The experimental study of spacial distribution of particles produced in the pulse arc discharge

V D Goncharov and R V Yashkardin
St. Petersburg Electrotechnical University (ETU), 197376, Saint Petersburg, Russia
E-mail: vdgoncharov@rambler.ru

Abstract. The results of experimental researches of special particle sputtering produced due to the energy impact of the pulse discharge plasma moving along the surface of the extended electrodes. The particles distribution study of the substrates placed at the different areas regarding the discharge was carried out using scanning probe microscope. It is shown that the major part of the produced particles had sizes from 50 to 500 nm and sputtered orthogonally to the surface of the electrodes and discharge motion vector.

1. Introduction
Using ultradispersed particles (UDP) and materials containing them in technology is very common nowadays. Such materials are widely used in chemical industry, car manufacturing, medicine etc. And there’s also a wide variety of methods of producing the UDP [1, 2]. One of such methods involves using pulse arc discharge moving along the surface of the long extended electrodes [3].

2. The device working principles and the order of the experiments
The principles of the device functioning is presented in the figure 1.

![Schematic description of the UDP production device](image)

Figure 1. Schematic description of the UDP production device.

The main discharge (2) in the device is in between main electrodes representing two steel beams in parallel to each other (1). In between the main electrodes there’s a dielectric inset (3). The capacitive battery (10) and the main electrodes are connected with co-axial power cable (13). The main discharge causing the appearance of the UDP on the surface of the main electrodes in ignited by the additive
spark discharge between the main (1) and the additive electrodes (11). The spark is caused by the high voltage impulse on the additive electrodes from the high voltage source (14). The energy accumulated in the capacitive batteries is released in the discharge area. The discharge starts its motion along the main electrodes (5) under the magnetic fields interaction. The interaction of the moving discharge with the main electrodes surface causes the formation (7) sputtering and splitting UDP (8). The detailed description of the processes taking place in the device is presented in the paper [4]. We gave up any hope to study the parameters of plasma [5] experimentally from the very beginning and focused on matching technological parameters, the shape of the voltage pulse and studying special distribution of the UDP.

Experimental researches on sputtering the particles on the glass substrate were carried out using the device in the figure 1. The glass substrates were chosen due to their consistent surface roughness (less than 5nm whereas estimated sizes of the particles were from 10 to 500 nm). So using these substrates allows to determine the number of the UDP quite accurately. The substrates (4) were situated opposite to the electrodes and in front and aside to the anode (1) and cathode (2) (with the semi-conductive inset (3) in between them) (figure 2(a)). There were three studied areas on each substrate: in the beginning (1) in the middle (2) and in the end (3) of the arc motion track (figure 2(b)). On the presented photo of the cathode one can see also the discharge ignition area (4).

![Figure 2. AFM studied substrates placements (a); photo of electrode surface with the discharge trace (b).](image)

The experiments were made using different types of sputtered targets (both magnetic and non-magnetic (titanium)). The study of the substrates surfaces were made using scanning probe microscope (SPM) Certus Light (NanoScanTech, Russia). We used a probe cantilever NSC 15 with resonance frequency 325 kHz. The maximal scale of the scanning area is 100×100 um. The number of probed points for each dimension can be varied. The more points – the more detailed picture. However, it also dramatically increases the time of scanning and the cantilever wear. That’s why we had to make a number of preparatory researches before moving on to the actual study of the particles sputtering distribution. And these experiments showed that:

- There’s nearly zero differences between particles distributions between 100×100 and 25×25 um scanning areas. Of course, the picture of smaller scanning scale is 4 times more detailed with the same resolution. That’s why further on we used that scale with the resolution 1000×1000 points (the time of one line pass was 1 second). In order to make sure that the scanning area was averagely covered by particles, the area for 25 um square scanning was chosen only after 500×500 points 100 um square preparatory study.
• The results of 25×25 µm scanning area can be extrapolated to 5×5 mm square area. After comparing the results of studying five different areas of 5×5 mm square (in each corner and in the center) we found the differences in surface integral parameters (waviness and roughness) never exceed 10%.

• The information about transverse sizes of the particles can be obtained very easily using Phase Imaging mode. For example, in the figure 3, the results of the substrate scanning in the middle of the discharge trace are presented. One can see the results of two different modes used (amplitude mode (a) and phase imaging (b)). The particles size distribution at the phase imaging mode is very clear and contrast compared to the Amplitude mode, and most of them are around 0.3–0.5 µm in diameter.

![Figure 3. Substrate surface AFM scanning results in the amplitude (a) and phase imaging (b) modes.](image)

3. Results of researches
Mostly the particles are sputtered perpendicularly to the electrodes surface. It can be noticed from the figures 4 and 5, where we can compare the particles sputtering distribution for the substrates situated in the different places around the discharge area. The substrates from figure 4(a),(b) and figure 5(a) were placed in the area 2 from figure 2 (figure 4(a) – near the cathode, figure 4(b) – distant over the electrodes, figure 5(a) – near the anode). The substrate from figure 5(d) was placed on the way of the discharge motion.

![Figure 4. Results of AFM scans of the substrates surfaces from different locations, near the cathode (a) and distant over the electrodes (b).](image)
Figure 5. Results of AFM scans of the substrates surfaces from different locations, near the anode (a) and place on the way of the discharge motion (b).

It’s obvious that:
- The particles on the surface of the substrate near the anode (figure 4(a)) are smaller than the ones near the cathode (figure 5(a)).
- Highest amount of particles was found on the surface of substract places right over the electrodes with the major part of particles minimal sizes 0.1–0.5 um. These particles are highly visible In Phase Imaging mode at figure 6 at 10×10 um scale.

Figure 6. Results of AFM scanning of the substrate surface with particles on it at phase imaging mode.

Figure 7. Results of AFM scanning of the substrates surfaces placed over the electrodes.
• The results of scanning also heavily depend on the studied area of the substrate choose. In particular, in the figure 7 the scanning results of the substrate placed over the electrodes. In the area, corresponding the beginning of the discharge trace (a) we find a minor number of particles, which are relatively massive. In the middle (b) a significant number of small particles. Studying their profile leads to the conclusion that they were moving nearly orthogonally to the substrate. By the end of the trace (c) the number of particles decreases and they become bigger once again.

4. Conclusions
The sizes and the number of particles are heavily dependent of the substrate placement. The first two discharges are cleaning and preparing the surface of the electrodes, so the surfaces of the substrates for new and a bit worn out electrodes sputtering are different. After the third discharge under the same conditions (the voltage and the capacity of the batteries, the height of the semi-electric inset) the average number of the particles and their size remains the same in all the experiments. The biggest particles (up to 3 um) were found on the substrate which was placed on the discharge motion direction.

The particles themselves drawn up along the discharge motion which shown that particles were moving angled to the substrate and still were fluid when touched it.

References
[1] Gorokhov M V, Kozhevin V M, Yavsin D A et al. 2012 Journal of Technical Physics 6 135–41
[2] Gubin S P, Koksharov Yu A, Khomutov G B and Yurkov G Yu 2005 Uspekhi Khimii 6 539–74
[3] Goncharov V D and Samsonov D S 2015 Journal of Technical Physics 5 37–42
[4] Yaskardin R V and Sorokin K S 2016 IEEE NW Russia Young Researchers in the Electrical and Electronic Engineering Conference (2016 ElConRusNW)
[5] Kostrin D K et al. 2016 Journal of Physics: Conference Series 729 012030