Investigation of Mg Ion Implantation for Current Blocking in Vertical Ga_2O_3 Transistors

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Vertical *n*-channel Ga_2O_3 transistors require an electron current blocking layer (CBL) to prevent direct source-drain leakage. Mg-ion (Mg^{++}) implanted Ga_2O_3 was studied 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 established the migration behavior of implanted Mg^{++} in Ga_2O_3 and presented evidence of implant activation, based on which a pathway for forming Mg^{++}-implanted CBLs is proposed.

Test structures comprising *n*-Ga_2O_3(top channel)/Ga_2O_3:Mg(CBL)/*n*-Ga_2O_3 were fabricated by implanting Mg^{++} into Sn-doped ($n = 2$~4×10^{18} cm^{-3}) β-Ga_2O_3 (001) substrates at 560 keV and a dose of 6×10^{14} cm^{-2} with a peak Mg concentration of 1.5×10^{19} cm^{-3} at 0.5–0.6 μm below the surface. Capless anneals were carried out between 600–1000°C at 100°C intervals for 30 min in N_2 to attempt Mg activation and implantation damage recovery. Patterned-top and blanket-bottom Ti/Au ohmic contacts were subsequently deposited. Current-voltage measurements were performed to assess vertical leakage through the Mg^{++}-implanted Ga_2O_3. Lateral conduction in the top channel served as an independent gauge of lattice recovery. An unannealed Mg^{++}-implanted control sample and an unimplanted reference sample were processed simultaneously.

Owing to extensive implantation damage, the unannealed control sample was effective in vertical current blocking (1 nA/cm^2 at 50 V) but also suffered a resistive top channel. Annealing at 600–800°C led to progressive damage recovery that caused higher vertical leakage (>1 mA/cm^2 at 45 V), while a modest 2-order improvement in lateral channel current density was observed. Implantation damage was largely reversed after annealing at 900°C as confirmed by transmission electron microscopy and x-ray diffraction, at which point the Mg^{++}-implanted Ga_2O_3 failed to block current and the channel conductivity rose steeply by 7–9 orders approaching that of the unimplanted reference sample (Figs. 1, 2). Interestingly, further lattice recovery at 1000°C not only restored current blocking but also rendered the top channel resistive (Figs. 1, 2). Such behavior could be explained by Mg diffusion toward the channel and activation as a compensating acceptor. Indeed, secondary ion mass spectroscopy (SIMS) revealed significant Mg redistribution beyond 900°C, transforming the ion profile from Gaussian into box-like with sharp decay into the bulk (Fig. 3). CBLs with well-defined depth and doping profiles are thus conceivable by controlling the implantation and annealing conditions of a single Mg^{++} implant, enabling an effective electron barrier with minimal implantation damage.

This work was partially supported by Council for Science, Technology and Innovation (CSTI), Cross-ministerial Strategic Innovation Promotion Program (SIP), "Next-generation power electronics" (funding agency: NEDO).

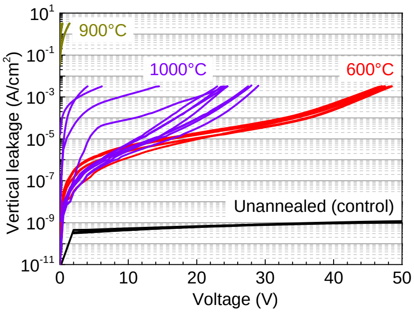

Fig. 1. Vertical leakage through Mg^{++}-implanted Ga_2O_3 before and after annealing (600/900/1000°C).

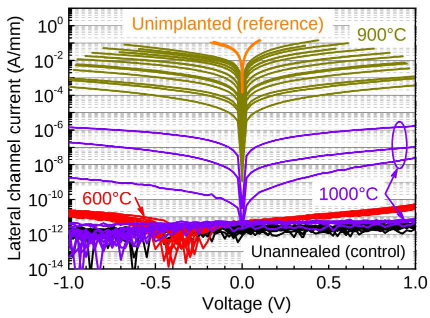

Fig. 2. Lateral conduction in top *n*-Ga_2O_3 channel before and after annealing (600/900/1000°C).

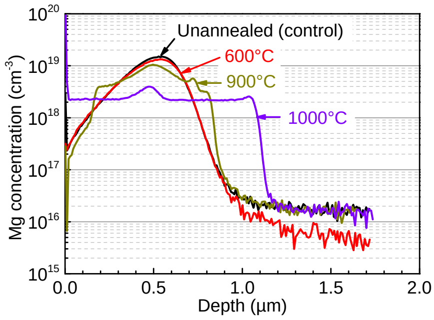

Fig. 3. SIMS profiles of Mg before and after annealing (600/900/1000°C). Mg diffusion transformed the as-implanted Gaussian profile into a box-like profile.