Insulated gate and surface passivation structures for GaN-based FETs

Tamotsu Hashizume and Hideki Hasegawa
Research Center for Integrated Quantum Electronics (RCIQE), Hokkaido University, Sapporo, Japan
hashi@rciqe.hokudai.ac.jp

Insulated-gate (IG) structures are very attractive for FET applications in terms of reduction of gate leakage, surface passivation, high dynamic input range in devices, etc. Moreover, an insulator film can act as a passivation layer, making the surface more stable in the device. A high value of dielectric constant is desirable for the gate insulator to achieve high transconductance. For a successful field control of the device, moreover, sufficiently low interface state density and large band discontinuity are indispensable at the insulator-semiconductor interfaces. This paper presents systematic characterization of insulated-gate and surface-passivation structures for GaN-based FETs.

We found that the deposition of SiO_2 film on GaN and AlGaN surfaces induced high-density interface states due to unexpected and uncontrollable oxidation reactions on the surfaces during the deposition process [1,2]. In comparison, the SiN_x/GaN passivation structure prepared by ECR-CVD with the ECR N_2-plasma treatment showed good interface properties with the minimum D_{it} value less than 1x 10^{12} $cm^{-2}eV^{-1}$ [1, 2]. No pronounced stress remained at the SiN_x/GaN interface. Thus the SiN_x film is effectively used for surface passivation of GaN-based FETs. However, serious leakage problems appeared in the SiN_x insulated gate structures due to the insufficient band discontinuities to GaN and AlGaN [2].

Al_2O_3 is one of the attractive candidates for a gate insulator applicable to AlGaN, due to its relatively high dielectric constant (~9) and large bandgap (~7.0 eV). We tried to form a thin Al_2O_3 film on the AlGaN surface through a process consisting of the molecular-beam deposition of thin Al film and its oxidation using ECR O_2-plasma. The in-situ and angle-resolved X-ray photoelectron spectroscopy analysis showed successful formation of the Al_2O_3 layer with an energy gap of 7.0 eV. From the valence band spectra, moreover, we estimated the valence band offset to be 0.8 eV. These results led to a large conduction-band offset of 2.1 eV at the $Al_2O_3/Al_{0.3}Ga_{0.7}N$ interface, as shown in Fig.1, being desirable for the insulated gate application to the AlGaN/GaN hetero-structure field effect transistors (HFETs).

The fabricated Al_2O_3-gate AlGaN/GaN HFETs showed good gate control of drain currents. No current collapse was observed in the Al_2O_3-gate HFETs under both pulse-mode gate stress and high drain voltage stress, indicating remarkable passivation effects of the present Al_2O_3-based insulated gate structure [2,3]. The Al_2O_3-gate structure was also used for controlling the surface potential and suppressing the gate leakage in $Al_{0.2}Ga_{0.8}N$/GaN HFETs having thin AlGaN barrier layers (7 nm). In comparison with Schottky-gate devices, the Al_2O_3 IG device showed successful gate control of drain current up to V_{GS}= +4 V without leakage problems. The threshold voltage in the Al_2O_3 IG HFET was about -0.3 V, resulting in the quasi-normally-off mode operation [4].

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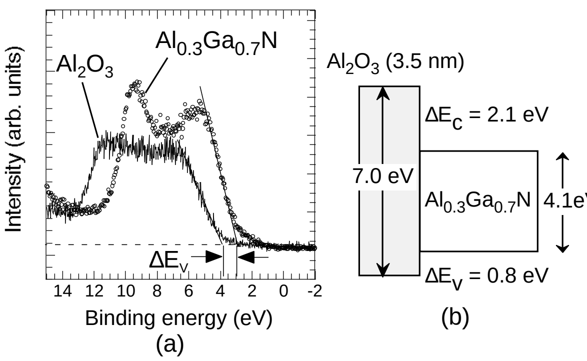

Fig.1 (a) XPS valence band spectra of the AlGaN surface before and after the passivation and (b) band alignment at the Al_2O_3/AlGaN interface.

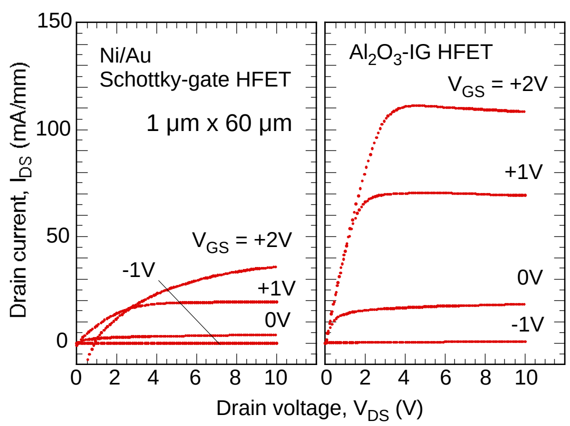

Fig.2 Drain I-V characteristics of the Ni/Au Schottky-gate and Al_2O_3-gate AlGaN/GaN HFETs with the AlGaN thickness of 7 nm.