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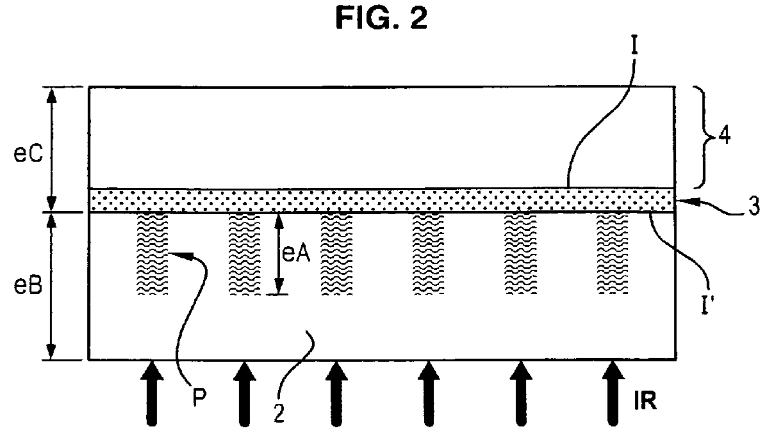
[Continued on next page]

(54) Title: PROCESS FOR TREATING A SUBSTRATE USING A LUMINOUS FLUX OF DETERMINED WAVELENGTH, AND CORRESPONDING SUBSTRATE

FIG. 2



(57) Abstract: The present invention relates in particular to a process for treating a substrate by means of a luminous flux (IR) of determined wavelength, this substrate comprising an embedded layer (3) which is absorbent, that is, which absorbs said luminous flux independently of the temperature, this embedded layer being interleaved between a first layer (2), said treatment layer, and a second layer (4), the first semi-conductive layer (2) having a coefficient of absorption of luminous flux which is low at ambient temperature and growing as this temperature rises, according to which said first layer (2) is irradiated by at least one pulse of said luminous flux (IR). It is especially remarkable in that - said luminous flux (IR) is applied in several places of the surface of the first layer (2) to heat regions of the embedded layer (3) and to generate in this first layer (2) by propagation of a thermal front opposite the heated regions of the embedded layer (3) heated zones forming thermal pillars (P), which dilate and generate constraints within the second layer (4), via the embedded layer (3).

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— *with information concerning incorporation by reference of missing parts and/or elements (Rule 20.6)*

PROCESS FOR TREATING A SUBSTRATE USING A LUMINOUS FLUX OF DETERMINED WAVELENGTH, AND CORRESPONDING SUBSTRATE

The present invention relates to a process for treating a substrate by means of a luminous flux of determined wavelength, and a corresponding substrate.

The process well known under the registered trade mark Smart Cut is a widely used transfer technique which generally consists of implanting a dose of atomic or ionic species in a donor substrate, to create therein an embrittlement zone at a determined depth, delimiting a thin layer to be transferred, adhering the donor substrate on a support substrate or receiver substrate and prompting fracturing of the donor substrate at the level of the embrittlement zone, causing the detachment of the thin layer adhering to the receiver substrate.

Such a process is generally satisfactory, yet it does require high doses of atomic species, with inevitable repercussions on the overall cost of execution.

There is still a need therefore to employ another process for treating a piece or a substrate, which finally detaches thin layers or thick layers of a substrate, efficiently, cleanly and using a process which is easy to execute.

Also, the article "*Laser heating of thick layers through the backwards, self-sustained propagation of a steep and steady state thermal front*", by Monsieur Michel BRUEL (2009), as well as French patent application No. 07 57986, describe an at least local heating process of a plate comprising at least one layer to be heated and a sub-layer.

In these documents, the sub-layer has the particular feature of being absorbent vis-à-vis a luminous flux of predetermined wavelength, this absorption occurring independently of temperature conditions.

Also, the layer to be heated has as such the particular feature of having a coefficient of absorption of the luminous flux which is low at ambient temperature and increases as this temperature rises.

If this layer to be heated is irradiated by means of said luminous radiation, the absorbent sub-layer can then be heated by passing through the layer to be heated which is to some degree transparent to a light beam.

In this way, the interface which separates the layer to be heated and the sub-layer is heated and then heats the layers which are adjacent to it, which will in turn make them absorbent such that the layers most distant from the absorbent layer will gradually become more and more absorbent.

This produces a "thermal front" which progresses quickly, very homogeneously and substantially adiabatically.

This technique therefore rapidly heats localised regions of a substrate to considerable depths which would be heated improperly only if a thermal treatment was undertaken where the sole intervening mechanism would be thermal diffusion, and at the end of a particularly long heating period.

The present applicant realised that it was possible to make use of such a technique to treat such a substrate so as to embrittle it.

In some circumstances this embrittlement could cause detachment of a layer of interest.

The thickness of such a layer, by way of non-limiting example as per the relevant application, can typically be in the range of 0.5 - 50 micrometers.

Therefore, a first aspect of the present invention relates to a process for treating a substrate by means of a luminous flux of determined wavelength, this substrate comprising an embedded layer which is absorbent, that is, which absorbs said luminous flux independently of the temperature, this embedded layer being interleaved between a first layer, said treatment layer, and a second layer, the first semi-conductive layer having a coefficient of absorption of luminous flux which is low at ambient temperature and growing as this temperature rises, a process according to which said first layer is irradiated in the direction of said embedded layer by at least one pulse of said luminous flux, characterised in that

- said luminous flux is applied at several places of the surface of the first layer to heat regions of the embedded layer and generate in this first layer by propagation of a thermal front, opposite to said heated regions of the embedded layer, heated zones forming thermal pillars which dilate and generate constraints within the second layer, via the embedded layer, and in that

- irradiation is used to produce constraints sufficient to initiate in the second layer, in the vicinity of its interface with said embedded layer, incipient fracture, at the very least generating structural defects making this region fragile.

According to other advantageous and non-limiting characteristics:

- prior to said irradiation, said substrate is subjected to chemical and/or mechanical treatment of its wafer to generate incipient fracture;

- said treatment is conducted by indentation of the wafer of the substrate, substantially at the level of the interface of the second layer with said embedded layer;

- prior to said irradiation, embrittlement treatment of said substrate is carried out in the first or in the second layer in the vicinity of its interface with said embedded layer, or in the embedded layer itself;

- said embrittlement treatment is selected from the following techniques: implanting of atomic species combined or not with thermal treatments, porosification, creation of an intermediate layer whereof the material has a mesh parameter different to that of the rest of said layer;

- said embedded layer is a continuous layer, without continuity solution;

- said embedded layer is a discontinuous layer, that is, constituted by a collection of discrete regions;

- a substrate is used whereof the absorbent embedded layer is a doped layer, for example made of silicon;

- the thickness of said second layer is preferably less than that of the first layer, their thickness ratio being between 1/2 to 1/100;

- said luminous flux is laser radiation, infrared for example, preferably of a wavelength of the order of 10.6 micrometers;

- a flux materialising in the form of at least one radiation of cylindrical or tapered form is used;

- a flux which progressively moves along the surface of said first layer, materialising in the form of lamellar irradiation is used;

- it is also possible that said embedded layer, in addition to being absorbent, has a thermal dilation coefficient greater than that of the material or materials of the other layers;

- at least one of said first and second layers is silicon.

Another aspect of the invention relates to a substrate comprising an embedded layer which is absorbent, that is, which absorbs a luminous flux of determined wavelength independent of the temperature, interleaved between a first layer having a coefficient of absorption of said luminous flux which is low at ambient temperature and growing as the latter increases, and a second layer, characterised in that the thickness of said second layer is less than that of the first layer, their thickness ratio being between 1/2 and 1/100.

Other characteristics and advantages of the present invention will emerge from the following detailed description of some preferred embodiments.

This description will be given in reference to the attached diagrams, in which:

Figure 1 is a schematic sectional view of a substrate comprising an embedded layer, which is suitable for being subjected to the treatment process according to the invention;

Figure 2 is a view similar to the preceding view, which illustrates the execution of said process;

Figure 3 is an enlarged view of a detail of the structure illustrated in Figure 2;

Figure 4 is a sectional and simplified view of a variant embodiment of the substrate;

Figures 5 and 6 are simplified views of two different embodiments of the process of the present invention;

Figure 7 is a view of another variant of this process.

The substrate shown in Figure 1 is suitable for being treated according to the process of the present invention.

This substrate 1 comprises an embedded layer 3 which is interleaved between a first layer 2 and a second layer 4.

The first layer 2, said "treatment" layer, silicon for example, has the particular feature of having a coefficient of absorption of luminous flux of predetermined wavelength, which is low at ambient temperature and growing as this temperature rises.

Therefore, when this layer comprises lightly doped silicon, for example at a level of around a few 10^{15} atoms/cm^3, then this material is transparent to radiation of laser type emitting in far infrared (for example a wavelength of the order of 10.6 micrometers).

The above embedded layer 3 is for example a layer which is epitaxied on the layer 2. This layer has the particular feature of being significantly absorbent for the above luminous flux and substantially independently of the temperature.

One way of making this layer absorbent, when it is a semi-conductor, is to dope it with another atomic species for example.

Therefore, this embedded layer can for example be a layer of silicon of a micrometer in thickness doped at a level of the order of 1.10^{20} atoms/cm^3, for example with atoms of boron, phosphorous or arsenic.

The second layer 4 is as such a layer epitaxied on the preceding one, for example also made of silicon.

Referenced 5 in this figure is an optional zone of the layer 4, very close to its interface I with the embedded layer, 3 which has the characteristic of being embrittled.

This localised embrittlement treatment can be carried out in the layer 4 via its rear face 40 by well known embrittlement treatment such as implantation of atomic species combined or not with thermal treatments, or the creation of pores in this zone 5 (treatment of porosification).

Another example of treatment is the creation of an intermediate layer whereof the material has a mesh parameter different to that of the rest of the layer.

Therefore, the layer 4 can be created in the following manner, for example: creation of an epitaxied layer of 2 µm in thickness of Si-Ge on silicon where the percentage of germanium represents more than 20% and on which another layer of silicon of 20 µm has been grown by epitaxy, for example.

Advantageously, the thickness of the second layer 4 is less than that of the first layer 2, their thickness ratio being preferably and typically between 1/2 and 1/100, in such a way that application of the process forming the subject of the invention is also not a result of embrittlement inside the layer 2. The corresponding thicknesses of the layers 2 and 4 have been referenced eB and eC in Figure 2.

As illustrated in Figure 2, the process according to the invention consists of irradiating the first layer 2, by its front face 20, by means of a luminous flux whereof the wavelength is determined so that this flux is absorbed by the embedded layer 3, while being transparent, at least in the first instance, for the layer 2.

In the above case where the substrate is based on silicon, the luminous flux is preferably laser radiation in the infrared field.

This is symbolised by the black arrows in Figure 2, referenced IR.

In a first phase of this process, infrared radiation passes through the whole layer 2 and is absorbed by the layer 3 which heats locally.

This heating spreads to the layer 2 at the level of its interface I' with the layer 3 and its regions become less and less transparent due to the progressive elevation of their coefficient of absorption.

In the embodiment of Figure 2 in which the luminous flux IR materialises in the form of impacts of radiation of cylindrical or tapered shape, a series of thermal "pillars" symbolised by the reference P is generated within the layer 2.

These "pillars" are therefore heated regions of the layer 2, which are located opposite the zones of the layer 3 targeted by radiation.

The latter have a height eA which is a function of the energy output by the radiation luminous and of the duration of application of the latter.

The present applicant has disclosed the fact that due to the elevation of temperature localised of the layer 2 these thermal pillars, as shown in Figure 3, dilate and generate constraints C, especially shearing constraints, which locally deform the embedded layer 3, and are transmitted to the second layer 4, near the interface.

The present process therefore consists of using irradiation to a level of constraints sufficient for initiating incipient fracture, in the second layer 4, in the vicinity of its interface I with the embedded layer 3. At the very least, the process generates structural defects in the layer 4, which make it fragile locally.

The following simple rules are applied to determine the values of the parameters to be used to obtain conditions relative to the level of constraint:

The temperature of each thermal pillar and its height are selected such that theoretical dilation of this thermal pillar, in the vertical direction (that is, perpendicularly) in free space (that is, taken in isolation, as if not found in the structure) would be at least equal to 4/1000 of its diameter.

For example, with a laser flux materialising in a cylindrical form of diameter 50 µm, thermal pillars of diameter substantially equal to 50 µm are produced. The temperature of each pillar is brought to a temperature of 1273°K, or a delta T of 1000°K with the ambient temperature. The average coefficient of dilation in this temperature range is of 2.5*E-6.

The height eA of pillar to be made to satisfy the criterion cited above is calculated:

$$eA*2,5*10^{-6}*1000 = (4/1000)*50,$$

Or eA = 80 µm

Of course, optimal parameters can be optionally selected by using commercially available simulation software.

This incipient fracture is all the easier to use, as indicated earlier, if the incipient fracture and/or the embrittlement of the substrate of the layer 4 has been carried out in the zone 5.

The incipient fracture consists of subjecting the substrate to previous chemical and/or mechanical treatment of its wafer, for example to form an indentation there.

In this case, it will be preferable to use irradiation, in the first instance, near the indentation, then more and more closely to propagate the incipient fracture inherent to the indentation.

Also, for inasmuch as the thickness eC is very slight vis-à-vis eB, the capacity of the layer 4 to deform and generate an incipient fracture is considerable, this initiation spreading closer and closer to separate a fraction of the layer 4 from the rest of the substrate, and an added mechanical constraint will have to be made.

In reference to Figure 4, this deals with a structure 1 of the same type as the preceding, but the absorbent layer 3 of which is not continuous.

It presents by comparison a continuity solution, such that it constitutes a multitude, that is, an ensemble of discrete regions 31, forming so many "blocks" of absorbent material.

Such a "layer" is made for example by epitaxy on the entire surface of the structure, then localised etching via a mask. After the mask is removed, the second layer 4 is then epitaxied in turn.

One alternative, for example, is to proceed with implantation, for example of arsenic according to a dose of the order of 10^{16} atoms/cm^2 via a mask, then annealing at 1050°C for 3 hours.

Therefore, as shown in Figures 5 and 6, inasmuch as one of the layers 2 and 4 has a low luminous flux coefficient of absorption at ambient temperature and growing as the temperature rises, the structure could be irradiated from below or from above.

According to the scheme of Figure 8, the layer 3, in addition to being absorbent, has a thermal dilation coefficient greater than that of the surrounding material, that is, of the material of layers 2 and 4. This boosts the capacity to form incipient fracture within the structure.

Some embodiments of the process according to the invention are described hereinbelow.

<u>Example 1</u>

A layer of 2.5 micrometers of silicon strongly doped by atoms of boron at a boron concentration of (10^{20} atoms/cm^3) is formed on a silicon substrate having a thickness of around 200 micrometers, lightly doped in type n (10^{15} atoms/cm^3), via an epitaxy technique of CVD type.

A layer of lightly doped silicon of type n (a few 10^{15} atoms/cm^3), of 20 micrometers in thickness is cultivated above this layer by epitaxy of CVD type.

The resulting structure is then soaked for a few minutes in an aqueous solution of ethylene-diamine pyrocatechol, well known to the expert for preferably attacking the silicon doped p. The doped layer p is thus attacked chemically at the periphery.

An indentation of around 2.5 micrometers in height and around ten micrometers in depth is made, on the peripheral part of the substrate (wafer), thus creating initiation which could serve as starting point for propagation of fracture, substantially at the level of or near the doped layer.

A laser flux CO_2 is then applied to this structure in the form of a cylindrical flux of 50 microns in diameter of pulses of 600 nanoseconds in duration and energy of 20 J/cm^2.

A thermal pillar of cross-section of substantially 50 micrometers and extending from the doped layer p over approximately a height of 60 micrometers is created at each pulse. The temperature reached, substantially homogeneous over the entire height of the pillar, is around 1400°C.

Preferably, and independently of the example hereinabove, the first thermal pillar is made near (distance less than or equal to a hundred micrometers) the indentation, so as to propagate the incipient fracture inherent to the indentation.

The whole surface of the substrate then undergoes creation of thermal pillars. Each new thermal pillar is built at a distance sufficiently close (for example less than 100 microns) to the point where the preceding pillar was created, so the fracture can be propagated more and more closely. This creation of pillars can be carried out continuously, in the sense that the laser beam then emits continuously and is moved at a speed such that the laser flux waits 600 nanoseconds only at each point.

Example 2

A layer of 2.5 micrometers of If strongly doped p by boron, at a concentration of 10^{20} atoms/cm^3 is formed on a substrate of If in thickness of around 200 micrometers by an epitaxy technique of CVD type.

A layer of silicon-germanium of 2 micrometers in thickness is cultivated above this layer by epitaxy of CVD type in which, due to dynamic regulation of gaseous flux in the epitaxy machine while this layer is being made, the germanium concentration passes progressively from 5% at the base of the layer to reach 25% in the middle of the thickness of the layer to reduce again to around 5% in the upper part of the layer. A lightly doped layer of type n (a few 10^{15} atoms/cm^3) of 20 micrometers in thickness is made above this layer of Si-Ge by epitaxy.

This structure is then treated similarly to that already described.

The absorbent embedded layer is not necessarily a layer made of doped silicon. It can comprise any semi-conductive layer which has a band gap less than the energy of the photon (component of luminous flux). It can also simply be a layer of oxide.

Example 3

In this case, the first layer is made of "intrinsic" Si (that is, without doping) of around 20 micrometers in thickness, on which an absorbent layer of 10 micrometers of intrinsic Germanium (non doped) and a layer of SiGe (0.8/0.2) of 50 micrometers (second layer) are cultivated successively. The luminous flux is generated by a laser of wavelength equal to 1.08 micrometers.

Example 4

The first layer here is a silicon substrate of 500 micrometers in thickness, to which circuits have been transferred (by adhesion and thinning of a plate comprising circuits at its surface). The circuit layer of 20 micrometers in thickness constitutes the second layer. A planarised layer of oxide has been formed at the surface of the circuits to enable this transfer stage. The first layer has also been oxidised. After assembly and thinning, the layer or layers of oxide form the absorbent layer.

Formation of circuits can be completed after transfer to the first layer, for example by forming interconnections, contacts, etc.

The exposed face of this layer of circuits (second layer) is then assembled with a final support, and a laser of wavelength of 10.6 micrometers is applied to the exposed face of the first layer, according to the invention, so as to transfer the first layer to the final support.

Claims

1. A process for treating a substrate (1) by means of a luminous flux (IR) of determined wavelength, this substrate (1) comprising an embedded layer (3) which is absorbent, that is, which absorbs said luminous flux independently of the temperature, this embedded layer being interleaved between a first layer (2), said treatment layer, and a second layer (4), the first semi-conductive layer (2) having a coefficient of absorption of the luminous flux which is low at ambient temperature and growing as this temperature rises, a process according to which said first layer (2) is irradiated in the direction of said embedded layer (3) by at least one pulse of said luminous flux (IR),

characterised in that

- said luminous flux (IR) is applied in several places of the surface of the first layer (2), to heat regions of the embedded layer (3) and to generate, in this first layer (2) by propagation of a thermal front, opposite the heated regions of the embedded layer (3), heated zones forming thermal pillars (P), which dilate and generate constraints within the second layer (4), via the embedded layer (3), and in that

- irradiation is carried out to produce sufficient constraints to initiate, in the second layer (4), in the vicinity of its interface (I) with said embedded layer (3), incipient fracture, at the very least generation of structural defects making this region fragile.

2. The process as claimed in Claim 1, characterised in that, prior to said irradiation, said substrate (1) is subjected to chemical and/or mechanical treatment of its wafer to generate incipient fracture.

3. The process as claimed in Claim 2, characterised in that said treatment is conducted by indentation of the wafer of the substrate, substantially at the level of the interface (I) of the second layer (4) with said embedded layer (3).

4. The process as claimed in Claim 1 or 2, characterised in that, prior to said irradiation, embrittlement treatment of said substrate (1) is used in the first (2) or in the second layer (4), in the vicinity of its interface (I) with said embedded layer (3), or in the embedded layer itself.

5. The process as claimed in Claim 3, characterised in that said embrittlement treatment is selected from the following techniques: implanting of atomic species combined or not with thermal treatments, porosification, creation of an intermediate layer whereof the material has a mesh parameter different to that of the rest of said layer (2, 4).

6. The process as claimed in any one of Claims 1 to 4, characterised in that said embedded layer (3) is a continuous layer, without a continuity solution.

7. The process as claimed in any one of Claims 1 to 4, characterised in that said embedded layer (3) is a discontinuous layer, that is, constituted by an assembly of discrete regions (31).

8. The process as claimed in any one of the preceding claims, characterised in that a substrate (1) is used whereof the absorbent embedded layer (3) is a doped layer, for example made of silicon.

9. The process as claimed in any one of the preceding claims, characterised in that the thickness of said second layer (4) is less than that of the first layer (2), their thickness ratio being between 1/2 and 1/100.

10. The process as claimed in any one of the preceding claims, characterised in that said luminous flux (IR) is laser radiation, for example infrared, preferably having a wavelength of the order of 10.6 micrometers.

11. The process as claimed in Claim 9, characterised in that a flux (IR) is used, materialising in the form of at least one radiation of cylindrical or tapered form.

12. The process as claimed in Claim 9, characterised in that a flux (IR) is used, which moves progressively along the surface of said first layer (2), materialising in the form of lamellar irradiation.

13. The process as claimed in any one of the preceding claims, characterised in that in addition to being absorbent said embedded layer (3) has a thermal dilation coefficient greater than that of the material or materials of the other layers (2; 4).

14. The process as claimed in any one of the preceding claims, characterised in that at least one of said first and second layers (2, 4) is made of silicon.

15. A substrate (1) comprising an embedded layer (3) which is absorbent, that is, which absorbs a luminous flux (IR) of determined wavelength independent of the temperature, interleaved between a first layer (2) having a coefficient of absorption of said luminous flux low at ambient temperature and growing as the latter rises, and a second layer (4), characterised in that the thickness of said second layer (4) is less than that of the first layer (2), their thickness ratio being between 1/2 and 1/100.

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FIG. 1

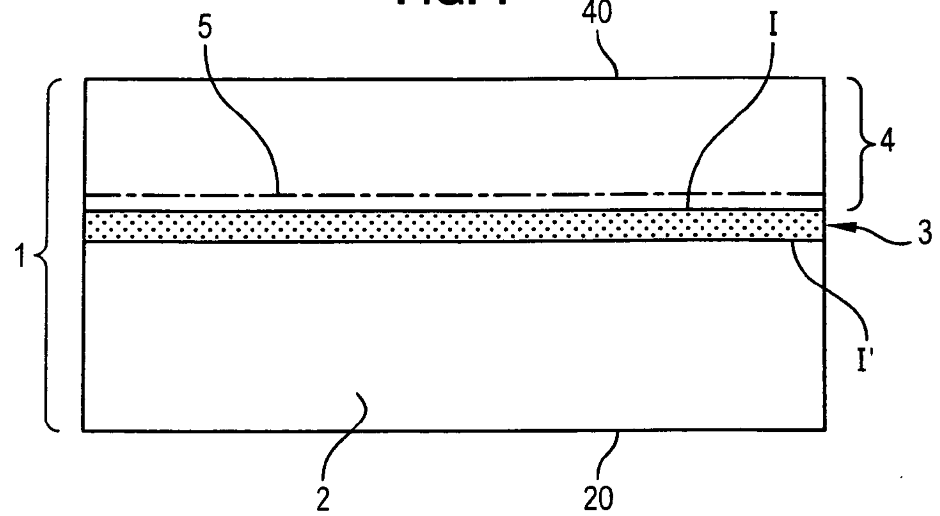


FIG. 2

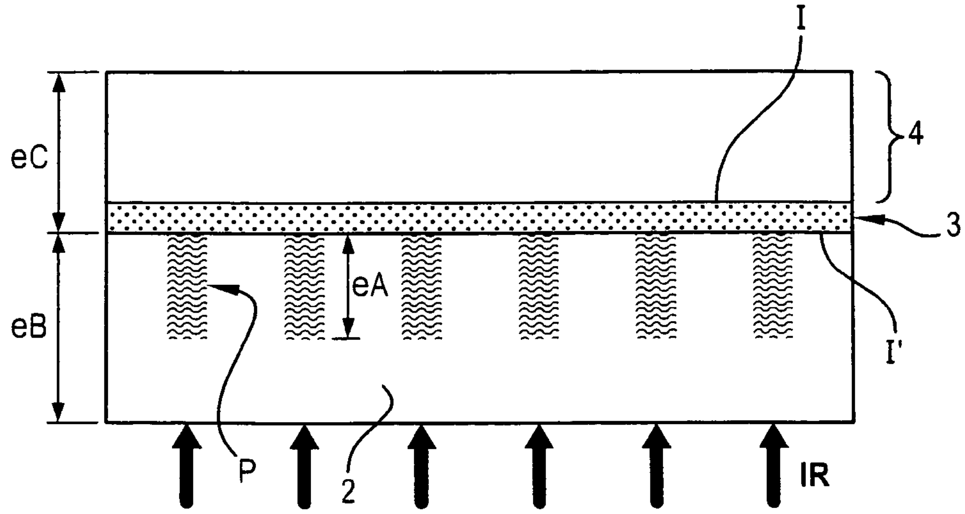


FIG. 3

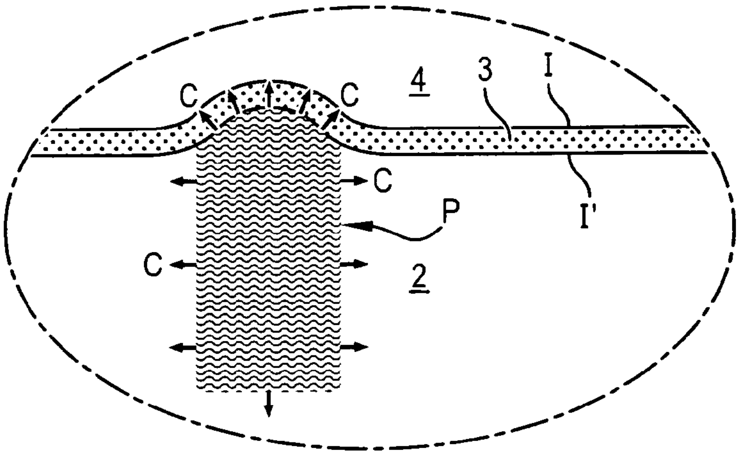


FIG. 4

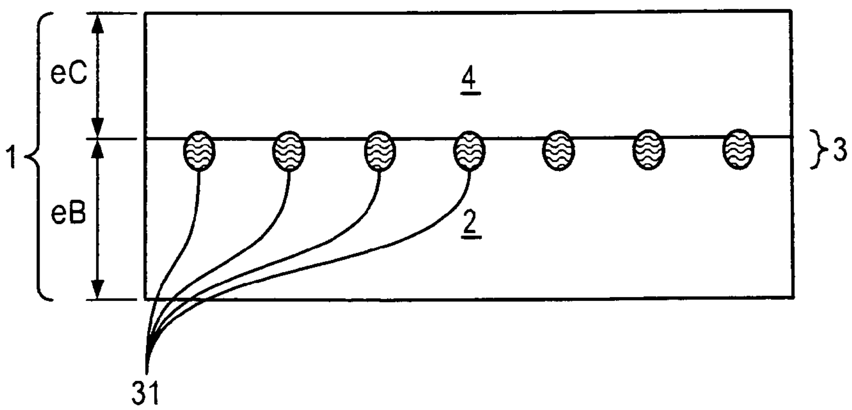


FIG. 5

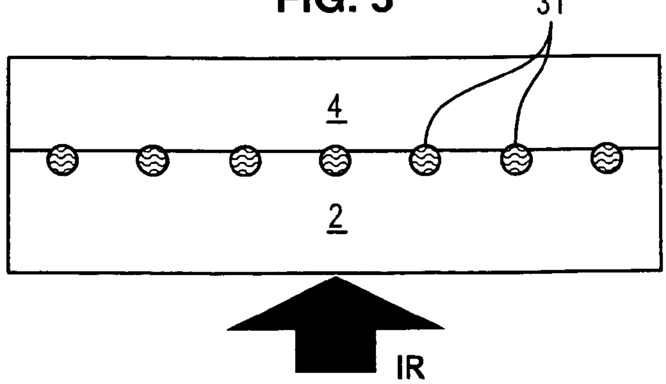


FIG. 6

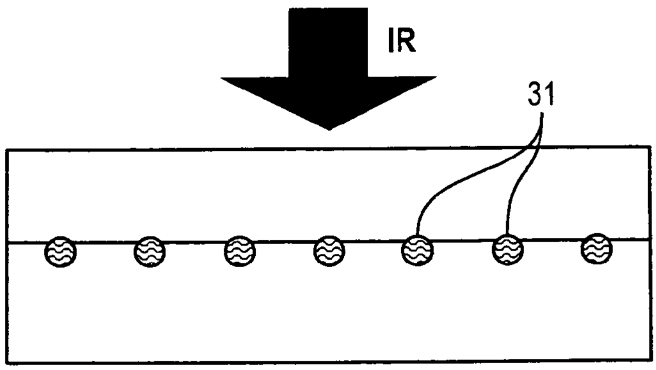
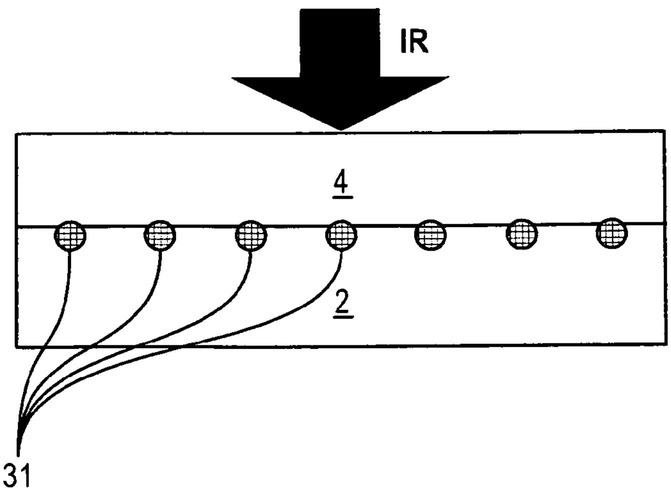


FIG. 7



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2011/065259

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01L21/302 H01L21/78 H01L21/268
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 practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	FR 2 938 116 A1 (APLINOV [FR]) 7 May 2010 (2010-05-07)	15
A	page 12, line 26 - line 31; claims	1-14
A	US 4 456 490 A (DUTTA SUBHADRA [US] ET AL) 26 June 1984 (1984-06-26) claims; figures	1-15

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

[X] 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

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Date of the actual completion of the international search	Date of mailing of the international search report
7 February 2012	14/02/2012

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INTERNATIONAL SEARCH REPORT

Information on patent family members

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