Low-temperature layer splitting of (100) GaAs by He+H coimplantation and direct wafer bonding

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The present letter introduces a low-temperature GaAs layer splitting approach by He+H coimplantation which—in combination with direct wafer bonding—enables monolithic integration of GaAs with different substrates. The influence of He+H coimplantation on blistering and layer splitting of GaAs is studied and the optimum coimplantation conditions are determined. Thin GaAs layers are transferred onto Si after bonding of He+H coimplanted GaAs and Si substrates via a spin-on glass intermediate layer and subsequent annealing at only 225 °C for 14 h. Cross-sectional transmission electron microscopy investigations show a high quality of the GaAs/SOG bonding interface. © 2003 American Institute of Physics. [DOI: 10.1063/1.1567045]

The combination of III–V semiconductors with mature silicon technology has been a goal for many years. Monolithic integration of GaAs into silicon technology requires fabrication of high-quality single crystalline GaAs layers onto silicon and would result in applications in optoelectronics, microwave electronics, and high-temperature electronic devices. Heteroepitaxial growth of GaAs layers on Si was intensively studied, but due to the lattice mismatch of about 4%, an unacceptable high density of threading dislocations is still present.1,2 Recently, scientists from Motorola reported on device-quality GaAs epitaxial layers grown onto Si by molecular-beam epitaxy.3 A SrTiO3 buffer layer was epitaxially grown supposedly in order to absorb the effects of the different lattice constants of GaAs and Si. As yet, no independent evaluation of the grown GaAs layers concerning the density of threading dislocations has been reported.

One of the most promising approaches to transfer high-quality single crystalline thin layers on any substrates (including amorphous materials) without any epitaxial relationship to the film, is layer transfer also known as smart-cut, layer splitting, or layer exfoliation by hydrogen implantation and direct wafer bonding. This approach was introduced by Bruel in 19954 as a method for the fabrication of high-quality silicon-on-insulator wafers. The layer splitting process consists of three steps: (i) implanting a device wafer with a relatively high dose (1016–1017 cm−2) of either hydrogen (H+ or H2+), or helium (He+), (ii) direct bonding of the implanted wafer to a host substrate, and (iii) annealing of the bonded pair, first to increase the bonding energy and then to achieve splitting. If an implanted wafer is annealed without stiffening the implanted surface by bonding it to a second wafer, blistering or exfoliation occurs instead of splitting. It was shown that in order to achieve blistering/splitting after a postimplantation anneal, the implantation temperature must fall within a temperature window specific to each material.5

Attempts on transferring GaAs layers onto Si by layer splitting were reported by Jalaguier et al.,6 but relatively high splitting temperatures of 400–700 °C were required. When dissimilar materials are used, it is desirable that the splitting temperature is low enough to avoid stress problems associated with the difference in thermal expansion coefficients. Recently, Gawlik et al.7 proposed a low-temperature GaAs splitting approach by two-step hydrogen implantation and wafer bonding.

In the present work, we are proposing a He+H coimplantation which enables a low-temperature splitting and layer transfer of GaAs. The influence of He+H coimplantation on the blistering and splitting of different materials (i.e., Si and InP) was previously reported.8,9 Agarwal et al.8 showed that the minimum dose necessary to induce blistering and exfoliation of silicon can be decreased by a factor of 3.5 by He+H coimplantation. In this case, the helium atoms provide the pressure inside the cavities more efficiently than molecular hydrogen. Moreover, they stabilize the hydrogen bound to the cavity walls facilitating the propagation of the buried cracks.10 The main goal in the present study is to define optimum conditions for a low-temperature GaAs layer splitting approach by He+H coimplantation and wafer bonding.

Semi-insulating (100) GaAs wafers (Freiberger Compound Materials GmbH) were coimplanted with low He+ doses followed by range matched H2+ implantation. In order to minimize ion channeling, implantation was performed under a 7° sample tilt. Nomarski optical microscopy, atomic force microscopy (AFM), and scanning electron microscopy were used to investigate blister formation and exfoliation of He+H coimplanted and annealed samples. The formation of platelet-like defects and their evolution after annealing were analyzed by cross-sectional transmission electron microscopy (XTEM).

The implantation parameters are summarized in Table I and the optimum conditions for the blistering of coimplanted (100) GaAs are indicated in bold. Surface blister formation was investigated by annealing the as-implanted GaAs at elevated temperatures and the onset of blistering was obtained for each annealing temperature. The activation energies of blistering were determined from an Arrhenius plot. As expected, it can be seen from Fig. 1 for low dose H-implantation that the blistering times are about ten times...
FIG. 1. Activation energies of the onset of blistering obtained on He+ H coimplanted GaAs. Coimplantation of He+ (5 x 10^{15} cm^{-2} at 105 keV) followed by (a) H2^+ (2 x 10^{16} cm^{-2} at 160 keV) and (b) H2 (3 x 10^{16} cm^{-2} at 160 keV) was performed at room temperature.

2(b)]. Therefore, a relatively high surface roughness of the transferred layer is expected after splitting.

In order to transfer a thin GaAs layer onto a Si substrate, a He + H coimplanted GaAs wafer was bonded to a Si wafer via a spin-on glass (SOG) film. Due to the mismatch in the thermal expansion coefficients between GaAs and Si, it is desirable that the annealing temperature after bonding does not exceed 250°C. It was shown earlier that room-temperature GaAs/Si bonding via a SOG film is a reliable approach to obtain high bonding energies after low-temperature annealing. In order to remove any metallic contaminants, the GaAs wafer was chemically cleaned with 5% HCl solution and then rinsed in de-ionized (DI) water. After cleaning, the GaAs wafer was brought in contact with the SOG/Si wafer at room temperature. Annealing of the bonded pair at 225°C for about 14 h induced splitting of the thin GaAs layer and its transfer onto Si. XTEM of this structure shows a high quality of the bonding interface (see Fig. 3). The microroughness of the transferred layer measured by AFM in contact mode indicates a root-mean-square value of ~17 nm, therefore a soft-polishing step is required in order to improve the surface quality of the transferred layer.

In conclusion, we have shown that a low-temperature GaAs layer splitting approach by He + H coimplantation and wafer bonding can be used for the transfer of single crystalline GaAs films onto silicon wafers. The electronic quality of the transferred GaAs layer still has to be investigated.

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