Extended Abstracts of the 2018 International Conference on Solid State Devices and Materials, Tokyo, 2018, pp543-544

Fabrication and characterization of asymmetric metal/Ge/metal diodes with Ge-on-Insulator substrate

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Abstract

The direct band gap (DBG) electroluminescence (EL) was investigated for asymmetric metal/Ge/metal diodes fabricated on p-type bulk Ge and Ge-on-insulator (GOI) substrates with acceptor concentration of 2.2 × 10^{16} cm^{-3}. The EL intensity of GOI diodes is approximately eight times higher than that of bulk Ge diodes, because the electron population in direct conduction band can be enhanced by using GOI substrates, in which a higher current density can be achieved owing to the small thickness of GOI. In addition, defect-related photoluminescence peaks were observed for GOI substrates with varied intensity and energy in the range of 0.70-0.75 eV. Those defects also contribute to the low-energy part of EL spectrum in GOI diodes.

1. Introduction

To maintain CMOS scaling down, the MOSFET channel length has been already shrunk to several nanometers, which is approaching to physical limitation. To further enhance the performance of ULSI, many researchers proposed the so called post scaling technology such as high mobility channel, tunnel field-effect transistor, and spin field-effect transistor. On the other hand, with improving MOSFET performance, intra-chip interconnect delay is becoming a bottle neck of overall performance of ULSI. One solution is to replace metal interconnect with optical one, because the optical interconnect has advantages such as high speed, low noise, and low power consumption [1]. To realize this, optical devices should be fabricated by using materials those are Si-platform friendly. Therefore, we proposed an asymmetric metal/Ge/metal (MGM) structure and demonstrated direct band gap (DBG) electroluminescence (EL) at a wavelength of 1.55 μm [2-5]. However, the efficiency of this DBG-EL is still low due to small number of electrons in direct conduction band (DCB), because Ge is not a real DBG semiconductor. In this study, we fabricated asymmetric MGM diodes on a Ge-on-Insulator (GOI) substrate to enhance the current density J in active region, consequently increase electron population in DCB, because the injected carriers can be confined in the thin Ge layer. As the result, EL intensity I_{EL} was clearly enhanced by replacing bulk Ge with GOI. We also measured micro-photoluminescence (μ-PL) spectra to investigate the crystallinity of GOI.

2. Experimental

To fabricate GOI substrates, H^+ ion implantation (peak depth of about 800 nm) was performed for a p-Ge (100) substrate (N_A = 2.2 × 10^{16} cm^{-3}) with SiO_2 (100 nm) deposited. After the SiO_2 layer was removed by dilute HF, an Al_2O_3 (3 nm) layer was deposited by atomic layer deposition. A p-Si (100) substrate (N_A = 3 × 10^{15} cm^{-3}) was also prepared, on which a SiO_2 (50 nm) layer was grown by thermal oxidation. Then, the Al_2O_3/Ge substrate was bonded with the SiO_2/Si substrate in the air, formed a Ge/Al_2O_3/SiO_2/Si structure, which was subsequently annealed at 300°C for 1 hour to enhance the bonding strength. After that, the sample was heated to 400°C, and the Ge layer was split at the position with maximum density of H^+ ion (~ 800 nm away from the Al_2O_3/Ge interface). Finally, chemical mechanical polishing was performed to decrease the surface roughness of GOI [6]. By using the GOI substrate, we fabricated asymmetric MGM diodes, as shown in Fig. 1. After cleaning, Ge islands were formed by chemical etching. Then, Ti/Pt (20 nm/30 nm) and TiN (50 nm) layers were deposited and patterned independently to form the electrodes. All the above metal layers were deposited using an rf magnetron sputtering method and patterned using a lift-off process, followed by a post-metallization annealing in N_2 at 400 °C for 30 min. The surface of the active region was passivated using ultrathin SiO_2/GeO_2 bilayer [7]. Then, a 250 nm-thick SiO_2 layer was deposited by physical vapor deposition, followed by annealing in N_2 at 385 °C for 30 min. At last, Al electrodes were formed using a thermal evaporation method followed by a contact annealing in N_2 at 300 °C for 10 min. The fabricated device structure was also shown in fig. 1. We also fabricated same structure device on bulk p-Ge (100) substrate (N_A = 2.2 × 10^{16} cm^{-3}) for comparison.

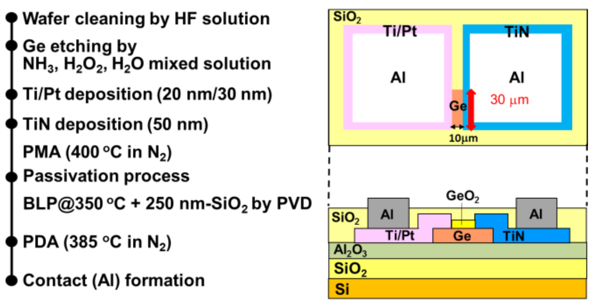

Fig. 1 Fabrication process flow, top and cross sectional views of device structure.

3. Results and discussions

Figures 2 and 3 show EL spectra for bulk Ge and GOI diodes, respectively. The peak at 0.8 eV corresponds to DBG energy of Ge. I_{EL} of GOI diodes is apparently higher than that of bulk Ge diodes, in particular, eight times higher under the current intensity I = 50 mA. In the case of GOI diodes, the Ge layer is very thin (300-500 nm), in which J is much higher than that in bulk Ge diodes, because the injected carriers are confined in the thin Ge layer. As a result, I_{EL} is increased because the electron population in DCB increases with increasing J. Therefore, I_{EL} for GOI diodes superlinearly increased with increasing I, as shown in Fig. 4.

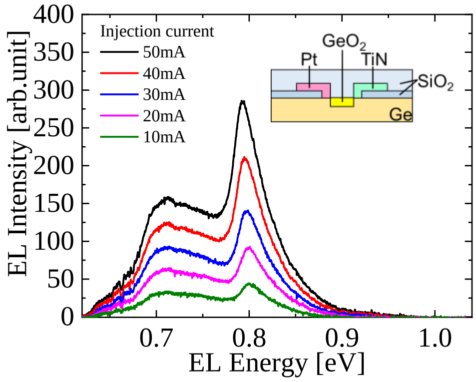

Fig. 2 EL spectra for bulk Ge diodes.

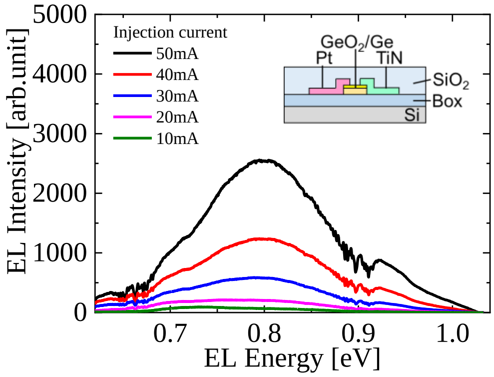

Fig. 3 EL spectra for GOI diodes.

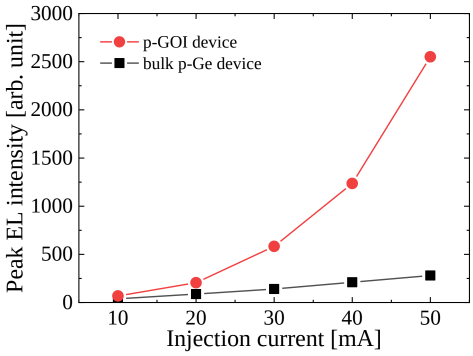

Fig. 4 Dependence of EL peak intensity on current intensity.

Different from bulk Ge diodes, the EL spectra for GOI diodes show very broad profiles. To investigate this, we performed μ-PL measurement (532 nm laser, power: 10 mW, spot diameter: < 2 μm) for bulk Ge and GOI substrates, as shown in Fig. 5. As for bulk Ge, almost identical spectra were observed at different measurement positions. Therefore, only one spectrum of bulk Ge was plotted. On the other hand, μ-PL spectra of GOI varied depending on measurement position. The peaks at energy below band gap show varied energy and intensity, implying their defect nature. Most of the defects were generated during the GOI fabrication process because the fluctuation of defect signal could only be observed for GOI. As for EL spectra, the area of active region is much greater than that of laser spot, and defect related EL signals (with varied peak position) were collected from all the active region, resulted in a broad profile at the low-energy part. EL signal also extended to higher energy region for GOI diodes, because more electrons can reach higher energy positions due to the enhanced J.

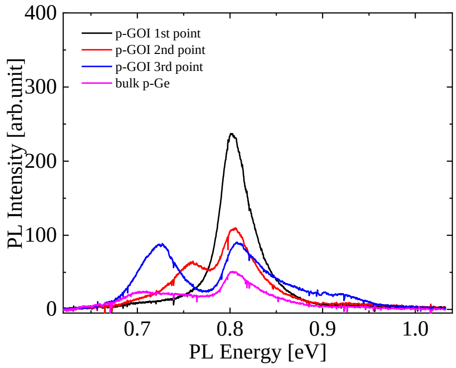

Fig. 5 PL spectra for bulk Ge and GOI substrates.

4. Conclusions

Asymmetric MGM diodes were fabricated on GOI, of which I_{EL} was enhanced by eight times comparing with bulk Ge diodes, due to the increased electron population in DCB. The broad profile of EL spectrum for GOI diodes is contributed by both defects and increased electron population at higher energy position.

Acknowledgements

H^+ ion implantation was carried out in Shanghai Institute of Microsystem and Information Technology, Chinese Academy of Sciences. This work was supported by (JSPS) KAKENHI (grant number 17H03237) and the Sasakawa Scientific Research Grant from The Japan Science Society.

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