Title	容量-周波数-温度マッピングによるワイドキャップ金属-絶縁体-半導体デバイスの解析手法
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Dissertation Abstract

Characterization method for wide-gap metal-insulator-semiconductor devices by using capacitance-frequency-temperature mapping

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Wide-gap semiconductor GaN is anticipated for its potential to overcome the trade-off relation between speed and power in semiconductor devices. In particular, GaN-based metal-insulator-semiconductor heterojunction field-effect transistors (MIS-HFETs) have been investigated extensively owing to the merits of gate leakage reduction and passivation to suppress the current collapse. For both gate-insulator or passivation applications, controlling insulator-semiconductor interfaces is critical for device performances. Therefore, it is important to characterize and analyze the interface states. In fact, we observe frequency dispersion in C-V characteristics of MIS devices, attributed to electron trapping/detrapping at interface mid-gap states leading to gate-control impediment. Such mid-gap states in GaN-based devices have been characterized and analyzed by conductance method, Terman method, photo-assisted C-V method, and deep level transient spectroscopy. Although the conductance method is widely used, there are difficulties in the analysis of deep interface states with long trapping time constants in MIS devices based on wide-bandgap materials like GaN. Also, the analysis results obtained from the conductance method is affected by the assumed value of the insulator capacitance.

In this work, we proposed and developed a method using capacitance-frequency-temperature (C-f-T) mapping obtained from the temperature-dependent C-V-f characteristics for GaN-based MIS devices, based on the Lehovec equivalent circuit. From constant-capacitance contours, exhibiting a straight line behavior in the mapping, an activation energy E_{a} corresponding to an interface state energy level can be extracted for a wide range of gate biases without assuming any parameter. The gate bias dependence of the activation energies leads to many insights into the MIS devices. The effectiveness of the method is exemplified by application to AlN/AlGaN/GaN MIS devices. Through characterizing the activation energies modulated by the gate biases, we can obtain the gate-control efficiency of the MIS devices, i.e., the ratio of the bandbending change in the semiconductor to the total gate voltage change. Even though the Lehovec equivalent circuit is based on an AC small-signal model, we find that its DC limit, described by the insulator capacitance, the semiconductor capacitance, and the interface state density, gives the gate-control efficiency. Therefore, we can evaluate the interface state density from the experimentally obtained gate-control efficiency, using the values of insulator and semiconductor capacitances. From the activation energies corresponding to a wide range of gate biases, we can obtain the gate-control efficiency and the interface state density corresponding to deep interface states in comparison with the conductance method. Moreover, it is shown that the gate-control efficiency and the interface state density have correlations with the linear-region intrinsic transconductance. In addition, we give characterization of the AlN-AlGaN interfaces by using X-ray photoelectron spectroscopy, in relation with the results of the analysis.

In summary, we have proposed and developed the C-f-T mapping method, a characterization method for wide-gap MIS devices. The method gives activation energies of electron trapping for a much extended range of gate biases, compared to the conventional conductance method. The effectiveness of the method is exemplified by applications to the AlN/AlGaN/GaN MIS devices, with evaluation of the gate-control efficiency, the interface state density, related to the intrinsic transconductance. The C-f-T mapping method provides the insights of deep interface states, being useful in the characterization of wide-gap MIS devices.

Keywords: wide-gap MIS devices, C-V characteristics, frequency dispersion, C-f-T mapping, interface states, AlGaN/GaN