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Observation of structural changes in carbon films under external influences ☆

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Abstract

Carbon films obtained by the plasma chemical deposition method from the multicomponent stream of ionized particles on the various substrates are investigated. Structural formations with parallel lines were observed under the microscope on the film surface. Apparently, charge accumulation takes place along these lines. When the film locally is heated then micro tube-like structure peculiarities are formed along these lines. Observed peculiarities are periodic in nature with well-established formation phases.

Possibly, the charge accumulation lines coincide with the micro tube-like formations as our observations revealed. It is important to stress that the parameters of micro tube-like formations, i.e., the period of sinus-like formations and their linear dimensions are dependent on the technological parameters.

Metal–carbon film-Si sandwich-like system's volt–ampere characteristics show irreversible breakdown due to structural changes taking place in system and being observed microscopically. Obviously, this is due to applied strong electric fields ($\sim 10^5 - 10^6$ V/cm).

Thus, origination of micro- and nano-formations both on the surface and in the bulk of carbon films under strictly controlled conditions is possible to obtain from multicomponent ion streams.

Keywords: Plasmo-chemical deposition; Nano-formations; DLC films

1. Introduction

Carbon nano-tubes attract a huge interest recently with wide range of possible applications. Their creation on the silicon substrates can be obtained by depositing a suspension of purified bulk nanotube samples, or by the chemical vapor deposition method [1,2]. DLCs are attractive also in nano-composite materials' domain.

The used DLC films were obtained by the plasmo-chemical deposition method [3,4]. Obtainment of definitely arranged structures possessing predictable properties is one of the advantages of the method. Upon controlling the technological parameters and composition of the plasma one could obtain diverse micro- and nano-formations.

For some cases, formations could be created after the film's post-deposition treatment. Different formations could be obtained on differing heat and electric field regimes.

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2. Experimental results and discussion

Plasmo-chemical dissolution of C_7H_8 and C_6H_{12} yielded multicomponent carbon films obtained from direct current radial ion source. Thermal evaporation or magnetron scattering

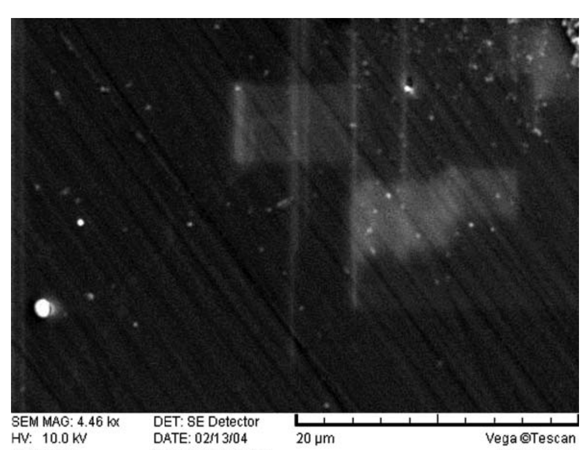

Fig. 1. SEM image of the deposited film.

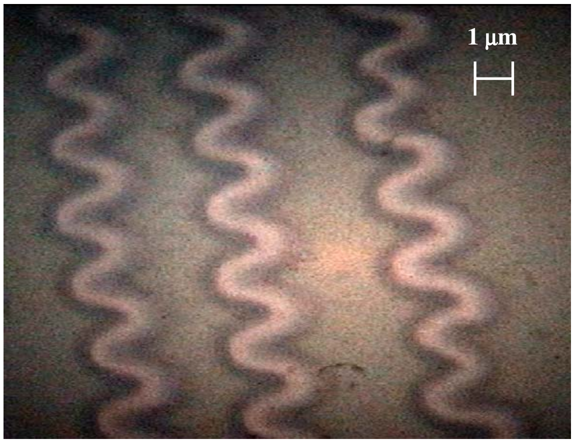

Fig. 2. The formations originated after thermal impact.

methods were used for the introduction of some additives into the plasma stream to control the properties of the films and for the obtainment of structural formations.

The used technological regime as well the nature of additives and their concentration strongly affects the nano-composite formations. It is to be emphasized that the obtained formations have orderly structures. Actually, the scanning electron microscopic (SEM) studies show rectilinear regions which evidenced the charge accumulation (Fig. 1). The external influence (local thermal impact) leads to sinus-like formations' origination along the regions of charge accumulation (Fig. 2).

Presumably, electric charge took part in shaping the structures since there is a definite correlation between these regions. Apparently, oxygen does play a role in the formation of these structures, as they are formed in ambient conditions. Some experiments were carried out in vacuum to prove this supposition. It turned out that the structures formed only after the introduction of oxygen into the plasma, while they are missing in the environs of nitrate or argon ions present in the plasma. Presumably, the observed formations are a result of special interaction between the accumulated charge and oxygen. Elucidation of the mechanism of development of these formations demands special in-depth studies to be covered separately.

Note that the ordered structures are created only by introducing the additional ions in the plasma stream. Structure ordering is dependent on the type of additions. Rectilinear structures are obtained during the addition of metal ions while complex sinus-like structures are formed during the introduction of organic hydrocarbons into the plasma stream. In both cases the obtained structures could be considered as micro- or even nano-tube-like formations. The diameter of the tubes varies between 30 µm up to 200 nm. Nevertheless, the type, intensity and external point of impact have no influence on the characteristics and dimensions of the formations. Moreover, tube-like structures also develop during long-term storing at ambient environs. However, film growth conditions affect strongly the dimensions of the structures. The kinetic energy of particles bombarding the substrate plays a key role.

Experimentally it was shown that the size of the nano-structures increases during decreasing acceleration voltage. Consequently, the higher the kinetic energy of the particles the lesser the dimensions of the clusters making up the structure. It is to be noted that there exists some limiting voltage exceeding of which lessens the probability of incipient formations.

Origination of the micro- or nano-formations primarily under the strong electric fields applied across the film thickness is investigated also. For this end, sandwiched DLC films are deposited on the surface of n-type Si substrate. The thickness of the films varies in between 100 and 200 nm. For electric leads, Cu or Al coatings were deposited by the vacuum technique on the DLC surface. The rear lead was formed from GaZn paste. Parallel conductance technique was used to measure the electrical response of the structures.

Both the active (G) and reactive (C) impedance components of Cu-DLC-n-Si structure were measured at 10 kHz with varying bias voltage (U) applied to the field-controlled electrode. Obtained structures' volt–ampere characteristics were determined too (Fig. 3).

Capacitance and equivalent parallel conductance relationships for Cu-DLC-n-Si structure are presented in Fig. 4, from

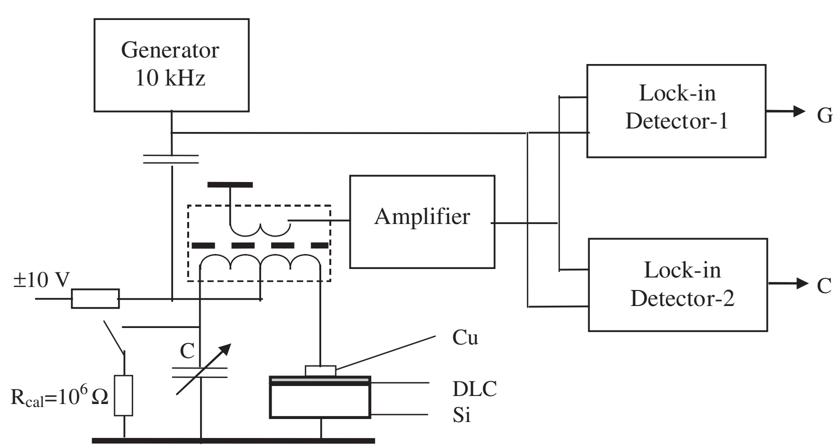

Fig. 3. Experimental set-ups for impedance and volt–ampere investigations. Experimental conditions: sinusoidal voltage amplitude: ca 0.1 V; resistive impedance range: 10^{-9}–10^{-5} mho; capacitance impedance range: 0.1–200 pF. Measurement lies within 5% of accuracy. For some samples, DC bias voltage (in between ±10 V) also was applied.