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Electrical Characterization of Nanometer Structures with Graphene Directly Grown on SiO_2 by Alcohol Chemical Vapor Deposition

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Abstract

Graphene directly grown on SiO_2 by alcohol chemical vapor deposition (CVD) was delineated into nanometer structures, and electrically characterized. Depending on the structures and sizes, aperiodic Coulomb-blockade feature and transport with a large gap were observed, although the film is rather defective as indicated by Raman spectrum and carrier mobility.

1. Introduction

Graphene has attracted much attention owing to its unique band structure and excellent transport characteristics [1]. Among various preparation methods of graphene, direct growth on insulator without transfer process [2] is of practical importance, but electrical characterization in nanometer regime has lagged behind since higher priority is set in improving the basic property such as carrier mobility. In this report, characteristics of graphene directly grown on SiO_2 by alcohol chemical vapor deposition (CVD) are evaluated in nanometer structures. Unique features of graphene are found to be kept even in such a disordered material.

2. Experiment

Graphene film was directly deposited on SiO_2/Si substrate by alcohol CVD [2]. The growth conditions are summarized in Table 1. The film thickness (1.6 nm) was obtained from the spectroscopic reflectance assuming the optical constants by Blake et al. [3], and confirmed by atomic force microscope (AFM) after making a step by etching. The graphene surface was found to have local roughness comparable to its average thickness.

Fabrication procedure of the test structure is illustrated in Fig.1. First, p^+ Si substrate was oxidized to form 95-nm-thick SiO_2, on which the graphene was deposited (a). Then, the graphene is delineated by electron beam (EB) lithography and O_2 reactive ion etching (RIE) (b). The Au/Ti electrodes was formed by photolithography, metal deposition and liftoff (c). Note that the substrate was used as a bottom gate to modulate the electrical conduction through the graphene.

3. Result and discussion

Figure 2 shows the Raman spectra of the graphene on SiO_2. As can be seen from the relatively large D peak, the graphene is defective and presumably consists of nanograins. The domain size is estimated to be 17 nm from the ratio of the integrated intensity of D and G peaks (I_D/I_G) [4].

Figure 3 shows the modulation of the graphene resistance by the gate voltage V_g at 300 K. The film shows only p-type conduction, and the mobility is calculated to be 44 cm^2/Vs from the slope and sheet resistance of 3.7 kΩ. As shown in Fig. 4, the sheet resistance is insensitive to temperature down to 10 K with slight increase by 7%, indicating the potential barrier between domains is low even though the film is as thin as 1.6 nm and defective.

We fabricated nanometer-size graphene patterns with single or multiple constrictions as shown on the top of Fig. 5. Although the structure is not made as intended, structures with minimum constriction width of 13, 28 and 21 nm can be seen in SEM images of Fig. 5 (a), (b) and (c), respectively. Most of the structures show aperiodic Coulomb-blockade feature as depicted in Fig. 5 (b) and (c), indicating the presence of multiple barriers and energy-level quantization in the dot between barriers. The structure with narrowest constriction [Fig. 5(a)] shows the large transport gap on the negative-V_g side. Narrow width and also the edge roughness possibly contribute to the opening of the gap [5].

4. Conclusion

We evaluated the electrical characteristics of the graphene thin films directly grown on SiO_2 by alcohol CVD. Although the film is rather defective, the sheet resistance is insensitive to temperature down to 10 K. Structures with nanometer constriction mostly showed aperiodic Coulomb-blockade feature, and one with 13-nm constriction exhibited n-type conduction with a clear transport gap.

References

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Table 1 Conditions for graphene chemical vapor deposition (CVD) using ethanol as a carbon source.

Temperature	1000	°C
Gas flow rate		
Ethanol	3	sccm
Ar	200	sccm
Pressure	1330	Pa
Substrate	SiO_2/Si	
Time	25	min
Thickness	1.6	nm

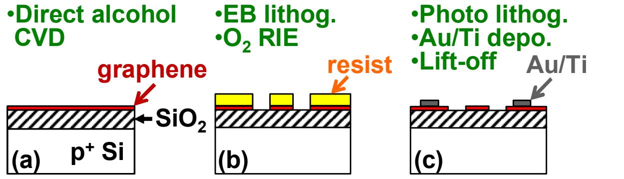

Fig. 1 Fabrication steps of the test structures. Si substrate, heavily doped with boron, is used as the bottom gate. Graphene is delineated by electron beam (EB) lithography and O_2 reactive ion etching (RIE).

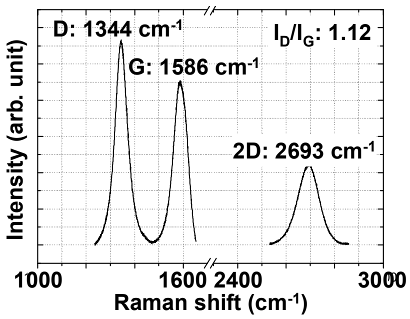

Fig. 2 Raman spectrum of the graphene thin film deposited directly on SiO_2. From the ratio of integrated D and G peak intensities (I_D/I_G), domain size of the graphene is estimated to be 17 nm [4].

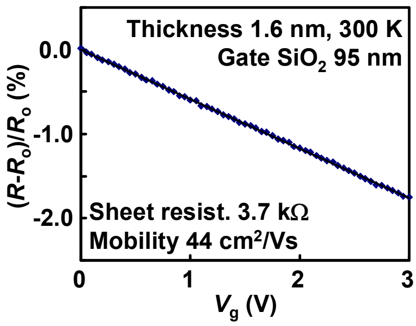

Fig. 3 Modulation of the graphene resistance by the gate voltage V_g. From the slope of this line and the sheet resistance, field-effect mobility is calculated to be 44 cm^2/Vs.

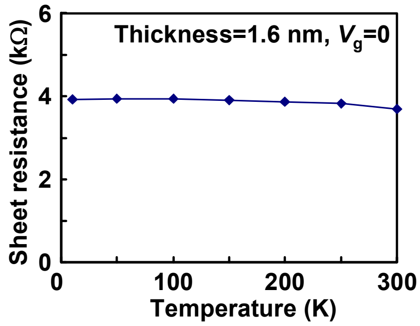

Fig. 4 Temperature dependence of the graphene sheet resistance. Resistance increase at 10 K is only 7%, indicating that potential barrier between domains is low even in such a disordered structure.

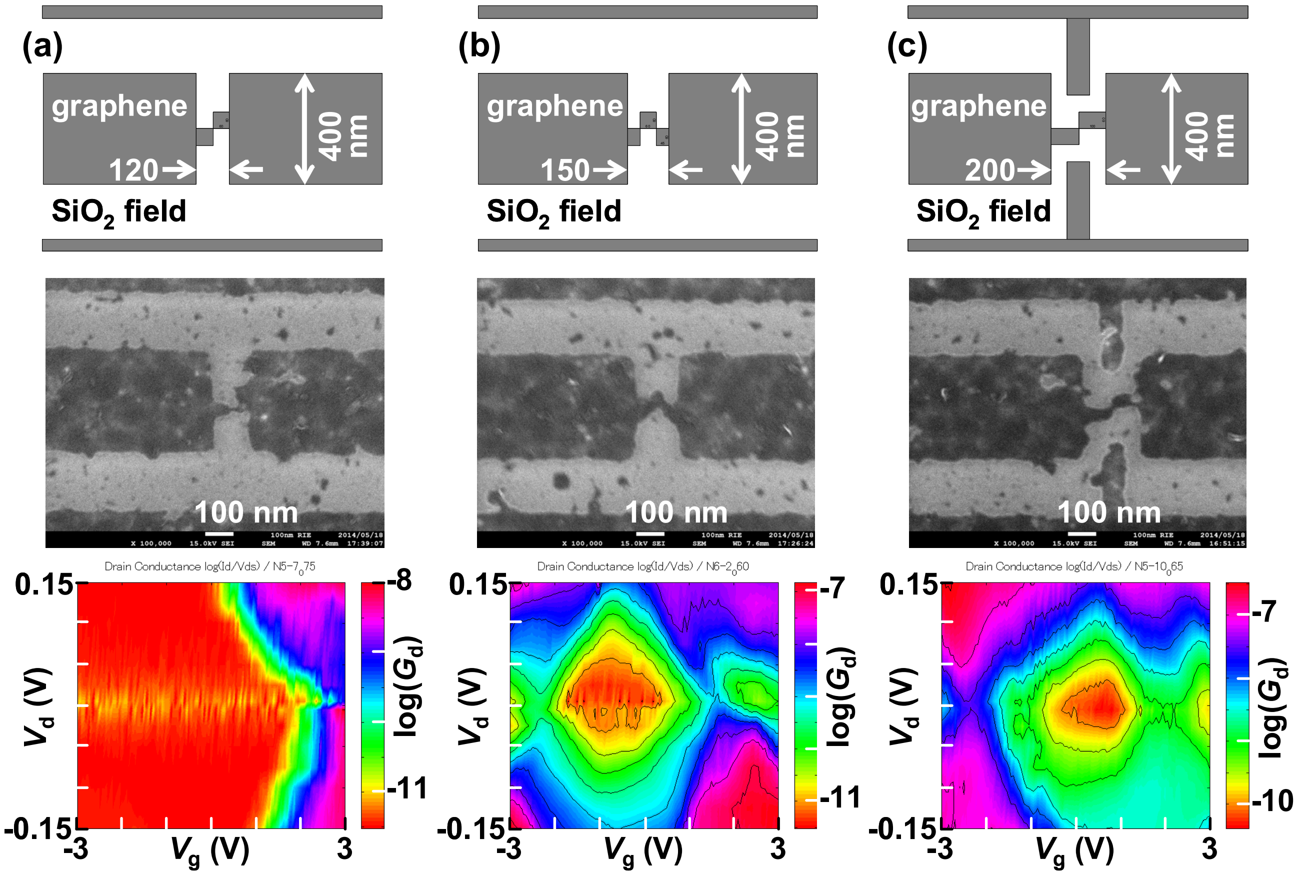

Fig. 5 Correlation among layout design (top), SEM of the fabricated structure (middle), and conductance (I_d/V_d) contour plot measured at 10 K (bottom). Narrowest constriction widths are 13, 28, and 21 nm for electrode structures (a), (b), and (c), respectively.