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Electrical Conductance in Graphene Contacting with Metal

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1 Introduction

Graphene has recently attracted great attention due to its extremely high carrier mobility. However, the contact resistance between graphene and metal electrode is a limiting factor of the device performance for scaled graphene-based field-effect transistors. Therefore, it is important to understand the properties of graphene contacting with metals. It was reported that the contact resistance showed gate bias dependence [1]. This result indicates that the carrier density of graphene underneath the metal electrode is modulated by the back gate voltage. However, the electrical properties of graphene contacting with the metal have not been directly extracted and researched yet. In this research, we investigated the carrier modulation in graphene underneath the metal electrode.

2 Simple simulation of current flow path

First, the current flow path should be considered in the device with the electrically floating metal on the graphene channel, as shown in Fig.1. Previously, we determined the transfer length, i.e. the effective contact length, ($d_T = \sqrt{\rho_{C\square}/R_{ch}}$, where $\rho_{C\square}$ is the specific contact resistivity and R_{ch} is sheet resistance of graphene) as ~1μm [1]. When the length of the metal L_M is very long ($L_M >> 2d_T$), the current preferentially flows through the metal. However, with decreasing the metal length, the resistance of the path (i) becomes larger than the resistance of graphene by taking account of the contact resistance, which results in the preferential current flow through graphene (path (ii)). In this case, it is possible to detect the carrier modulation in graphene underneath the metal electrode by electrical measurements. Fig.2 shows the current ratio for paths (i) and (ii) calculated simply by Kirchhoff 's law. It is evident that the current flows more preferentially through graphene for larger (a) $\rho_{C\square}$ and (b) smaller L_M. Based on these calculations, the condition for detecting the carrier modulation in graphene is roughly $L_M < 2d_T = 2\mu$m.

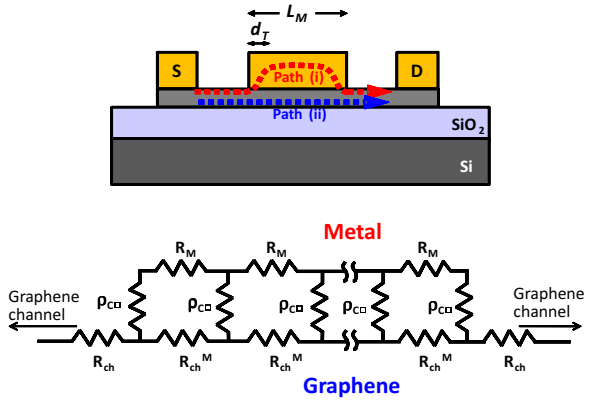

Fig. 1: Schematics of the current flow pathes and simple resistor network model. d_T and L_M are the transfer length and the metal length respectively.

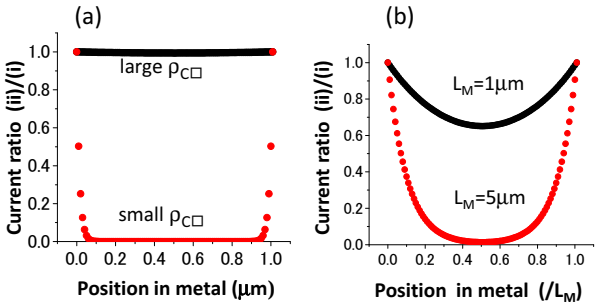

Fig. 2: Calculated current ratio (ii)/(i) for (a) different contact resistivities and (b) different metal lengths. The transverse axis is normalized by L_M

3 Experimental verification

Fig.3(a) shows an optical microscope photograph of the fabricated graphene FET device. Monolayer graphene was prepared from Kish graphite using mechanical exfoliation. Ni electrodes were used in this study. For analyzing this device, the channel resistance (R_{ch}^1) including both graphene underneath the metal and not contacting with metal was initially measured by the four-probe measurement using voltage probe v_2 and v_3, as shown in Fig.3(b). Then, the intrinsic graphene resistances (R_{ch}^2 and R_{ch}^3) were also estimated by voltage probe v_1 and v_2. Finally, the resistance in the metal region (R_{ch}^M) could be obtained by subtracting R_{ch}^2 and R_{ch}^3 from

R^1_{ch}. It should be noted that (R^M_{ch}) includes graphene, metal and contact resistance, and that Ni electrode on the channel was kept floating electrically during the measurement. The mobility of this device was between 3500 and 5000cm^{2}V^{-1}s^{-1} and Dirac point varied from 1.2 to 2.1V depending on the position.

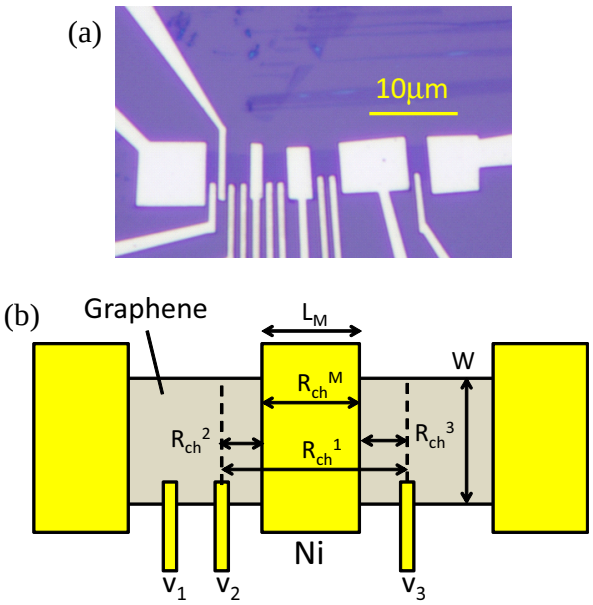

Fig. 3: (a) Optical microscope photograph of the fabricated graphene FET device. (b) A schematic top view of the device for extracting the resistivity of graphene underneath the metal.

Fig.4 shows the resistivity of graphene with (ρ^M_{ch}) and without (ρ_G) various lengths of Ni electrode as a function of back-gate voltage. ρ_G, without Ni, shows a sharp gate bias dependence, while ρ^M_{ch}, with Ni, is modulated more significantly as the length of Ni electrode becomes shorter. This result clearly indicates the modulation of the carrier density in graphene underneath the metal as expected analytically.

In addition, we have noticed a small negative shift of the peak position in Fig.4. This implies that graphene underneath the Ni electrode is negatively doped. This cannot be explained by the simple charge transfer model on the basis of the work function difference, since the work functions of Ni (5.2 eV) and graphene (4.5 eV) suggests the hole doping in graphene [2]. On the other hand, it is reported that the strong coupling between p_z-orbitals in graphene and d-orbitals in Ni results in the n-doping in graphene from the XPS results of graphene on Ni(111) [3]. More data are obviously needed to conclude the doping effect quantitatively, but the present experiment will suggest the charge-transfer direction in a specific position in the graphene channel.

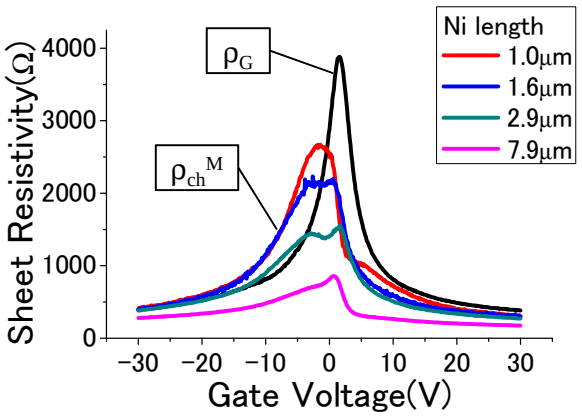

Fig. 4: Sheet resistivity of graphene with (ρ^M_{ch}) and without (ρ_G) various lengths of Ni.

4 Conclusion

We have demonstrated the conductance modulation in graphene contacting with the metal by the back-gate voltage. The longer metal electrode results in larger effect in terms of the total resistance change. Moreover, graphene underneath Ni was negatively doped. These results suggest that graphene may not be degraded by the metal deposition on it. Since the modulation of the carrier density in graphene underneath the metal is determined by the relative magnitude between contact resistivity and graphene resistivity, it is straightforwardly expected that both the metal resistivity and thickness should affect the results quantitatively.

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