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Letter

Effects of dielectric material properties on graphene transistor performance

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ABSTRACT

Graphene has attracted attention due to its excellent electrical properties; however, the electrical performance of graphene devices, including device hysteresis, mobility, and conductivity, tends to be limited by the supporting dielectric layer properties. In this work, the impact of a dielectric material on a graphene transistor was investigated by fabricating graphene field effect transistors integrated with four different dielectric substrates (SiO_2, Al_2O_3, Si_3N_4 and hexagonal boron nitride) and by comparing the transistor performances. Results revealed that the carrier transport characteristics of the graphene transistors, including the hysteresis, Dirac point shift, and mobility, were highly correlated with the hydrophobicity-induced charge trapping and surface optical phonon energies of the dielectric materials.

1. Introduction

Although graphene shows great promise as a material for future electronic devices and fundamental physics applications with its superior properties [1–5], the performance of graphene-based devices is significantly influenced by the substrate material and the quality of the interface between the graphene and the substrate. Extensive experimental and theoretical studies [6–9] have shown that the degradation of graphene-based devices results from substrate-induced charge traps and various scattering mechanisms, which limit the carrier mobility, induce the hysteresis behavior of the I–V characteristics, and the Dirac point shift. Efforts to improve graphene device performance must seek to understand the dependence of graphene-base device performance on the dielectric substrate material, and to identify optimized material systems and process parameters. In this work, we systematically investigated the impact of various dielectric materials, including SiO_2, Si_3N_4, Al_2O_3 and hexagonal boron nitride (h-BN) on the electrical characteristics of graphene transistors. Electrical transport measurements were used to compare the carrier transport properties of graphene transistors with various dielectric materials under atmospheric conditions, under vacuum, or after an annealing process.

2. Experimental

The h-BN and graphene films were synthesized by a chemical vapor deposition (CVD) process on a copper foil using a borazine ($B_3N_2H_6$) and a CH_4 as precursors. Thedetailed process conditions can be found elsewhere [10]. The quality of the CVD-synthesized graphene and h-BN was confirmed by Raman spectroscopy. After growth, the CVD-grown graphene film was transferred onto a dielectric substrate using a spin-coated polymethyl methacrylate (PMMA) layer and an ammonium persulfate aqueous solution. The dielectric substrates were prepared on highly doped Si substrates submitted to thermal oxidation (90 nm SiO_2), atomic layer deposition (71 nm Al_2O_3), plasma-enhanced chemical vapor deposition (74 nm Si_3N_4), and then transfer of the CVD-grown h-BN (3 nm) onto the 90 nm SiO_2 layers. The thickness of each dielectric was determined to provide good optical contrast with graphene at visible wavelengths, based on a theoretical estimate for optical contrast [11]. Each substrate was cleaned in a piranha solution prior to graphene transfer. After transfer, graphene field effect transistors (FET) were fabricated using photolithography and a metal lift-off process (Fig. 1a). Ti/Au source and drain electrodes were patterned on the graphene. The highly doped Si substrate was used as the back gate. The channel width and length

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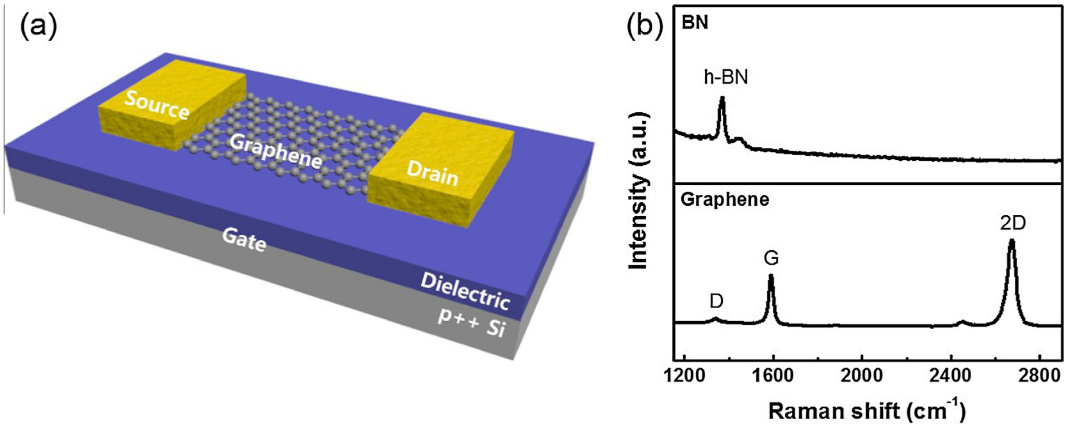

Fig. 1. (a) Schematic diagram showing a graphene FET device. (b) Raman spectra of CVD-grown h-BN and graphene transferred onto a SiO_2/Si substrate.

were 10 μm and were defined by photolithography and O_2 plasma etching.

3. Results and discussion

Raman spectra of the h-BN and graphene are shown in Fig. 1b. The Raman spectrum of h-BN showed a dominant peak at 1368 cm^{-1} due to the B-N vibrational mode (E_{2g}) of h-BN [12]. The G and 2D peaks of graphene were located at 1587 and 2690 cm^{-1}, and the intensity ratio of the G and 2D (G/2D) bands was 0.4, corresponding to the properties of a single layer graphene [13], as confirmed by atomic force microscopy measurements. Electrical transport measurements were performed to investigate the impact of various dielectric materials on the FET performance properties. Fig. 2 shows the transfer characteristics of four different types of graphene FET at source–drain voltages of Vds = 0.1 V. We measured the graphene FET under atmosphere ambient conditions immediately after fabrication. The same measurements were conducted under a vacuum pressure of 1×10^{-6} Torr. All measurements were conducted at room temperature. As shown in Fig. 2, the transfer characteristics improved under the vacuum environment and after thermal annealing (200 °C, 4 h), exhibiting the more

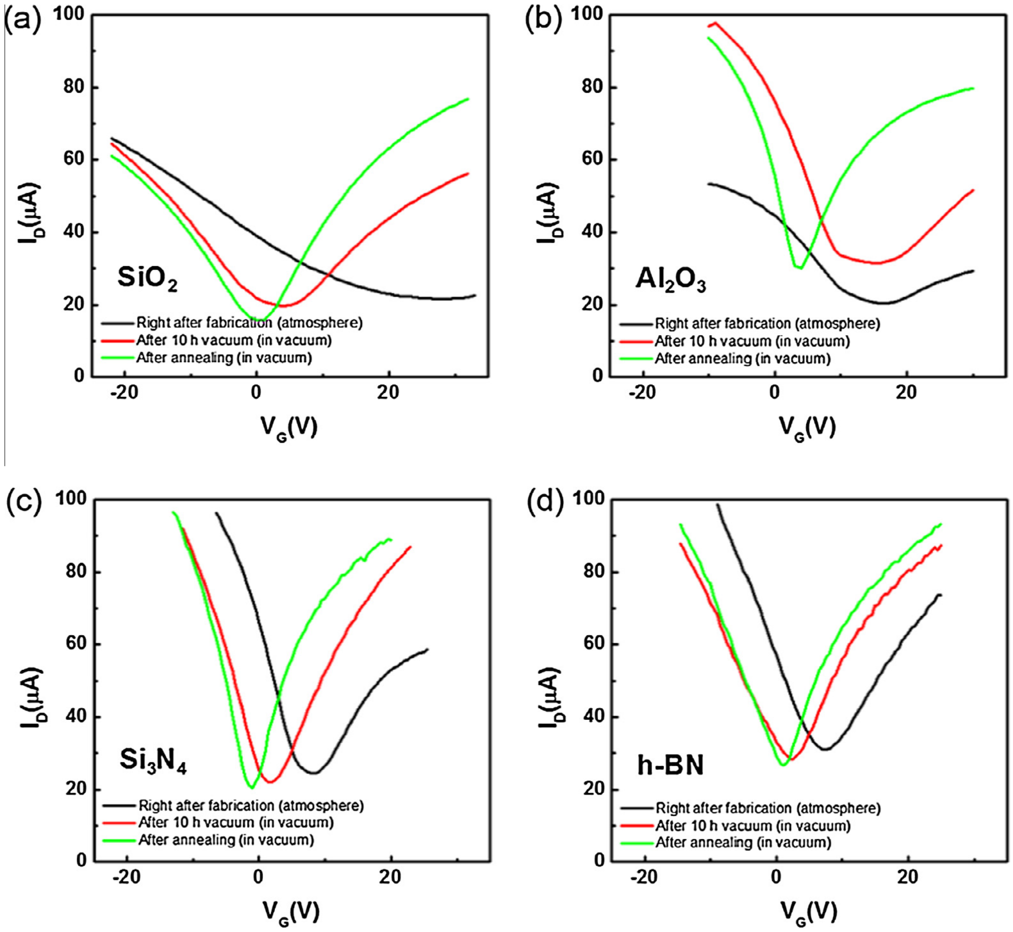

Fig. 2. Transfer characteristics of the graphene FET on (a) SiO_2, (b) Al_2O_3, (c) Si_3N_4, and (d) h-BN substrates.