Mg Ion Implantation Technology for Vertical Ga_2O_3 Power Devices

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Vertical n-Ga_2O_3 power devices make use of insulating or p-type materials for forming current blocking layers (CBLs) to prevent direct source-drain leakage. Mg-ion (Mg^{++}) implanted Ga_2O_3 was investigated in this work as a CBL in light of semi-insulating Ga_2O_3 obtained by Mg compensation doping of n-type bulk crystals. Systematic thermal anneals and electrical measurements presented evidence of implant activation and illustrated a pathway for forming CBLs in Ga_2O_3 devices.

Test structures comprising n-Ga_2O_3/Ga_2O_3:Mg(CBL)/n-Ga_2O_3 were fabricated on Si-doped β-Ga_2O_3 (001) epilayers (5–7 µm, n~10^{16} cm^{-3}) grown by halide vapor phase epitaxy on Sn-doped (n~3×10^{18} cm^{-3}) substrates. Mg^{++} implantation was performed at 560 keV and a dose of 4×10^{13} cm^{-2} with a peak concentration of 1×10^{18} cm^{-3} at ~0.6 µm below the surface. Capless thermal anneals were carried out at 800, 900, and 1000°C for 30 min in N_2 to attempt Mg activation and implantation damage recovery. A 100-nm-thick n^+ top contact layer was formed by Si ion implantation. Patterned-top and blanket-bottom Ti/Au ohmic electrodes were subsequently deposited for current-voltage measurements to assess vertical conduction through the Mg^{++}-implanted Ga_2O_3 (Fig. 1). Pt Schottky electrodes were also deposited for capacitance-voltage (C-V) analysis.

Ga_2O_3 as-implanted with Mg^{++} was highly resistive owing to lattice damage. Leakage through the CBL annealed at 800°C remained low (<1 mA/cm^2 at 200 V) as only limited damage reversal had taken place. A higher annealing temperature of 900°C led to significantly increased conduction through the CBL (1 mA/cm^2 at 60–90 V) consistent with improved crystal quality. However, the effect of damage recovery saturated beyond 900°C and only slight degradation in current blocking capability (1 mA/cm^2 at 40–80 V) was observed with 1000°C annealing. The similar blocking characteristics between structures annealed at 900°C and 1000°C suggested that the electron barrier was no longer dominated by lattice defects; instead, a distinct mechanism that could be unambiguously ascribed to Mg activation as compensating acceptors had given rise to a new barrier in the current path. In addition, Mg diffusion observed in all annealed samples led to uniform Mg depth profiles at a level consistent with the background Si doping (Fig. 2), resulting in carrier compensation throughout the epilayers as revealed by C-V measurements (Fig. 3). CBLs with well-defined thicknesses and doping can thus be conceived by controlling the implant dosage and annealing conditions.

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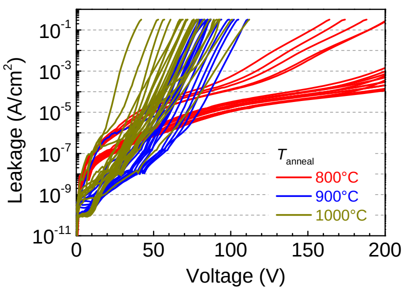

Fig. 1. Vertical leakage through annealed Mg^{++}-implanted Ga_2O_3.

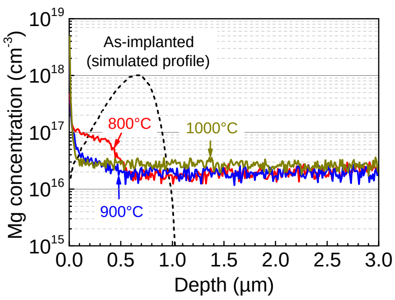

Fig. 2. Secondary ion mass spectroscopy depth profiles of Mg showing significant diffusion upon thermal annealing.

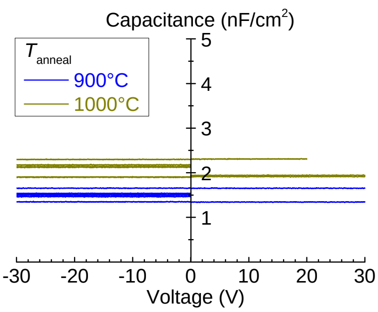

Fig. 3. Flat C-V profiles of fully-compensated epilayers annealed at 900 and 1000°C as a result of Mg diffusion and activation as acceptors.

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