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Formation of nanostructures on the cathode in an electric arc discharge

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One of the widespread and economic methods of carbon nanomaterials (CNM) synthesis is an arc evaporation of graphite[1]. Products, formedinplasmaduetotheevaporationofgraphiteanode and containing CNM, are deposited on cathode and on reactor cold walls. Takenspecimensareexaminedfordifferentcharacteristics with little attention to physical-chemical processes, taking place at both on electrodes and in plasma.
This work represents the authors'opinion and offers amodel (scheme) of CNM formation as a depositon cathode, based on charged particles behavior in electromagnetic field patterns at the experimental temperature and pressure gradients along the arc axis.

Keywords: arc discharge, nanostructure, graphite anode,physical-chemical process.
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1 Introduction

It is needed to show the physics of processes, affectingon the formation and composition of arc discharge, creating for the anode destruction for better understanding of carbon nanostructures formation mechanism in the arc space between electrodes.

Note that in fluence of both electric and magneticfields on the creating carbon particles is a key factor during the formation of carbon nano structures. Carbon arcbetween electrodes can be seen as a flexible conductorof electric current, having its own magnetic field. The magnetic force lines of the arc represented as concentric circles, encircling round the center of the arc column. As a result of these factors interaction, a charged particle of the arc column will move to an inward spiral from the anode to the cathode.

2 Results and discussions

The plasma formed between the graphite electrodes in the inter electrode space, unlike the metal conductors, has two main competing flows of charged particles – electron and cation flows. The latter consists of carbon, the carbon cluster cations and shards of graphene sheets with a positive charge. Velocity of positive charged particles moving will depend on the electric field creating between electrodes.

Counter motion of electrons and positively charged particles makes them collide. But unlike the metal matrix, cations in arc, as well as electrons, create their own magnetic field while moving. At the collision of oppositely charged particles the energy of their interaction depends on their momentum. Collisions can lead to the destruction of existing constructions and their atomization and also to the ionization of neutral atoms.

Densities of charged particles over the cross section of electric arc are not the same. Electrons move closer to the arc axis. Greater number of positive particles is held in the arc by the magnetic field. Temperature of centralpartofarc is about $1 \cdot 10^4$ °C (fig. 1), sharply decreasing to the periphery along the radius. At the trans formation of graphite to the vapor, volume, taken by the carbon atoms, enlarges more than in 5500 times.

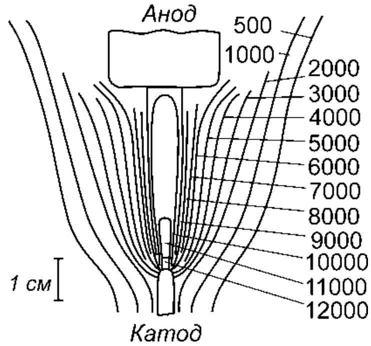

Figure 1 – Distribution of temperature zones (c) along the axis of the electric arc between the graphite electrodes at the current of 200 A [2].

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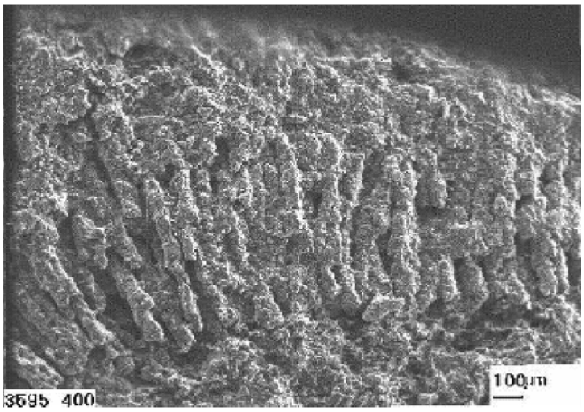
Neutral particles due tot hegradients of temperature and pressure move from the arc axis to the periphery, getting in the volume covered by the helium atoms.

Rotarymotion of positively charged particles in the-column of electric arc, created by the electromagnetic field, randomly reduces the speed of charged particles diffusion from the axis to the periphery and tightenst the axis of column, creat in gahotionized gas.

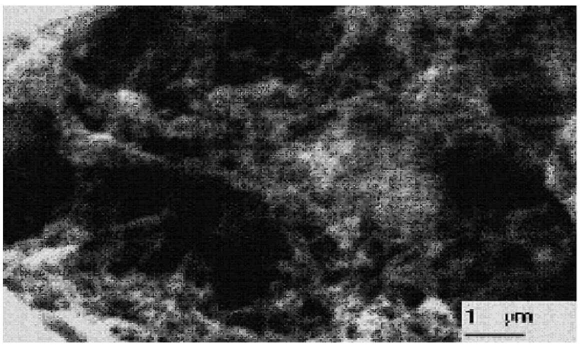
Thus, a longitudinal magnetic field results the arc column a rotation around the axis, consisting of various charged particles, and tightens it. Changing of the density of particles along the arc column axis leads to the changing of frequency of their collision with the flow of electrons.

Electromagnetic field action on the charged partics of arc column stimulates their condensation on the cathode and formation of various nanostructures.

Experiments [3-4] has shown that deposit, formingon the cathode, consist soft woparts: loose cores formed by the multiwall nanotubes (MNT), having a minimum of structural defects and a solid crust (fig.2-3), formed by the layer of graphite like structures, having a minimum number of MNT in their volume.



a)



b)

Figure 2 – Core of deposit: a) common view of conglomerates, consisting of nanotube beams; b) nanotube beams.

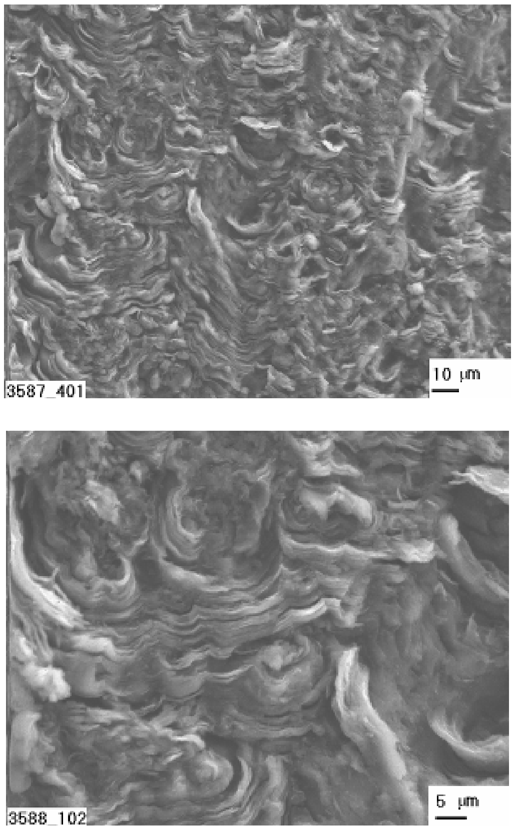


Figure 3 – Shell of deposit, formed by graphitelike structures

Given all this, the processes occurring in the arc between carbon electrodes can be represented diagrammatically as follows (fig.4). At the arc discharge an electron-beam ($e_к$), bombarding anode, initiates the process of graphite anode cleavage into graphene monolayer sheets and packages, consisting of several graphene sheets. It is occur red afracture of edgelinks (fig.5), and also knocked out a certain number of electrons from carbon atoms in graphene. It leads to the positive charging of sheets and packages.

Positively charged particles, movingunder the action of electromagnetic field from anode to cathode along the arc axis, constantly collide with the electron flux.

It is occurred apartial destruction of some of the graphene sheets and atomization of carbon. Packages canbe flaked in to grapheme sheets. Graphene sheets, having a high surface energy on the opened sides and noncompensated links on the edges, being turned into CNT, createa-deposit core (as construction elements with little electric resistance), as well as grapheme packages (with a greater ratio of mass with respect to charge), consisting of more than one sheet, create a deposit shell. The winding down of grapheme sheets is occurred also due to the turbulence of moving particles flow.

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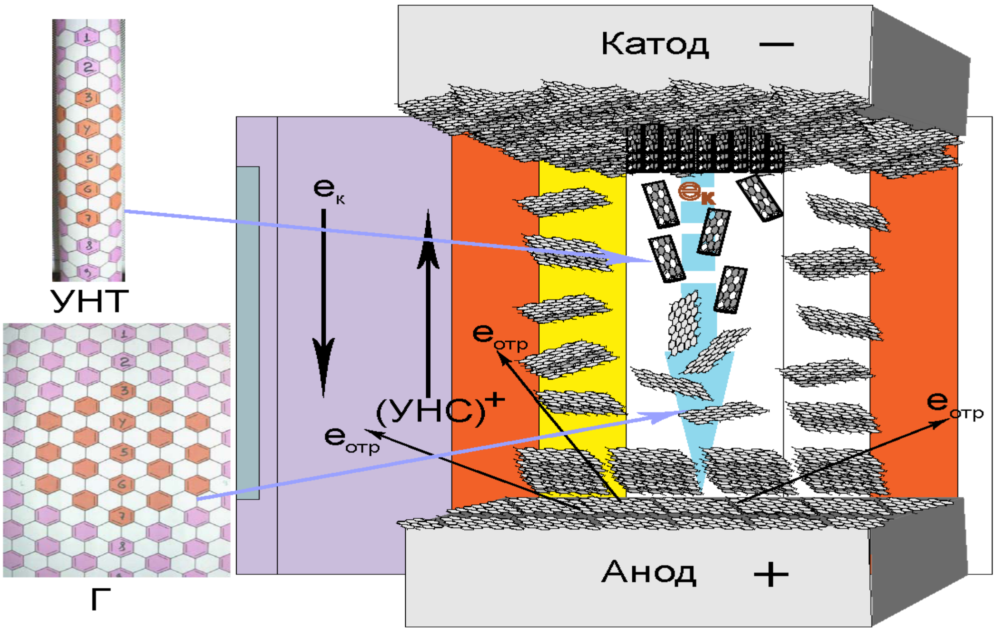

Figure 4 – Scheme of deposit formation: $e_{к}$ – electron flow with a power below 8 kWt (U=25-30B, I=300A), moving from cathode to anode; $e_{отр}$ – reflected electrons; $(CNS)^{+}$ – carbon nanostructures with positive charge; Г – grapheme sheets; CNT – carbon nanotubes.

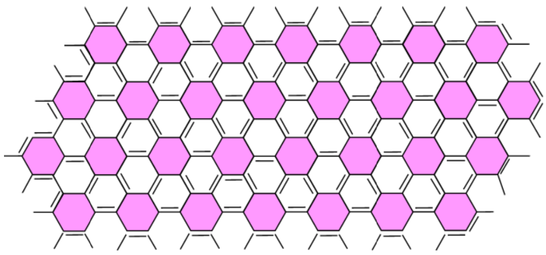

Figure 5 – Graphene sheet with unsaturated edge links (“broken”).

CNTbeamsatthemomentofformationonthecathodesurfaceandinarchaveahightemperature ehich leads to the formation of deposit core from pure carbon, as well as at such temperatures sublime all the metals and compounds. In case of presence in atoms vapour phase of refractory metals from the fourth, fifth and sixth groups, latter form carbides, consisting the composition of crust, as the low-temperature part of the deposit.

Particles, adsorbed on the surface of the cathode, are arranged in such a way that the newly formed carbon layer could have a minimal electrical resistance cause the layer in the moment of formation becomes the conductor of current and it conducts an electron flow with a current from 100 to 300 A [3,4].

3 Conclusion

Based on the literature data about the physical processes occurring in the plasma of electrical discharge, and experimental observations to the electric arc evaporation and dispersion of graphite is offered an uncontroversial model the the products formation processes on the cathode - conglomerates of multilayer nanotubes indeposit core and layered graphitelike structures in the crust of deposit.

It is shown that even at the stage of forming deposit material already programmed for resistance to high current loads. That’s why nanostructural component sofdeposit, which are multi layer carbon nanotubes by the electromechanical properties can be used in force blocks of nanoelectronic schemes.

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