Schottky Diode characteristics of ZnO/graphene/Cu heterojunctions formed by direct bonding technique

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Abstract

Schottky barrier heights between graphene and semiconductors have been already reported for GaAs, Si, SiC and ZnO [1-5]. Generally, surface treatments for semiconductors significantly affect the Schottky barrier heights. Oxide semiconductors, however, are free from oxidation in the atmosphere at room temperature (RT). On the other hand, direct bonding technique at RT can afford ideal heterojunctions by minimizing additional thermal effect on the respective material [6, 7].

We investigated Schottky barrier diodes formed by graphene and ZnO (oxide semiconductor) using direct bonding technique in the atmosphere at RT.

Single layer graphene on Cu foils formed by CVD was purchased from Graphene Platform Co. Ltd. Figure 1 shows two schematic Schottky diode structures formed by direct bonding technique in the atmosphere at RT. The ZnO was either single crystals (+c plane) or polycrystalline films formed on sapphire substrates by pulsed laser deposition (PLD). The VI/II ratios of the ZnO films were changed by applying bias voltages on the grid inserted between the substrate and the ZnO target in PLD [5, 6]. The ZnO surfaces were cleaned by only organic solvent (acetone) and deionized water.

Figure 2 shows a Raman spectrum of the graphene on the Cu foil where the peak intensity ratio of I_{2D}/I_G was approximately 3, indicating a monolayer thickness. Figure 3 shows I-V characteristics of ZnO/Cu heterojunctions for ZnO single crystals under different bonding pressures. As the pressure was increased, both the forward and the reverse currents increased. Figure 4 shows the effect of the bonding pressure on the forward currents. As the pressure was increased, the currents increased first and they were saturated for the pressure of more than about 300 g/cm^2. This implies that reliable heterojunction characteristics can be obtained by our direct bonding technique. Figure 5 shows I-V characteristics of the ZnO/Cu and ZnO/graphene/Cu heterojunctions for single crystals under a bonding pressure of 300 g/cm^2. The difference of work functions between graphene (4.5 eV) and Cu (4.65 eV) is only 0.15 eV and the forward currents were almost the same values. Figure 6 shows I-V characteristics of ZnO/Cu and ZnO/graphene/Cu heterojunctions for polycrystalline ZnO films. The forward currents tended to be straight and this suggested that the currents changed from the thermionic emission for single ZnO crystals to tunneling currents for polycrystalline films. The deep energy levels in the polycrystalline films played important roles in the tunneling mechanism. The threshold voltage was decreased by inserting graphene and the forward currents were increased. Figure 7 shows the forward currents of the heterojunctions for polycrystalline ZnO films with different defect densities. As the VI/II ratios of the ZnO films deviated from the stoichiometric composition (1:1), the forward currents were increased by a factor between 2 and 3. This indicates that the tunneling currents were caused mainly by the deep energy levels of vacancies and interstitial atoms in the ZnO films [8] and, they were also affected by the difference between the Fermi energy surfaces of graphene and Cu.

References

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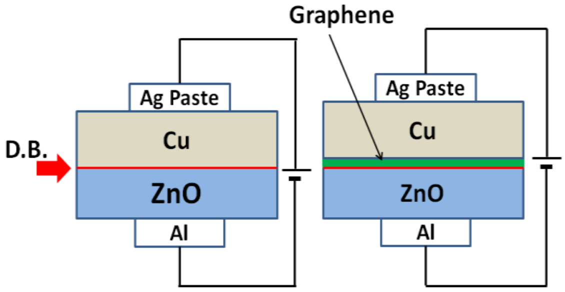

Fig. 1 Schematic heterojunction structures

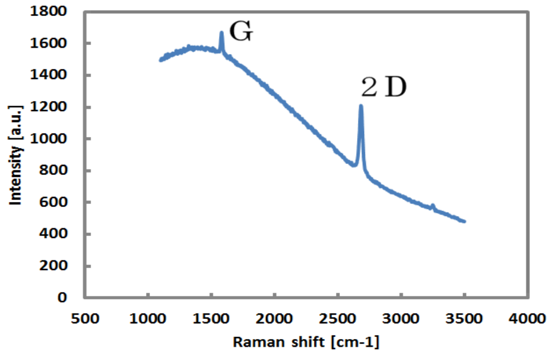

Fig. 2 Raman Spectrum of graphene on Cu foil

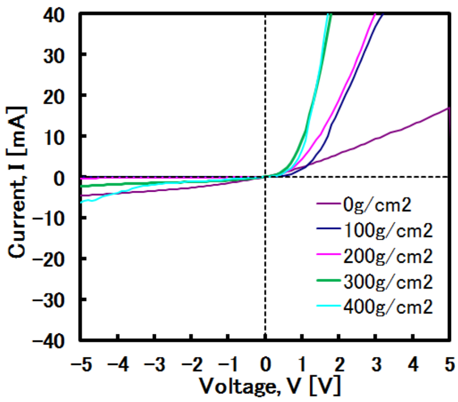

Fig. 3 I-V curves of ZnO/Cu under different DB pressures

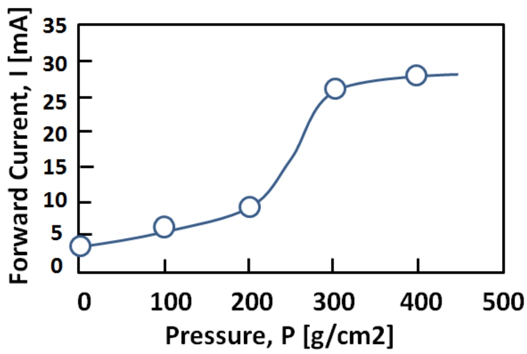

Fig. 4 Effect of DB pressure on the forward currents of ZnO/Cu junction

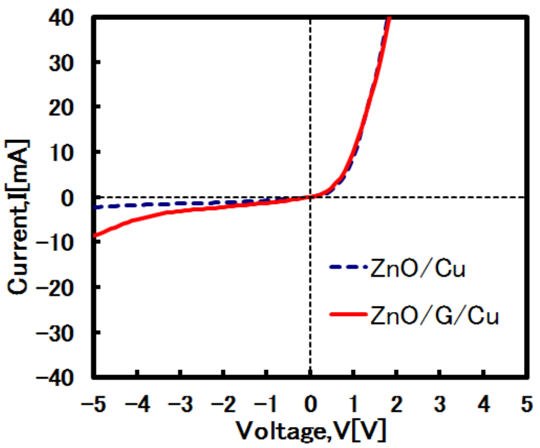

Fig. 5 I-V curve of ZnO/graphene/Cu for single crystal ZnO

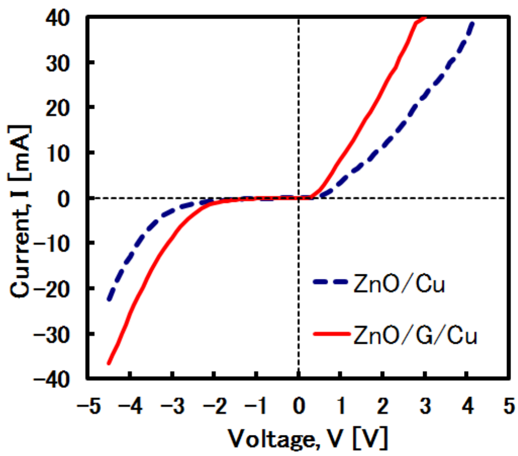

Fig. 6 I-V curve of ZnO/graphene/Cu for polycrystalline ZnO

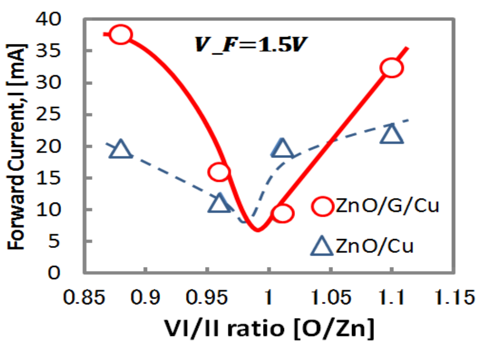

Fig. 7 Effect of VI/II ratio of ZnO on forward currents