

Electrical and optical characterization of field-effect transistors containing graphene layers doped with HNO₃, AuCl₃, and RhCl₃

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Abstract

Doping graphene is currently one of the most important issues to be solved in the fundamental studies and applications of graphene. Tuning of electrical and optical properties in graphene, of great importance to realize graphene-based electronics/photonics, can be done by doping because the doping leads to a shift of the Fermi level. Chemical doping extensively employed to make graphene n- or p-type by using various adsorbates involves charge transfer between the adsorbates and the graphene [1]. For instance, HNO₃, AuCl₃, and RhCl₃ have been widely used as a p-type dopant in which electrons are extracted from graphene into the adsorbates [2]. There have been several reports on fabrication and characterization of doped graphene layers [2-4], but very few attempts have been made to study how the doping effect varies depending on the kind of dopant. Here, we employ three dopants, HNO₃, AuCl₃, and RhCl₃ to fabricate p-type graphene layers and compare their structural and electrical properties. Large-scale single-layer graphene was synthesized by using chemical vapor deposition, and subsequently transferred to 300 nm SiO₂/p-type Si wafers used as the back gate of graphene field-effect transistors (GFETs). The Cr/Au source and drain electrodes of 0.1 mm length and 0.3 mm separation for GFETs were deposited on the graphene films by using a mask in a RF magnetron sputtering. Single-layer graphene sheets were identified by an optical microscope, and chemically doped with HNO₃, AuCl₃, and RhCl₃ at a concentration of 10mM. By HNO₃, AuCl₃, and RhCl₃ doping, the sheet resistance decreased from 750 to 500, 220, and 350 ohm/sq, and the work function increased from 4.58 to 4.7, 4.8, and 5.2 eV, respectively, indicating p-type graphene [2,5]. To study the influence of the HNO₃, AuCl₃, and RhCl₃ doping on the Raman spectra of graphene films, they were measured under a 532 nm (2.33 eV) laser excitation. As shown in Fig. 1, Raman spectra of the transferred layers exhibited three intense features, D, G, and 2D peaks at ~1350, ~1580, and ~2700 cm⁻¹, respectively, uniquely characteristic of undoped graphene films. The G and 2D bands were blue-shifted from 1587 to 1592, 1602, and 1596 cm⁻¹ and from 2682 to 2685, 2689, and 2688 cm⁻¹, respectively, by HNO₃, AuCl₃, and RhCl₃ doping. By current–voltage measurements, the transfer characteristics (drain current I_{SD} vs back-gate voltage V_{DG}) of the GFETs were compared before and after HNO₃, AuCl₃, and RhCl₃ doping. The threshold voltages of the graphene GFETs were at V_{DG} ~ 6, 30, 58, and 70 V before and after HNO₃, AuCl₃, and RhCl₃ doping, respectively, as shown in Fig. 2. These results are discussed based on possible physical mechanisms.

References

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Figures

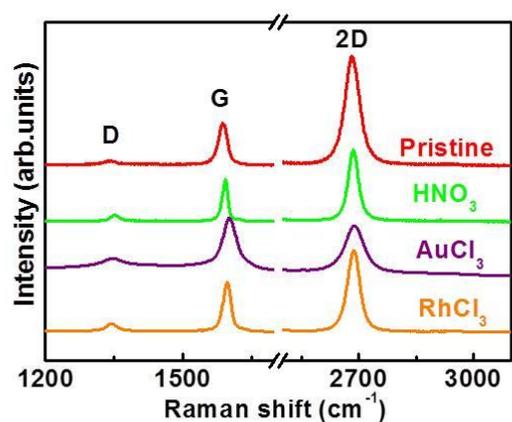


Fig. 1. Raman spectra of undoped and doped graphene layers on SiO₂. The doping was done at 10 mM with three different dopants, HNO₃, AuCl₃, and RhCl₃.

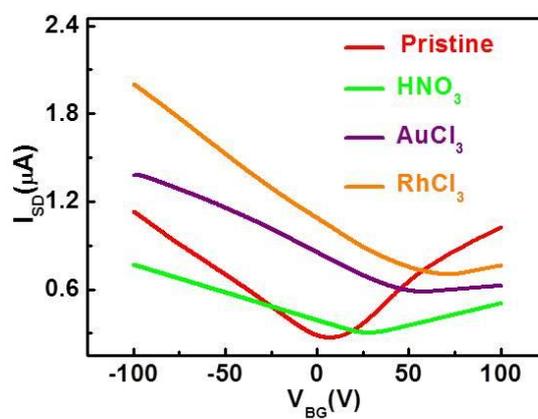


Fig. 2. I_{SD} - V_{BG} curves of GFETs containing pristine and doped graphene layers. The doping was done at 10 mM with three different dopants, HNO₃, AuCl₃, and RhCl₃.