hybrid III/V-on-silicon photonic integrated circuit application, IEEE JOURNAL OF SELECTED TOPICS IN QUANTUM ELECTRONICS, 2016, Vol. 22, No. 6, 8200612

SUMMARY OF INVENTION

TECHNICAL PROBLEM

[0008] In the techniques in Patent Literatures 1 and 2, since the semiconductor element and the substrate for heat dissipation are directly bonded to each other, it is necessary to apply a high temperature and pressure for bonding. Therefore, semiconductor elements need to be transferred and mounted one by one (transferring and mounting speed: 0.1 to 1 piece/second) by using a flip chip (hereinafter also referred to as "FC") bonder capable of high temperature bonding, and there is a problem that the transfer and mounting step takes a long time. In addition, in Non Patent Literatures 1 and 2, wafers are collectively subjected to the high temperature bonding, and although the step is shortened in time, it is necessary to transfer and mount semiconductor elements one by one. In both Non Patent Literatures 1 and 2, it is desired to transfer an epitaxially grown thin film crystal, but there is a problem that the thin film crystal is brittle and damaged during transportation. Therefore, a step of transporting the thin film crystal together with a substrate and then peeling off the substrate is required.

[0009] On the other hand, in the techniques in Patent Literatures 3 and 4 and Non Patent Literature 2, a large number of semiconductor elements can be transferred and mounted at one time, but since a size of a stamp depends on a wafer size, the number of semiconductor elements for simultaneous transfer is limited. In addition, it is necessary to prepare a stamp according to a design of the circuit substrate each time, and there is a problem that defective chips are also transferred at the same time. Since the resin used for the stamp head has insufficient heat resistance, there is also a problem that it cannot be applied to a technique requiring mounting at a high temperature such as direct bonding.

[0010] In addition, the polyimide copolymer presented in Patent Literatures 5 and 6 has high heat resistance, but has very high adhesiveness since it is specialized in process passability after adhering to a substrate or a copper foil, and when it is intended to be applied to a transfer application for a minute device such as a semiconductor element, the application is difficult, due to the difficulty of the transfer itself and a large amount of residue caused by the adhesive remaining on the chip surface after transfer.

[0011] That is, there are problems that a process time in the FC bonder mounting for the

semiconductor chip is long, and damages occur during transferring and mounting of the thin film semiconductor chip, and inability to avoid both problems is a further problem.

SOLUTION TO PROBLEM

[0012] The present inventors have found that the above problems can be solved by producing a semiconductor device by a laser lift-off (LLO) technique using a laminate 1 in which a laser-absorbing temporary adhesive layer 1, a protective layer 1, and a semiconductor layer 1 are laminated in this order on a laser-transmitting substrate 1 and a laminate 2 in which a pressure-sensitive adhesive layer is laminated on a support substrate 2.

[0013] In order to solve the above problems, the present invention is characterized by the following (1) to (17).

(1) A laminate including: a laser-transmitting substrate 1; and a laser-absorbing temporary adhesive layer 1, a protective layer 1, and a semiconductor layer 1 laminated in this order on the laser-transmitting substrate 1.

(2) The laminate according to the above (1), in which the semiconductor layer 1 is a compound semiconductor.

(3) The laminate according to the above (2), in which the compound semiconductor is AlGaInAs, InGaAs, InP, InGaAsP, AlAs, InAs, GaAs, AlN, AlP, GaN, InN, or SiC.

(4) The laminate according to any one of the above (1) to (3), in which the protective layer 1 is at least one of an oxide film and a nitride film.

(5) The laminate according to the above (4), in which the protective layer 1 contains SiO_2.

(6) A method for producing a laminate, successively including:

a step (I) of using a laminate 1, in which a laser-absorbing temporary adhesive layer 1, a protective layer 1, and a semiconductor layer 1 are laminated in this order on a laser-transmitting substrate 1, and a laminate 2, in which a pressure-sensitive adhesive layer is laminated on a support substrate 2, to cause a surface of the laminate 1 on a semiconductor layer 1 side and a surface of the laminate 2 on a pressure-sensitive adhesive layer side to face each other; and

a step (II) of irradiating the laser-absorbing temporary adhesive layer 1 with a laser from a surface side of the laminate 1 opposite to the surface thereof on the semiconductor layer 1 side while transmitting the laser through the laser-transmitting substrate 1, and transferring a structure in which the protective layer 1 and the semiconductor layer 1 are laminated to the

to 5 mm from the viewpoint of handling the substrate.

[0093] (Pressure-Sensitive Adhesive Layer)

Next, the pressure-sensitive adhesive layer included in the laminate 2 will be described.

The pressure-sensitive adhesive layer has a pressure-sensitive adhesive property even after thermal curing, a curing treatment in which a crosslinking agent or a curing agent reacts, or the like, and an object held in the pressure-sensitive adhesive layer can be reversibly held and detached.

[0094] The pressure-sensitive adhesive layer is a resin layer having a pressure-sensitive adhesive property. Examples of the resin that can be contained in the pressure-sensitive adhesive layer include, but are not limited to, a resin having a glass transition temperature of 100°C or lower, such as a polyimide, a polyimide precursor, a polybenzoxazole, a polybenzoxazole precursor, a urethane resin, a novolac resin, a polyhydroxystyrene, a polyester resin, an acrylic resin, an aramid resin, a silicone, and a polyimide silicone resin.

[0095] The pressure-sensitive adhesive layer adheres, in a pressure-sensitive manner, to the semiconductor layer 1 in forming a laminate 3. It is preferable that the pressure-sensitive adhesive layer has heat resistance and mechanical properties that allow the semiconductor layer 1 to be directly bonded to a circuit substrate in a state where the pressure-sensitive adhesive layer and the semiconductor layer 1 adhere to each other in a pressure-sensitive manner during production of a semiconductor device thereafter. The heat resistance is preferably 200°C or higher, and more preferably 250°C or higher. The heat resistance means the 1% mass loss temperature of a cured film of the pressure-sensitive adhesive layer. "Having mechanical properties" means that when directly bonding the semiconductor layer 1 to a circuit substrate at a high temperature, protrusion due to melting of the pressure-sensitive adhesive layer does not adversely influence the direct bonding.

[0096] The elastic modulus of the pressure-sensitive adhesive layer at 200°C is preferably 0.1 MPa or more, more preferably 0.3 MPa or more, and still more preferably 0.5 MPa or more. Since solvent etching of the semiconductor layer 1 and removal of the photoresist or the protective layer 1 may be performed in a state where the pressure-sensitive adhesive layer and the semiconductor layer 1 adhere to each other in a pressure-sensitive manner, it is preferable that the pressure-sensitive adhesive layer has chemical resistance. Examples of the solvent to be used include acids such as hydrofluoric acid, buffered hydrofluoric acid, hydrochloric acid,

by copolymerizing a diamine containing the diamine residue (A0) and another diamine containing the diamine residue (A3).

[0103] Further, by copolymerizing the diamine residue (A3) in addition to the diamine residue (A0), the polyimide copolymer (A) can be crosslinked with a crosslinking agent to be described later. In addition, due to an effect of a hydrogen bond of the hydroxy group in the diamine residue (A3), an effect of keeping the elastic modulus constant in heating the pressure-sensitive adhesive layer is obtained.

[0104] The polyimide copolymer (A) constituting the pressure-sensitive adhesive layer preferably contains the diamine residue (A0) in an amount of 50.0 mol% to 95.0 mol% in 100.0 mol% of all the diamine residues. In the case where the diamine residue (A0) is contained in an amount of 50.0 mol% or more, the pressure-sensitive adhesive layer exhibits a good pressure-sensitive adhesive property, and the semiconductor layer 1 can be laminated on the pressure-sensitive adhesive layer with a high probability. In the case where the diamine residue (A0) is 95.0 mol% or less with respect to 100 mol% of all the diamine residues, temporal stability of the pressure-sensitive adhesive layer is improved, and a positional deviation of the semiconductor layer 1 when being stored in the state of the laminate 3 to be described later can be reduced. The diamine residue (A0) is more preferably contained in an amount of 80.0 mol% to 93.0 mol% in 100.0 mol% of all the diamine residues. In the case of 80 mol% or more, the pressure-sensitive adhesive layer exhibits good flexibility, and when the semiconductor layer 1 is transferred from the laminate 1 by using a laser to be described later, the semiconductor layer 1 can be laminated with high positional accuracy. In the case of 93 mol% or less, the step of applying heat or pressure such as direct bonding can be passed through.

[0105] In addition, the polyimide copolymer (A) constituting the pressure-sensitive adhesive layer according to the present embodiment preferably contains the diamine residue (A3) having a phenolic hydroxy group. In the case where the polyimide copolymer (A) contains the diamine residue (A3), the hydroxy group in the diamine residue (A3) is hydrogen-bonded, so that the elastic modulus at a high temperature can be kept constant, and protrusion of the pressure-sensitive adhesive layer in the direct bonding step can be prevented. In addition, in the case of adding a crosslinking agent, the resin on the surface of the pressure-sensitive adhesive layer is crosslinked, and when the semiconductor layer 1 laminated on the pressure-sensitive adhesive layer is to be separated from the pressure-sensitive adhesive layer, cohesive failure of the pressure-sensitive adhesive layer is reduced, and the adhesive residue on the surface of the

adhesive layer 1 (reference numeral 12) is then removed from the laminate 4 (reference numeral 600) (FIG. 8B). The removal of the laser-absorbing temporary adhesive layer 1 may be performed by wet cleaning with a solvent, a peeling liquid, or the like, or may be performed by dry-etching. At this time, a step (III') of removing a part of the pressure-sensitive adhesive layer to pattern the pressure-sensitive adhesive layer, which is to be described later, is also preferably performed collectively since the step can be simplified.

[0150] The method for producing the laminate 3 according to the embodiment of the present invention preferably includes the step (III) of removing a part of the pressure-sensitive adhesive layer in the laminate 3 obtained in the step (II) of constituting the laminate 3 and patterning the pressure-sensitive adhesive layer.

[0151] The laminate 3 preferably has a shape in which a part of the pressure-sensitive adhesive layer is removed and the pressure-sensitive adhesive layer is patterned. The patterning referred to here means that, as illustrated in FIG. 9A, in the pressure-sensitive adhesive layer (reference numeral 22), there is a difference in thickness between a pressure-sensitive adhesive layer (reference numeral 24) present between the semiconductor layer 1 (reference numeral 14) and the support substrate 2 (reference numeral 21) and a pressure-sensitive adhesive layer (reference numeral 25) on a portion of the support substrate 2 (reference numeral 21) not having the semiconductor layer 1 (reference numeral 14). At this time, the difference in thickness between the pressure-sensitive adhesive layer (reference numeral 24) present between the semiconductor layer 1 (reference numeral 14) and the support substrate 2 (reference numeral 21) and the pressure-sensitive adhesive layer (reference numeral 25) on the portion of the support substrate 2 (reference numeral 21) not having the semiconductor layer 1 (reference numeral 14) is preferably at least 0.5 μm. In particular, as illustrated in FIG. 9B, the laminate 3 (reference numeral 300) preferably includes only the pressure-sensitive adhesive layer (reference numeral 24) present between the semiconductor layer 1 (reference numeral 14) and the support substrate 2 (reference numeral 21) as the pressure-sensitive adhesive layer. That is, in the laminate 3, the pressure-sensitive adhesive layer other than the portion between the semiconductor layer 1 and the support substrate 2 is preferably removed. The protective layer 1 is preferably removed from the laminate 3 simultaneously with or after the removal of the pressure-sensitive adhesive layer, to expose the surface of the semiconductor layer 1. This is to facilitate the bonding between the laminate 3 and the circuit substrate and the removal of a pressure-sensitive adhesive layer-attached support substrate 2 in the subsequent

removing the pressure-sensitive adhesive layer after removing the support substrate 2, the semiconductor device (reference numeral 400) in which the semiconductor layer 1 (reference numeral 14) is bonded to the circuit substrate (reference numeral 41) can be obtained (FIG. 10C). Similarly, in the case where the pressure-sensitive adhesive layer does not have laser absorbability and the laser-absorbing layer 2 is included between the support substrate 2 and the pressure-sensitive adhesive layer, the pressure-sensitive adhesive layer-attached support substrate 2 can be peeled off from the semiconductor layer 1 by laser irradiation from the support substrate 2 side. In this case, after the support substrate 2 is removed, the laser-absorbing layer 2 is removed together with the pressure-sensitive adhesive layer.

[0160] As described above, the semiconductor device can be produced by bonding the semiconductor layer 1 to the circuit substrate by thermocompression-bonding. The circuit substrate may be an SOI wafer on which an optical waveguide is formed, as described in Non Patent Literatures 1 to 3 (Alexander W. Fang et al., Electrically pumped hybrid AlGaInAs-silicon evanescent laser, OPTICS EXPRESS, 2006, Vol. 14, No. 20, p9203; Jing Zhang et al., III-V-on-Si photonic integrated circuits realized using micro-transfer-printing, APL Photon., 2019, 4, 110803; and LUO et al., Wafer-scale dies-transfer bonding technology for hybrid III/V-on-silicon photonic integrated circuit, IEEE JOURNAL OF SELECTED TOPICS IN QUANTUM ELECTRONICS, 2016, Vol. 22, No. 6, 8200612), or may be a substrate of Si, Cu, Al, or the like, in order to emphasize a heat dissipation property. As described in Non Patent Literatures 1 and 2 (Alexander W. Fang et al., Electrically pumped hybrid AlGaInAs-silicon evanescent laser, OPTICS EXPRESS, 2006, Vol. 14, No. 20, p9203; and Jing Zhang et al., III-V-on-Si photonic integrated circuits realized using micro-transfer-printing, APL Photon., 2019, 4, 110803), after the semiconductor layer 1 is transferred, a plurality of semiconductor layers 1 can be collectively processed on the circuit substrate.

[0161] The semiconductor layer 1-attached circuit substrate can be suitably used as a semiconductor device. As the semiconductor device, a semiconductor communication element, an image pickup element, an amplifier element, or the like is suitably used. These are suitable for a silicon photonic semiconductor device to which a silicon photonics technology is applied, such as high-speed communication and high-speed processing such as data center and machine learning, distance sensors (Lidar), health care (health monitor mounted on smart watch), and sensor applications for gas detection.

[0162] In the semiconductor device, after the semiconductor layer 1 is bonded to the circuit

transmitting substrate 1, and a laminate 2, in which a pressure-sensitive adhesive layer is laminated on a support substrate 2, to cause a surface of the laminate 1 on a semiconductor layer 1 side and a surface of the laminate 2 on a pressure-sensitive adhesive layer side to face each other; and

a step (II) of irradiating the laser-absorbing temporary adhesive layer 1 with a laser from a surface side of the laminate 1 opposite to the surface thereof on the semiconductor layer 1 side while transmitting the laser through the laser-transmitting substrate 1, and transferring a structure in which the protective layer 1 and the semiconductor layer 1 are laminated to the laminate 2 to form a laminate 3 in which the pressure-sensitive adhesive layer, the semiconductor layer 1, and the protective layer 1 are laminated in this order on the support substrate 2.

[7] The method for producing a laminate according to the above [6], in which

in the step (II),

the structure 1 is a structure 2 in which the laser-absorbing temporary adhesive layer 1, the protective layer 1, and the semiconductor layer 1 are laminated, and

the laminate 3 is a laminate 4 in which the pressure-sensitive adhesive layer, the semiconductor layer 1, the protective layer 1, and the laser-absorbing temporary adhesive layer 1 are laminated in this order on the support substrate 2.

[8] The method for producing a laminate according to the above [6] or [7], further including:

a step (III) of removing a part of the pressure-sensitive adhesive layer in the laminate 3 and patterning the pressure-sensitive adhesive layer.

[9] The method for producing a laminate according to the above [7] or [8], further including:

a step (III') of removing a part of the pressure-sensitive adhesive layer in the laminate 4 and patterning the pressure-sensitive adhesive layer.

[10] The method for producing a laminate according to the above [8], in which the step (III) includes a step (III-A) of performing dry-etching or wet-etching on the pressure-sensitive adhesive layer in the laminate 3 by using the semiconductor layer 1 or the protective layer 1 in the laminate 3 as a mask.

[11] The method for producing a laminate according to the above [9], in which the step (III') includes a step (III'-A) of performing dry-etching or wet-etching on the pressure-

CLAIMS

[Claim 1]

A laminate comprising:

a laser-transmitting substrate 1; and

a laser-absorbing temporary adhesive layer 1, a protective layer 1, and a semiconductor layer 1 laminated in this order on the laser-transmitting substrate 1.

[Claim 2]

The laminate according to claim 1, wherein the semiconductor layer 1 is a compound semiconductor.

[Claim 3]

The laminate according to claim 2, wherein the compound semiconductor is AlGaInAs, InGaAs, InP, InGaAsP, AlAs, InAs, GaAs, AlN, AlP, GaN, InN, or SiC.

[Claim 4]

The laminate according to any one of claims 1 to 3, wherein the protective layer 1 is at least one of an oxide film and a nitride film.

[Claim 5]

The laminate according to claim 4, wherein the protective layer 1 contains SiO_2.

[Claim 6]

A method for producing a laminate, successively comprising:

a step (I) of using a laminate 1, in which a laser-absorbing temporary adhesive layer 1, a protective layer 1, and a semiconductor layer 1 are laminated in this order on a laser-transmitting substrate 1, and a laminate 2, in which a pressure-sensitive adhesive layer is laminated on a support substrate 2, to cause a surface of the laminate 1 on a semiconductor layer 1 side and a surface of the laminate 2 on a pressure-sensitive adhesive layer side to face each other; and

a step (II) of irradiating the laser-absorbing temporary adhesive layer 1 with a laser

from a surface side of the laminate 1 opposite to the surface thereof on the semiconductor layer 1 side while transmitting the laser through the laser-transmitting substrate 1, and transferring a structure 1 in which the protective layer 1 and the semiconductor layer 1 are laminated to the laminate 2 to form a laminate 3 in which the pressure-sensitive adhesive layer, the semiconductor layer 1, and the protective layer 1 are laminated in this order on the support substrate 2.

[Claim 7]

The method for producing a laminate according to claim 6, wherein

in the step (II),

the structure 1 is a structure 2 in which the laser-absorbing temporary adhesive layer 1, the protective layer 1, and the semiconductor layer 1 are laminated, and

the laminate 3 is a laminate 4 in which the pressure-sensitive adhesive layer, the semiconductor layer 1, the protective layer 1, and the laser-absorbing temporary adhesive layer 1 are laminated in this order on the support substrate 2.

[Claim 8]

The method for producing a laminate according to claim 6, further comprising:

a step (III) of removing a part of the pressure-sensitive adhesive layer in the laminate 3 and patterning the pressure-sensitive adhesive layer.

[Claim 9]

The method for producing a laminate according to claim 7, further comprising:

a step (III') of removing a part of the pressure-sensitive adhesive layer in the laminate 4 and patterning the pressure-sensitive adhesive layer.

[Claim 10]

The method for producing a laminate according to claim 8, wherein

the step (III) includes a step (III-A) of performing dry-etching or wet-etching on the pressure-sensitive adhesive layer in the laminate 3 by using the semiconductor layer 1 or the protective layer 1 in the laminate 3 as a mask.

[Claim 11]

The method for producing a laminate according to claim 9, wherein

the step (III') includes a step (III'-A) of performing dry-etching or wet-etching on the pressure-sensitive adhesive layer in the laminate 4 by using the semiconductor layer 1, the protective layer 1, or the laser-absorbing temporary adhesive layer 1 in the laminate 4 as a mask.

[Claim 12]

The method for producing a laminate according to claim 6, 8, or 10, further comprising:

a step (IV) of removing the protective layer 1 from the laminate 3.

[Claim 13]

The method for producing a laminate according to claim 7, 9, or 11, further comprising:

a step (IV') of removing the laser-absorbing temporary adhesive layer 1 and the protective layer 1 from the laminate 4.

[Claim 14]

A method for producing a semiconductor device, comprising:

a step (V) of causing a surface of the laminate obtained by the method for producing a laminate according to claim 12 on the semiconductor layer 1 side to face a surface of a circuit substrate on which a circuit is formed, and bonding the semiconductor layer 1 in the laminate to the circuit substrate by thermocompression-bonding.

[Claim 15]

The method for producing a semiconductor device according to claim 14, further comprising:

after the step (V), a step (VI) of removing a pressure-sensitive adhesive layer-attached support substrate 2 from a structure in which the semiconductor layer 1 in the laminate is bonded to the circuit substrate.

[Claim 16]

The method for producing a semiconductor device according to claim 14, wherein the semiconductor device is a silicon photonic semiconductor device.

[Claim 17]

A laminate comprising:

a support substrate 2, a pressure-sensitive adhesive layer, a semiconductor layer 1, and a protective layer 1 laminated in this order, wherein

the pressure-sensitive adhesive layer has a patterned shape.

[Claim 18]

A semiconductor device, produced by the method according to claim 6.

[Claim 19]

A device for producing a semiconductor device, implementing the steps of the method for producing a laminate according to claim 6.