Transport Characteristics of Optically-Excited and Electrically-Injected Minority Electrons across p-Si/n-SiC Hetero-Interfaces

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***Abstract*—We report on the photoresponse of p-Si/n-SiC heterojunctions and the electrical characteristics of SiC/Si heterojunction bipolar transistors (HBTs), both of which are fabricated by bonding SiC and Si layers. We find that in the photoresponse measurements the square root of the quantum yield almost linearly depends on the photon energy and the absorption edge (1.2 V) is close to the bandgap of Si (1.12 eV), which implies that the achieved signal is attributed to the minority electrons optically excited in the p-Si layer and collected in the n-SiC layer across the hetero-interfaces. The characteristics of the SiC/Si HBTs reveal the common-base current gain α of ≈ 0.9 for the base-collector bias voltage of 0 V at room temperature. These results indicate that SiC/Si hetero-interfaces are applicable for novel minority-carrier-based semiconductor devices.**

I. Introduction and Background

4H-SiC has been widely applied for the state-of-the-art power devices and systems due to its advantages as wide-gap semiconductors. 4H-SiC/Si junctions can be a practical constituent in advanced SiC-based devices since SiC/Si junctions are assumed to be more tolerant against harsh environments in comparison with metal-SiC junctions. We previously demonstrated SiC/Si diodes fabricated using the surface-activated bonding (SAB) method: We confirmed their excellent characteristics as well as the stability against a 1000-°C annealing [1]. In this work, we report on the photoresponse of p-Si/n-SiC junctions [2] and the electrical characteristics of SiC/Si heterojunction bipolar transistors (HBTs) [3] with the emphasis on the behaviors of minority electrons.

II. Results

We measured the photoresponse of SAB-based p-Si/n-SiC heterojunctions to a monochromatic light incident on the backside of SiC substrates. Note that photons with an energy $\hbar\omega$ between the bandgaps of SiC and Si are absorbed in the p-Si after they pass through the SiC substrates. The bias voltages were preset to be 0 V (shorted). The square root of the photoyield $\sqrt{Y}$ is shown in Fig. 1(a). The absorption edge is $\approx$1.2 eV, which is close to the bandgap of Si. For $\hbar\omega$ close to the absorption edge, $\sqrt{Y}$ almost linearly depends on $\hbar\omega$. The observed photoyield is, consequently, likely to be attributable to minority electrons, which were optically excited in the p-Si, driven toward the Si/SiC interfaces due to the internal electric field, and collected in the n-SiC.

We also fabricated SiC/Si heterojunction bipolar transistors with SAB-based emitter (n-SiC)/base (p-Si) hetero-interfaces. Their room-temperature common-base characteristics after the

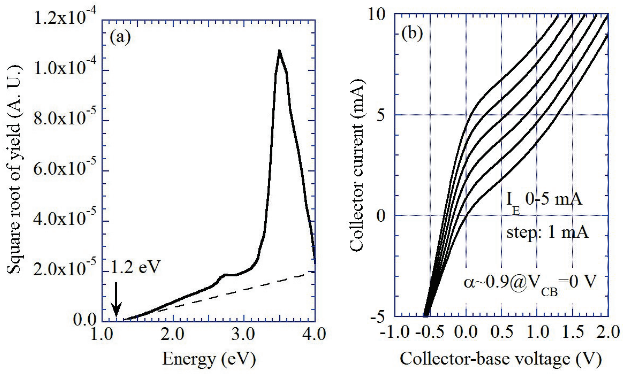

Fig. 1. (a) Square root of the yield of photoresponse of p-Si/n-SiC junctions at 0 V. (b) Common-base characteristics of SiC/Si HBTs after the annealing at 700 °C.

post-process annealing at 700 °C is shown in Fig. 1(b). The emitter current was varied between 0 and 5 mA with a 1-mA step. By the annealing, the common-base current gain α at the base-collector bias voltage of 0 V increased from ~ 0 [3] to ≈ 0.9, which corresponded to the common-emitter current gain β of 9. The achieved current gain implies that minority electrons are efficiently injected from the SiC emitter to the Si base. The results for the p-Si/n-SiC junctions and SiC/Si HBTs suggest that the SiC/Si hetero-interfaces can be essential parts of SiC-based advanced functional devices.

Acknowledgment

This work was partly supported by "Creative research for clean energy generation using solar energy"program of Japan Science and Technology Agency (JST).

References

[1] J. Liang, S. Nishida, M. Arai, and N. Shigekawa, "Effects of thermal annealing process on the electrical properties of p^{+}-Si/n-SiC heterojunctions", Appl. Phys. Lett. **104**, 161604 (2014).

[2] M. Shingo, J. Liang, N. Shigekawa, M. Arai, and K. Shiojima, "Mapping of Si/SiC p-n heterojunctions using scanning internal photoemission microscopy", Jpn. J. Appl. Phys. **55**, 04ER15 (2016).

[3] J. Liang, S. Shimizu, S. Nishida, N. Shigekawa, and M. Arai, "4H-SiC/Si Heterojunction Bipolar Transistors Fabricated by Surface Activated Bonding", ECS Solid State Lett. **4**, Q55 (2015).