Title	多端子ホール測定および高周波測定によるオーミック金属下半導体の特性評価法とその応用
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Abstract

For all kinds of semiconductor devices, formation of Ohmic contacts is a key technological element. In general, electrical properties of semiconductors are modified by formation of Ohmic-metals; the sheet resistance, the carrier concentration, the carrier mobility, and the depletion width under the formed Ohmic-metals differ from those before the formation. In order to clarify mechanisms of Ohmic contacts, it is important to evaluate semiconductor properties under Ohmic-metals. For measurements of the modified electrical properties, the end and floating contact resistance methods have been developed. However, these methods can measure only the sheet resistance; the carrier concentration and mobility cannot be evaluated. For a semiconductor with an Ohmic-metal, since the current is distributed in both the semiconductor and the Ohmic-metal, without knowing the current distribution, Hall measurements cannot determine the carrier concentration and mobility in the semiconductor. By knowing the potential and current distribution in the semiconductor, the carrier concentration and mobility under the Ohmic-metal should be evaluated, but the depletion width cannot be directly measured. The depletion width can be evaluated by measuring the depletion capacitance. However, it is difficult to accurately measure the depletion capacitance for Ohmic contacts by using a MHz-band LCR meter, because the imaginary part of admittance is much less than the parallel real part. By using a GHz-band measurements, where the imaginary part is comparable to the real part, the depletion capacitance should be evaluated.

In this work, in order to evaluate the carrier concentration and mobility under an Ohmic-metal, we proposed a characterization method using multi-probe Hall devices, from which we can know the voltage and current distribution. In addition, we proposed a characterization method to evaluate the depletion width under an Ohmic-metal from high-frequency measurements of floating contact impedance. The usefulness of these methods is exemplified by an application to Ohmic contacts for n-type GaN and AlGaN/GaN heterostructures.

By multi-probe Hall characterization for n-GaN and AlGaN/GaN heterostructures, we find that the sheet electron concentration under the Ohmic-metal is larger than that before the Ohmic-metal formation, indicating that high-doping takes place in the semiconductor. The electron mobility under the Ohmic-metal is also larger than that before the formation. This cannot be explained by donor doping with ionized impurity scattering. Considering polarization doping induced by a strain due to the Ohmic-metal, the increase in the electron mobility can be quantitatively explained based on a theoretical calculation taking into account ionized impurity and polar optical phonon scattering. This suggests that polarization doping is essential to the high-density doping in the semiconductor.

Furthermore, in order to confirm that high-density donors do not exist in the semiconductors under the Ohmic-metals, we investigated the semiconductor electrical properties after the Ohmic-metal removal. Multi-probe Hall characterization shows that the sheet electron concentration after the Ohmic-metal removal return to the value before the Ohmic-metal formation. In addition, we find that the Ni/Au Schottky contacts on the semiconductor before the Ohmic-metal formation and after the Ohmic-metal removal show the almost same characteristics. These results indicate that donors do not exist after the Ohmic-metal removal, suggesting that, although high-density doping takes place, high-density donors are not formed under the Ohmic-metal. Therefore, we conclude that the high-density doping in the semiconductor under the Ohmic-metals is attributed to polarization doping, playing a significant role in Ohmic contact formation.

Characterization methods proposed in this work are useful to obtain insights into Ohmic contact formation in various semiconductors.

Keywords: Ohmic contact, multi-probe Hall measurement, transmission line model, n-GaN, AlGaN/GaN heterostructure