Electrical characteristics of SAB-Based n^+-n Ge/4H-SiC heterojunctions

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Abstract— **n^+-Ge/n-4H-SiC heterojunctions were formed by surface activated bonding. The electrical characteristics of the heterojunctions were experimentally investigated by measuring their current-voltage (I-V) and capacitance-voltage (C-V) measurements. The band diagram of heterojunctions was estimated based on the C-V characteristics.**

Keywords-*surface activated bonding; Ge; 4H-SiC*

I. INTRODUCTION

Germanium (Ge) is promising material for high-speed and high-frequency devices due to its high carrier mobility. In particular, the mobility of holes of Ge is one of the highest among those of conventional semiconductors. We have to note, however, that Ge has a low breakdown field and a low thermal tolerance due to its narrow band gap. In contrast, 4H silicon carbide (4H-SiC) is a good candidate as materials for power devices because of its high breakdown field and excellent thermal tolerance. Therefore Ge/4H-SiC may be an ideal combination for power devices with excellent high-speed and, high-frequency characteristics, and high temperature properties.

The number of previous reports for the fabrication of Ge/4H-SiC heterojunctions is limited [1-3] because of the difficulty in epitaxial growth. In this work, we fabricated n^+-n Ge/4H-SiC heterojunctions by surface activated bonding, using which heterojunctions can be made of semiconductor materials with different crystal structures and lattice constants at room temperature. We investigated the electrical characteristics of the heterojunctions by measuring their current-voltage (I-V) and capacitance-voltage (C-V) measurements.

II. EXPERIMENTAL

We used heavily doped n-Ge substrates (1×10^{19} cm^{-3}) and n-4H-SiC epitaxial substrates, which were made of a 2.8-μm-thick n-doped epitaxial layer 1×10^{17} cm^{-3} and a 0.5-μm-thick buffer layer 2×10^{18} cm^{-3} grown on an n^+-doped 4H-SiC (0001) substrate 1×10^{19} cm^{-3} for fabricating the heterojunctions. Ohmic contacts were formed on the backsides of Ge substrates before bonding by evaporating Ni/Au multilayers. Contacts on the backsides of 4H-SiC substrates were achieved by evaporating Al/Ni/Au multilayers and annealing at 1000 °C for 60 s in N_2 ambient. Then, we bonded these substrates by using SAB [4-5]. The bonded samples were diced into 4 mm^2 pieces. Their I-V and C-V characteristics were measured using an Agilent B2092A Precision Source Measurement Unit and an Agilent E4980A Precision Impedance Analyzer, respectively.

III. RESULTS AND DISCUSSIONS

The I-V characteristics of Ge/4H-SiC heterojunctions measured at room temperature, which are shown in Fig. 1, revealed rectifying properties. The ideality factor (n) was estimated to be 1.69 by fitting.

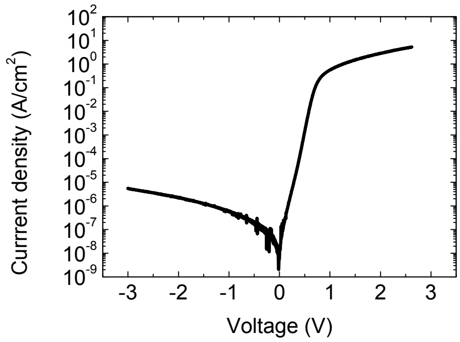

Fig.1. I-V characteristics of Ge/4H-SiC heterojunctions measured at room temperature.

The C-V characteristics at room temperature and frequency of 100 kHz are shown in Fig. 2. The impurity concentration, which was estimated to be $\approx1.0\times10^{17}$ cm^{-3} on the scheme of one-side abrupt junctions, was in agreement with the nominal impurity concentration of the 4H-SiC epitaxial layer. The flat-band voltage was found to be 1.0 V.

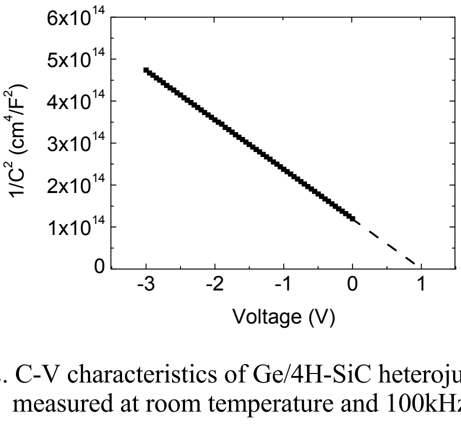

Fig.2. C-V characteristics of Ge/4H-SiC heterojunctions measured at room temperature and 100kHz.

The I-V characteristics measured at various temperatures between 293 and 474 K are shown in Fig. 3. It can be seen that higher the temperature, current density is larger. Assuming that the thermionic emission (TE) is the only relevant conduction mechanism based on the carrier concentration of 4H-SiC epitaxial layer, the relationship between the conductance at 0 V G and the temperature T is given by

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$$\mathrm{Ln}|G/T| = \mathrm{Ln}|qA^*/nk_B| - q\varphi_B/k_BT \qquad (1)$$

where k_B is the Boltzmann constant, A^* is the Richardson constant, φ_B is the Shottky barrier height.

The relationship between G/T and T is Fig. 4. Although the relationship cannot be fitted using a single line, Schottky barrier height was rudely estimated to be 0.37-0.97 eV, which corresponded to a flat-band voltage of 0.24-0.84 V.

The result that the data points in Fig. 4 are not placed along a single straight line suggests that other conduction mechanisms than simple TE additively play a certain role in the I-V characteristics at lower ambient temperatures. Such view is likely to explain the difference between the flat-band voltage estimated from the I-V characteristics and that from the C-V characteristics (1V). We consequently assume that the flat-band voltage based on the C-V measurements is the intrinsic one. The band diagram based on this assumption is shown in Fig. 5, which suggests that the band diagram of Ge/4H-SiC heterojunction reveals Type I features. The estimated conduction-band offset (1.15 eV) was slightly smaller than a previously-reported one (1.30 eV in [2]). The discrepancy might be related to a higher doping concentration of 4H-SiC epitaxial layers used in this work.

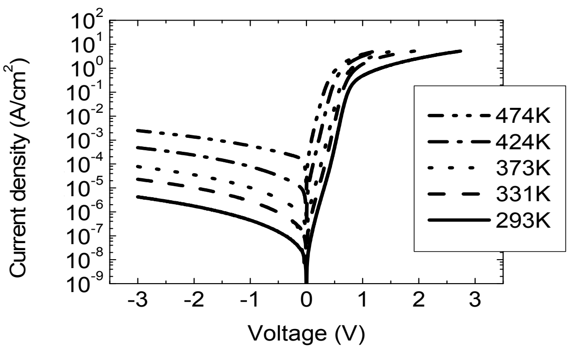

Fig.3. I-V characteristics of Ge/4H-SiC heterojunctions measured at various temperatures.

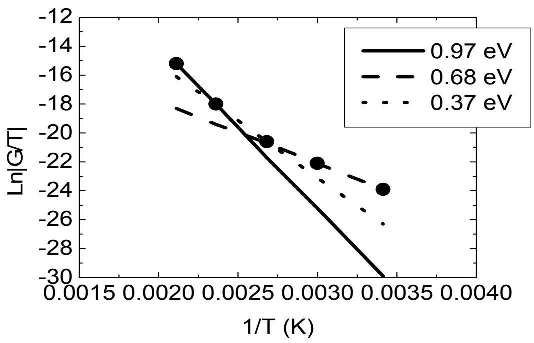

Fig.4. Relationship between the conductance at 0 V and the temperature. Lines for Schottky barrier height of 0.97, 0.68, and 0.37 eV are also shown.

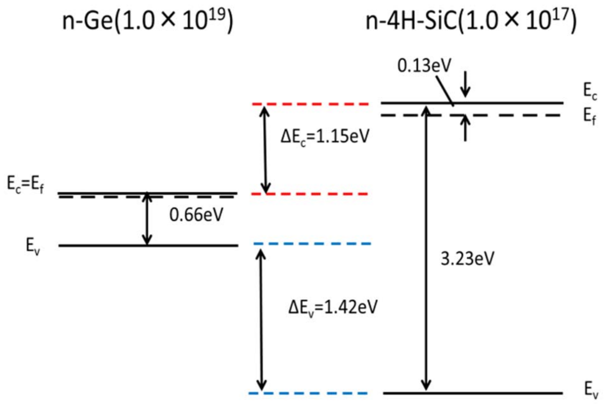

Fig.5. Band diagram of n^+-Ge/n-4H-SiC heterojunctions estimated for the flat-band condition.

IV. CONCLUSION

We formed n^+-n Ge/4H-SiC heterojunctions by SAB and investigated their electrical characteristics. The I-V characteristics measured at various ambient temperatures revealed that conduction mechanisms other than TE, such as thermionic field emission, are also significant at lower temperatures. We estimated the band diagram of Ge/4H-SiC junctions based on the C-V measurements, which revealed Type I features.

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