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Linear magnetoresistance in monolayer epitaxial graphene grown on SiC

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ABSTRACT

We have observed classical linear magnetoresistance (LMR), which persists to room temperature, in clean monolayer epitaxial graphene grown on SiC. Such results are consistent with the resistor network model based on density inhomogeneity in a disordered two-dimensional system, though the observed LMR is non-saturating possibly due to formation of a quantum Hall-like state beyond the highest measurement magnetic field. Given the prospect of epitaxial graphene in high-frequency transistors, our experimental data pave the way for integration of magnetic sensing devices with high-frequency devices based on wafer-scale graphene.

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1. Introduction

Magnetoresistance (MR) is one of the most studied physical phenomena in the field of condensed matter physics [1]. For example, MR studies lead to the observations of fascinating effects such as the integer [2] and fractional quantum Hall effect [3] and can find great applications such as giant magnetoresistance (GMR) devices [4–7]. Although some MR effects of quantum origins are interesting [1–5], classical MR phenomena [8–10] are equally important as they may find practical device applications in magnetic sensors and so on.

With the advent of graphene, which is a layer of carbon atoms bonded in a hexagonal lattice [11], a lot of MR studies on such a two-dimensional material have been reported [12,13]. In 2003, Parish and Littlewood proposed the random resistor network model of a macroscopically inhomogeneous semiconductor that well interpreted the linear magnetoresistance due to the coupling of individual inhomogeneous regions as random resistor network, which was so called the classical linear magnetoresistance [8]. In particular, linear magnetoresistance (LMR) effects have been studied in gold nanoparticle decorated graphene [14] and in bilayer mosaic graphene due to the two-dimensional resistor network [10]. Such interesting results are strongly related to inhomogeneity [10,14] and the random resistor network model.6 Here we report an alternative approach to achieving LMR in clean monolayer epitaxial graphene (EG) grown on SiC [15,16]. Since EG can be of wafer size and find great applications in high-frequency devices [17], our experimental results provide possibilities of integrating magnetic sensing devices with high-frequency applications.

Epitaxial graphene was grown on a chemical-mechanical polished 6H-SiC(0001) wafer at 1850 °C for 30 min under an Ar gas pressure at 98 kPa using a controlled Si sublimation process [18] that results in mostly monolayer graphene near the center region of wafer, which fabricated our quantum Hall devices. Such monolayer epitaxial graphene near center region have been confirmed by Raman spectrum based on the fitting of the 2D peak near 2700 cm^{-1} using a single Lorentzian [19] as shown in Fig. 1. The inhomogeneity of graphene films near metal contacts and SiC substracts were confirmed by the optical microscopy and atomic force microscopy (AFM) images so as to reveal the surface morphologies as shown in the inset of Fig. 1 and Fig. 2. Specifically, we observe the presence of bilayer graphene bands, where few-nm high pleats form due to compression of the graphene layer as the substrate thermally contracts as shown in Fig. 2. The bilayer EG regions were observed in close proximity to terrace edges of the SiC substrate as shown in Fig. 2. Such regions have been shown to disrupt transport in the quantum Hall regime by creating islands of carrier density inhomogeneity [20,21].

To measure transport properties for a Hall-bar configuration, we first deposited a metal bilayer (5-nm Pd +10-nm Au) directly on the as-grown epitaxial graphene in order to prevent contamination from photoresist residues. Secondly, we performed standard optical lithography and finally the protective metal was removed from the Hall bars using diluted aqua regia, a process

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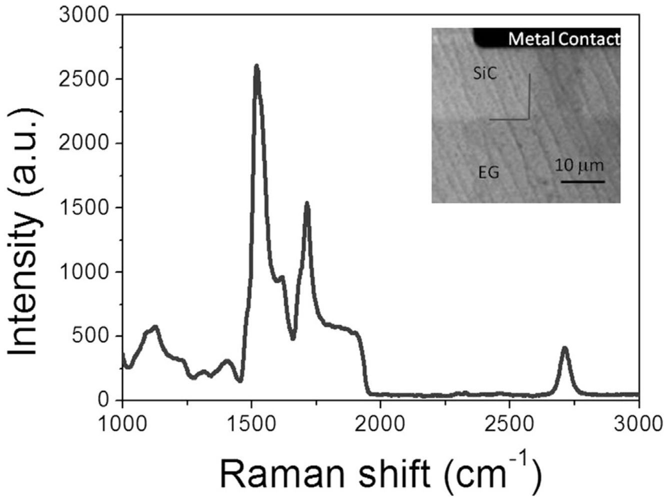
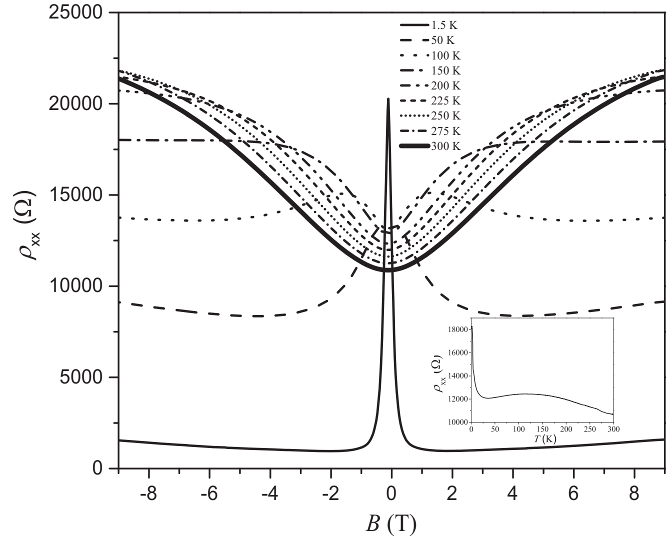


Fig. 1. Raman spectra of monolayer graphene grown on SiC, which is a typical spectra for SiC graphene. The data were obtained using a wavelength of 514.5 nm near the center of the sample, which is identified as single-layer graphene based on fitting of the 2D peak near 2700 cm^{-1} using a single Lorentzian. The inset shows an optical microscopy image that is enhanced in contrast to reveal the monolayer epitaxial graphene and few-micron terraces with some bilayer patches.

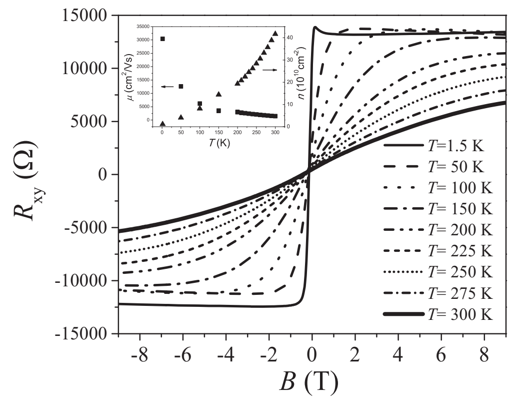
shown to produce low-carrier-density epitaxial graphene devices [18]. Four-terminal longitudinal resistivity ρ_{xx} and Hall resistance R_{xy} were measured using standard ac lock-in techniques.

2. Results and discussion

Fig. 3(a) and (b) show ρ_{xx} and R_{xy} measurements of our primarily-monolayer epitaxial graphene at various temperatures. Very high Hall mobility is observed at low carrier density and low temperature, and is associated with the effect of the SiC substrate [22,23]. At $T=1.5$ K, the measured carrier density and mobility are 1.15×10^{10} cm^{-2} and 30,500 cm^2/(Vs), respectively. As shown in



(a)



(b)

Fig. 3. (a) ρ_{xx} (B) at various T. The inset shows ρ_{xx} as a function of T. (b) R_{xy} as a function of magnetic field at $T=1.5$ K. The inset shows the mobility and carrier density as a function of T.

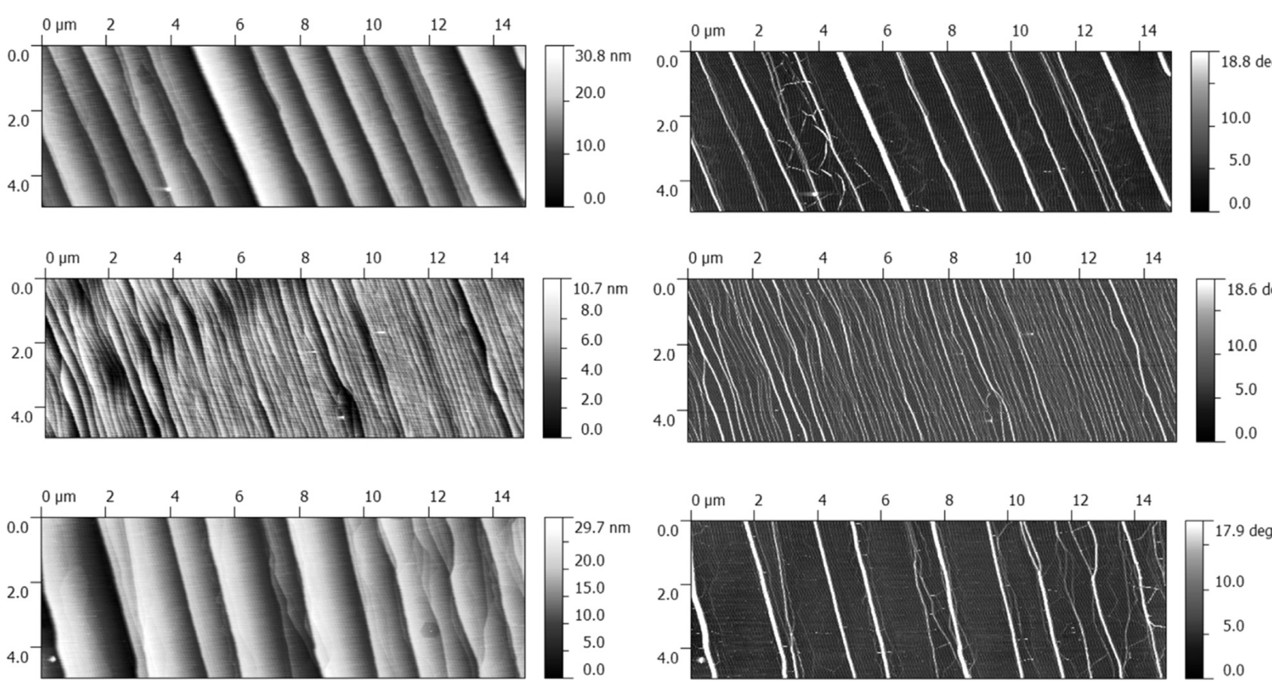


Fig. 2. Left panel (a) Surface (Height) and (b) phase of the AFM measurements taken at three different parts of the monolayer epitaxial graphene.