated photodetector semiconductor device for near-infrared applications.

This object is achieved with the near-infrared photodetector
20 semiconductor device according to claim 1. Embodiments derive from the dependent claims.

The definitions as described above also apply to the following description unless stated otherwise. The term
25 "trench" will be used to denote any suitable opening or recess of arbitrary shape, which can be etched into a semiconductor layer.

The near-infrared photodetector semiconductor device
30 comprises a semiconductor layer of a first type of conductivity with a main surface, a trench or a plurality of trenches in the semiconductor layer at the main surface, a SiGe alloy layer in the trench or the plurality of trenches,

and an electrically conductive filling material of a second type of conductivity in the trench or the plurality of trenches, the second type of conductivity being opposite to the first type of conductivity. The first type of conductivity may be n-type conductivity and the second type of conductivity p-type conductivity, for instance, or vice versa.

In an embodiment of the near-infrared photodetector semiconductor device, the SiGe alloy layer is doped for the second type of conductivity, and the filling material comprises a portion of the SiGe alloy layer. The SiGe alloy layer may fill the trench or the plurality of trenches.

A further embodiment comprises a silicon layer in the trench or the plurality of trenches. The silicon layer may especially comprise polysilicon. The SiGe alloy layer and the silicon layer may fill the trench or the plurality of trenches.

In a further embodiment the silicon layer is doped for the second type of conductivity, and the filling material comprises a portion of the silicon layer. In this case the SiGe alloy layer may be undoped or intrinsically doped.

In a further embodiment the SiGe alloy layer is doped for the second type of conductivity, the silicon layer is undoped or intrinsically doped, and the filling material comprises a portion of the SiGe alloy layer.

A further embodiment comprises a contact region of the first type of conductivity in the semiconductor layer at the main surface, the contact region being at a distance from the

trench or the plurality of trenches. An electrically
conductive contact connection is electrically conductively
connected with the filling material, and a further
electrically conductive contact connection is electrically
5 conductively connected with the contact region.

In further embodiments the trench or at least one of the
trenches of the plurality of trenches has a smooth or a
grooved sidewall.

10

In further embodiments the semiconductor layer of the first
type of conductivity is silicon, and the SiGe alloy layer is
epitaxially grown on the silicon. A differential or selective
epitaxy of the SiGe alloy layer enables to vary and adapt the
15 germanium content during the deposition of the SiGe alloy
layer.

The arrangement of the SiGe alloy layer in the trench or the
plurality of trenches increases the absorption length and
20 thus improves the light sensitivity of the photodetector
semiconductor device in the spectral range of red and near-
infrared light.

The following is a more detailed description of examples of
25 the photodetector semiconductor device in conjunction with
the appended figures.

Figure 1 is a cross section of a photodetector semiconductor
device comprising trenches with smooth sidewalls.

30

Figure 2 is a cross section of a further photodetector
semiconductor device comprising trenches with
smooth sidewalls.

Figure 3 is a top view of an arrangement of the trenches.

Figure 4 is a top view of a further arrangement of the
5 trenches.

Figure 5 is a cross section of a photodetector semiconductor
device comprising trenches with grooved sidewalls.

10 Figure 6 is a cross section of a further photodetector
semiconductor device comprising trenches with
grooved sidewalls.

Figure 7 is a diagram showing examples of the relative
15 germanium content x as a function of the level h
above a silicon surface.

Figure 1 is a cross section of a photodetector semiconductor
device. At least one trench 2 is formed at a main surface 10
20 of a semiconductor layer 1, which may especially be silicon.
The semiconductor layer 1 has a first type of conductivity.
The number of trenches is arbitrary; Figure 1 shows a
plurality of three trenches 2, by way of example. A SiGe
alloy layer 3 is arranged in each trench 2 and on the main
25 surface 10. If the semiconductor layer 1 is silicon, the SiGe
alloy layer 3 can be epitaxially grown on the silicon. The
SiGe alloy layer 3 comprises silicon and germanium, and it
may also comprise an optional additive like carbon, for
instance. The shape of the trenches 2 can be adapted to the
30 epitaxial growth. The sidewalls of the trenches 2 can be
perpendicular or inclined with respect to the main surface
10. The sidewalls can be smooth, as shown in Figure 1, or
rough. Bottom areas of the trenches 2 can be flat or curved.

The SiGe alloy layer 3 has a second type of conductivity opposite to the first type of conductivity. The first type of conductivity may be n-type conductivity and the second type of conductivity p-type conductivity, or vice versa. The SiGe alloy layer 3 may completely fill the trenches 2, as shown in Figure 1. In this case the large volume of the SiGe alloy layer 3 enhances the absorption of near-infrared light.

A contact region 4 of the first type of conductivity may be arranged in the semiconductor layer 1 at the main surface 10 and at a distance from the trenches 2. The contact region 4 comprises a doping concentration that is higher than the doping concentration of the semiconductor layer 1 in order to allow the formation of an ohmic contact. A contact connection 6 comprising an electrically conductive material is arranged contacting the SiGe alloy layer 3, and a further contact connection 8 comprising an electrically conductive material is arranged contacting the contact region 4. The contact connections 6, 8 may be formed by plugs in an intermetal dielectric and may connect the SiGe alloy layer 3 and the contact region 4 with conductor tracks 7, 9 in a metal layer of a wiring, for example. Details of the wiring, which are arbitrary, are not shown in Figure 1.

Figure 2 is a cross section of a further photodetector semiconductor device. Elements of the photodetector semiconductor device according to Figure 2 that correspond to elements of the photodetector semiconductor device according to Figure 1 are designated with the same reference numerals. The photodetector semiconductor device according to Figure 2 comprises a silicon layer 5 in the trenches 2. The silicon layer 5 may especially comprise polysilicon. The SiGe alloy

layer 3 and the silicon layer 5 may completely fill the trenches 2. The silicon layer 5 may also be applied on the SiGe alloy layer 3 above the main surface 10, as shown in Figure 2.

5

If the SiGe alloy layer 3 is doped for the second type of conductivity, the silicon layer 5 may be undoped or intrinsically doped. In this case the contact connection 6 is arranged in such a manner that it contacts the SiGe alloy layer 3. As the refractive index of silicon is lower than the refractive index of SiGe, total reflection of light at the boundary between the silicon layer 5 and the SiGe alloy layer 3 yields a longer optical path and enhanced light absorption.

15 The silicon layer 5 may be doped for the second type of conductivity, especially in situ during its deposition. If the silicon layer 5 is doped for the second type of conductivity, the SiGe alloy layer 3 may be undoped or intrinsically doped. In this case the contact connection 6 is arranged in such a manner that it contacts the silicon layer 5. If the SiGe alloy layer 3 is undoped, the space charge region extends over the entire portion of the SiGe alloy layer 3 that is arranged within the trenches 2, and this results in a better carrier collection efficiency.

25

Figure 3 is a top view of an arrangement of the trenches 2 for an example in which the trenches 2 are cylindrical. The SiGe alloy layer 3 and the conductor track 7 are indicated in Figure 3 in order to facilitate the comparison with the cross section shown in Figure 1.

30

Figure 4 is a top view of a further arrangement of the trenches 2 for an example in which the trenches 2 have

longitudinal extensions and are parallel to each other. The shapes and arrangements of the trenches 2 are not restricted to these examples, but may vary according to individual requirements.

5

Longer optical paths can be achieved with trenches 2 comprising grooved or corrugated sidewalls. The trenches 2 can be etched into the semiconductor layer 1, and the etching process can be performed in such a way that it yields grooved or corrugated surfaces of the sidewalls. Such etching processes are known per se in semiconductor technology and need not be described here.

10

Figure 5 is a cross section of a photodetector semiconductor device comprising trenches 2 with grooved sidewalls. Elements of the photodetector semiconductor device according to Figure 5 that correspond to elements of the photodetector semiconductor device according to Figure 1 are designated with the same reference numerals. The shape of the sidewalls makes the difference between the devices according to Figures 1 and 5.

20

Figure 6 is a cross section of a further photodetector semiconductor device comprising trenches 2 with grooved sidewalls. Elements of the photodetector semiconductor device according to Figure 6 that correspond to elements of the photodetector semiconductor device according to Figure 2 are designated with the same reference numerals. The shape of the sidewalls makes the difference between the devices according to Figures 2 and 6.

25

30

Figure 7 is a diagram showing some examples of the relative germanium content x of the $\text{Si}_{1-x}\text{Ge}_x$ alloy in the SiGe alloy

layer 3 as a function of the level h above the surface on which the SiGe alloy layer 3 is grown. The $\text{Si}_{1-x}\text{Ge}_x$ alloy may especially be epitaxially grown on a silicon surface, as indicated on the right side of the diagram. The relative germanium content x of the alloy $\text{Si}_{1-x}\text{Ge}_x$ can be varied during the deposition of the SiGe alloy layer 3, so that the properties of the SiGe alloy layer 3 can be adapted to the requirements of individual embodiments.

The line x' in the diagram of Figure 7 represents an example of a continuous linear decrease of the germanium content x from $h = 0$ to the maximal level h_{max} , which corresponds to the total thickness of the SiGe alloy layer 3. The line x'' represents an example of a continuous linear increase of the germanium content x from $h = 0$ to the maximal level h_{max} . The relative germanium content x may instead be essentially constant, so that the SiGe alloy layer 3 is homogeneous. Such a SiGe alloy layer 3 is represented in Figure 1 by the horizontal line x''' .

An integrated circuit of the photodetector semiconductor device can be formed by a conventional CMOS process, for instance, which is known per se and need not be described here. The formation of the trenches 2 and the SiGe alloy layer 3 may take place after the CMOS process. Instead, the trenches 2 can be etched at an earlier stage of the CMOS process. In this case the trenches 2 are subsequently filled with a sacrificial filling, which may be an oxide of the semiconductor material, for instance. After the CMOS process, the sacrificial filling is removed, which may be effected by wet etching, for instance, to open the trenches 2, and the SiGe alloy layer 3 is subsequently deposited.

Deep trenches provide long optical paths within the SiGe alloy layer in the vertical direction. A differential or selective epitaxial growth of the SiGe alloy layer guarantees monocrystalline growth with low defect density at the Si/SiGe interface, thus enabling the formation of photodetectors with low dark current. The efficiency in photocarrier collection is enhanced by an increase of the width of the space charge region within the SiGe alloy. The efficiency in photocarrier collection is also enhanced when the relative germanium content of the SiGe alloy layer continuously increases or decreases with increasing distance from the silicon surface on which the SiGe alloy layer is epitaxially grown. Hence an integrated near-infrared photodetector semiconductor device comprising the described features has many advantages and is favourable for a wide variety of applications.

List of reference numerals

	1	semiconductor layer
	2	trench
5	3	SiGe alloy layer
	4	contact region
	5	silicon layer
	6	contact connection
	7	conductor track
10	8	further contact connection
	9	further conductor track
10	10	main surface

Claims

1. A near-infrared photodetector semiconductor device,
comprising:

5 a semiconductor layer (1) of a first type of conductivity
with a main surface (10),
a trench or a plurality of trenches (2) in the semiconductor
layer (1) at the main surface (10),
a SiGe alloy layer (3) in the trench or the plurality of
10 trenches (2), and
an electrically conductive filling material (3, 5) of a
second type of conductivity in the trench or the plurality of
trenches (2), the second type of conductivity being opposite
to the first type of conductivity.

15

2. The near-infrared photodetector semiconductor device
according to claim 1, further comprising:
a silicon layer (5) in the trench or the plurality of
trenches (2).

20

3. The near-infrared photodetector semiconductor device
according to claim 2, wherein the silicon layer (5) is doped
for the second type of conductivity, and the filling material
comprises a portion of the silicon layer (5).

25

4. The near-infrared photodetector semiconductor device
according to claim 3, wherein the SiGe alloy layer (3) is
undoped or intrinsically doped.

30

5. The near-infrared photodetector semiconductor device
according to claim 2, wherein the SiGe alloy layer (3) is
doped for the second type of conductivity, the silicon layer

(5) is undoped or intrinsically doped, and the filling material comprises a portion of the SiGe alloy layer (3).

6. The near-infrared photodetector semiconductor device
5 according to one of claims 2 to 5, wherein the silicon layer (5) comprises polysilicon.

7. The near-infrared photodetector semiconductor device
according to one of claims 2 to 6, wherein the SiGe alloy
10 layer (3) and the silicon layer (5) fill the trench or the plurality of trenches (2).

8. The near-infrared photodetector semiconductor device
according to one of claims 1 to 3, wherein the SiGe alloy
15 layer (3) is doped for the second type of conductivity, and the filling material comprises a portion of the SiGe alloy layer (3).

9. The near-infrared photodetector semiconductor device
20 according to one of claims 1 to 8, wherein the first type of conductivity is n-type conductivity, and the second type of conductivity is p-type conductivity.

10. The near-infrared photodetector semiconductor device
25 according to one of claims 1 to 8, wherein the first type of conductivity is p-type conductivity, and the second type of conductivity is n-type conductivity.

11. The near-infrared photodetector semiconductor device
30 according to one of claims 1 to 10, further comprising:
a contact region (4) of the first type of conductivity in the semiconductor layer (1) at the main surface (10), the contact

region (4) being at a distance from the trench or the plurality of trenches (2),
an electrically conductive contact connection (6) electrically conductively connected with the filling
5 material, and
a further electrically conductive contact connection (8) electrically conductively connected with the contact region (4).

10 12. The near-infrared photodetector semiconductor device according to one of claims 1 to 11, wherein the trench or at least one of the trenches of the plurality of trenches (2) has a smooth sidewall.

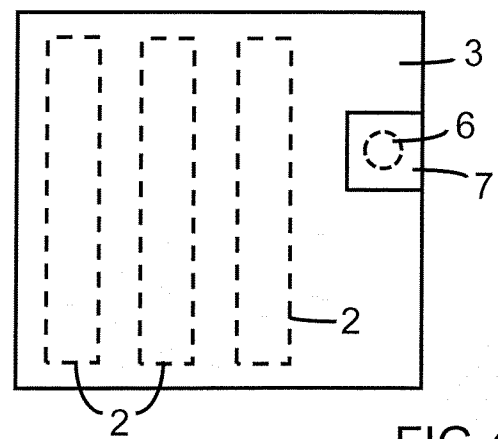
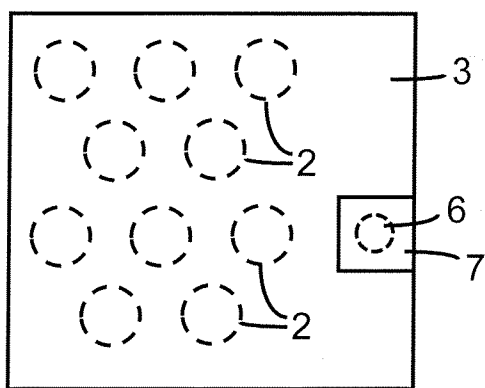
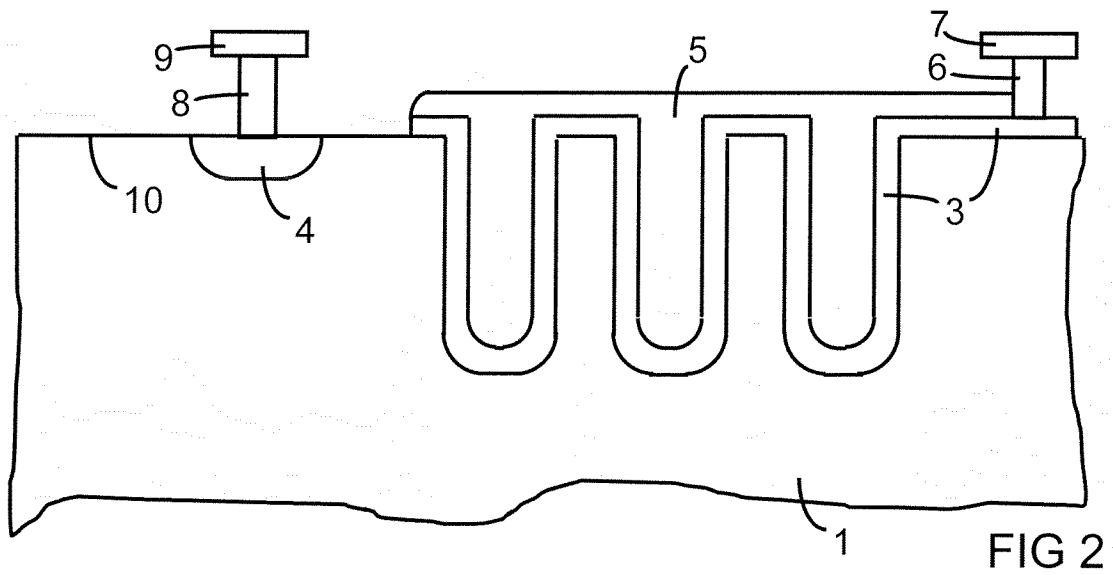
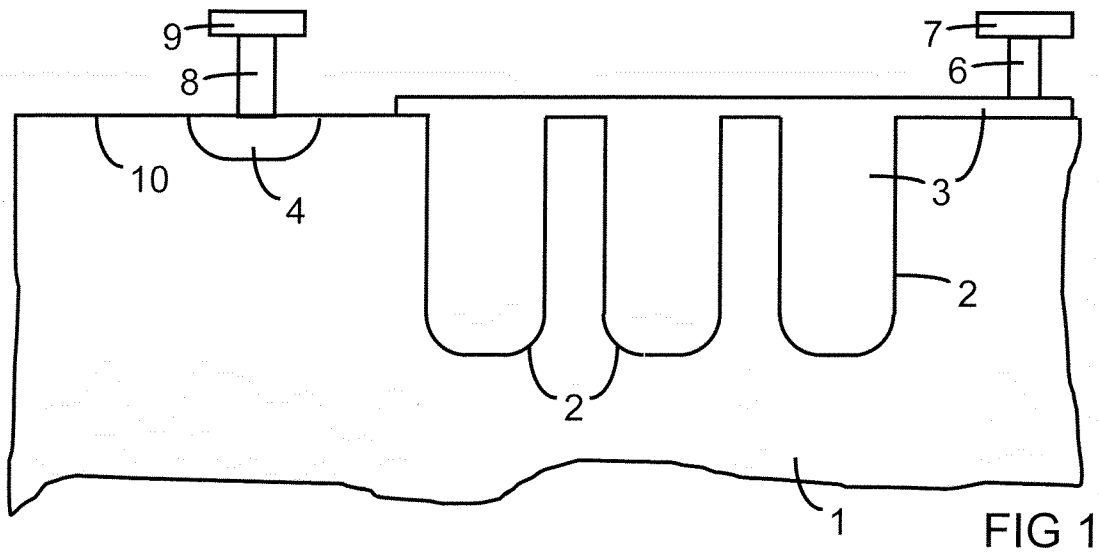
15 13. The near-infrared photodetector semiconductor device according to one of claims 1 to 11, wherein the trench or at least one of the trenches of the plurality of trenches (2) has a grooved sidewall.

20 14. The near-infrared photodetector semiconductor device according to one of claims 1 to 13, wherein the semiconductor layer (1) comprises silicon and the SiGe alloy layer (3) is epitaxially grown on the silicon.

25 15. The near-infrared photodetector semiconductor device according to claim 5, wherein
the semiconductor layer (1) is silicon,
the SiGe alloy layer (3) is epitaxially grown on the silicon in the trench or the plurality of trenches (2) and on the
30 main surface (10),
the silicon layer (5) is applied on the SiGe alloy layer (3) in the trench or plurality of trenches (2) and above the main surface (10),

the SiGe alloy layer (3) and the silicon layer (5) completely fill the trench or the plurality of trenches (2), and a contact connection (6) contacts the SiGe alloy layer (3).

1/2



2/2

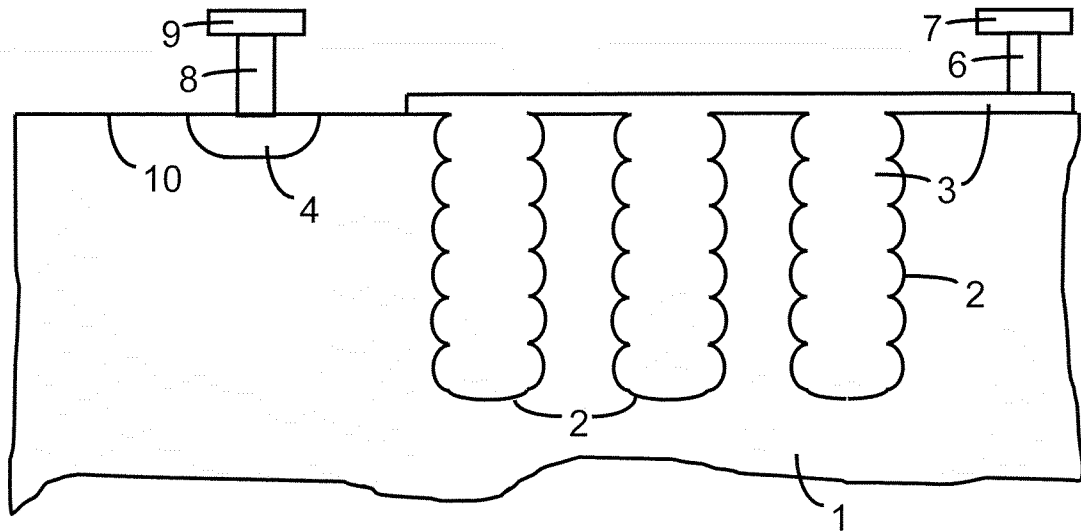


FIG 5

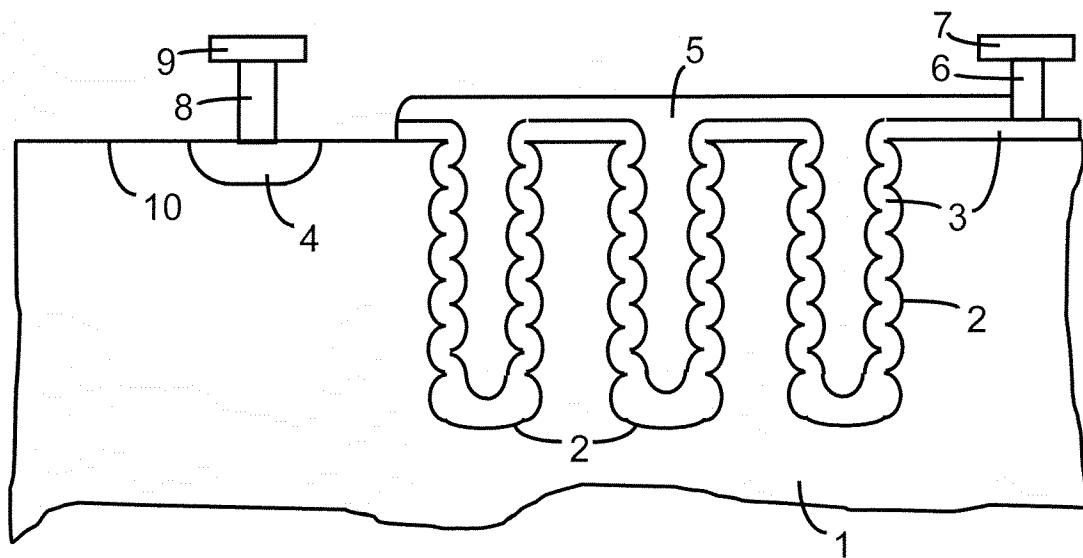


FIG 6

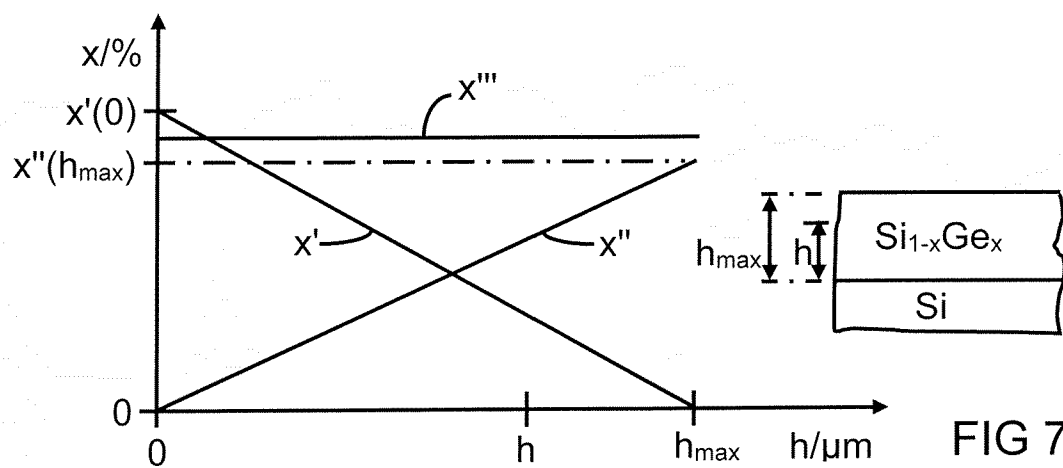


FIG 7

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2018/081086

A. CLASSIFICATION OF SUBJECT MATTER
 INV. H01L27/146 H01L31/028
 ADD.

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)
 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 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 2005/127275 A1 (YANG MIN [US]) 16 June 2005 (2005-06-16)	1-4,6,7, 9-11,13, 14
Y A	paragraphs [0010] - [0020], [0024], [0025] figures 1, 2A	12 15
Y	----- WO 2016/062614 A1 (AMS AG [AT]) 28 April 2016 (2016-04-28)	12
A	page 5, line 11 - page 6, line 21	13
X	US 2005/133723 A1 (LEE JONG J [US] ET AL) 23 June 2005 (2005-06-23)	1-4, 7-12,14
A	paragraphs [0045] - [0049], [0053] figures 7-11, 15	15
	----- -/-	



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

7 January 2019

Date of mailing of the international search report

17/01/2019

Name and mailing address of the ISA/

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

Authorized officer

Markmann, Markus

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/081086

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2011/012221 A1 (FUJIKATA JUNICHI [JP] ET AL) 20 January 2011 (2011-01-20)	1-3,5, 7-10,12, 14
A	paragraphs [0213] - [0254] figures 8-1, 8-2, 8-3 -----	15
X	US 2005/040445 A1 (MOULI CHANDRA [US]) 24 February 2005 (2005-02-24)	1,2, 7-10,12
A	paragraphs [0035] - [0051], [0054] figure 2 -----	15

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2018/081086

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2005127275 A1	16-06-2005	NONE	
WO 2016062614 A1	28-04-2016	EP 3012857 A1 US 2017316976 A1 WO 2016062614 A1	27-04-2016 02-11-2017 28-04-2016
US 2005133723 A1	23-06-2005	JP 2005183948 A US 2005133723 A1 US 2005153474 A1 US 2007012876 A1	07-07-2005 23-06-2005 14-07-2005 18-01-2007
US 2011012221 A1	20-01-2011	JP 5232981 B2 JP WO2009110632 A1 US 2011012221 A1 WO 2009110632 A1	10-07-2013 14-07-2011 20-01-2011 11-09-2009
US 2005040445 A1	24-02-2005	US 2005040445 A1 US 2005145848 A1	24-02-2005 07-07-2005