Aperture-Limited Conduction in Vertical β-Ga_2O_3 MOSFETs with Nitrogen-Implanted Current Blocking Layer

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Ga_2O_3 is attractive for power electronics owing to its ultrawide bandgap and the availability of economical melt-grown native substrates. Capitalizing on ion-implantation doping technologies for Ga_2O_3, we have demonstrated vertical Ga_2O_3 MOSFETs in which drain current (I_D) is conducted through an aperture opening bounded by current blocking layers (CBLs) [1]. It is imperative that the aperture size (L_{ap}) be properly engineered to prevent current choke while maintaining a small specific on-resistance. In this work, we studied the influence of L_{ap} on the on-state characteristics of current aperture vertical Ga_2O_3 MOSFETs, the results of which were suggestive of diffusion of acceptors into the aperture.

The vertical Ga_2O_3 MOSFETs, shown schematically in Fig. 1, were fabricated on a Si-doped n^--Ga_2O_3 drift layer grown by halide vapor phase epitaxy on an n^+-Ga_2O_3 (001) substrate. Implantation of nitrogen ions (N^{++}) and silicon ions (Si^+) formed the nitrogen-doped CBLs, Si-doped n-type channel, and Si-doped n^{++} source contacts. Details of the device fabrication process are described in [1]. The MOSFETs had a nominal gate length of 2.5 μm, a source width of 2×200 μm, an aperture width of 200 μm, and variable L_{ap} of 5, 10, 15, and 20 μm.

Figure 2 shows the DC output characteristics of the vertical MOSFETs at a gate voltage (V_G) of +5 V. Devices with an L_{ap} of 20 μm displayed linear I_D turn-on with drain voltage (V_D), whereas those with L_{ap} of 5 and 10 μm displayed Schottky characteristics that indicated the presence of an electron barrier in the current path due presumably to aperture choke, the onset of which took place at an L_{ap} of 15 μm. Assuming a built-in voltage equal to the bandgap of Ga_2O_3 (4.5 eV) at the aperture–CBL junction, a depletion region of about 0.6 μm thus formed at each of the two lateral junctions would not have pinched even the smallest aperture, given that the simulated lateral implant straggle was only about 0.5 μm.

The turn-on voltage (V_{ON}) displayed by the devices could be explained by a presence of acceptors in the aperture and modeled by a planar-doped barrier diode (Fig. 3), wherein an electron barrier was created by a negative acceptor sheet charge (σ_A) at a depth corresponding to the projected range of N^{++}. These acceptors had most likely originated from lateral diffusion of native point defects from the ion-implanted CBLs as migration of nitrogen should be negligible [2, 3]. Diffusion resulted in a gradient in σ_A across the aperture, which translated to a gradient in barrier height such that turn-on would be initiated at the center of the aperture. Owing to a finite diffusion length of the acceptors, the minimum barrier height to overcome and hence V_{ON} decreased as L_{ap} increased. A diode with an σ_A of 1.8×10^{12} cm^{-2} required 15 V to turn on—the situation for an L_{ap} of 5 μm. Further work is underway to determine the physical nature of σ_A so as to devise strategies to eliminate V_{ON}.

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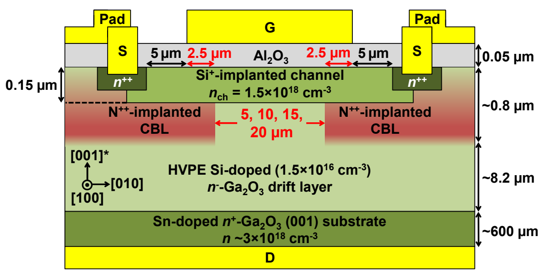

Fig. 1. Cross-sectional schematic of vertical Ga_2O_3 MOSFET.

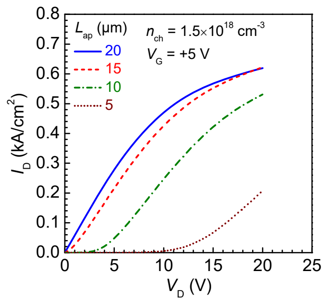

Fig. 2. L_{ap} dependence of DC I_D–V_D characteristics at V_G = +5 V.

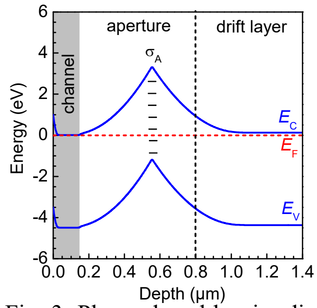

Fig. 3. Planar-doped barrier diode model for analyzing V_{ON} vs. σ_A at the center of the aperture.