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Large magnetoresistance of amorphous carbon films

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ABSTRACT

Magnetoresistance (MR) of pure amorphous carbon thin films deposited by pulsed laser deposition at various deposition temperatures was studied. Maximum MR of 46% was observed at 2 K under the magnetic field of 7 T for the sample deposited at temperature of 500 °C. No tendency of MR saturation was observed up to 7 T. The MR decreases rapidly with the increase in measurement temperature and vanishes after 40 K. The transport mechanism of all the samples follow Efros-Shklovskii variable range hopping model. The characteristics temperature decreasing from 2540 K to 1290 K and localization length increasing from 5.3 nm to 10.7 nm with increasing fraction of C(sp^2) from 72% to 84%. The lower disorder degree may results in higher MR.

1. Introduction

Semiconducting amorphous carbon (a-Carbon) has attracted a great attention due to its wide applications, such as field emission, pressure sensing, gas sensing, solar cells, electronics and optical industry [1-6]. Among these applications, the magnetoresistance (MR) is one of the most compelling property due to its relation with spintronic applications [7-10].

Different allotropes of carbon have also attracted a significant research interest due to its potential in obtaining different band gap depending upon its symmetry hybridization [11-13]. Tunable electrical and optical properties via controlling the ratio of C(sp^2) and C(sp^3) hybridization carbon made this material more fascinating. Some low temperature electronic transport properties of these different structured carbon materials are alike to that of disordered semiconductors where hopping conduction and electron localization plays a significant role [14,15].

The transport properties of doped a-Carbon films have been studied intensively. Negative and positive MR was observed and possible mechanisms were proposed [8,16,17]. However, for pure a-Carbon films, the MR properties needed to investigate because it could help to reveal the influence of amorphous nature of such materials on their magnetotransport properties. Moreover, a clear understanding of transport mechanism of the disordered a-carbon thin films is still lacking. The a-carbon was reported to have different conduction mechanisms such as weak localization [14], wave function shrinkage [18], spin blockade, electron-electron interaction [16], grain boundary scattering [19], and variable-range hopping (VRH) model [20]. Therefore, understanding of the electron transport properties of disordered a-carbon have great significance of study.

The MR properties of a-Carbon specimens synthesized by pulsed laser deposition (PLD) on glass/SiO_2 substrates were investigated in this study. As the deposition temperature in PLD has a significant influence on the degree of disorder of a-Carbon thin films. A series of a-Carbon thin film specimens were fabricated at different temperatures by PLD. The effect of degree of disorder on their transport properties was studied systematically.

2. Material and methods

Pulsed laser deposition (PLD) technique was used to prepare all our a-Carbon samples. Glass substrates with a thickness of 1 mm and Silicon wafer with an amorphous layer of SiO_2 of 300 nm in thickness on the surface were used to grow the a-Carbon thin films.

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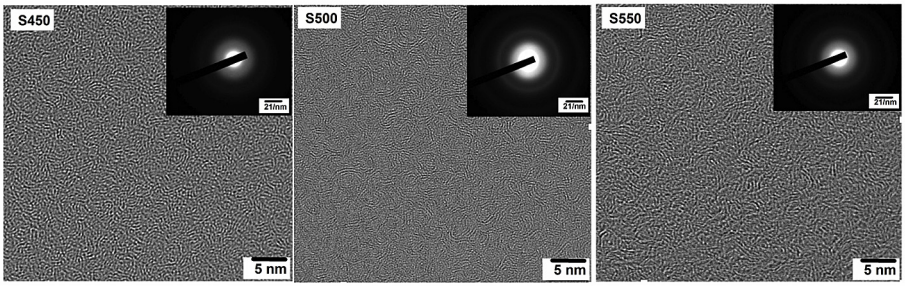

Figure 1. HRTEM images and diffraction patterns for samples S450, S500 and S550.

Sonication was performed on the substrates with acetone and then in ethanol for 30 min, and finally the sample was rinsed by de-ionized water to remove surface contamination.

First, the target was prepared from pure graphite (99.9%) powder. The powder was cold pressed under 50 MPa into a cylindrical target with diameter of 20 mm and thickness about 8 mm. The as-pressed target was further sintered at 1300 °C under pressure of 200 MPa in Ar protected atmosphere for 30 min. Then the target and substrates were fixed in the PLD chamber for deposition. After that, the chamber was pumped to 1.5×10^{-3} Pa. The substrates were heated to a pre-set temperature (450, 500 and 550 °C). The specimens prepared at these three temperatures were named as S450, S500 and S550, accordingly. Then the carbon target was bombarded for 10 min by the Laser (Lambda Physik LPX-205) at laser energy of 300 mJ/pulse and frequency of 6 Hz. The carbon films deposited on the glass/SiO_2 substrate were then followed by the 30 min annealing and then let the chamber cool down up to room temperature. The samples were then used for further characterization. The resistance measurement was done by standard four-probe method. The metal electrodes were prepared by standard indium pressing method with size of ~1 mm^2 for each electrode. The total sample length is ~10 mm and width is ~5 mm while the size of potential electrode is ~1 mm^2.

The resistivity measurements and magneto-transport properties were performed with the physical property measurement system (PPMS, Quantum design) from 300 K to 2 K and under magnetic field of 0–7 T. Raman spectrum was measured by Renishaw InVia Raman spectroscopy using excitation wavelength of 514 nm. The sp^2-carbon and sp^3-carbon are denoted by $C(sp^3)$ and $C(sp^2)$, respectively. High Resolution Transmission Electron Microscopy (HRTEM) (JOEL−2011) was used to investigate the structure of a-Carbon thin films.

3. Results and discussion

The structure of these a-Carbon specimens was studied by HRTEM. Fig. 1 shows that the a-Carbon films have amorphous disordered structure. The samples S450 and S550 have more disordered structure as compared to the S500, which might also be estimated from their diffraction patterns (insets of Fig. 1).

The thickness of all the samples is about 45 nm. It was observed that our carbon films were amorphous and composed of C(sp^2) and C(sp^3) hybrid carbon. As the carbon materials having dominant C(sp^2) clusters are considered as good conductors while carbon materials with dominant C(sp^3) clusters are considered as insulators [16]. The ratio of C(sp^2)/C(sp^3) can be used for a good

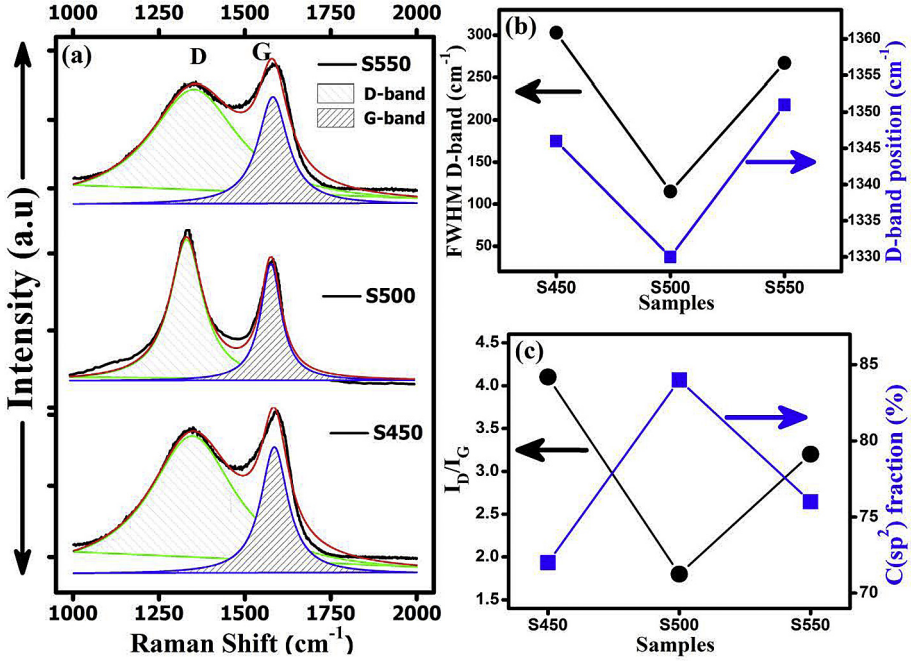

Figure 2. (a) Raman spectrum; (b) FWHM and peak position of D-band; (c) I_D/I_G ratio and C(sp^2) atomic %, for samples S450, S500 and S550. (A colour version of this figure can be viewed online.)