The study on the effects of crystal defects on electrical properties for nitride semiconductor electron devices

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This is a doctoral thesis that discusses the effects of crystal defects on electrical properties in AlGaN/GaN heterostructure field effect transistors (HFETs). AlGaN/GaN HFETs have been extensively studied as promising future electronic devices for high-speed, high-power, and high-temperature operation. For further improvement in device performances, however, there still remain various issues to be solved. For example, reduction in gate leakage current through the Schottky barrier, suppression of current collapse, reduction in source-drain leakage current through the GaN buffer layer, and improvement in off-state breakdown voltage are required to improve the achievable power density. This doctoral thesis focuses on the reduction in source-drain leakage current and the improvement in off-state breakdown voltage for AlGaN/GaN HFETs.

The source-drain leakage current is called as the GaN buffer leakage current for AlGaN/GaN HFET, and it is closely related to the crystalline quality of the GaN buffer layer. In this thesis, the effects of threading dislocations (TDs) in the GaN buffer layer on the GaN buffer leakage current and the off-state breakdown voltage are revealed by the space-charge-limited current (SCLC) conduction mechanism.

At first, we studied the photoluminescence (PL) images of GaN and AlGaN/GaN heterostructure wafers obtained by UV lamp excitation. We have found that the intensity of PL increased with an increase in the GaN buffer leakage current. This correlation should be useful to understand the drain-source leakage current in AlGaN/GaN HFETs. In addition, the effects of crystal defects on the GaN buffer leakage current were studied from the correlation between the PL images and the crystal defects.

Secondly, effects of the TDs on the luminescence properties and the GaN buffer leakage current were studied using the correlation between the optical properties, the electrical properties, and the crystal defects. Moreover, we have found that the off-state breakdown voltage increased with decreasing thickness of the GaN layer in spite of the increase in TD density.

Thirdly, a correlation between traps formed by TDs and the off-state breakdown voltage was analyzed using the SCLC conduction mechanism which takes into account the deep traps. We found that the trap density increases with decreasing thickness of the GaN layer. Therefore, these results suggest that traps formed by TDs influence the off-state breakdown voltage of the GaN layer. Thus, this doctoral thesis provides academic and industrial information for further development of AlGaN/GaN HFETs.