Extended Abstracts of the 2015 International Conference on Solid State Devices and Materials, Sapporo, 2015, pp972-973

Effect of Nitridation for SiO_2/SiC Interface on Defects Properties near Conduction Band Edge

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Abstract

We have investigated the effect of NO-annealing for SiO_2/4H-SiC interface properties. The electrical properties of NO-annealed sample are different from that of the wet-annealed sample. The NO-annealing generates positive charge in the insulator. The D_{it} from E_i+1.5 eV (E_C−0.1 eV) to the near the conduction band edge increases by the NO-annealing. The type of D_{it} near the conduction band edge in the nitrided SiO_2/SiC interface is identified as donor. It is considered that Coulomb scattering causes decreasing the n-channel mobility in the nitridation of the SiO_2/ SiC interface by the NO-annealing.

1. Introduction

4H-SiC semiconductor is a wide bandgap semiconductor whose properties are well-suited for high-power applications. However, it is difficult to realize the ideal on-resistance of 4H-SiC MOSFET owing to its low channel mobility. It is considered that the mobility is limited by trapped inversion carriers at interface states and near the interface, which cause Coulomb scattering. In order to decrease the interface state density (D_{it}), nitridation and wet annealing processes for a SiO_2/SiC interface are often performed. The wet annealing process decreases the D_{it} near the conduction edge and the electron mobility increased up to 244 cm^2/Vs[1]. Also, the nitridation annealing process improves an SiO_2/SiC interface properties, being effective for increasing the channel electron mobility as high as 100 cm^2/Vs [2]. However, in the channel mobility at a nitrided interface is still much lower than a value expected from the bulk electron mobility of 4H-SiC (> 800 cm^2/Vs) [3]. To further improve the mobility, it is important to reveal mobility-limiting factors at the nitridation SiO_2/SiC interface. In this study, we investigated the effect of NO-annealing on SiO_2/SiC interface properties compared with wet-annealed samples.

2. Experimental

Gate SiO_2 layers were formed by using low pressure chemical vapor deposition and wet-oxidation methods on n-type 4H-SiC(11-20) face substrate with an n-type epitaxial layer (epitaxial layer thickness: 15 μm, electron concentration: 4-6 ×10^{15} cm^{-3}). These SiO_2 thicknesses are ranging from 75 nm to 100 nm. After the formation of gate SiO_2 layers, annealing was performed under the NO gas atmosphere or the wet atmosphere. Here, the wet and NO atmosphere annealing are referred to as Depo.+Wet and Depo.+NO, respectively. Also, the sample of wet atmosphere annealing for the wet-oxidized SiO_2/SiC sample is named Oxidation+Wet. In order to estimate the D_{it}, MOS capacitors were fabricated with a Ti / n^+-type poly-Si electrode on the gate SiO_2 layer. The D_{it} of the MOS capacitor was estimated by using the conductance method, Gray-Brown method, and deep level transient spectroscopy (DLTS) method. Surface potential fluctuation (SPF) was also estimated by using the conductance method.

3. Results and discussion

Figure 1 shows capacitance-voltage (C-V) characteristics of MOS capacitors prepared with various conditions. These C-V curves of Depo.+Wet and Oxidation+Wet samples show similar characteristics. The flatband voltage (V_{fb}) of wet-annealed samples was estimated to be 4.7 V, which shift to positive side compared with the ideal-V_{fb} (0.2 V).

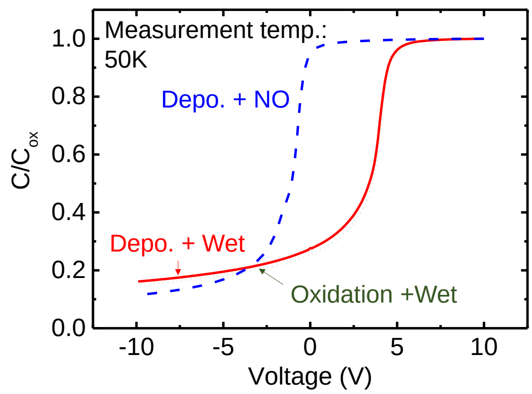

Fig. 1. C-V characteristics of MOS capacitors with wet- and NO-annealing for deposited- and wet-oxidized-SiO_2 samples measured at 50 K.

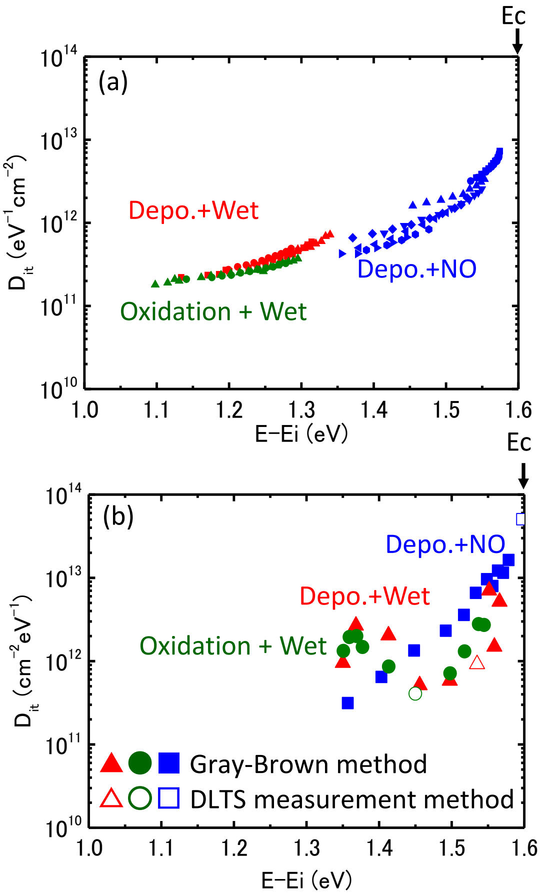

Fig. 2. Interface state densities evaluated by using (a) the conductance method (b) Gray-Brown and DLTS methods.

This means that the wet-annealing generates positive charges. In contrast, the C-V characteristic of Depo.+NO sample is different from the wet-annealed samples. The V_{fb} of NO-annealed sample was estimated to be −0.35 V. This means that the NO-annealing generates positive charges.

Figures 2 (a) and 2(b) show the D_{it} distributions estimated by the conductance method and Gray-Brown and DLTS measurement methods, respectively. The D_{it} distributions of wet-annealed samples are similar, meaning that characteristics of the deposited- and the oxidized-SiO_2 are not different after wet-annealing. In the case of Depo.+NO sample, the D_{it} distribution estimated by the conductance method coincides with that of Gray-Brown and DLTS results. On the other hand, the D_{it} distribution of the wet-annealed sample is different from that of NO-annealed sample. The D_{it} of the NO-annealed sample from E_i+1.5 eV (E_C−0.1 eV) to near the conduction band edge is higher than that of wet annealed samples.

Figure 3 shows the energy distribution of the surface potential fluctuation (SPF) of MOS capacitors. In the wet-annealed samples, the SPF increases toward the conduction band edge. This means that the type of D_{it} is identified as acceptor [4]. In contrast, the SPF of NO-annealed sample decreases toward the conduction band edge. This means that the type of D_{it} is donor.

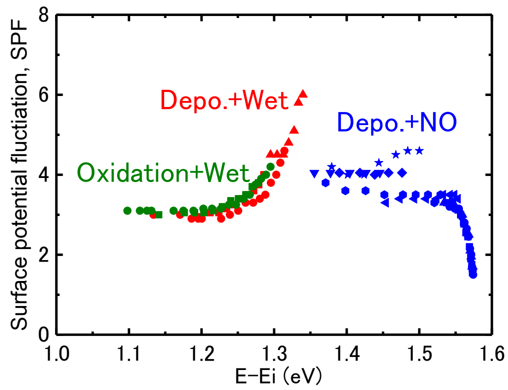

Fig. 3. Energy distribution of the surface potential fluctuation (SPF) on MOS capacitors with Wet- and NO-annealing for deposited- and wet-oxidized- SiO_2 samples.

It is well known that nitrogen is introduced the at SiO_2/SiC interface by the NO-annealing [5]. The donor level of nitrogen in 4H-SiC is E_c−0.05 eV on the hexagonal site and E_c−0.10 eV on quasicubic site [6]. Thus, it is considered that increasing the D_{it} in the NO-annealed sample would be caused by the nitrogen introduction. In the case of NO-annealing, the mobility might be limited by Coulomb scattering which is caused by charges from interface states near the conduction band edge at the nitrided SiO_2/ SiC interface.

4. Conclusions

We investigated the effect of NO- and wet-annealing on SiO_2/4H-SiC interface properties. The characteristics of the deposited- and the oxidized-SiO_2 samples are not different after wet-annealing. The wet- and NO-annealing cause the voltage-shift of C-V characteristics with negative and positive charges, respectively. The D_{it} in NO-annealed samples around E_i+1.5 eV (E_C−0.1 eV) and near the conduction band edge is higher than that of the wet-annealed sample. The D_{it} type of wet- and NO-annealing are identified as acceptor and donor types, respectively. Thus, it is considered that Coulomb scattering causes decreasing the n-channel mobility in the nitridation of the SiO_2/ SiC interface by the NO-annealing.

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