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Fermi Level Pinning at Metal/4H-SiC Contact Induced by SiC_xO_y Interlayer

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Abstract

The impacts of SiO_2 sputtering on the 4H-SiC surface state and on the metal (Al, Mo and Ni)/4H-SiC contacts have been systematically investigated. We clarified that SiO_2 sputtering forms an about monolayer-thick SiC_xO_y interlayer (IL) on the SiC surface and that causes Fermi level pinning (FLP) at ~0.8 eV below the conduction band edge of 4H-SiC, which is not same as the charge neutrality level of 4H-SiC. These results support the possibility to control the Schottky barrier height (SBH) of metal/4H-SiC by inserting the IL.

1. Introduction

The wide-band gap semiconductor 4H-SiC is an attractive material for high-power electronic devices such as Schottky barrier diodes (SBDs) and metal-oxide-semiconductor field-effect transistors [1]. For developing these power devices, the control of Schottky barrier height (SBH) and the decrease of contact resistivity are still big issues.

It is reported that plasma exposure and metal deposition drastically change electrical properties of metal/SiC contacts [2]. For almost cases, the formation of SiC_xO_y interlayer (IL) is somehow related to the modification of electrical properties. But the influence of SiC_xO_y IL on the electrical properties of metal/SiC contact has not been sufficiently understood yet. According to the recent report about 4H-SiC gate-stack, an ultra-thin SiC_xO_y IL is formed at the interface between deposited-oxide and 4H-SiC [3]. Considering that metal/SiC contact is usually formed at the place experiencing oxide deposition and its removal processes, understanding the chemical nature of SiC_xO_y IL formed by oxide deposition and its impact on the electrical property of metal/4H-SiC contact is essentially important.

In this study, we investigated the impact of SiO_2 deposition on 4H-SiC surface from the viewpoint of the SiC_xO_y IL formation. The effect of SiC_xO_y IL on the interface electrical property of metal/4H-SiC contact was also discussed.

2. Experimental procedures

N-type 4H-SiC(0001) wafer with a 5.0 μm-thick epitaxial layer with $N_D=1\times10^{16}$ cm^{-3} was used as the substrate. **Figure 1** shows the sample preparation flow. After chemical cleaning the substrate with diluted hydrofluoric acid (DHF), a 10 nm-thick SiO_2 layer was deposited at room temperature using RF magnetron sputtering system. The sputtering power (P_{rf}) for the SiO_2 deposition was ranging from 10 to 150 W. Subsequently, DHF etching for 2 min was carried out to remove the SiO_2 layer. The chemical bonding state of the 4H-SiC surface after DHF etching was investigated using X-ray photoelectron spectroscopy (XPS).

For some samples, a 100-nm-thick metal electrode (Ni, Mo, or Al) was deposited after DHF etching. The current density-voltage (*J*-*V*) and the capacitance-voltage (*C*-*V*) characteristics were measured to evaluate of the SBH of metal/4H-SiC(0001) contacts.

3. Results and discussion

First, the XPS measurement revealed the chemical bonding state of IL formed by SiO_2 sputtering. **Figure 2(a)** shows Si 2p core level spectra measured at a take-off angle (TOA) of 15° for samples experienceing the SiO_2 sputtering at various P_{rf} and DHF etching. Peak positions related to SiC and SiO_2 are indicated with broken lines [4]. Spectra were normalized by the SiC substrate peak. Since all spectra seems to be composed of three components; SiC substrate and two kinds of sub-oxide components, peak separation of Si 2p spectra was carried out by assuming these three components. As a reference, the separation result of the sample with P_{rf} = 150 W is shown in **Fig. 2(b)**. It is found that the area intensity of peak 1 for all samples is similar value, while that of peak 2 increases with increasing P_{rf}. This suggests that any residual SiC_xO_y exists even after DHF etching due to its higher chemical stability compared to SiO_2 [5] and C-rich SiC_xO_y is

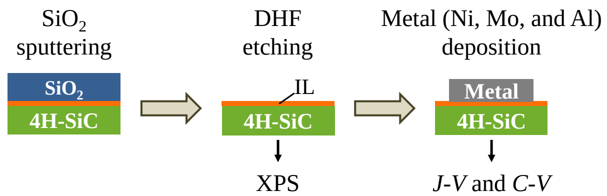

Fig. 1 Schematics of the sample preparation flow.

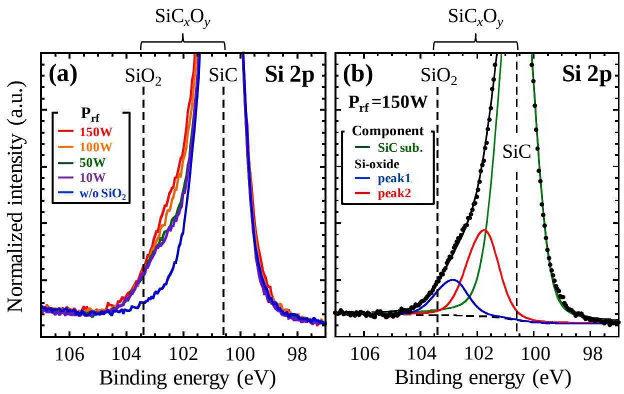

Fig. 2 (a) Si 2p core level spectra measured at TOA of 15° for samples after the SiO_2 sputtering at various P_{rf} and the DHF etching process. The peak separation result of the sample with P_{rf} of 150 W is shown in (b).

formed with increasing P_{rf}. The residual SiC_xO_y thickness was estimated to be an about 0.4 nm using SiC peak and both peak 1 and 2.

Next, the influence of SiC_xO_y interlayer on the electrical properties of metal/4H-SiC contact is discussed. **Figure 3** shows the *J-V* characteristics of (a) Ni/4H-SiC and (b) Al/4H-SiC contacts for samples without and with SiO_2 sputtering at various P_{rf}. Rectifying characteristics can be observed for all samples. For Ni/4H-SiC samples, the *J-V* curve shifts to a higher current side with increasing P_{rf} as indicated with a black arrow. This result means increasing the saturation current density with decreasing the SBH. On the other hand, for Al/4H-SiC contacts, the *J-V* curve shifts to a lower current side with increasing P_{rf}, suggesting the SBH increase.

The SBH values were estimated according to the thermionic emission current equation for forward *J-V* characteristics. Here, Richardson's constant was assumed to be 146 $Acm^{-2}K^{-2}$ [6]. **Figure 4** shows SBH of various samples as a function of the metal work function. Noted that the SBHs estimated from *C-V* curves (*not shown*) well agreed with those from *J-V* one. An ideal contact with the slope parameter (S) ~ 1 is realized for samples without SiO_2 sputtering, while the S value approaches 0 as increasing P_{rf}. The SBH of metal/4H-SiC contacts with P_{rf} of 150 W is pinned almost at ~0.85 eV with a small S value of 0.10. Furthermore, the fitted linear function for samples with P_{rf} from 50 to 150 W cross at one point at 0.8 eV below the conduction band edge at E_C−~0.8 eV for metal/SiC contacts.

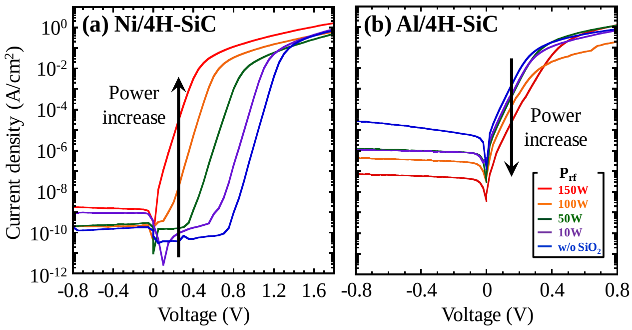

Fig. 3 *J-V* characteristics measured at room temperature of (a) Ni/4H-SiC and (b) Al/4H-SiC contacts for samples without and with SiO_2 sputtering at various P_{rf} and DHF etching.

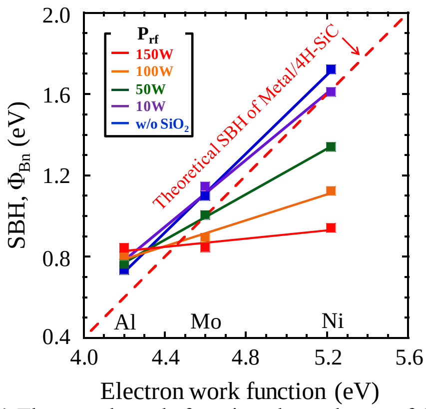

Fig. 4 The metal work function dependence of SBH for samples prepared with various P_{rf}.

Considering that the reported charge neutrality level (CNL) of 4H-SiC is E_C−~1.4 eV [8], the dominant mechanism of FLP of metal/4H-SiC contact is not originated from the metal induced gap state. Based on our experimental results, the formation of SiC_xO_y interlayer should be related to FLP phenomenon. To verify this hypothesis, a 1-nm-thick SiC_xO_y layer and 100-nm-thick Ni electrode were successively sputtered on a cleaned 4H-SiC surface. The designed composition ratio of Si/C is ~0.5. **Figure 5** shows the *J-V* characteristics for samples without and with a SiC_xO_y interlayer. A *J-V* shift to a higher current side by inserting an SiC_xO_y layer is observable. The SBH of Ni/SiC_xO_y/4H-SiC contact was estimated to be 1.1 eV, which is slightly higher than 0.8 eV where a pinned position is. While the FLP is not perfect, this result supports that the FLP at metal/4H-SiC contact is caused by SiC_xO_y interlayer, not originated from the nature of 4H-SiC. The FLP strength should be related to the composition ratio of SiC_xO_y layer.

4. Conclusions

We investigated the impact of surface modification with SiO_2 sputtering deposition on metal/4H-SiC contacts. We found that an ultra-thin SiC_xO_y IL is formed on the 4H-SiC surface after SiO_2 sputtering and this layer is stable even after the chemical etching procedure with DHF solution. FLP of metal/4H-SiC contact is caused due to a SiC_xO_y interlayer at E_C−0.8 eV of 4H-SiC where does not correspond to CNL of 4H-SiC. These results suggest that intentional FLP caused by inserting IL is an important view for both controlling of SBH and decreasing the contact resistivity.

Acknowledgements

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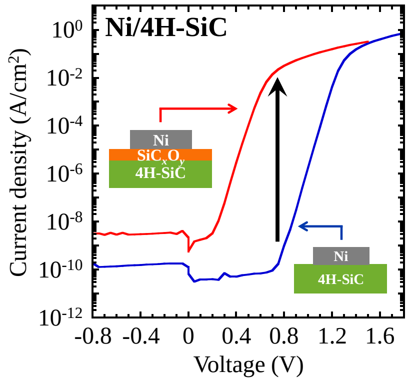

Fig. 5 *J-V* characteristics of Ni/4H-SiC and Ni/SiC_xO_y/4H-SiC diodes.