# Structure and properties of particles deposited from vacuum arc discharge plasma on the way from the cathode spot up to the walls of a vacuum chamber

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**Abstract.** The author has analyzed the structure and properties of micro-particles, which are deposited from arc discharge plasma near the cathode on the substrate and walls of the vacuum chamber. Cathode was grade BT1.0 titanium spraying in nitrogen and acetylene. Particles and films formed in plasma flow with superposing of electric and magnetic fields. The dependence of physical properties of microparticles on the operation modes of the cathode pack has been analyzed. Possible mechanisms for forming fractal structures in vacuum arc discharge plasma have been considered.

## 1. Introduction

The cathode spot is the basis of arc discharges. Cathode spot products are electrons, ions and particles including liquid droplets [1–2]. Forming films from the cathode material or its compounds on substrate are resulted from a number of hard controllable processes. The analysis of these processes is complicated by the interaction of plasma particles moving in magnetic and electrical fields. Superposition of discharge and metal plasma with drops in it refers to dust plasma [3–4]. The structure of cathode plasma streams in vacuum arc in the presence of magnetic and electric fields is highly studied. However, the structure and properties of the particles deposited from plasma flow are still unstudied.

The purpose of the work is to study the structure, phase and elemental composition, and granulometry of fine powders.

## 2. Objects and methods of research

Powders with fine structure on the basis of titanium carbonitride were synthesized from arc discharge plasma on the unit NNV-6.6 I4. The material of the cathode is grade BT 1.0 titanium. Plasma forming gases, including coal-containing acetylene, were injected in the area of spraying titanium cathode. The powder deposited on the walls was extracted with a vacuum cleaner. To separate strong magnetic fraction we carried out magnetic separation of the powder in fields 0.2 T combined with simultaneous vibration. After separating with the use of the vibration shakers with the cell diameters 20, 60, 100, 140 and 180 μm, we determined and analyzed 5 groups of powders deposited on the walls of the vacuum chamber from arc discharge plasma. The dependence of mass fraction of dust particles on their size after separation on vibration shakers is shown in figure 1.

To study the structures and properties of micro-particles and films we used complex techniques and equipment: X-ray diffractometers DRONE-6 and Hecus S3-MICRO, electron microscope Quanta 200 i

3D FEI, particle size analyzer Shimadzu SALD -3101, analyzer TGA/SDTA851e, IR spectrophotometer IRAffinity-1 and ESR spectrometer PS 100. Magnetic properties were investigated at room and nitrogen temperatures.

We studied fine powders obtained by several operating modes of the cathode pack [5]. The main modes are the first mode (substrate potential is 250 V, arc current is 75 A, focusing coil current is 0.6 A) and the second mode (substrate potential is 0 V, arc current is 25 A, the walls of the vacuum chamber was an anode) without a focusing coil (0 A).

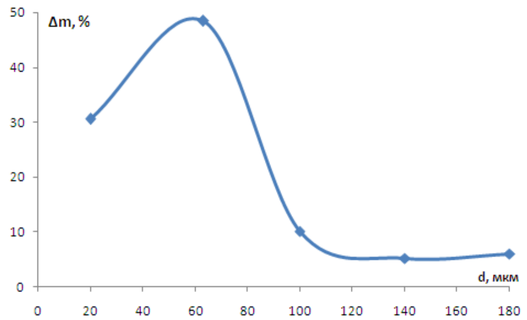


**Figure 1.** Dependence of dust particles from their size after separation with the use of the vibration shaker.

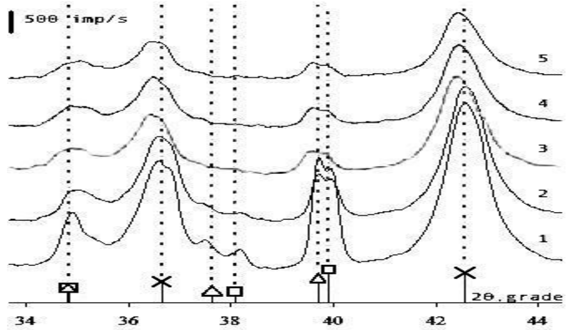


**Figure 2.** Plots of the X-ray diffraction pattern from powders of different sizes (1 – 20 μm; 2 – 63 μm; 3 – 100 μm; 4 – 140 μm; 5 – 180 μm). Bottom: bar X-ray data according to PDF-files (x – δ-TiN; □ – α-Ti; Δ – α-Ti 0.83 N 0.17) [9].

## 3. Results

The powders obtained from titanium-carbon-nitrogen low temperature plasma are multiphase mixtures of TiN (FCC-structure) and TiNC (HCP structure). The results of the radiographic analysis (figure 2) [9] and X-ray fluorescence analysis demonstrate complex phase and element compositions of obtained fine powders containing magnetic and nonmagnetic factions. Their elemental composition after magnetic separation varies and depends on the operation modes of the cathode pack. It has been determined that under the said deposition modes, the main part of obtained fine powder is titanium nitride, formed trough the carbide cycle reaction taking place during plasma particles movement [6].

The comparison of the dispersion of the particles obtained under different operation modes of the cathode pack (interelectrode potential, fractal focusing coil current) has been made. Uneven distribution of the participles has been found. The dependence of the distribution of particles on their diameters is determined by the deposition mode and is shown in figure 3.

The dependence of the titanium content in dust particles on their sizes is shown in figure 4. After magnetic separation, we detected iron in the powders, although there had not been iron in such numbers in the original material of the cathode (grade BT1.0 titanium).

## 4. Discussion

The results of analyzing carbonitride titanium based structures can be interpreted in terms of solid-state reactions. In analyzing these reactions, the interaction of ions in different states must be taken into account. The role of nitrogen in forming compounds in plasma chemical processes is not fully studied and raises a number of discussions. It is known [7] that the interstitial non metals atoms (C, N, O) in the lattice of transition metal atoms lead to the formation of strong chemical bonds between metal and non metal that significantly affects the chemical and physical properties. The paper [8] provides information of the nature of interstitial refractory phases as of solid solutions. The state of Me-Me-bonds, that form a lattice metal frame, plays the determining role. Some authors argue that three-dimensional lattices of NaCl-type, which are formed by the covalent bonds, are responsible for their high hardness.

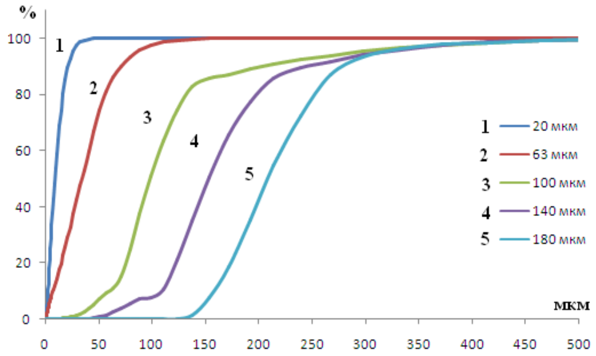


**Figure 3.** The dependence of the normalized number of particles on the diameter.

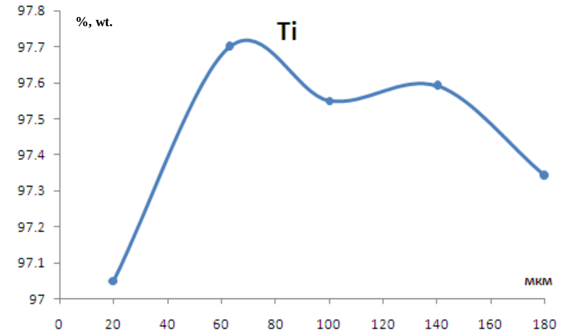


**Figure 4.** Dependence of the content of titanium on the dimensions of dust particles of particles.

Earlier, we used the method of small-angle X-ray scattering to determine the fractal structure of the arc discharge plasma particles [9]. The analysis of the conditions of forming these particles from the drop fraction of low-temperature plasma showed that the flow of ions of the moving cathode spot in arc discharge can be considered, at a specific point in time, as a current layer. The theory of current layers suggests that in plasma there are the magnetic field "special" lines, which are resulted from perturbations on distances exceeding the dimensions the neighborhood layer [10]. Growth front instability may be the reason for the formation of fractals. This condition is probably magnetic field dissipation in a small plasma area, in particular in the area of the cathode spot, where electrical and magnetic fields are parallel to each other [11].

## References

[1] Anders A 2008 *Cathodic Arcs: From Fractal Spots to Energetic Condensation* (Berkeley: Springer Science) 540
[2] Lyubimov G A and Rakhovsky V I 1978 *UFN* **125** 665
[3] Smolanov N A 2016 *Journal of Physics: Conference Series* **669** 012055
[4] Fortov V E, Khrapak A G, Khrapak S A, Molotkov V I and Petrov O F 2004 *UFN* **174** 495
[5] Smolanov N A 2017 *Journal of Surface Investigation* **11** 353
[6] Chesnokov V V and Buyanov R A 2005 *Krit. tekhn. Membrany* **4** 75
[7] Samsonov G V 1969 *Nitridy* (Kiyev: Naukova dumka)
[8] Zhilyaev V A 2012 *Materialovedeniye* **4** 3
[9] Smolanov N A and Neverov V A 2015 *Pis'ma Mater.* **5** 179
[10] Frank A G 2010 *UFN* **180** 982
[11] Ledentsov L S and Somov B V 2015 *UFN* **185** 113