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Electrical Characteristics of Multigraphene Films Grown on High-Resistivity Silicon Carbide Substrates

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Abstract—Multigraphene films grown by sublimation of the surface of semi-insulating 6H-SiC substrates in a vacuum have been studied. The films exhibit a semiconductor-type conductivity. A conclusion is made that this type of conduction is supposedly determined by defects present between separate graphene crystals constituting the carbon layers under study.

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1. INTRODUCTION

Interest in deposition of planar nanocarbon layers (graphene layers) has increased in recent years. These layers exhibit metallic conductivity, are stable at room temperature, and can be used to fabricate nanotransistors [1, 2]. The INTEL company considers graphene as a possible basis for microelectronics of the future [3]. In our previous studies [4, 5], we demonstrated that nanocarbon films can be formed on the surface of both conducting and semi-insulating SiC substrates by sublimation in a vacuum [6]. Studies employing Raman spectroscopy and the high-energy electron diffraction (HEED) technique have shown that the layers obtained are films with a thickness of five (or more) graphite monolayers (multigraphene) with a structure formed by separate graphene fragments with linear dimensions of ~(15–50) nm [5].

The aim of this study was to examine the electrical properties of the films by using current–voltage and galvanomagnetic measurements in a wide temperature range.

2. SAMPLES

The multigraphene films under study were produced by sublimation of the surface of a high-resistivity 6H-SiC substrate. The maximum sample area was 1.3×1.3 cm^2. To prepare the graphene films for electrical measurements, we formed test structures on their surface having the configuration of a Hall-bar by photolithography and etching with an argon beam through a photoresist mask. The electrical contacts were formed by thermal evaporation in vacuum. The topology of the test structure is shown in Fig. 1.

To prepare the surface of graphene films to technological operations aimed to form test structures, the films were boiled in ultrapure (deionized) water to remove microscopic particles settled on the surface. Water was removed from the surface of the samples by centrifugation. The finishing treatment was made using a complex-forming compound (methanol). The quality of the surface preparation was monitored by Auger spectroscopy. The contact pads were formed by explosive photolithography. A two-layer Ti/Au metallization was used to form the contact pads of the Hall structures. A 20-Å-thick Ti sublayer was deposited to improve the adhesion for the main metallic coating (Au) the thickness of which was 300 nm.

3. CURRENT–VOLTAGE CHARACTERISTICS

The current–voltage (I–V) characteristics of graphene-like films were studied on two silicon carbide substrates in the temperature range T = 77–300 K. The applied voltage did not exceed ±5 V. The I–V characteristics are almost linear within these voltage and temperature ranges (Fig. 2).

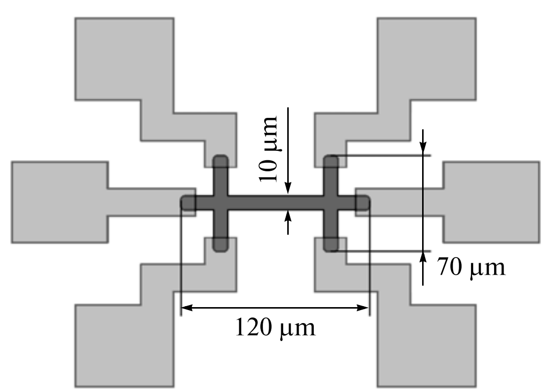

Fig. 1. Topology of the test structure for studies of the Hall effect and measurements I–V characteristics of films.

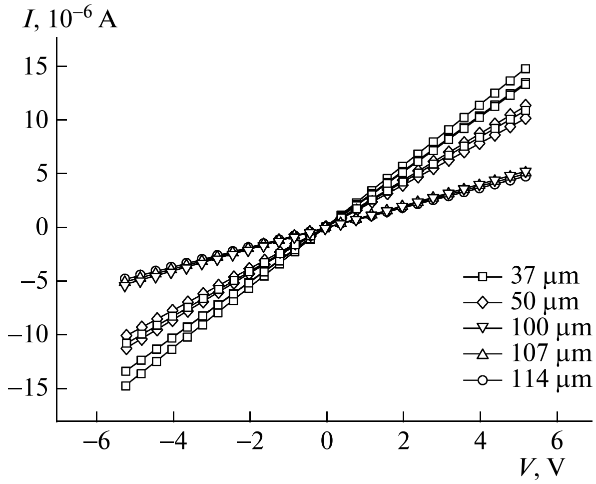

Fig. 2. I–V characteristics of structures with various lengths (indicated in the figure) on silicon carbide substrate GR18 at room temperature.

The resistance R of the structures depends on the stripe length, which could be varied within the range L = 37–114 μm, and is different for different substrates. For example, the room-temperature resistance of the films is within the range 0.3–1.1 MΩ for structures on substrate GR18 (Fig. 3a) and 3–12 MΩ on substrate GR20 (Fig. 3b) and varies proportionally to the stripe length. Measurements of the I–V characteristics of the structures in the temperature range 77–300 K demonstrated that the resistance of the structures decreases with increasing temperature (Fig. 4). The type of functional dependence of the resistance on temperature can be determined only rather uncertainly. The dependence is nearly of power-law type with exponents from –0.6 to –2...–8. If the temperature dependence is assumed to be thermally activated, the activation energies of resistance fall within the range from –7...–10 to –20...–100 meV.

One more film on SiC substrate GR19 was used for measurements in the temperature range 2–300 K. The resistance of the film increased with decreasing temperature in the entire temperature range (see the inset in Fig. 4).

4. HALL EFFECT

Hall effect was measured in the temperature range T = 2–300 K. A negative magnetoresistance was observed at a temperature of ~77 K in low magnetic fields (≤0.8 T). At liquid-helium temperatures, the I–V characteristic became nonlinear. Different samples exhibited either an n- or p-type conduction. The scatter of the Hall mobility for the best sample was ~(300–1000) $cm^2 V^{-1} s^{-1}$ at room temperature.

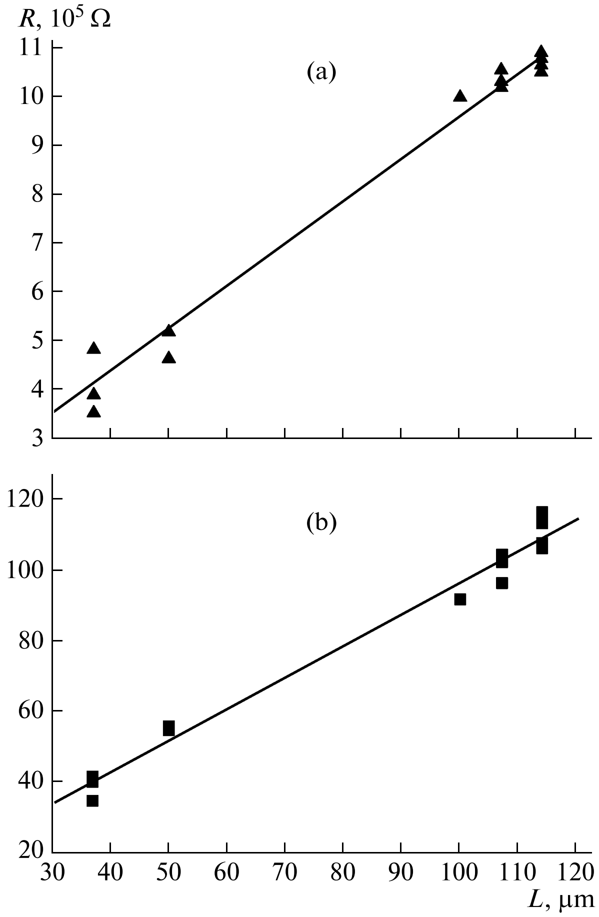

Fig. 3. Resistance R vs. the length for the structures on substrates (a) GR18 and (b) GR20 at room temperature.

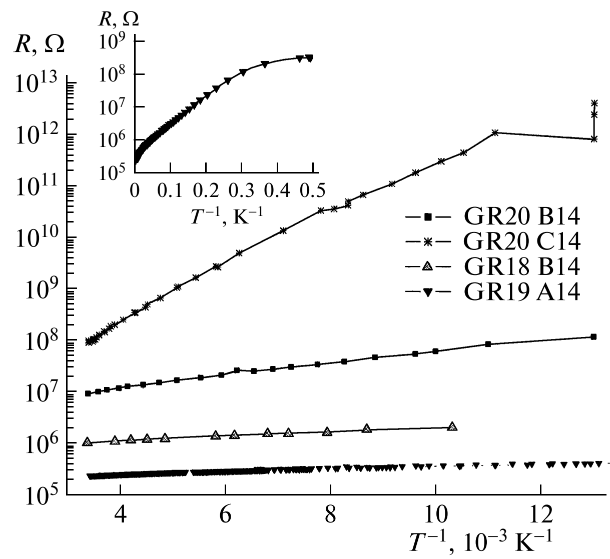

Fig. 4. Resistance R vs. inverse temperature for four structures on silicon carbide substrates GR18, GR19, and GR20 in the temperature range 77–300 K and for the structure on substrate GR19 (inset) in the temperature range 2–300 K. Structure length 100 μm.

5. DISCUSSION OF RESULTS

Both the resistivity of the films (calculated resistivity of a film is approximately 0.03 Ω cm for the sample on substrate GR18 and 0.3 Ω cm for the sample on substrate GR20 at room temperature and film thickness assumed to be 3 nm) and the type of the temperature dependence of the resistance (decrease in resistance with increasing temperature) might indicate that the structure of the films obtained is close to that of bulk graphite, since it is known that these specific features are observed for graphite in its characterization in the direction perpendicular to carbon layers. However, it was found in the case under consideration (by using the HEED technique) that the film has a polycrystalline structure, with crystallites oriented in the plane of the substrate. Thus, the effects we observed (high resistance with a negative temperature dependence) may presumably be due to specific features of the carrier transport across boundaries of crystallites constituting the layers under study. These features may be due to presence of a large number of structural defects at boundaries of separate fragments of graphene. In particular, it has already been noted that the presence of defects of the "armchair" type leads to a semiconductor-type conduction of a graphene film [1].

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