# Formation and dynamics of active Brownian particles in gas-discharge plasma

***Senoshenko R.V.* [1,2,@], *Kononov E.A.* [1], *Vasiliev M.M.* [1,2] *and Petrov O.F.* [1]**

[1] Joint Institute for High Temperatures of the Russian Academy of Sciences, Izhorskaya 13 Bldg 2, Moscow 125412, Russia
[2] Moscow Institute of Physics and Technology, Institutskiy Pereulok 9, Dolgoprudny 141701, Russia
[@] Correspondence: Senoshenko@mail.ru

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## Introduction

Active particles are able to convert external energy into their own directed motion. Dust plasma is one of the most common active systems in the nature, containing charged micro- and nanoparticles. In gas-discharge plasma such systems of active Brownian particles can exchange energy and matter with the environment. A characteristic property of metal-coated microparticles is their modification in the plasma medium. When they are in a gas-discharge plasma, such particles can absorb the external radiation and become active. The results of experimental obtaining of active Brownian particles in gas-discharge plasma and investigation of their motion under the action of laser radiation using different metals (aluminium, copper and nickel) as a cathode are presented.

## Experimental setup

The experiment was done in a vertical glass tube with a length of 1250 mm and an inner diameter of 40 mm with horizontal axial branches for the cathode and anode (Fig. 1). The lower tube end was closed and the upper part of the tube was connected to a vacuum system. The tube was filled with argon to an effective pressure of 13.3 Pa, which was continuously supplied into it during the experiment to keep the constant pressure in the system.

The cathode was composite and consisted of three separate metal cylinders 8 mm high and 12 mm in diameter made of different metals (copper, nickel and aluminium), each of which was connected in parallel through a vacuum connection to a constant current source of 1 mA. A potential of 100 V was applied to the anode.

After the discharge stabilisation, the cathode operating material was changed one by one. Particle generation at synchronous connection of all three cathodes was also investigated.

A solid-state laser with a wavelength of 532 nm and an intensity of 0.15 W/cm$^2$ was applied to the particles in the first stratum of the discharge. A homogeneous beam with a diameter of 30 mm was oriented normally to the tube. The observed motion was recorded by a high-speed video camera with a recording rate of 200 fps at a resolution of 1024x1024 pixels.

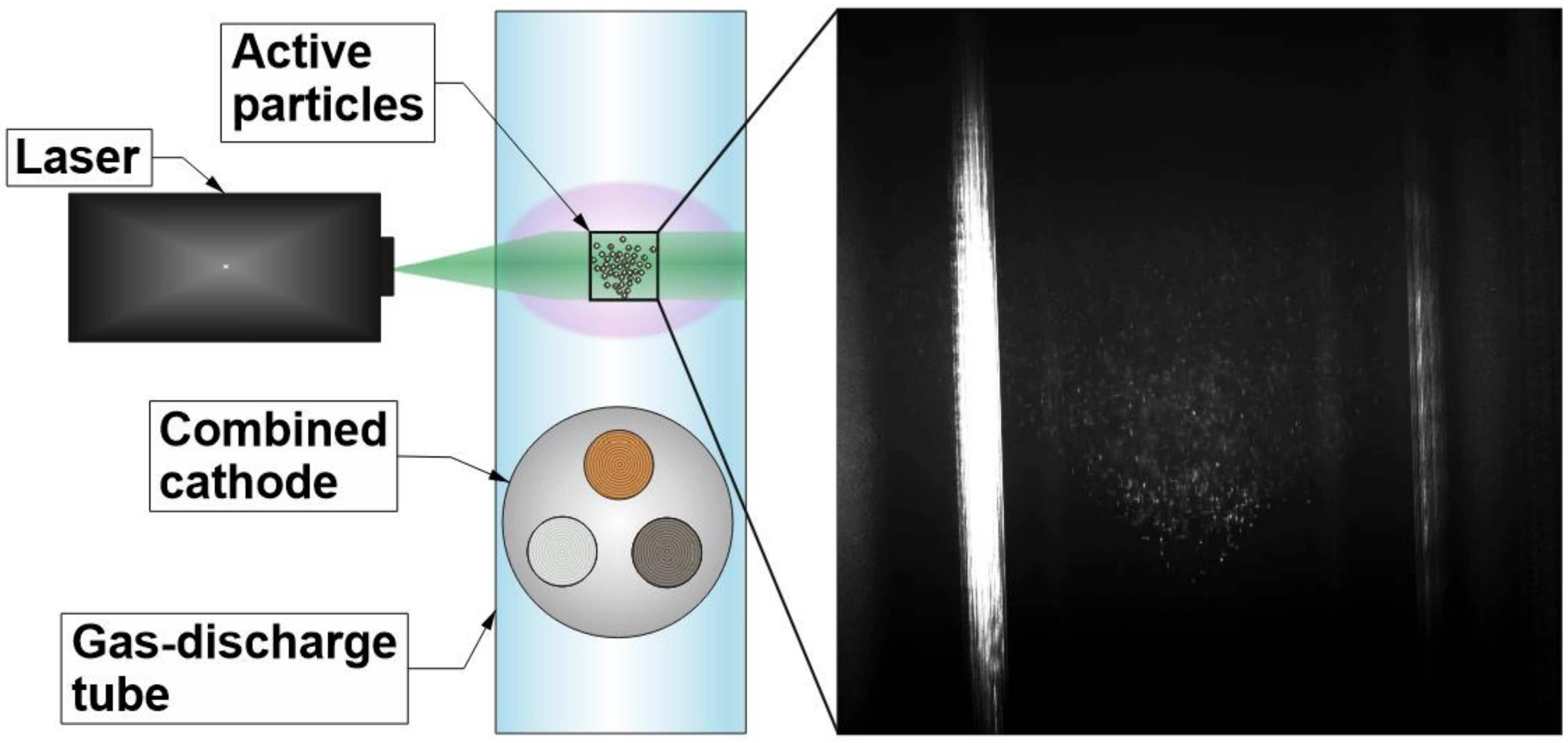


**Figure 1.** Scheme of an experimental setup and example of the generated cloud of active particles.

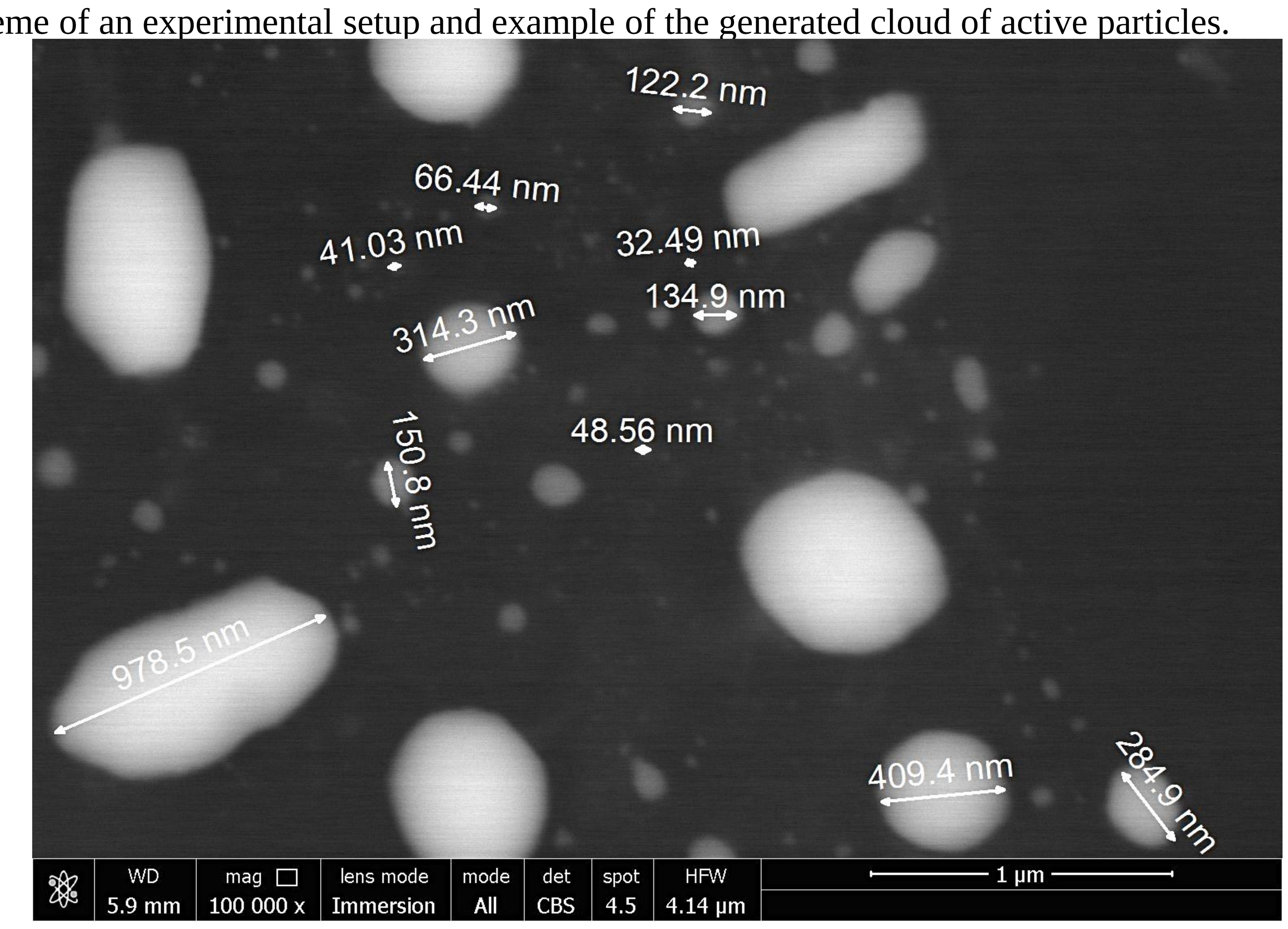


**Figure 2.** Image of synthesised active particles from scanning electron microscope.

## Results

The formation of submicron and micron particle clouds in the strata of the positive discharge column was observed (Fig. 2). The rate of particle condensation and their dispersion depended on the cathode material. The stratum volume was filled with copper cathode in 120 s, and with aluminium cathode in 280 s, with nickel cathode condensation of large particle units was observed after tens of minutes. For the aluminium cathode, stratum filling was observed to be mostly filled with submicron particles, the number of large particles was a few tens, and the configuration of the fields in the stratum can be determined from the shape of the cloud. The charge of submicron particles was significantly different from that of large particles. For the copper cathode, no submicron particles were observed, and the number of large particles was a few hundreds.

Collective oscillating motions of clouds of condensed particles were observed. For the aluminium cathode, the wavelength was 1299 µm and the frequency was 13.3 Hz. For the copper cathode, the wavelength was 657 µm and the frequency was 7.7 Hz. Intense particle ablating on the cathode surface was also observed, with a flash frequency of 20 Hz for the aluminium cathode and 10 Hz for the copper cathode. No flashes were observed for the nickel cathode. The data obtained show the spread of metallic impurities throughout the gas discharge.

In the optical spectra recorded from the glow discharge plasma, the lines of neutral and ionised metal atoms from the cathode material are very weakly observed (Fig. 3). Most of the vacant metallic impurity is deposited on the walls of the discharge tube or condensed into dust clouds.

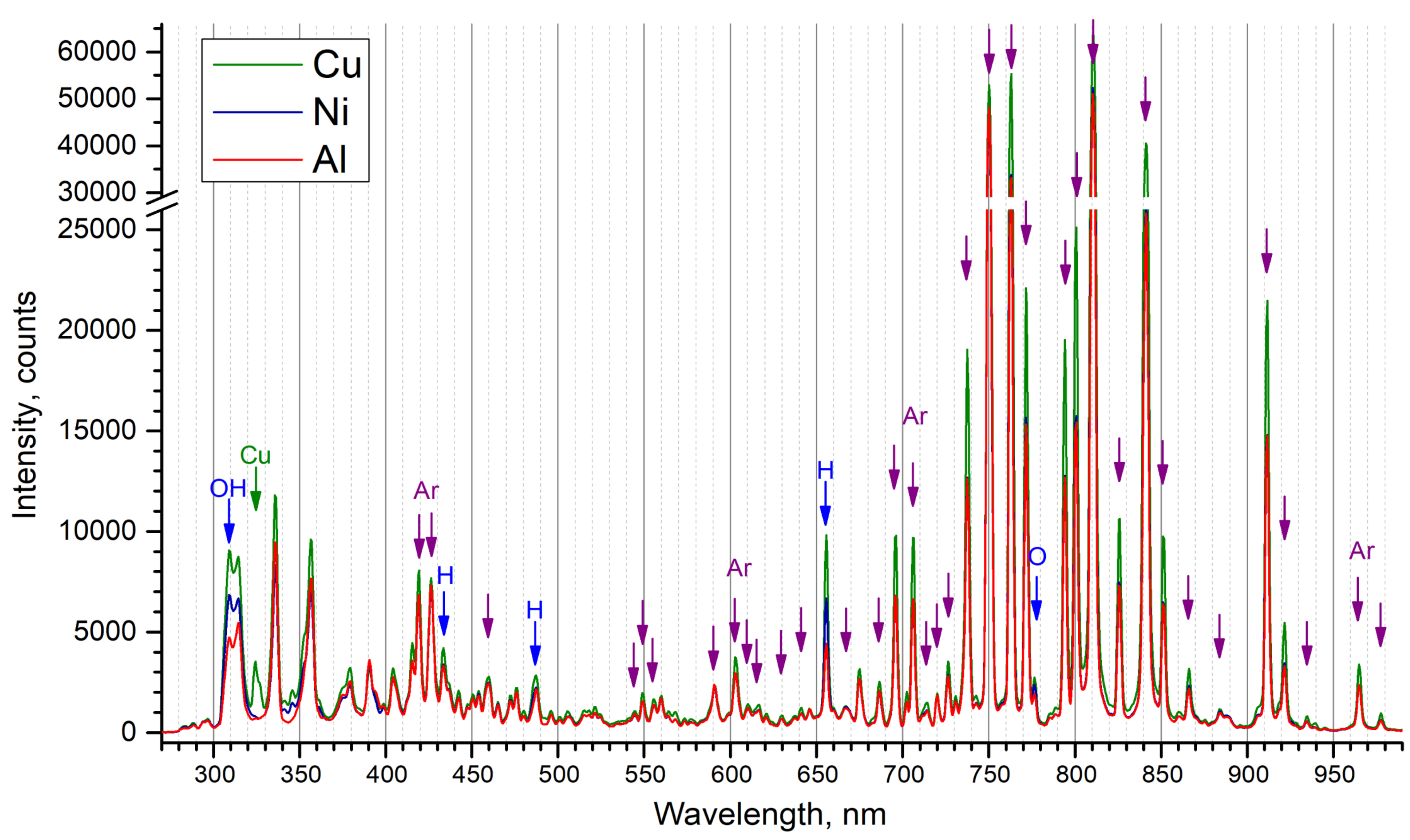


**Figure 3.** Plasma luminescence spectrums in the near-cathode region of glow discharge when using copper, nickel and aluminium cathodes - green, blue and red lines.

## Conclusion

The formation of clouds of submicron and micron active particles was experimentally observed. The rate of their synthesis depended on the cathode material. It is shown that the cathode used material is affected by effective sputtering. The lines of neutral and ionised metal atoms of the cathode are observed in the optical spectra.