Negative Contact Resistances Apparently-Appeared at Graphene/Metal Contacts

Ryo Nouchi, Tatsuya Saito, Nobuhiko Mitoma, Katsumi Tanigaki

WPI-AIMR and Department of Physics, Tohoku University, 6-3 Aoba, Aramaki, Aoba-ku, Sendai, Japan
nouchi@sspns.phys.tohoku.ac.jp

Graphene, a single atomic layer of graphite, has been attracting incredible attention for its unique physical properties and for its applicability to future high-speed electronic devices. In order to investigate electrical properties of graphene and to construct graphene devices such as field-effect transistors (FETs; see Fig. 1a), metallic materials should make a contact with graphene. The metal contacts have been reported to affect the electronic property through charge transfer (CT) from the metals to graphene and charge-density pinning of graphene at the metal-graphene interfaces, where the gate voltage, V_G, cannot tune the charge density of graphene at the metal electrodes [1] (Figs. 1b, 1c). We have studied the effect of such metal contacts to transfer characteristics (V_G dependence of the drain current, I_D) of graphene FETs, and have reported that charge-density depinning can occur at easily-oxidizable metal contacts [2,3], which is contrary to what has been experimentally observed to date. In this presentation, we focus on metal contacts with charge-density pinning, and show that the metal-to-graphene CT is accountable for many intriguing features such as “negative” contact resistances.

The contact resistance, R_C, is one of the most important parameters to characterize metal contacts [4]. Figure 2a shows the V_G dependence of R_C, which is normalized by the contact width W, of graphene FETs with Ag contacts, where R_C was extracted by the commonly-used transfer length method (TLM; see Fig. 2b). Surprisingly, the extracted R_C becomes negative near the charge neutrality point, V_{NP} (V_G corresponding to the minimum I_D in transfer characteristics). Although there is one report on the apparently negative contact resistance at Ti contacts [5], the detailed investigation has not been performed so far.

Figure 2c displays the simulated result using a simple model which assumes that a total resistance of the graphene channel is obtained by integrating the local resistivity along the channel [3]. Although the simulation considers only the channel region, apparently R_C becomes finite and negative near V_{NP} if CT from metal contacts is taken into account. The TLM presumes a homogeneous channel, which is not applicable to the actual devices due to the charge-density inhomogeneity induced by the metal-to-graphene CT. The asymmetry of the R_C-V_G characteristics indicates hole doping from Ag contacts, which is in agreement with what can be derived from other features such as a V_{NP} shift with decreasing the channel length [6].

References

[1] T. Mueller, F. Xia, M. Freitag, J. Tsang and P. Avouris, Phys. Rev. B **79** (2009) 245430.
[2] R. Nouchi, M. Shiraishi and Y. Suzuki, Appl. Phys. Lett. **93** (2008) 152104.
[3] R. Nouchi and K. Tanigaki, Appl. Phys. Lett. **96** (2010) 253503.
[4] H. H. Berger, Solid-State Electron. **15** (1972) 145.
[5] P. Blake, R. Yang, S. V. Morozov, F. Schedin, L. A. Ponomarenko, A. A. Zhukov, R. R. Nair, I. V. Grigorieva, K. S. Novoselov and A. K. Geim, Solid State Commun. **149** (2009) 1068.
[6] R. Nouchi, T. Saito and K. Tanigaki, submitted.

Figures

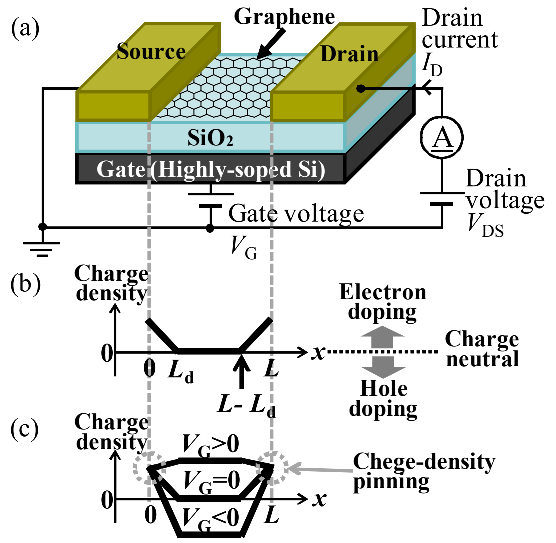
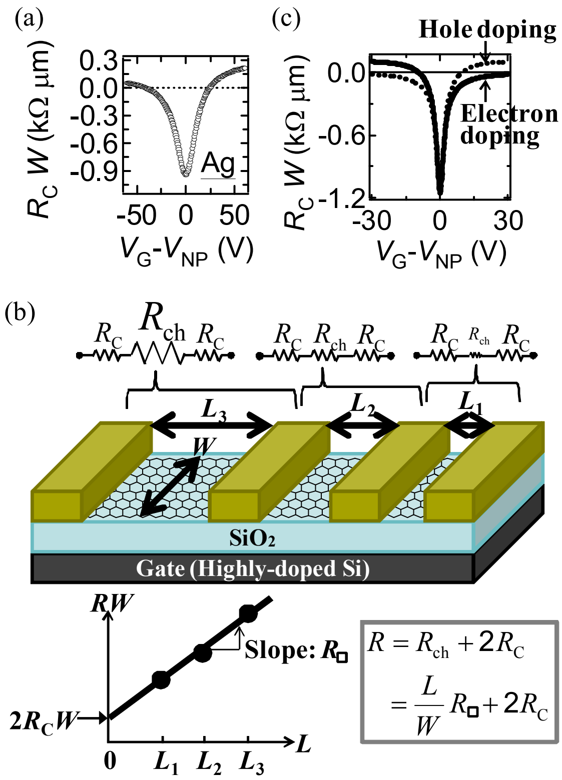


Figure 1. Metal-contact effect on graphene FETs. (a) Schematic diagram of a graphene FET. Simplified charge-density profiles including (b) the contact-doping effect and (c) the charge-density pinning at the contacts.



$$R = R_{ch} + 2R_C = \frac{L}{W} R_{\square} + 2R_C$$

Figure 2. Extraction of R_C from the TLM analysis. (a) R_C-V_G characteristics of Ag contacts. (b) Schematic illustration of the TLM. (c) Simulated R_C-V_G characteristics of electron- (solid line) and hole-doped (dashed line) contacts.