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Wide Bandgap Material Transfer as a Flagship Technology for Future High Power Devices

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Today's environmental requirements for energy efficiency call for better management of electrical energy with minimum leakage at all levels: from DC phone chargers to power transmission via electrical vehicles. Wide bandgap (WBG) semiconductors are better suited for high-voltage and low-loss power devices than traditional Si-based power devices. The most commonly used are SiC, GaN and diamond with bandgap values of 3.2 eV, 3.4 eV and 5.5 eV respectively. However, the challenge of producing these competitive materials economically and efficiently remains. For example, the fabrication of SiC substrates is very energy-intensive, since it is carried out at 2400°C, i.e. 1000°C higher than for Si. To cite another example, the size of diamond substrates today is no more than a few square millimeters, while 300 mm Si wafers are on the market, limiting the appeal of such a material.

The ability to transfer only a thin layer of high-quality WBG material on a substrate that offers either the advantage of being less expensive or the advantage of its own function (thermal, electrical or insulating...) is therefore very interesting. The Smart Cut™ process combines an ion implantation with a bonding step and allows to create a structure that otherwise could not be made using deposition techniques. Relatively new direct covalent bonding techniques now make it possible to relax the draconian characteristics imposed on surfaces and substrates to enable such bonding with materials renowned for their outstanding properties. This opens up new possibilities in terms of assembly.

Significant improvements in electrical performance have been achieved by combining the advantages of a polycrystalline substrate with very low resistivity and a high-quality 4H-SiC transferred layer [1, 2]. However, the H⁺ ion implantation used for the Smart Cut™ process leads to electrical deactivation and partially disorders the material. We report studies of healing and reactivation mechanisms of a transferred 4H-SiC thin film over a wide range of temperatures. After 950°C (splitting temperature), the thin SiC layer is still insulating. A 1300°C anneal allows the material to fully relax and reorganize with no further evolution beyond this temperature. The dopant reactivation takes place at higher thermal budgets. The transferred layer then recovers the donor doping level and electrical conductivity after 1700°C [3].

We also develop the transfer of Ila diamond onto larger and less expensive substrates [4]. The two key technological steps of the Smart Cut™ process (ion implantation and bonding) are studied:

- A simplified process using a single ion implantation step at high temperature has been developed [5]. The diamond material after such implantation is studied in terms of sp²/sp³ ratio (XPS), hydrogen concentration (SIMS) and exfoliation capability.
- A wide range of bonding conditions are studied: direct bonding (manual, Surface Activated Bonding - SAB -), metal bonding (Ti, Au...) with a special care on bonding parameters (the flatness, the coefficient of thermal expansion and the roughness values). This part is particularly difficult because of the remarkable properties of diamond: its low coefficient of thermal expansion and its hardness make surface preparation and adhesion very challenging.

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