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Photoemission Spectroscopy Measurements of p$^+$-Si/n-SiC and n$^+$-Si/n-SiC Junctions by Surface Activated Bonding

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Abstract

Photoemission spectroscopy measurements were performed for p$^+$-Si/n-SiC and n$^+$-Si/n-SiC junctions that had been fabricated using the surface activated bonding. The optical absorption edge was estimated to be 1.36-1.4 and 1.6 eV for the p$^+$-Si/n-SiC and n$^+$-Si/n-SiC junctions, respectively. The difference in the optical absorption edges as well as that in the responses to bias voltages were discussed in conjunction with the potential profile across the bonding interfaces.

1. Introduction

Wide-bandgap semiconductor/narrow-bandgap semiconductor junctions are assumed to be the ideal combinations of materials for electron devices since high-breakdown voltages (wide bandgap) and high switching speeds (narrow bandgap) could be simultaneously realized. As an example for such systems, Si/SiC junctions were fabricated and characterized by several authors [1-3]. We previously fabricated Si/4H-SiC junctions using the surface activated bonding (SAB) [4], in which the two substrates were bonded just after activating their surfaces using Ar beams. We found that their bonding interfaces were tolerant against an annealing at temperatures as high as 1000 ºC [2]. We also found that the flat band voltages in the capacitance-voltage (C-V) characteristics of p$^+$-Si/n-SiC and n$^+$-Si/n-SiC junctions were close to each other, which suggested that interface states with a density of ~10^{13} cm^{-2}·eV^{-1} were distributed at the Si/SiC interfaces [3]. We have to note, however, that C-V characteristics are in general influenced by several artifacts. Other methods are, consequently, sought for in order to quantitatively understand the electrical properties of Si/SiC bonding interfaces.

By measuring photoemission spectroscopy of metal/wide-bandgap Schottky contacts, it was found that the spatial variation in the photo yield *Y*, the photocurrent per monochromatic single incident photon, was in correlation with that of the Schottky barrier height [5]. In this paper, the electrical properties of p$^+$-Si/n-SiC and n$^+$-Si/n-SiC junctions were investigated by examining their photoemission spectra while bias voltages were applied.

2. Results and Dicussions

Sample Preparation

We prepared n-type SiC epi layers (~5.4×10^{15} cm^{-3}, 10 μm) grown on n$^+$-4H-SiC (0001) substrates as well as n$^+$- and p$^+$-Si (001) substrates. The carrier concentrations of n$^+$- and p$^+$-Si substrates were estimated to be equally ~2.6×10^{19} cm^{-3}. We bonded the Si substrates to the SiC epi layers using the SAB so that p$^+$-Si/n-SiC and n$^+$-Si/n-SiC junctions were obtained. Contacts to the n$^+$-SiC, p$^+$-Si, and n$^+$-Si substrates were achieved by evaporating Al/Ni/Au (n$^+$-SiC and p$^+$-Si substrates) and Ti/Au (n$^+$-Si substrates). The junctions were annealed at 800 °C for 1 min. in the N_2 ambient.

We measured the photocurrent across these junctions at room temperature while they were illuminated by focusing monochromatic lights on the backside of SiC substrates and extracted *Y* as the function of photon energy $h\nu$ (photoemission spectroscopy). The cross sections of p$^+$-Si/n-SiC and n$^+$-Si/n-SiC junctions are schematically shown in Figs. 1(a) and 1(b), respectively.

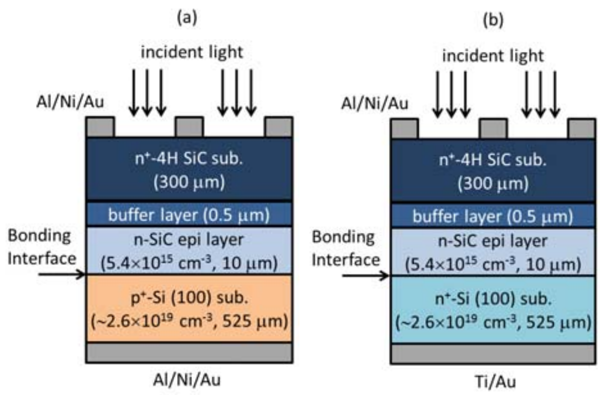

Fig. 1. Schematic cross sections of (a) p$^+$-Si/n-SiC and (b) n$^+$-Si/n-SiC junctions.

Photoemission spectra

The relationships between $\sqrt{Y}$ and $h\nu$ for the shorted and negatively-biased (-3 V) p$^+$-Si/n-SiC junctions are shown in Fig. 2(a). Incident photons with $h\nu$ between 1.12 and 3.23 eV (bandgaps of Si and 4H-SiC) should be absorbed in the Si substrate. Y for this energy range is likely to be rudely proportional to $(h\nu - E_0)^2$ with the absorption edge E_0 due to the indirect characteristics of Si. We found in Fig. 2(a) that $\sqrt{Y}$ of the p^+-Si/n-SiC junctions linearly depended on $h\nu$ for $h\nu$ between 2 and 2.5 eV. E_0 was estimated to be 1.36-1.40 eV irrespective of bias voltages by the least square fitting for this photon energy range. Results of measurements for n^+-Si/n-SiC junctions are shown in Fig. 2(b). Similar dependencies of Y were also observed in this figure. E_0 was estimated to be ≈1.6 eV when these junctions were biased at -3 V.

We also found that the magnitude of $\sqrt{Y}$ was largely enhanced by applying negative bias voltages to the n^+-Si/n-SiC junctions. In the p^+-Si/n-SiC junctions, in contrast, a slight (×1.3 times) increase in $\sqrt{Y}$ was observed when a negative bias voltage was applied.

Discussions

Interface states that are assumed to be distributed at the Si/SiC interfaces might build negative (positive) sheet charges, which should induce a potential well (potential barrier) in the conduction band of Si in the vicinity of interfaces. The observed difference in E_0 between the p^+-Si/n-SiC and n^+-Si/n-SiC junctions is consistent with this view. The marked change in the magnitude of $\sqrt{Y}$ due to the negative-bias voltages in the n^+-Si/n-SiC junction is assumed to stem from the possible variation in the potential profile of Si in the vicinity of bonding interfaces. These results suggest that the photoemission spectroscopy is useful for investigating transport characteristics of carriers across the bonding interfaces as well as their electrical properties.

3. Conclusions

The photoemission spectroscopy measurements were performed for p^+-Si/n-SiC and n^+-Si/n-SiC junctions fabricated using the surface activated bonding. A larger absorption edge was observed for the photo yield spectra of the p^+-Si/n-SiC junctions. A marked variation in the magnitude of the photo yield was observed when the n^+-Si/n-SiC junctions were negatively biased. These results might be attributable to the contribution of the interface states in accordance with a view obtained from the capacitance-voltage characteristics of Si/SiC junctions.

Acknowledgements

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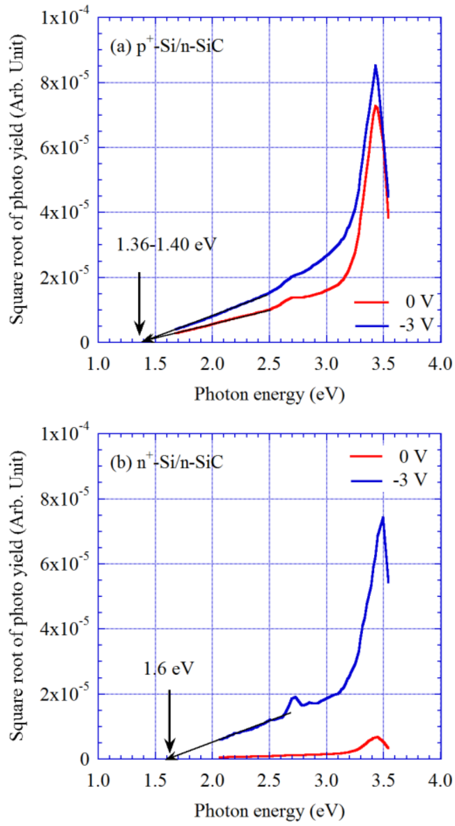

Fig. 2. Photoemission spectra of (a) p^+-Si/n-SiC and (b) n^+-Si/n-SiC junctions.