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Production of iron nanotubes in plasma

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Abstract

The paper presents the experimental installation, the procedure of obtainment and some mechanisms of iron nanotubes formation in plasma. The inner and outer diameters of nanotubes produced in this manner are located within regions like 0.1–0.45 nm and 2.2–14 nm, respectively. The length takes values between 5 and 12 nm. We emphasize that a quantized description of diameters formation is conceivable. To this aim a diameter quantum like $d_{iq} \approx 1.2$ nm can be proposed.

The experimental results obtained are discussed.

Keywords: Iron nanotubes; Plasma; Vapors; Diffusion; Inner diameter

1. Introduction

Cylinder-shaped nanosized systems are referred to as nanotubes [1]. Such advanced materials are of a special interest because of promising technological applications [2–11]. The scientific understanding of both production methods and formation mechanisms have been addressed in several respects [12,13] and the same concerns related properties [14–16]. Applications of nanotubes concern many areas such as vacuum microelectronics [17], light emitters [18], accumulators [19], hydrogen storage [20] and last but not at least nanoelectromechanical systems [21,22]. Note that in order to produce high-stability magnetorheological suspensions (MRS‘s) we have to use organoclay [23], polyacrylic acid [24] and guar-gum [25a]. The possibility to obtain stable MRS‘s with the help of iron-nanosystems has been discussed before [25b–d]. The point is that iron-nanotubes can be used as additive materials in liquid-matrices. This leads, under well-established conditions, to nanotube networks containing magnetizable microparticles. It should be emphasized again that the magnetic and rheological properties of MRS‘s produced in this way look promising for future applications.

2. Experimental installation

The experimental installation (Fig. 1) used for iron nanotubes production comprises the plasma generator A, enclosure for particle generation B, subassembly C for the fixing–positioning and training of material in plasma, power source D, enclosure E for particle collection and subassembly F for material advance in plasma.

The plasma generator is one with axial stabilization. Electrode 1 is made of wolfram +2% Th and its diameter is 0.010 m. The nozzle 2, made of copper, has 0.014 m diameter and is interchangeable.

The generator is cooled with water (0.00025 m^3/s flow) at a water pressure of 0.15 MN/m^2. It functions with argon. The argon flow can be continuously adjusted between 0.0001 $m^3/s \pm 5\%$ and 0.001 $m^3/s \pm 10\%$.

The particle enclosure is detachable from the plasma generator. Visualization of the enclosure is achieved through window 4. By means of the connector 5, the particles are carried by the argon into the particle collection enclosure.

The subassembly C for material fixing–positioning–training in plasma is joined to the particle generation enclosure.

The material undergoing processing in plasma (position 7 in Fig. 1) is placed on the rod 8 by means of the clutch end (well cooled). The piston 10 ensures tightening at low and high pressure of the group formed of the plasma generator and the particle generation enclosure.

Training of the material in plasma is achieved by means of the subassembly F. It allows a forward–backward movement

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of the rod by means of the electric motor 14 with velocity reducer.

The advance of the material in plasma can be achieved continuously between 0.000010 m/s ± 0.5% and 0.0005 m/s ± 1.0%. The power source is of the type KND-350 M (Automatika Ljubljana-Viszék Budapest). It generates an electric current through a purely ohmic resistance continuously adjustable between $0.5A_{dc} \pm 1\%$ and $10A_{dc} \pm 1\%$ and $10A_{dc} \pm 1\%$ and $315A_{dc} \pm 1.5\%$.

The particle collection enclosure (position E in Fig. 1) is an oil filter. Particles of nanometric dimensions are collected in the liquid matrix 17 (mineral oil).

2.1. Proposed model

The plasma arc is ignited in argon medium, between the wolfram electrode and the electrode rod (carbon steel). At the argon plasma temperature $T_0 \approx 10{,}000$ K, the surface of the anode is brought to the vapor phase.

The distance "*d*" between the wolfram electrode and the electrode rod is kept constant by the constant training of the material in plasma. A constant metal vapors flow results in mixture with argon plasma.

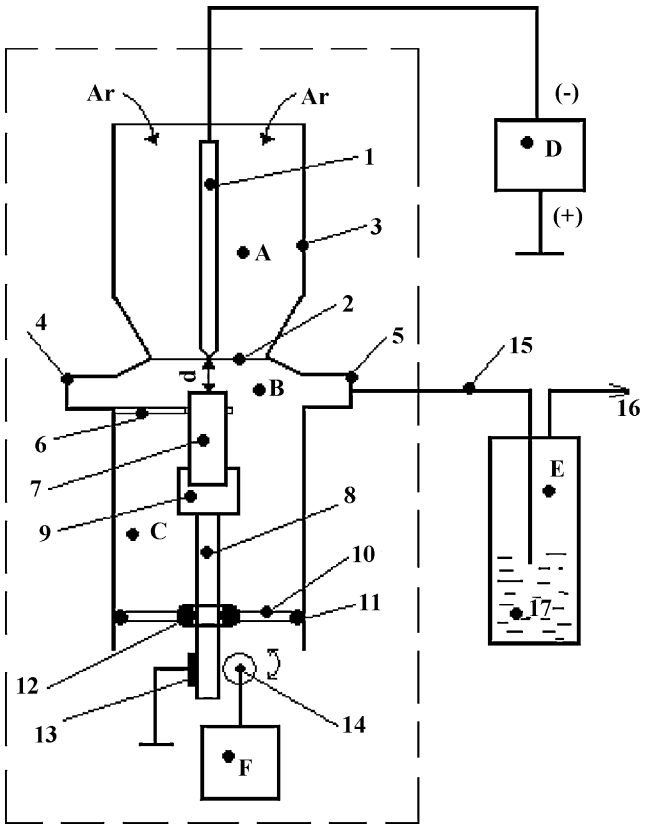

Fig. 1. Experimental installation (overall configuration): (A) plasma generator (1, wolfram electrode; 2, nozzle; 3, generator body); (B) particle generation enclosure (4, window; 5, connection; d, electrod–material distance); (C) subassembly for material fixing, positioning and training in plasma (6, protection ring; 7, carbon steel bar; 8, rod; 9, clutch; 10, piston; 11 and 12, tightening rings; 13, mobile electric contact; 14, electric motor with velocity reducer); (D) power source; (E) particle collection enclosure (15 and 16, tubes; 17, mineral oil); F-material advance in plasma subassembly.

The tension p_i of the iron vapors depends on the temperature T_0 of the plasma [26]:

$$p = p_0 \exp\left(\frac{\Delta L_v}{R}\frac{T_0 - T_b}{T_0 T_b}\right) \quad (1)$$

in which $p_0 = 7.28$ N/m^2 is the vapor tension at the boiling temperature $T_b = 3145$ K of the iron; $\Delta L_v = 340$ kJ/mole is the latent heat of iron vaporization and R is the ideal gases universal constant.

At the pressure p, the molar concentration of the vapors [27] is:

$$C_0 = \frac{p_0}{RT_0}\exp\left(\frac{\Delta L_v}{R}\frac{T_0 - T_b}{T_0 T_b}\right) \quad (2)$$

The graphic representation of $C_0 = C_0(T_0)$ is obtained by using the expression (2) and is shown in Fig. 2.

The molar concentration of the vapors–plasma mixture is much higher compared with the iron vapors molar concentration. It results that the vapor particles do not feel one another. So, the fluid medium formed of vapors and plasma can be assimilated to an ideal gas.

We consider the iron vapors–plasma movement to be stable. This means that along each current line cylinders of iron vapors and plasma are formed. We consider the cylinders thus formed to be at sufficiently great distances to avoid interaction.

The diameter d_0 of the cylinders results from the general law of ideal gases and is calculated with the formula [27,28]:

$$d_0 = 2\left(\frac{1}{\pi}\frac{m_0}{\mu C_0 L_0}\right)^{0.5} \quad (3)$$

where m_0 is the vapors mass, $\mu = 0.056$ kg/mol is the molar mass of the iron vapors and L_0 is the length of the cylinders.

At a certain moment, the cylinders reach areas in the particle generation enclosure where the temperature is close or equal to that of the "dew point" ($T_1 \approx 2000$ K). Then, the surface of the cylinder changes into a liquid membrane.

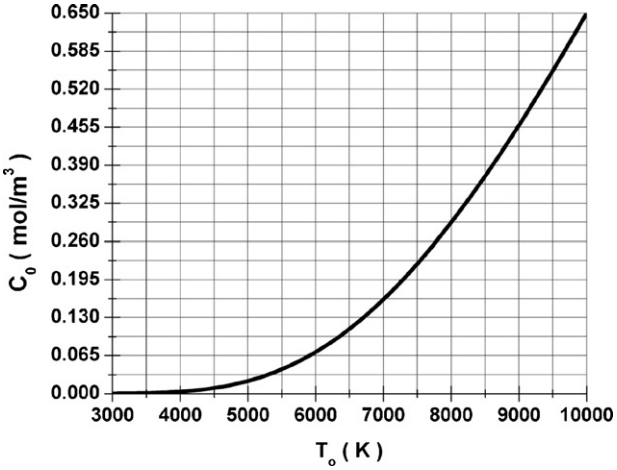

Fig. 2. The molar concentration C_0 of the iron vapors function of the plasma temperature T_0.