Argon gas atoms trapping by carbon dendrites

M P Danilaev¹, E A Bogoslov¹, Y E Polskii¹
¹ Kazan National Research Technical University named after A.N.Tupolev - KAI, 10, Karl Marx st., Kazan, 420111, Russia.

Abstract. The conditions of argon gas atoms trapping by carbon dendrites, which growing in atmospheric pressure gas-discharge plasma, are considered in that paper. It’s showing that the argons atoms trapping by the carbon diamond-like cell can occur in arc gas discharge with current density more than \( J_0 \sim 45 \text{ mA/s}^2 \) and provided that the eximer molecules of noble gas and carbon atoms (e.g., ArC) can be formed.

During the last years, investigations of carbon nanoparticle properties have attracted considerable attention of many researchers. Some properties of these particles depend on the way of their fabrication. The formation of carbon nanoparticles in gas discharge is one of the most perspective ways of their fabrication.¹³ Many carbon structures (e.g., scaly,² vertical,⁵ dendrite species) with reproducible physico-chemical properties were formed in gas-discharge plasma at atmospheric pressure. The gas discharge is usually switched on in the inert gas atmosphere in the presence of initial products of carbon nanoparticle synthesis, e.g., monomer vapor⁷. The formation of structurally ordered carbon nanoparticles, such as graphene sheets, carbon diamond-like cell and their conglomerates, is possible in the temperature range from 800 °C to 3000 °C⁸. Such temperatures are provided by arc discharges. The electron energy in such discharges⁹ is sufficient to initiate the excimer molecule formation, e.g., ArC. These molecules can appear as growth centers of the graphene sheet conglomerates in the discharge volume. In this case, the argon atom can be trapped by carbon diamond-like cell if the growth characteristic time of the cell is less than the excimer molecule characteristic life time. It should be noted that the characteristic carbon diamond-like cell size (0.142 nm) is of the same order as the argon atom characteristic size (0.142 nm)¹⁰. Therefore, the argon atom does not get out of the cell without cell destroying.

In the present paper, the growth conditions of the carbon dendrites with argon atoms trapped by carbon diamond-like cell are considered.

The investigation of carbon dendrite growth conditions was performed experimentally. The scheme of experimental device is shown in Fig. 1.

Carbon dendrites were obtained in alternating current arc-discharge plasma (frequency ~40 kHz) from various monomers: styrene, acrylonitrile, methyl methacrylate, benzene and propylene. The argon flow was 200 ml/min and was regulated with an uncertainty less than 10%. The electrodes have a “needle-needle” configuration: steel needle electrodes with curvature radius of 0.5 mm. The condition \( T_e / T \sim 10 \) was hold in the experiments, where \( T_e \) – electron temperature in arc discharge, \( T \) – thermodynamic temperature near the needle electrode.³ The carbon dendrite growth stopped when the relation \( T_e / T \) was reduced due to the decrease of \( T_e \) or the increase of \( T \).
thermodynamic temperature was 800–1200 °C depending on monomer type. It was measured by a pyrometer with measurement error no more than 5%. The carbon dendrite growth occurred from the needle surface in opposite direction until the short circuit of the discharge gap.

The carbon dendrite growth started from the formation of one or more channels on the top of needle electrode. The number of branches depends on the field intensity and increases with increasing field intensity. So, the cauliflower-like structures were formed (Fig. 2).

![Figure 1](image1.png)

**Figure 1.** The scheme of experimental device: 1 – cylinder with argon, 2 – valve, 3 – multi-phase gas flow formation device, 4 – monomer ejector, 5 – inlet connection pipe, 6 – needle electrodes, 7 – carbon dendrite, 8 – outlet connection pipe, 9 – reactor, 10 – dielectric barrier, 11 – electrode, 12 – high voltage pump source.

![Figure 2](image2.png)

**Figure 2.** Carbon dendrites foto from such monomers: (a) styrene; (b) acrylonitrile; (c) benzene; (d) methyl methacrylate.
The minimum discharge power necessary for the formation of carbon dendrites was ~200 W. The carbon dendrite growth rate increases with increasing discharge power. When the discharge power became more than ~300 W, the carbon dendrite growth stopped because of the strong electrode heating.

While the field intensity changed within the range 0.6 – 3 kV/sm (the precision of measurements was ~10%), the average carbon dendrite growth rate was ~3.5 mm/min for dendrite from benzene, ~1 mm/min for dendrite from styrene, ~0.7 mm/min for dendrite from propylene, ~0.5 mm/min for dendrite from methyl methacrylate and acrylonitrile. In case of benzene, the highest carbon dendrite growth rate is due to the fact that benzene ring does not require additional reactions for the formation of carbon unit cell hexagonal structure.

The analysis of carbon dendrite structure was carried out on the auger electron spectrometer JAMP 9510F ("JEOL", Japan). Experimental conditions: ultra-high vacuum better than 1·10⁻⁹ mm Hg; temperature +23 °C. The micrographs and auger spectra are presented in Fig. 3 for carbon dendrite from propylene.

![Image](image-url)

**Figure 3.** Micrographs and auger spectra for carbon dendrite from propylene.

The auger spectra (Fig. 3c) obtained from the central part of dendrite contain line corresponding to argon. The amplitude of this line did not change after keeping the sample at 1·10⁻⁹ mm Hg for three days. It indicates that the central part of dendrite has crystal structure containing diamond-like cells. This fact is also confirmed by the electron beam diffraction (Fig. 4). The latter was obtained at the transmission electron microscope Zeiss Libra 120 with integrated OMEGA filter. Experimental conditions: accelerating voltage of ~120 kV; electron source – LaB₆.
The samples contain regions with ordered structure, which produces pronounced diffraction peaks, as well as regions with an amorphous structure producing poorly-defined diffraction rings. The carbon amorphous phase prevails on the periphery. This phase cannot trap argon atoms. The presence of argon atoms in the central part was observed only in case of dendrite formed from propylene. It is because of higher current density in gas discharge ($j_0 \sim 45 \text{ mA/s}^2$) compared to current density for dendrites formed from other monomers: styrene ($j_0 \sim 25 \text{ mA/s}^2$), acrylonitrile ($j_0 \sim 28 \text{ mA/s}^2$), methyl methacrylate ($j_0 \sim 35 \text{ mA/s}^2$), benzene ($j_0 \sim 30 \text{ mA/s}^2$).

The characteristic time of carbon diamond-like cell formation for carbon dendrite from propylene is $\sim 1 \text{ ns}$. This time is less than the excimer molecule characteristic life time ($\sim 10 \text{ ns}$)\(^1\). Thus, the argons atoms trapping by the carbon diamond-like cell can occur in arc gas discharge with current density more than $j_0 \sim 45 \text{ mA/s}^2$ and provided that the eximer molecules of noble gas and carbon atoms (e.g., ArC) can be formed.

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