Barrier Height Stability and Reverse Leakage Mechanisms in Ni/Ga_2O_3 (001) Schottky Barrier Diodes

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Introduction

Ga_2O_3 Schottky barrier diodes (SBDs) have shown promising performance as power rectifiers recently [1-3], showcasing the fast-improving material quality as well as the touted high electric field strength (6-8 MV/cm). In an SBD, the barrier height ($q\phi_B$) largely determines the turn-on voltage and the reverse leakage current. Previous studies on the barrier height of different metal contacts on Ga_2O_3 indicate a certain level of Fermi-level pinning [4,5], likely due to interface-trap states. Under different temperature (T) or biasing conditions, the filling of those trap states could be altered and thus the barrier height could be unstable, as evidenced in previous studies [6]. For Ga_2O_3 grown by halide vapor phase deposition (HVPE), a chemical-mechanical polishing (CMP) process is used to flatten the surface. In this work, we examine the barrier height stability of Ni/Ga_2O_3 SBDs fabricated on the CMP-ed surface via repeated and temperature-dependent I-V measurements. We found that post metallization annealing (PMA) improves the barrier height stability. In addition, the reverse leakage mechanisms of the non-field-plated SBDs have been identified.

Experimental Process

As shown in Fig. 1, the diodes are fabricated on a (001) β-Ga_2O_3 substrate. The 10-μm lightly-doped drift layer is grown by HVPE with the epitaxial surface flattened by CMP. The Ti/Au ohmic contact is first formed on the backside using the process reported previously [3]. After lithography and acid cleaning, Ni/Au (40 nm/150 nm) anode contact is formed by lift-off. The diodes are measured before and after PMA, which is performed at 300 °C for 20 minutes. The measurement sequence is as such: (1) repeated forward I-V measurements at 25 °C; (2) T-dependent forward I-V measurements from 25 °C to 200 °C; (3) T-dependent reverse I-V measurements from 200 °C to 25 °C. A single effective mass of 0.31 m_0 is used for both the tunneling effective mass and the effective Richardson constant A^*.

Results and Discussion

As shown in Fig. 2, the diode before PMA exhibits a positive shift of the turn-on voltage after the first forward I-V scan, suggesting an increase of the barrier height (59 meV), likely due to the trapping of electrons near the Schottky contact. In comparison, the diodes after PMA show a much smaller shift (7 meV). The shift did not recover at 25 °C within the measurement period (~1 hour). Fig. 3 shows the temperature-dependent forward I-V characteristics of the diodes, from which the ideality factor and the barrier height are extracted from the thermionic-emission (TE) model. The ideality factor is slightly improved with PMA (Fig. 4). Fig. 5 plots the T-dependent reverse leakage current as a function of the parallel-plane surface electric field, which is calculated based on the one-dimensional doping profile and the reverse bias. The leakage characteristics below 100 °C shows negligible T-dependence, thus attributed to the leakage along the anode edge, where a much higher field than the 1-D parallel-plane value is expected due to field crowding. At such high fields, the leakage current is dominated by field-emission, hence showing negligible T-dependence. The leakage current component with a distinct T-dependence is dominated by contributions from the bulk of the anode. It is found that this bulk current agrees well with the sum of the thermionic-field emission (TFE) and the TE currents, suggesting that both processes are involved. A semi-empirical image-force lowering model considering the saturation of barrier-lowering beyond ~0.22 MV/cm is found to yield the best fitting. The temperature-dependence of the extracted $q\phi_B$ is summarized in Fig. 6. A reduction of $q\phi_B$ with increasing temperature is observed in diodes before PMA, likely due to thermally-assisted de-trapping of the trapped electrons. In diodes after PMA, the extracted $q\phi_B$ is nearly constant with temperature, suggesting that the PMA improves the stability of the barrier height.

Conclusion

Barrier height instability is observed in Ni/Ga_2O_3 Schottky contacts on CMP-ed surface, likely due to electron trapping near the interface. The trapping may arise from surface damage. A PMA at 300 °C largely removes the instability. The bulk leakage current is from both the TFE and the TE processes, while the edge current due to field emission.

Acknowledgement

Supported in part by NSF DMREF 1534303 and AFOSR (FA9550-17-1-0048), carried out at the Cornell Nanoscale Science and Technology Facilities (CNF) sponsored by the NSF NNCI program (ECCS-1542081)

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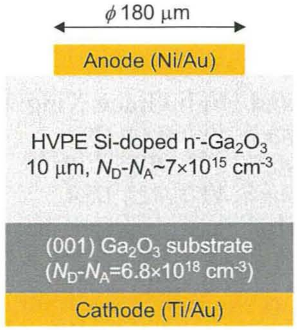

Fig. 1. Schematic cross-section of the Ni/Ga_2O_3 SBDs. The net doping concentration of the drift layer is determined to be ~7×10^{15} cm^{-3}.

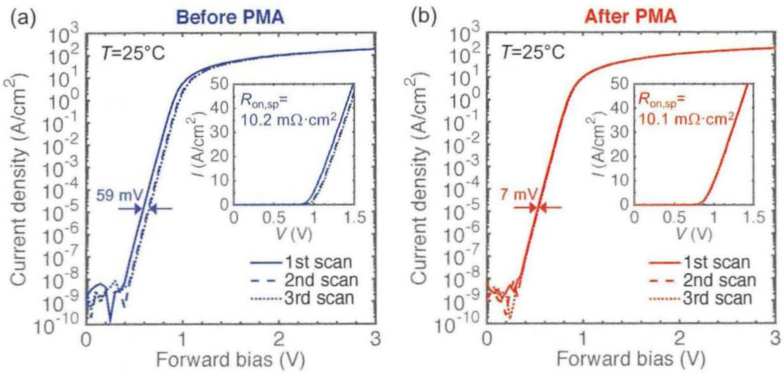

Fig. 2. Repeated forward *I-V* measurements of the SBDs (a) before PMA and (b) after PMA. Three consecutive forward scans from 0 V to 5 V are performed on each diode. A positive shift of the turn-on voltage in clearly observed in the SBD before PMA. The diode after PMA shows a much smaller shift.

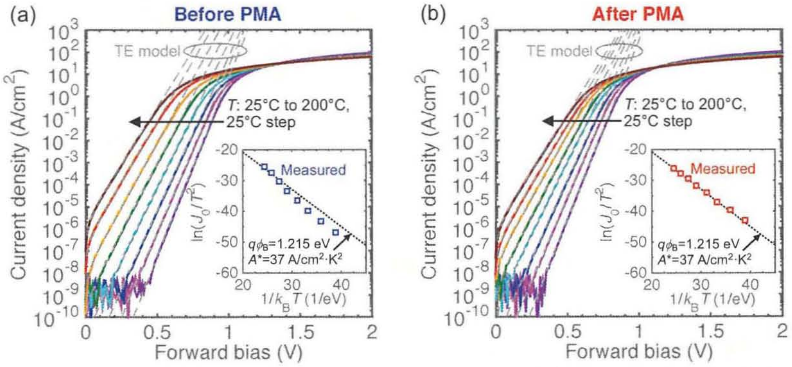

Fig. 3. Temperature-dependence of the forward *I-V* characteristics of the SBDs (a) before PMA and (b) after PMA. Insets show the Richardson's plot, in which the dotted line is drawn based on $q\phi_B$=1.215 eV. To minimize the effect of turn-on voltage/barrier height instability under repeated scans, the 2nd scans at each temperature are used for the *T*-dependent analysis.

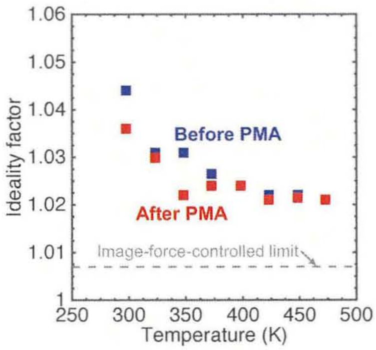

Fig. 4. Temperature-dependence of the ideality factor before and after PMA. Dotted line shows the image-force-controlled limit. A slight improvement is observed after PMA.

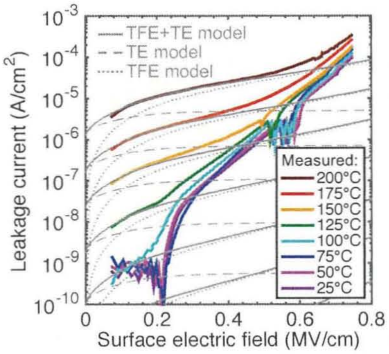

Fig. 4. *T*-dependent reverse leakage current *vs.* the parallel-plane surface electric field of the diode before PMA. The sum of TFE and TE model yields the best fitting results for the bulk leakage contribution. Deviation is due to the leakage current from the anode edge.

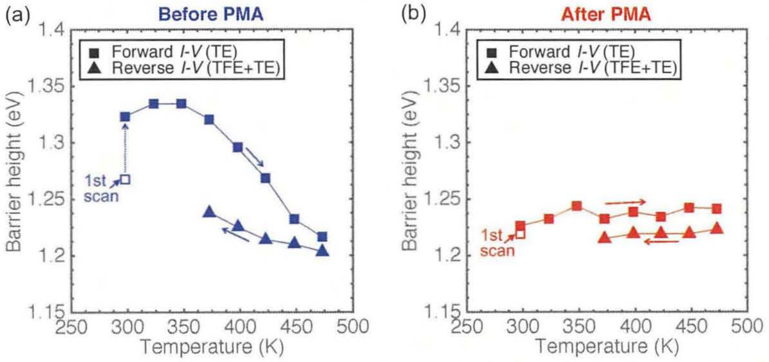

Fig. 5. Temperature-dependence of the barrier height (a) before PMA and (b) after PMA. The barrier height is extracted from both the forward and reverse *I-V* characteristics considering the image-force-lowering effect. A reduction of $q\phi_B$ with increasing temperature is observed in the diode before PMA, especially during the forward *I-V* measurements. The reduction is likely due to the de-trapping of the trapped electrons. After PMA, the barrier height is nearly constant with temperature.

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