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THE ARC DISCHARGE IN THE LIQUID PHASE

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ABSTRACT

The processes occurring on the electrodes and in the liquid phase during the arc discharge in the liquid phase (ADL) have been considered in the present work and we explain the mechanism of carbon nanostructures (CNS) formation proposing the model based on the analysis of existing regularities in behaviour of charged particles under extreme temperature and pressure gradients.

The CNS synthesis by ADL method has been performed in dielectric liquids: hydrocarbons, liquid gases (N_2, Ar, He etc.), deionized water and others. Suspension containing clusters of synthesized nanostructures has been formed by the synthesis.

The efficiency of this method is sharply increased by using arc discharge in the liquid phase where powder reagent layer is used as anode. To increase the frequency of electrodes clamping and moving apart, an electromagnetic vibrator has been used in this method and it brings and takes away the cathode from the powder reagent at a specified frequency. For ADL, nanostructures form simultaneously at several points on the conducting particle surface as a result of microscopic acts of arc discharge. These nanostructures are generated from the liquid phase and anode vapors and represent the product exhibiting rather interesting physical and chemical properties.

Based on the analysis of the observations performed in the course of carbon nanostructures synthesis, the model of nanostructures formation by arc discharge in the liquid phase has been proposed in this paper. Presence and absence of deposit on the cathode have been explained.

INTRODUCTION

Materials which physical properties can be controlled by varying them within wide limits occupy a particular place among modern metallic materials. These materials are used extensively in different fields of engineering and industry and define to a large extent the pace of scientific and technical progress. Magnetic metals and alloys can be realistically assigned to such materials [1-2].

Magnetic properties of metals and alloys depend on many technological and physical factors: conditions of their production, chemical composition, structural state, number and distribution of different stable and metastable phases in a material etc. which in turn are determined to a large measure by different types of external actions on a material during its production (mechanical, thermal, magnetic, thermomechanical, thermomagnetic, ultrasonic etc. treatments) [3].

Synthesis of superfine, ultradispersed and nanodispersed magnetic materials provides unique possibilities for physicists and technologists. Magnetic properties of materials with the superfine or ultradispersed structure can be changed over very a wide limits by varying their dispersion, phase state, surface state and other factors [4-5]. This paper realizes one of such possibilities by the example of superfine iron and nickel powders produced by the method of electric arc dispersion in dielectric liquid media.

After the discovery of fullerenes and carbon nanotubes methods of their synthesis has been constantly investigated and improved. In parallel with the arc method in the gaseous phase and the pyrolytic method of synthesis of carbon nanostructures, since 2000 we have investigated and developed the method of arc synthesis in the liquid phase. For the last decade, this method is used in increasing frequency to produce different nanostructures as the method alternative to the arc discharge in the gaseous phase (ADG).

In the eighties we began our work on producing ultradispersed metal powders by the electroerosion method [6-8] and continue it today. Besides carbon nanostructures produced by evaporation of carbon electrodes in the liquid phase, there appears a possibility to produce metal-carbon composites by sublimation of metal in the carbon-containing liquid. In this case the metal nanoparticles form along with carbon nanostructures on their surface.

The main positive features [5, 8] of the method used are as follows:

1. high temperature in the arc zone, > 4000 K;

2. high cooling rate of evaporated products, > 10^9 K/s;

3. high degree of dispersion. The particles range in size from 1 to 100 nm;

4. high nucleation rate at a low growth rate of a particle.

This method does not require using of unhealthy gases, vacuum equipment or expensive lasers. The proposed method provides a possibility of producing a wide range of materials by varying the conditions for synthesis and it presents a way of modifying the chemical composition of electrodes and a medium, in which the synthesis is carried out [9]. At present time different research groups over the world are engaged in such studies [10-19]. The liquid phase may be of different chemical compositions that affect the structure and composition of the produced nanoobjects being studied (Fig. 1).

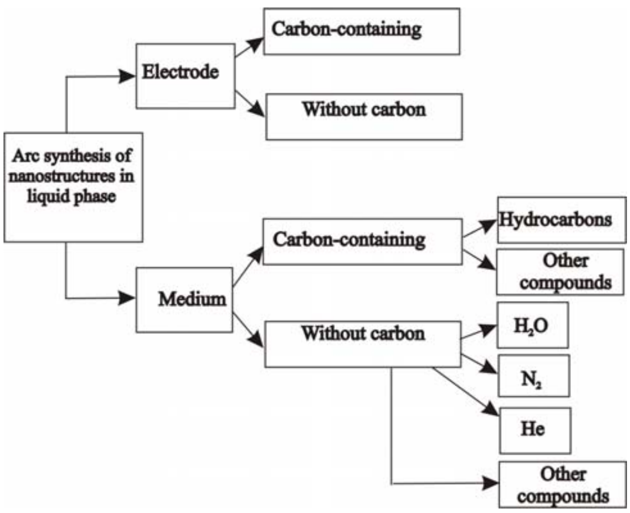

Figure 1. Diagram for possible combinations of medium and electrode materials in synthesis of nanostructures by the arc method in the liquid phase.

For the last decade, arc discharge in the liquid phase is used in increasing frequency to produce different nanostructures as the method alternative to arc discharge in the gas phase. ADL is considered to be a profitable method of nanostructures synthesis. This method does not require using of unhealthy gases, vacuum equipment or expensive lasers. In the present work we consider the processes occurring on the electrodes and in the liquid phase during the ADL process and explain the mechanism of carbon nanostructures (CNS) formation proposing the model based on the analysis of existing regularities in behaviour of charged particles under extreme temperature and pressure gradients.

NOMENCLATURE

Subscripts

ADL	arc discharge in the liquid phase
ADG	arc discharge in the gas phase
CNS	carbon nanostructures
ADLP	arc discharge in the liquid phase where a layer of powder reagent is used as an anode

RESULTS

Synthesis of CNS by the ADL method is performed in dielectric liquids: hydrocarbons, liquid gases (N2, Ar, He etc.), deionized water and others. Suspension containing clusters of synthesized nanostructures is formed by the synthesis.

Discharge in liquid is initiated by moving apart electrodes that were initially clamped. High-temperature arc column that appears between the electrodes converts both the anode material and the liquid phase surrounding this anode into the vapor phase.

When electrode spacing does not exceed 1mm, the deposit similar to that formed in ADG is generated on the cathode.

When moving apart the electrode is more than 1 mm, deposit on the cathode does not formed and the whole resulting product is either in suspension in the liquid phase or on the bottom as residue.

Efficiency of this method is sharply increased by using arc discharge in the liquid phase where a layer of powder reagent is used as an anode (ADLP) (Figure 2). In this case in clamping the electrodes, each conducting particle being among the similar ones is, on the one hand, an anode and, on the other hand, a cathode. To increase the frequency of electrodes clamping and moving apart, this method uses an electromagnetic vibrator

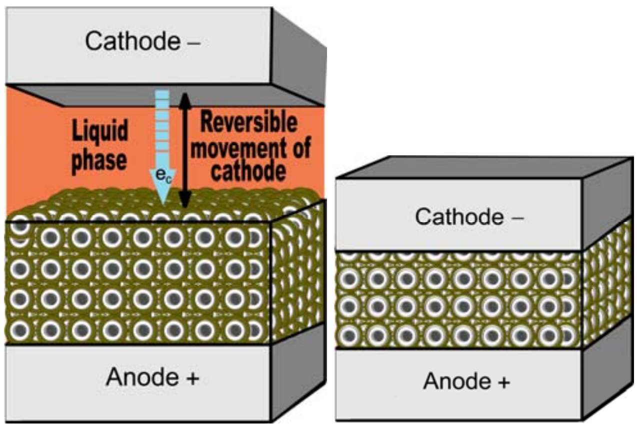

Figure 2 Schematic diagram of action of the arc discharge apparatus in the liquid phase with a dispersed anode.

that brings and takes away the cathode from the powder reagent at a specified frequency. A large amount of nanoproduct is formed by a large number of electric discharges.

DISCUSSION

On the basis of our phenomenological model of the processes occurring in the electrode spacing in the liquid phase, one can expect the following variants of the process proceeding.

1.During ADL, when electrode spacing is less than 1 mm, liquid phase goes into a vapor state (Figure 3) thus providing conditions similar to those in ADG. As this takes place, carbon vapor, carbon nanostructures and fragments of graphene sheets interact under the action of electromagnetic forces and move in different directions.

The vapor phase at the interface (gas - liquid phase) condenses due to the temperature gradient. The charged particles, moving from the anode to the cathode, form deposit. When colliding with electron flux, a minor part of these particles and neutral particles are thrown out the arc zone and quenched in crossing the interface.

Near the quenching zone, the particles constituting the gas phase agglomerate through the saturation of dangling bonds, create different nanoforms and assemble in clusters.

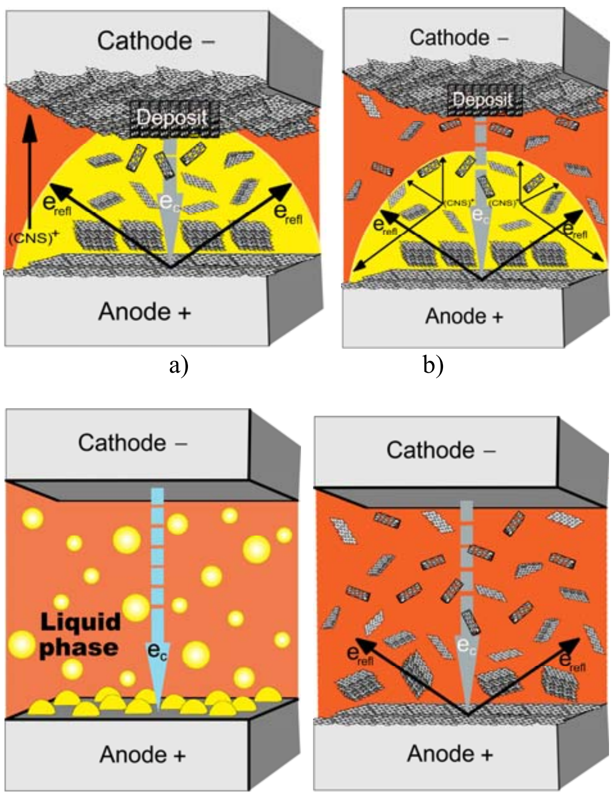

Figure 3 Mechanism of carbon nanostructures formation in the liquid phase.

2. When electrodes are moved apart at the distance exceeding a vapour bubble diameter, deposit stops to form on the cathode (Figure 3, b). This is attributed to that the particles forming the deposit and having plasma temperatures now must overcome the layer of liquid. Approaching to the interface (g-l), these particles undergo quenching. In the quenching zone, the particles begin to agglomerate, form clusters and lose their reactivity.

Breaking away from the anode surface, the bubbles go into the volume of liquid phase (Figure 3, c). All structures contained in a bubble and formed by anode evaporation remain enclosed in the volume of the bubble. Vapor, getting to the zone of lower temperatures, condenses, bubbles shut and their content goes in the liquid phase (Figure 3, d). Nanoparticles in liquid can assemble in clusters and precipitate or be in suspension.

In the case of co-evaporation of metal and graphite or metal in the hydrocarbons medium, metal nanoparticles encapsulated in the carbon matrix or other composites can be produced by condensation of vapors mixture in the shutting bubbles.

3. For ADLP, nanostructures form simultaneously at several points on the conducting particle surface as a result of microscopic acts of arc discharge similar to those shown in Figure 2, a. These nanostructures are generated from the liquid phase and anode vapors and represent the product exhibiting rather interesting physical and chemical properties.

CONCLUSION

Based on the analysis of the observations performed in the course of carbon nanostructures synthesis, the model of nanostructures formation by arc discharge in the liquid phase has been proposed.

Presence and absence of deposit on the cathode have been explained.

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REFERENCES

[1] Vonsovskiy S.V. Magnetism, Moscow: Nauka, 1971, 1032 p.

[2] Magnetic properties of metals and alloys, edited by Vonsovskiy S.V. Moscow: Gostekhizdat. 1961, 560 p.

[3] Gusev A.I., Rempel A.A. Nanocrystalline materials, Cambridge: Cambridge International Science, 2004, 149 p.

[4] Chuistov K.V., Shpak A.P., Perekos A.E. et. al., Small-size metallic particles: production conditions, atomic and electron structure, magnetic properties and practical implementation. *Metal Physics and Advanced Technologies*, Vol.4, № 4, 2003, pp.235-245.

[5] Chuistov K.V., Perekos A.E., Zalutskiy V.P. et al., The effect of production conditions on structural state, phase composition and fineness of iron and iron-based powders made by electric-spark

erosion, *Metal Physics and Advanced* Technologies, Vol. 16, № 8, 1997, pp. 865-875.

[6] Dubovoy A.G., Perekos A.E., Chuistov K.V. Structure and magnetic properties of small amorphous particles of metallic Fe-15 at.% B alloy, *Physics of Metals,* Vol. 6, № 5, 1985, pp. 1085-1088.

[7] Dubovoy A.G., Zalutskiy V.P., Ignat'ev I.Yu. Structure, magnetic parameters and thermal stability for small amorphous particles and amorphous strips of Fe-15 at.% B., *Physics of Metals*, Vol. 8, № 4, 1990, pp. 804-807.

[8] Chuistov K.V., Perekos A.E. Structure and properties of small-size metallic particles. 1. Phase-structure state and magnetic characteristics (Review), *Metal Physics and Advanced Technologies,* Vol. 17, № 1, 1998, pp. 57-84.

[9] Schur D.V., Dubovoy A.G., Zaginaichenko S.Yu., Adejev V.M., Kotko A.V., Bogolepov V.A., Savenko A.F., Zolotarenko A.D. Production of carbon nanostructures by arc synthesis in the liquid phase, *Carbon,* Vol. 45, № 6, 2007, pp. 1322-1329.

[10] Loiseau A., Demoncy N., Stephan O. et al., Filling carbon nanotubes using an ARC discharge. In: Science and Application of Nanotubes, New York: Kluwer Academic Publishers, 2000, 398 p.

[11] Schur D.V., Dubovoy A.G., Lysenko E.A. et al., Synthesis of nanotubes in the liquid phase, Extended Abstracts of 8th International Conference, "Hydrogen Materials Science and Chemistry of Carbon Nanomaterials" (ICHMS'2003), Sudak (Crimea, Ukraine), 2003, pp. 399-402.

12. Schur D.V., Dubovoy A.G., Zaginaichenko S.Yu., Savenko A.F. Method for synthesis of carbon nanotubes in the liquid phase, Extended Abstracts of International Conference on Carbon, Providence (Rhode Island, USA): American Carbon Society. 2004. P. 196-198.

13. Antisari M.V., Marazzi R., Krsmanovic R. Synthesis of multiwall carbon nanotubes by electric arc discharge in liquid environments, *Carbon.* 2003. **41**(12): 2393-2401.

14. Biro L.P., Horvath Z.E., Szalmas L. et al., Continuous carbon nanotube production in underwater AC electric arc, *Chemical Physics Letters*. 2003. **372**(3-4): 399-402.

[15] Sano N., Nakano J., Kanki T. Synthesis of single-walled carbon nanotubes with nanohorns by arc in liquid nitrogen, *Carbon*, Vol. 42, № 3, 2004, pp. 686-688.

[16] Qui J., Li Y., Wang Yu. et al., Synthesis of carbon-encapsulated nickel nanocrystals by arc-discharge of coal-based carbons in water, *Fuel,* Vol. 83, № 4-5, 2004, pp.615-617.

[17] Bera D., Kuiry S.C., McCutchen M. et al., In-situ synthesis of palladium nanoparticles-filled carbon nanotubes using arc discharge in solution, *Chem. Phys. Lett*, Vol. 386, № 4-6, 2004, pp. 364-368.

[18] Montoro L.A., Lobrano Renata C.Z., Rosolen J.M. Synthesis of single-walled and multi-walled carbon nanotubes by arc-water method, *Carbon*, Vol. 43, № 1, 2005, pp. 200-203.

[19] Ishlinsky A.Yu. Polytechnic Dictionary, Moscow: Soviet Encyclopedia, 1989, 611 p.