

as not to heat up and is thick enough to maintain the layer to be separated at a temperature below a determined threshold for the duration of the exposure to the light flux.

However, for certain materials of the layer to be separated and/or of the final carrier where applicable, such a thermal barrier layer may not be sufficient.

Thus, for example, in the case where the layer to be separated comprises a stack of ferromagnetic materials such as CoFeB/MgO, an interdiffusion of the atoms takes place from a temperature of about 400 to 600°C. In the case where the layer to be separated is made of graphene, a degradation of the electrical properties takes place from a temperature of 600°C. In the case of a layer to be separated made of molybdenite (MoS₂), a modification of the hybridization and a reaction with other materials may take place from a temperature of about 450 to 600°C. In the case where the layer to be separated is made of a phase-change alloy, such as GeSbTe, melting and a transition to the amorphous phase take place from about 600°C.

Likewise, depending on the composition of the final carrier to which the layer to be separated is to be transferred, said carrier may be affected by the thermal budget applied in order to dissociate the sacrificial layer. Thus, for example, if the final carrier comprises electronic circuits containing copper, extrusion of the copper lines may take place from 400°C. In the case where the final carrier is made of a polymer material (for example a plastic material), it may decompose from 200°C.

In such cases, in order to carry out the separation at low temperature, one possible technique is to remove the substrate via an etch from the rear face of the layer to be separated, in such a way that said substrate cannot be recycled for another use.

Another conceivable method based on the LLO technique, when the final carrier is sensitive to temperature, is to transfer the layer to be separated to a temporary substrate which is not liable to be affected by the thermal budget for dissociation of the sacrificial layer, then to transfer the layer to be separated to the final carrier. However, this method takes longer and is more expensive than the LLO method since it requires that the layer of interest be transferred twice.

BRIEF DESCRIPTION OF THE INVENTION

Embodiments of the invention seek to overcome the aforementioned drawbacks and in particular to design a dismantlable composite structure comprising a sacrificial layer capable of dissociating through the application of a limited thermal budget (typically corresponding to a temperature of lower than 500°C) generated through the absorption of a light flux.

According to an aspect of the present invention, there is provided a method for separating a composite structure that is dismantlable by means of a light flux, the method including: providing the dismantlable composite structure comprising successively: a substrate, an optically absorbent layer made of a material suitable for at least partially absorbing a light flux, the substrate being substantially transparent to the light flux, a sacrificial layer suitable for dissociating under the application of a temperature higher than a dissociation temperature,

made of a material different from that of the optically absorbent layer, at least one layer to be separated, applying a light flux through the substrate, the light flux being absorbed at least in part by the optically absorbent layer, so as to heat the optically absorbent layer, heating the sacrificial layer by thermal conduction from the optically absorbent layer, up to a temperature higher than or equal to the dissociation temperature, dissociating the sacrificial layer under the effect of the heating.

To this end, an embodiment of the invention proposes a composite structure that can be dismantled by means of a light flux, comprising successively:

- a substrate,
- an optically absorbent layer made of a material suitable for at least partially absorbing a light flux, the substrate being substantially transparent to said light flux,
- a sacrificial layer suitable for dissociating under the application of a temperature higher than a dissociation temperature, made of a material different from that of the optically absorbent layer,
- at least one layer to be separated.

The term "composite" is understood to mean that the structure is formed of a stack of different materials, exhibiting in particular different properties in terms of optical absorption and temperature resistance.

The term "dismantlable" is understood to mean that the composite structure is able to separate along a plane parallel to its main surfaces, into two parts which each retain their integrity, with the exception of a sacrificial layer which is located at the interface between the two parts and which dissociates to allow said separation.

The term "substantially transparent material" is understood to mean a material that allows at least 90% of the light flux that it receives to pass. In other words, the product of the thickness of said material and of the coefficient of absorption of the light flux by said material is less than 0.1.

The term "optically absorbent material" is understood to mean a material that absorbs at least 90% of the light beam that it receives. In other words, the product of the thickness of said material and of the coefficient of absorption of the light flux by said material is greater than 2.3. The optical absorption coefficient, at the wavelength of the light flux, is preferably greater than 10^5 cm^{-1} .

The terms "on" and "between" referring to the relative position of two layers do not necessarily imply direct contact between said layers, unless such contact is specified.

By providing a sacrificial layer that is distinct from the optically absorbent layer, in comparison with the known method in which the sacrificial layer is merged with the optically absorbent layer, the composite structure according to embodiments of the invention has several advantages. Specifically, the thickness of the sacrificial layer may be minimized. Because of this, the amount of heat present after dissociation of said layer on the side of the layer to be separated will be lower. In addition, the sacrificial layer itself contributes to distancing the optically absorbent layer from the layer to be separated. As a result, the

composite structure may be separated using a lower thermal budget, which allows the use of a layer to be separated and/or of a final carrier which are sensitive to temperature as mentioned above.

According to other advantageous but optional features of said structure, considered alone or in combination when this is appropriate:

- the sacrificial layer is in contact with the optically absorbent layer;
- the sacrificial layer is made of a material that is substantially transparent to said light flux;
- the structure further comprises a first thermal barrier layer that is substantially transparent to said light flux, between the substrate and the optically absorbent layer;
- the structure further comprises a second thermal barrier layer between the sacrificial layer and the layer to be separated;
- the first and/or the second thermal barrier layer has a linear thermal conductivity coefficient of less than $10 \text{ W m}^{-1} \text{ K}^{-1}$;
- the first and/or the second thermal barrier layer comprises at least one of the following materials: silica (SiO_2), alumina (Al_2O_3);
- the structure further comprises a first film suitable for reflecting or absorbing the light flux, between the sacrificial layer and the layer to be separated;
- said first film comprises at least one of the following materials: silicon, silica (SiO_2), silicon carbide (SiC), molybdenum, silicon nitride (Si_3N_4);
- the structure further comprises, between the sacrificial layer and the layer to be separated, a second film suitable for distributing the heat over the entire area of the structure;
- said second film comprises at least one of the following materials: alumina (Al_2O_3), silica (SiO_2), polycrystalline aluminum nitride (AlN), polycrystalline silicon;
- the substrate comprises at least one of the following materials: sapphire, quartz;
- the optically absorbent layer comprises at least one of the following materials: silicon nitride (Si_3N_4), polycrystalline silicon, polycrystalline silicon carbide (SiC);
- the sacrificial layer comprises at least one of the following materials: silicon nitride (Si_3N_4), polycrystalline aluminum nitride (AlN), polycrystalline gallium nitride (GaN), indium tin oxide (ITO);
- the layer to be separated comprises at least one of the following materials: a metal, such as copper; a group IV material having a hexagonal crystal structure, such as graphene; a piezoelectric, ferromagnetic or ferroelectric material; a phase-change alloy, such as GeSbTe.

Another embodiment of the invention relates to a method for separating a dismantlable composite structure such as described above.

Said method comprises:

- applying a light flux through the substrate, said light flux being absorbed at least in part by the optically absorbent layer, so as to heat said optically absorbent layer,
- heating the sacrificial layer by thermal conduction from the optically absorbent layer, up to a temperature higher than or equal to the dissociation temperature,

- dissociating the sacrificial layer under the effect of said heating.

According to other advantageous but optional features of said method, considered alone or in combination when this is appropriate:

- the product of the thickness of the substrate and of the coefficient of absorption of the light flux by the substrate is less than 0.1;
- the product of the thickness of the optically absorbent layer and of the coefficient of absorption of the light flux by said layer is greater than 2.3;
- the light flux is applied in a pulsed manner;
- the wavelength of the light flux is between 100 and 12 000 nm;
- before the application of said light flux, the method comprises a step of bonding the composite structure to a carrier, the dissociation of the sacrificial layer leading to the transfer of the layer to be separated to the carrier;
- the carrier comprises at least one of the following materials: a semiconductor material, such as silicon; a metal, such as copper; a polymer.

Another embodiment of the invention relates to a method for producing a dismantlable composite structure such as described above. The method includes the following steps:

- providing the substrate,
 - forming, on the substrate, an optically absorbent layer made of a material suitable for at least partially absorbing a light flux, the substrate being substantially transparent to said light flux,
 - forming the layer to be separated on the optically absorbent layer,
- the method being characterized in that it comprises the formation of the sacrificial layer between the optically absorbent layer and the layer to be separated, said sacrificial layer being made of a material different from that of the optically absorbent layer.

Advantageously, the formation of the layer to be separated is implemented at a temperature lower than the dissociation temperature of the sacrificial layer.

The formation of the layer to be separated may comprise the deposition or the bonding of said layer on or to a seed layer. Said seed layer may comprise at least one of the following materials: platinum, nickel, copper.

BRIEF DESCRIPTION OF THE DRAWINGS

Other features and advantages of the invention will emerge from the detailed description which follows, with reference to the appended drawings, in which: