

Silicon would allow fabricating costs to be drastically decreased and substrates of large size to be accessed, but structures of III-N-alloy-on-silicon type are penalized by RF losses and by a poor dissipation of heat.

Composite structures, such as SopSiC or SiCopSiC structures, have also been investigated [1] but have not proved to be entirely satisfactory. These structures comprise a layer of single-crystal silicon or a layer of single-crystal SiC (intended to form a seed layer for the epitaxial growth of the gallium nitride) on a polycrystalline SiC substrate, respectively. Although polycrystalline SiC is a material that is inexpensive, that is available in the form of substrates of large size and that dissipates heat well, these composite structures are penalized by the presence of a layer of silicon oxide at the interface between the layer of single-crystal silicon or SiC and the polycrystalline SiC substrate, which forms a thermal barrier hindering the dissipation of heat from the layer of III-N alloy to the polycrystalline SiC substrate.

Brief description of the invention

One aim of the invention is therefore to remedy the aforementioned drawbacks and in particular limitations related to the size and cost of semi-insulating SiC substrates.

The aim of the invention is therefore to provide a process for fabricating a substrate for the epitaxial growth of a III-N alloy based on gallium, in particular with a view to forming HEMTs or other high-frequency, high-power electronic devices in which RF losses may be minimized and the dissipation of heat may be maximized.

An aspect of the invention provides a process for fabricating a substrate for epitaxial growth of a layer of gallium nitride (GaN), of aluminium gallium nitride (AlGaN) or of indium gallium nitride (InGaN), comprising the following successive steps:

- providing a base substrate comprising at least one layer of single-crystal silicon carbide,
- performing epitaxial growth of a layer of semi-insulating SiC on the layer of single-crystal SiC to form a donor substrate wherein the layer of semi-insulating SiC is doped with vanadium during its epitaxial growth,
- implanting ionic species into the layer of semi-insulating SiC so as to form a weakened region that defines a thin layer of single-crystal semi-insulating SiC to be transferred,
- bonding the layer of semi-insulating SiC to a receiver substrate having a high electrical resistivity,
- detaching the donor substrate along the weakened region so as to transfer the thin layer of single-crystal semi-insulating SiC to the receiver substrate.

By "high-frequency", what is meant in the present text is a frequency higher than 3 kHz.

By "high-power" what is meant in the present text is a power density higher than 0.5 W/mm injected through the gate of the transistor.

By “high electrical resistivity”, what is meant in the present text is an electrical resistivity higher than or equal to 100 $\Omega\cdot\text{cm}$.

By “semi-insulating SiC”, what is meant in the present text is silicon carbide having an electrical resistivity higher than or equal to $10^5 \Omega\cdot\text{cm}$.

This process allows a base substrate of high electrical resistivity and of high thermal conductivity comprising a layer of semi-insulating SiC having a crystal quality suitable for the subsequent epitaxial growth of a layer of gallium nitride to be formed and the final structure to benefit from the good properties thereof as regards the dissipation of heat and the limitation of RF losses. Since the layer of semi-insulating SiC makes direct contact with the substrate of high electrical resistivity and of high thermal conductivity, the structure further contains no thermal barrier.

A process that consisted in forming the layer of semi-insulating SiC by epitaxy directly on a substrate of high electrical resistivity would lead to the formation of a high number of dislocations in the semi-insulating SiC because of the insufficient crystal quality of the substrate of high electrical resistivity or the difference in lattice parameter between the material of said substrate and silicon carbide. In contrast, the process according to the invention makes it possible to use, as seed for the growth of the semi-insulating SiC, a layer of single-crystal SiC, the quality of which is optimal because it was obtained via transfer from the donor substrate.

According to advantageous but optional features of the invention, which may be implemented alone or in combination when this is technically possible:

- the receiver substrate has a difference in coefficient of thermal expansion with silicon carbide smaller than or equal to $3 \times 10^{-6} \text{ K}^{-1}$;
- the receiver substrate is chosen from a silicon substrate of high electrical resistivity, a substrate of polycrystalline SiC of high electrical resistivity, a polycrystalline AlN substrate, and a diamond substrate;
- the epitaxial layer of semi-insulating SiC has a thickness larger than or equal to 3 μm , preferably larger than or equal to 5 μm , and even more preferably larger than or equal to 10 μm ;
- the thin layer transferred to the receiver substrate has a thickness smaller than 1 μm ;
- the process further comprises a step of recycling the segment of the donor substrate detached from the transferred layer, with a view to forming a new donor substrate;
- said recycling comprises polishing a residual segment of the layer of semi-insulating SiC, the new donor substrate thus obtained being able to be used in a new step of implanting ionic species;

Claims

1. A process for fabricating a substrate for epitaxial growth of a layer of gallium nitride (GaN), of aluminium gallium nitride (AlGaN) or of indium gallium nitride (InGaN), comprising the following successive steps:
 - providing a base substrate comprising at least one layer of single-crystal silicon carbide,
 - performing epitaxial growth of a layer of semi-insulating SiC on the layer of single-crystal SiC to form a donor substrate, wherein the layer of semi-insulating SiC is formed by doping with vanadium during the epitaxial growth,
 - implanting ionic species into the layer of semi-insulating SiC so as to form a weakened region that defines a thin layer of single-crystal semi-insulating SiC to be transferred,
 - bonding the layer of semi-insulating SiC to a receiver substrate having a high electrical resistivity,
 - detaching the donor substrate along the weakened region so as to transfer the thin layer of single-crystal semi-insulating SiC to the receiver substrate.
2. The process according to Claim 1, wherein the receiver substrate has a difference in coefficient of thermal expansion with silicon carbide smaller than or equal to $3 \times 10^{-6} \text{ K}^{-1}$.
3. The process according to either of Claims 1 and 2, wherein the receiver substrate is chosen from a silicon substrate of high electrical resistivity, a substrate of polycrystalline SiC of high electrical resistivity, a polycrystalline AlN substrate, and a diamond substrate.
4. The process according to one of Claims 1 to 3, wherein the epitaxial layer of semi-insulating SiC has a thickness larger than or equal to $3 \text{ }\mu\text{m}$, preferably larger than or equal to $5 \text{ }\mu\text{m}$, and even more preferably larger than or equal to $10 \text{ }\mu\text{m}$.
5. The process according to one of Claims 1 to 4, wherein the thin layer transferred to the receiver substrate has a thickness smaller than $1 \text{ }\mu\text{m}$.
6. The process according to one of Claims 1 to 5, further comprising a step of recycling the segment of donor substrate detached from the transferred layer, with a view to forming a new donor substrate.

7. The process according to Claim 6, wherein said recycling comprises polishing a residual segment of the layer of semi-insulating SiC, the new donor substrate thus obtained being able to be used in a new step of implanting ionic species.
8. The process according to Claim 6, wherein said recycling comprises polishing a residual segment of the layer of semi-insulating SiC and performing epitaxial regrowth in order to increase the thickness of said layer of semi-insulating SiC to form the new donor substrate.
9. The process according to Claim 6, wherein said recycling comprises removing a residual segment of the layer of semi-insulating SiC to uncover the carbon face of the layer of single-crystal SiC and performing epitaxial growth of a new layer of semi-insulating SiC on the carbon face of the layer of single-crystal SiC to form the new donor substrate.
10. The process according to one of Claims 1 to 9, wherein:
 - the layer of single-crystal silicon carbide of the base substrate has a free carbon face,
 - the epitaxial growth of the layer of semi-insulating SiC is performed on said carbon face of the layer of single-crystal SiC,
 - the ionic species are implanted through the carbon face of the layer of semi-insulating SiC,
 - the carbon face of the layer of semi-insulating SiC is bonded to the receiver substrate,
 - at the end of the detachment, the silicon face of the transferred layer of single-crystal semi-insulating SiC is uncovered.
11. The process according to one of Claims 1 to 10, comprising fabricating the base substrate via the following successive steps:
 - providing a start substrate of single-crystal SiC having a silicon face,
 - implanting ionic species through the silicon face of the start substrate so as to form a weakened region that defines a thin layer of single-crystal SiC to be transferred,
 - bonding the silicon face of the start substrate to an intermediate carrier,
 - detaching the start substrate along the weakened region so as to transfer the thin layer of single-crystal SiC to the intermediate carrier and to uncover the carbon face of said transferred layer of single-crystal SiC, the intermediate carrier and the transferred layer of single-crystal SiC together forming the base substrate.

12. The process according to Claim 11, wherein the intermediate carrier is an SiC substrate having a crystal quality lower than that of the start substrate (50).
13. The process according to either of Claims 11 and 12, wherein the start substrate is bonded directly to the intermediate carrier after activation of each surface to be bonded by bombardment of neutral species.
14. The process according to either of Claims 11 and 12, wherein the start substrate is bonded to the intermediate carrier by way of a refractory bonding layer.
15. The process according to one of Claims 11 to 14, comprising a step of recycling the segment of the start substrate detached from the transferred layer, with a view to forming a new start substrate.
16. A Process for fabricating by epitaxy a layer of gallium nitride, of aluminium gallium nitride (AlGaN) or of indium gallium nitride (InGaN), comprising
 - providing a substrate fabricated using the process according to one of Claims 1 to 15,
 - performing epitaxial growth of the layer of gallium nitride, of aluminium gallium nitride (AlGaN) or of indium gallium nitride (InGaN) on the layer of semi-insulating SiC of said substrate.
17. The process according to Claim 16, wherein the layer of gallium nitride, of aluminium gallium nitride (AlGaN) or of indium gallium nitride (InGaN) has a thickness comprised between 1 and 2 μm .
18. The process for fabricating a high-electron-mobility transistor (HEMT), comprising:
 - fabricating by epitaxy a layer of gallium nitride, of aluminium gallium nitride (AlGaN) or of indium gallium nitride (InGaN) using the process according to either of Claims 16 and 17,
 - forming a heterojunction by epitaxy of a layer of a III-N material different from gallium nitride on the layer of gallium nitride, of aluminium gallium nitride (AlGaN) or of indium gallium nitride (InGaN),
 - forming a channel of the transistor level with said heterojunction,
 - forming a source, a drain and a gate of the transistor on the channel.