

DESCRIPTION

TITLE OF THE INVENTION: CARRIER PROVIDED WITH A BRAGG MIRROR, INTENDED FOR TRANSFERRING A LAYER BY LASER LIFT- OFF

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TECHNICAL FIELD OF THE INVENTION

[0001] The invention relates to a carrier provided with one or more layers to be transferred and intended to be separated from at least part of the carrier by laser radiation at a separation layer included in the carrier, for the manufacture of products in the semiconductor field.

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TECHNOLOGICAL BACKGROUND

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[0002] Of the thin-film transfer techniques used in the semiconductor industry, laser lift-off (LLO) has emerged as an effective method for separating a film or a stack of films or one or more ultra-thin layers from a carrier substrate by means of a layer, a so-called separation layer, whose separation or degradation is triggered by a laser.

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[0003] In general, the separation layer is irradiated by a laser through the carrier substrate. The separation layer must absorb a sufficient amount of light at the wavelength of the laser in order to promote the separation or the degradation (for example by locally melting the separation layer or for example by causing its dissociation into elementary components), while the carrier substrate must be substantially transparent at this wavelength. A balance must be struck between the power of the laser, the wavelength of the laser and the choice of materials (for the separation layer and the carrier substrate) in order to enable separation while protecting the layer(s) to be transferred from the impact of energy dissipation due to the light interaction processes: heat

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transfer due to absorption in the separation layer or direct absorption by the layer(s) to be transferred.

[0004] Patent US 11,069,865 B2 discloses a method for manufacturing a flexible OLED display panel, wherein the display panel is manufactured on a glass plate covered with an organic separation layer that strongly absorbs UV radiation. The display panel is detached from the glass plate by a laser lift-off operation, wherein the separation layer, capable of absorbing ultraviolet radiation, is irradiated through the glass plate by a laser operating in the ultraviolet range, facilitating the separation.

[0005] Document US 2021/028348 A1 discloses a method for separating a composite structure by means of a light flux.

[0006] Document US 2020/381674 A1 discloses a method for manufacturing a flexible OLED display comprising a laser radiation step to delaminate a flexible film from a base.

[0007] Document US 2022/406621 A1 discloses a manufacturing method comprising a layer peeling step by laser irradiation of an absorbing layer.

[0008] Recent developments have shown that inorganic materials such as TiN can be used as a separation layer in a laser lift-off process by using a laser having a wavelength in the infrared range (about 2000 nm for TiN). Similarly, it is known to use a GaN separation layer on a sapphire carrier using a laser having a wavelength in the ultraviolet range. These developments pave the way for the separation of ultra-thin films or layers with nanometer precision, with many potential developments such as 2.5D and/or 3D integration. Limitations remain due to the relatively low absorption rates of thin inorganic films, bearing in mind that the separation layer must also be thin enough to allow separation, that is, a few tens of nanometers thick in the case of TiN or GaN.

Disclosure of the invention

[0009] The applicant's objective is to improve the absorption rate of laser radiation by an inorganic thin film with a view to using this thin film as a separation layer in a laser lift-off operation.

[0010] In order to achieve this aim, one aspect of the invention is a carrier intended for laser lift-off, comprising a carrier substrate; a separation layer on the carrier layer, formed of an inorganic material with a thickness of between 10 nm and 100 nm; and a layer forming a Bragg mirror, the separation layer being interposed between the carrier substrate and the layer forming the Bragg mirror, the carrier being configured so that the carrier substrate is substantially transparent to laser radiation of a certain wavelength, the layer forming the Bragg mirror is substantially reflective to the laser radiation, and the separation layer can absorb some of the laser radiation, so that the carrier can separate into two parts at the separation layer under the action of the laser radiation, wherein the layer (Brg) forming a Bragg mirror is formed by a stack of first layers (L_L) with low refractive indices alternating with second layers (L_H) with high refractive indices, the high refractive indices being higher than the low refractive indices, the layers with low refractive indices consisting either (i) of silicon oxide for layers with high refractive indices consisting of a material selected from polycrystalline silicon, titanium nitride, titanium oxide, silicon nitride and aluminum oxide, or (ii) consisting of silicon nitride or aluminum oxide for layers with high refractive index consisting of polycrystalline silicon, and the layer forming the Bragg mirror has a thickness of between 0.1 μm and 10 μm or the layer forming the Bragg mirror consists of a number of pairs of layers each comprising one of the layers with a low refractive index and one of the layers with a high refractive index, the number of pairs being between 2 and 10.

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[0011] The presence of the Bragg mirror behind the separation layer enables the laser radiation used during a separation operation to be reflected back to

the latter, the laser source being located on the side of the carrier layer. As a result, the overall absorption rate of this radiation by the separation layer is considerably increased. Increasing the absorption rate of the separation layer is highly beneficial, particularly in the case of a thin inorganic layer, as it allows

5 the laser radiation to separate layers with minimized light intensity, thus reducing the potential damage to the layer or the layers to be transferred and/or to the carrier substrate. Additionally, the use of an inorganic separation layer makes it possible to separate extremely thin layers and/or with nanometric lateral precision, all the more easily as the inorganic layer is thin

10 and therefore has difficulty absorbing sufficient light energy to cause separation.

[0012] Another advantage is that, according to the invention, this optimization can be achieved without resorting to metals traditionally used to form a

15 reflective layer such as copper or aluminum, which are often not very compatible, if not completely incompatible, with so-called front-end manufacturing processes, wherein the atoms of these metals behave as impurities with prohibitive consequences on the semiconductor devices manufactured.

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[0013] According to additional non-limiting features of the carrier according to the invention, considered individually or according to any technically feasible combination:

[0014] - the number of pairs may be between 2 and 4;

25 [0015] - the layer forming the Bragg mirror can have a thickness of between 2 μm and 4 μm and a reflectivity greater than 90%;

[0016] - the layer forming the Bragg mirror can have a thickness of less than 3 μm and a reflectivity greater than 90%;

[0017] - the layer forming the Bragg mirror can be designed to reflect laser

30 radiation in the infrared range;

[0018] - the carrier substrate can be formed of monocrystalline silicon;

[0019] - the carrier may further comprise at least one of (i) a first thermal insulation layer interposed between the carrier substrate and the separation layer and (ii) a second thermal insulation layer interposed between the separation layer and the layer forming the Bragg mirror;

5 [0020] - one or more of the thermal insulation layers can be formed of silicon dioxide; and

[0021] - all the thermal insulation layers can be formed of silicon dioxide.

[0022] The invention extends to a structure comprising the carrier according to
10 the invention and a transfer layer on the carrier, the layer forming the Bragg mirror being interposed between the transfer layer and the separation layer.

[0023] The structure according to the invention, considered individually or according to any technically feasible combination:

15 [0024] - the structure may further comprise a third thermal insulation layer interposed between the transfer layer and the layer forming the Bragg mirror;

[0025] - one or more of the thermal insulation layers can be formed of silicon dioxide; and

[0026] - all the thermal insulation layers can be formed of silicon dioxide.

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BRIEF DESCRIPTION OF THE DRAWINGS

[0027] Other features and advantages of the invention will emerge from the following detailed description of the invention with reference to the appended
25 figures, wherein:

[0028] [Fig. 1] [Fig. 1] shows a structure according to the invention;

[0029] [Fig. 2] [Fig. 2] shows the structure according to the claim being separated; and

[0030] [Fig. 3] [Fig. 3] is a graph showing the reflectivity of Bragg mirrors.

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DETAILED DESCRIPTION OF THE INVENTION

[0031] First embodiment

[0032] A first embodiment of the present invention is disclosed by means of Figures 1 to 3 and the associated passages below.

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[0033] Figures 1 and 2 show a structure Strc consisting of a carrier 100 and a transfer layer Tr, intended to be separated from at least part of the carrier 100, which may have supported it during manufacture thereof, for example.

10 [0034] The transfer layer Tr may for example consist of a layer of semiconductor material such as a layer of monocrystalline silicon bonded to a layer of silicon oxide, or a layer comprising conventionally fabricated semiconductor components.

15 [0035] In the embodiment shown herein, the carrier 100 may comprise a carrier substrate Sprt on which are formed, in this order from the carrier substrate: a first thermal insulation layer Ins1, a separation layer Sep, a second thermal insulation layer Ins2, a layer Brg forming a Bragg mirror, a third thermal insulation layer Ins3, and the transfer layer Tr.

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[0036] The carrier substrate Sprt can be formed of solid monocrystalline silicon, for example a silicon wafer.

[0037] The first thermal insulation layer Ins1 and the second thermal insulation
25 layer Ins2 can each be formed of a layer of silicon oxide SiO₂ with a thickness of between 10 nm and 200 nm.

[0038] The separation layer can be formed of a layer of an inorganic material such as a layer of titanium nitride TiN with a thickness of between 1 nm and
30 50 nm.

[0039] The third thermal insulation layer Ins3 can be formed of a layer of silicon oxide SiO₂ with a thickness of between 200 nm and 1000 nm.

[0040] The first, second and third thermal insulation layer can alternatively
5 each be formed of silicon nitride, independently of one another.

[0041] The layer Brg forming the Bragg mirror can be formed of a stack of first layers L_L with low refractive indices n_L alternating with second layers L_H with high refractive indices n_H, the high refractive indices n_H being higher than the
10 low refractive indices n_L. The materials forming the layers with low refractive indices can be selected so as to obtain low and high refractive indices between 1.25 and 4.1, the differences between these indices preferably being less than 2.85.

15 [0042] The thicknesses of the alternating layers can be determined according to the following equations 1 and 2:

[0043] $d_H = \frac{\lambda}{4n_H}$ Eq. 1

20 [0044] $d_L = \frac{\lambda}{4n_L}$ Eq. 2

[0045] wherein d_H and d_L represent the thicknesses of the layers with high and low refractive indices, and λ represents the wavelength of the laser radiation used to separate the layers. The thicknesses of the layers L_L and L_H can be
25 between 10 nm and 1 μm, thicknesses with a compromise between a level of uniformity for the thin layers and an excessive thickness for the layer forming the Bragg mirror as a whole, preferably between 1 μm and 10 μm.

[0046] The layers L_L with low refractive indices can be made of silicon oxide,
30 and the layers with high refractive indices can be made of a material selected from polycrystalline silicon, titanium nitride, titanium oxide and silicon nitride.

Such materials are easy to deposit and widely used in the field of microelectronics, particularly for so-called “front-end” processes.

[0047] For a structure as described hereinbefore, the laser radiation used to perform the separation is in the infrared range, with a wavelength preferably between 700 nm and 10 μm , more specifically between 1 μm and 5 μm . For other structures based on other materials, the radiation can be performed by a laser with a wavelength preferably between 50 nm and 17 μm .

[0048] The ranges of layer thicknesses and refractive indices, and the nature of the carrier substrate, are naturally interrelated, and dependent on the laser radiation intended to be used. It must be ensured that, for the wavelength of the laser intended to be used to perform the separation, the carrier substrate is substantially transparent, the Bragg mirror reflective, and the separation layer absorbent.

[0049] [Fig.3] shows, by means of a graph, the importance and the relevance of the choice of materials to form the Bragg mirror. The graph in [Fig.3] comprises 6 curves, each representing the reflectivity, expressed in percent %, of a Bragg mirror based on its thickness, expressed in micrometers μm . The four curves BrRefl-1 to BrRefl-4 correspond to laser radiation at a wavelength of 2 μm for four Bragg mirrors, whose layers with low refractive indices are made of silicon dioxide SiO_2 , and whose layers with high refractive indices are made of silicon nitride Si_3N_4 , titanium dioxide TiO_2 , titanium nitride TiN and polycrystalline silicon Poly-Si, respectively. The two curves BrRefl-5 and BrRefl-6 correspond to laser radiation at a wavelength of 10 μm for two Bragg mirrors, whose layers with high refractive indices are made of polycrystalline silicon Poly-Si, and the layers with low refractive indices are made of silicon nitride Si_3N_4 and silicon oxide Al_2O_3 , respectively.

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[0050] For an incident laser having a wavelength of 2 μm , the reflectivity initially increases rapidly with the thickness of the Bragg mirror, reaching a

plateau close to perfect reflectivity of 100%. We find that for thicknesses between 4 μm and 10 μm , the reflectivity of the layer is close to 1, at over 95% reflectivity, for each of the four Bragg mirrors. This is also the case with thicknesses between 1 μm and 10 μm for Bragg mirrors whose layers with high refractive indices are made of titanium nitride or polycrystalline silicon. In the case of the latter, reflectivities in excess of 50% can even be observed at thicknesses of just 0.5 μm .

[0051] Another way of characterizing the Bragg mirrors is the number of pairs, each consisting of a layer with a high refractive index and a layer with a low refractive index, forming the Bragg mirror in question. Thus, to achieve a reflectivity of over 90% while limiting the thickness and the manufacturing complexity of a Bragg mirror, the number of pairs of layers between 2 and 10 is sufficient. It is even possible to limit the number of pairs to between 2 and 4, or even equal to 2 or 3, for $\text{SiO}_2/\text{Poly-Si}$ or SiO_2/TiN pairs. Minimizing the number of pairs means maximizing the difference between the high and low refractive indices of the two layers forming the pair in question.

[0052] For the case of an incident laser having a wavelength of 10 μm , similar observations can be made to the previous case, with reflectivities that initially increase rapidly with the thickness of the Bragg mirror, reaching a plateau close to the perfect reflectivity of 100%. We find that for thicknesses between 4 μm and 10 μm , the reflectivity of the layer is close to 1, at over 90% reflectivity, for each of the two Bragg mirrors. It should be noted that as the wavelength is longer than in the first case, the thickness of the stack increases mechanically.

[0053] Naturally, materials are selected in pairs of materials; a first material with a relatively low refractive index being coupled to a second material with a relatively high refractive index.

[0054] In operation, separation takes place at the separation layer, which first absorbs the energy of the incident laser radiation, then a second time following its reflection by the layer forming the Bragg mirror. By absorption, the separation layer is heated locally, eventually causing it to break down (in the case of a TiN layer, TiN breaks down into nitrogen gas and liquid Ti) and therefore detaching the two surrounding layers from each other. [Fig.2] shows this situation, with the layer Ins2 detaching from the layer Ins1 following the removal, or the degradation, of the separation layer Sep.

[0055] Preliminary calculations indicate an increase in laser radiation absorption of at least 15% in the TiN separation layer of the structure described hereinbefore.

[0056] Local heating caused by laser radiation can reach up to 2000°C, and heating of neighboring layers must be limited. In particular, the degradation of the layer of interest of the method, which is the transfer layer Tr, must be avoided. The thermal insulation layer Ins3 limits heating of the layer of interest. For this purpose, the thermal insulation layer Ins3 can be the thickest of the three thermal insulation layers.

[0057] It may also be advantageous to limit heating of the carrier substrate Sprt, particularly if it is to be reused. This is the role of the thermal insulation layer Ins1.

[0058] Finally, heating the Bragg mirror can significantly modify its refractive indices. This is the case, for example, if a polycrystalline silicon layer is used, whose structure can be transformed by recrystallization through excessive heating, causing it to lose its polycrystalline character and therefore radically altering its refractive index.

[0059] It should be noted that the thermal insulation layers Ins1, Ins2 and Ins3 are each individually optional, their respective usefulness having to be

examined on a case-by-case basis. Additionally, materials other than silicon oxide can be used, even if the latter is extremely convenient to use due to its physical characteristics and its high compatibility with semiconductor manufacturing processes.

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[0060] All the layers mentioned in this description can be formed by means of thin-film deposition methods well known and mastered in the semiconductor field.

10 [0061] Second embodiment

[0062] The first embodiment takes as an example the situation of a structure suitable for separation by infrared radiation, with, for this range of wavelengths, a transparent carrier substrate, a reflective Bragg mirror, and an absorbing separation layer. However, other situations can be considered.

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[0063] This second embodiment represents such a situation: it relates to a structure similar to that of the first embodiment and shown in the same figures, but comprising a layer of interest (GaN or other, depending on the intended applications) formed on a sapphire carrier substrate and comprising a GaN separation layer. In such a case, the materials and the thicknesses considered will have to be adapted to the wavelength of a radiation passing through the sapphire, that is, in the ultraviolet range, with a wavelength between 100 nm and 380 nm.

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[0064] Thus, the layer Brg forming a Bragg mirror can be made up of alternating 40 nm-thick SiO_2 layers and 26 nm-thick Si_3N_4 layers, with a total thickness preferably between 1 μm and 10 μm . If required, the thermal insulation layer(s) Ins1, Ins2 and Ins3 can each consist of a 50 nm to 100 nm thick layer of SiO_2 or Al_2O_3 . The separation layer Sep can be formed of a layer of GaN with a thickness of between 10 nm and 100 nm. The carrier substrate Sprt can be a sapphire Al_2O_3 substrate.

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[0065] In this case, the laser radiation used to perform the separation is in the ultraviolet range, with a wavelength preferably between 200 nm and 400 nm.

- 5 [0066] Preliminary calculations indicate an increase in laser radiation absorption in the separation layer of at least 40% in the GaN separation layer of the structure described hereinbefore.

- 10 [0067] Of course, the invention is not limited to the embodiments described hereinbefore and it is possible to add alternatives thereto without departing from the scope of the invention as defined by the claims.

Claims

[Claim 1] A carrier (100) intended for laser lift-off, comprising:

- a carrier substrate (Sprt);
- 5 - a separation layer (Sep) on the carrier layer, formed of an inorganic material with a thickness of between 10 nm and 100 nm;
- and
- a layer (Brg) forming a Bragg mirror, the separation layer (Sep) being interposed between the carrier substrate (Sprt) and the layer (Brg) forming the
- 10 Bragg mirror,
- the carrier being configured whereby:
- the carrier substrate is substantially transparent to laser radiation of a certain wavelength,
- the layer forming the Bragg mirror is substantially reflective with
- 15 respect to the laser radiation, and
- the separation layer (Sep) can absorb some of the laser radiation, so that the carrier can be separated into two parts at the separation layer (Sep) under the action of the laser radiation, wherein:
- the layer (Brg) forming a Bragg mirror is formed of a stack of first layers
- 20 (L_L) with low refractive indices alternating with second layers (L_H) with high refractive indices, the high refractive indices being higher than the low refractive indices,
- the layers with low refractive indices are either (i) made of silicon oxide for layers with high refractive indices made of a material selected from
- 25 polycrystalline silicon, titanium nitride, titanium oxide, silicon nitride, and aluminum oxide, or (ii) made of silicon nitride or aluminum oxide for layers with high refractive indices made of polycrystalline silicon, and
- the layer forming the Bragg mirror has a thickness of between 0.1 μm and 10 μm, or
- 30 - the layer forming the Bragg mirror is made up of a number of pairs of layers each comprising one of the layers with a low refractive index and one of

the layers with a high refractive index, the number of pairs being between 2 and 10.

[Claim 2] The carrier according to claim 1, wherein the number of pairs is
5 between 2 and 4.

[Claim 3] The carrier according to claim 2, wherein the layer forming the
Bragg mirror has a thickness of between 2 μm and 4 μm and a reflectivity
greater than 90%.
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[Claim 4] The carrier according to claim 2, wherein the layer forming the
Bragg mirror has a thickness less than 3 μm and a reflectivity greater than
90%.

[Claim 5] The carrier according to any one of claims 1 to 4, wherein the layer
(Brg) forming the Bragg mirror is designed to reflect laser radiation belonging
to the infrared range.
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[Claim 6] The carrier according to any one of claims 1 to 5, wherein the
carrier substrate (Sprt) is formed of monocrystalline silicon.
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[Claim 7] The carrier according to any one of claims 1 to 6, further
comprising at least one of (i) a first thermal insulation layer (Ins1) interposed
between the carrier substrate (Sprt) and the separation layer (Sep) and (ii) a
25 second thermal insulation layer (Ins2) interposed between the separation layer
(Sep) and the layer (Brg) forming the Bragg mirror.

[Claim 8] The structure (Strc) comprising the carrier (100) according to any
one of claims 1 to 7 and a transfer layer (Tr) on the carrier (100), the layer (Brg)
30 forming a Bragg mirror being interposed between the transfer layer (Tr) and
the separation layer (Sep).

[Claim 9] The structure according to claim 8, further comprising a third thermal insulation layer (Ins3) interposed between the transfer layer and the layer forming the Bragg mirror.

- 5 [Claim 10] The carrier according to claim 7 or the structure according to claim 9, one or more of the thermal insulation layers being formed of silicon dioxide.

- 10 [Claim 11] The carrier according to claim 7 wherein the two thermal insulation layers (Ins1, Ins2) are formed of silicon dioxide or the structure according to claim 12 wherein the three thermal insulation layers (Ins1, Ins2, Ins3) are formed of silicon dioxide.