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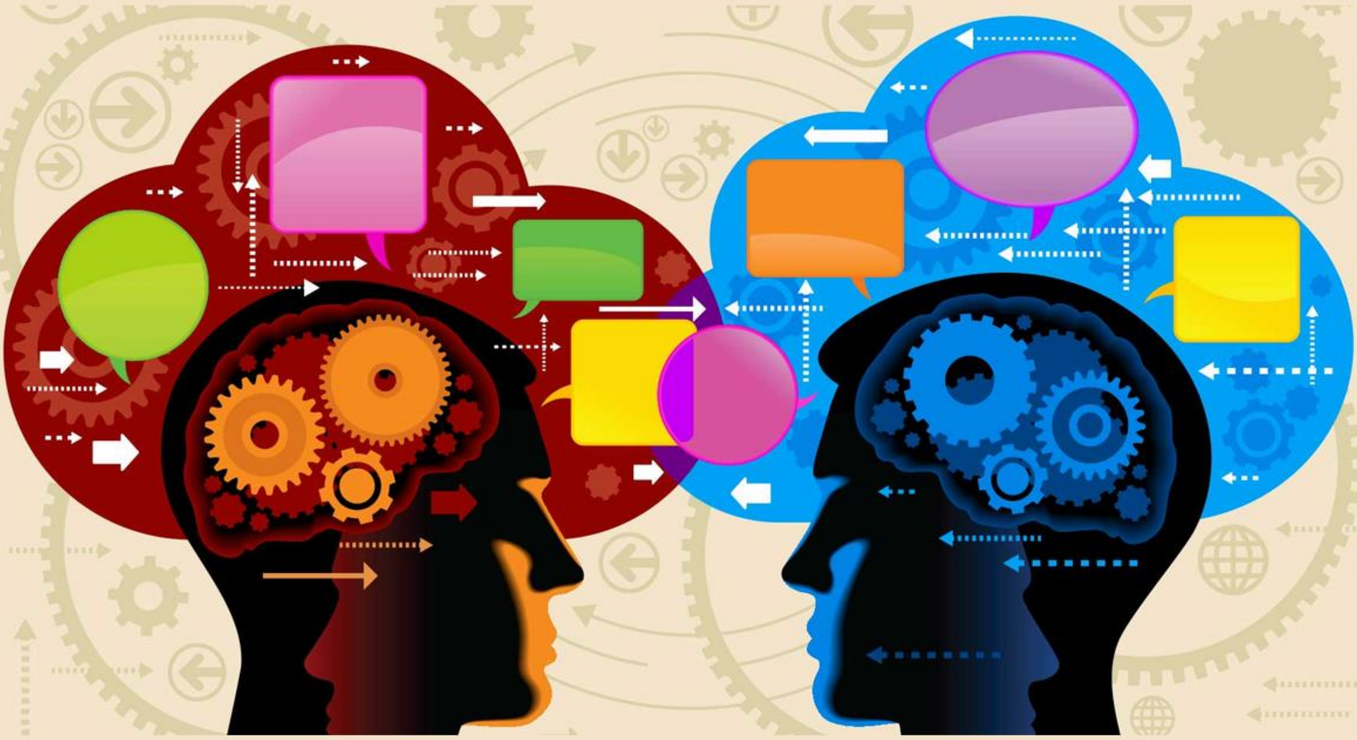

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ФИЗИКО-МАТЕМАТИЧЕСКИЕ НАУКИ

ELECTROLUMINESCENCE OF ALUMINUM OXIDES NANOPARTICLES IN OVERSTRESSED NANOSECOND DISCHARGE PLASMA IN HIGH PRESSURE AIR

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Introduction. The results of a study of the characteristics and kinetics of processes in a heterogeneous plasma based on mixed flows of a buffer gas -argon, an oxidizing agent - water molecules and aluminum dust are presented in [1]. In such a plasma, the gas component, liquid droplets, solids and plasma simultaneously coexist. The work is related to the search for effective and cheap hydrogen production technologies based on the plasma-chemical oxidation of aluminum in water vapor. As a result of such a stimulated process, aluminum dioxide is formed and thermal energy is released [2]. Moreover, the value of obtaining a hydrogen molecule does not exceed 1.5 eV/molecule, which is much more economical than the hydrolysis method of producing hydrogen.

When using a subnanosecond high-voltage discharge between aluminum electrodes, the results of studying the characteristics of aluminum atmospheric pressure plasma with the ecton mechanism of aluminum vapor injection are presented in [3].

The use of aluminum plasma and oxygen-containing gases can be used for the synthesis of nanostructures of aluminum oxides, which in the form of thin films or powders can be used in the form of luminophores, which stimulates the study of new physical methods of their synthesis [4, 5].

Currently, there is practically no work on the synthesis of alumina-based nanostructures using pulsed discharges with an ectonic mechanism [6] for the injection of aluminum vapor into an oxygen-containing gas plasma. The results of such studies of the synthesis conditions and some characteristics of copper, zinc, and iron oxides nanostructures are presented in [7–9].

This paper presents the results of a study of the synthesis conditions and the electroluminescence characteristics of aluminum oxide nanostructures that were synthesized in a plasma of an overstressed nanosecond discharge between aluminum electrodes in air and argon.

Aim. The aim of our study was to investigate the electroluminescence of aluminum oxide nanoparticles in plasma of an overstressed, bipolar nanosecond discharge ignited between aluminum electrodes at an interelectrode distance of 2 mm and an air pressure in the range of 50-202 kPa.

Materials and methods. The scheme of discharge chamber with a system of electrodes and a substrate for deposition of nanostructures is presented in our work [10].

To ignite the discharge, high voltage bipolar pulses with a total duration of 50-100 ns and an amplitude of ± (20-40) kV were applied to the electrodes.

The plasma volume depended on the repetition rate of voltage and current pulses and in the frequency range 10–150 Hz increased from 3 to 25 mm^3. The discharge was photographed using a digital camera, and as a scale, the distance between the electrodes was used to determine the plasma volume. With an interelectrode distance of 1-2 mm, the discharge gap was highly overstressed. The nanosecond discharge at a pressure of p = 5–202 kPa was quite uniform, which was caused by the action of the preliminary ionization system, which in this case can be played by a runaway electron beam and the accompanying x-ray radiation.

The voltage pulses at the discharge gap and the discharge current were measured using a wide-band capacitive divider, a Rogovsky coil, and a 6-LOR 04 wide-band oscilloscope. The temporal resolution of this recording system was 2-3 ns. The spatial characteristics of the discharge were studied using a digital camera. The pulse repetition rate varied in the range f = 35-1000 Hz. The plasma radiation spectra were recorded using an MDR-2 monochromator, a FEU-106 photomultiplier, a direct current amplifier, and an electronic potentiometer. The radiation of the discharge plasma was analyzed in the spectral range of 200-650 nm. The plasma radiation registration system was calibrated by the radiation of a deuterium lamp in the spectral range of 200-400 nm and a gang lamp in the range of 400-650 nm. The pulsed electric power of an overstressed nanosecond discharge was determined by graphically multiplying the waveforms of voltage and current pulses. The time integration of the pulsed power made it possible to obtain energy in one electric pulse, which was introduced into the plasma.

Thin nanostructured films based on the degradation products of aluminum electrodes and air molecules were deposited during 2-3 hours of operation of the reactor in the form of a thin transparent film on glass or quartz substrates, which were installed at a distance of 3 cm from the center of the discharge gap. The resulting films were studied for light transmission in the visible wavelength range. The experimental technique and technique for recording the transmission spectra of synthesized films are described in [11, 12].

Results and discussion. In Fig. 4 the characteristic emission spectra of an overstressed nanosecond discharge plasma between aluminum electrodes in air is shown. The experiments with argon, which were carried out in the same pressure range as with air, were also performed and demonstrated the absence of emission bands of nanostructures of aluminum oxides in an inert gas plasma (in the absence of oxygen molecules).

It can be seen from these spectra that the intensity of the glow of the discharge plasma in air at all the pressures studied by us exceeds the radiation intensity of spectral lines and discharge bands in argon. In the emission spectra of air plasma with a small admixture of aluminum vapor, radiation was detected at the transitions of atom and singly charged aluminum ion, nitric oxide radicals and nitrogen molecules, as in the emission spectra of a subnanosecond plasma in a similar medium [3]. In an argon-based discharge, radiation was predominantly recorded at transitions of an atom and an aluminum ion.

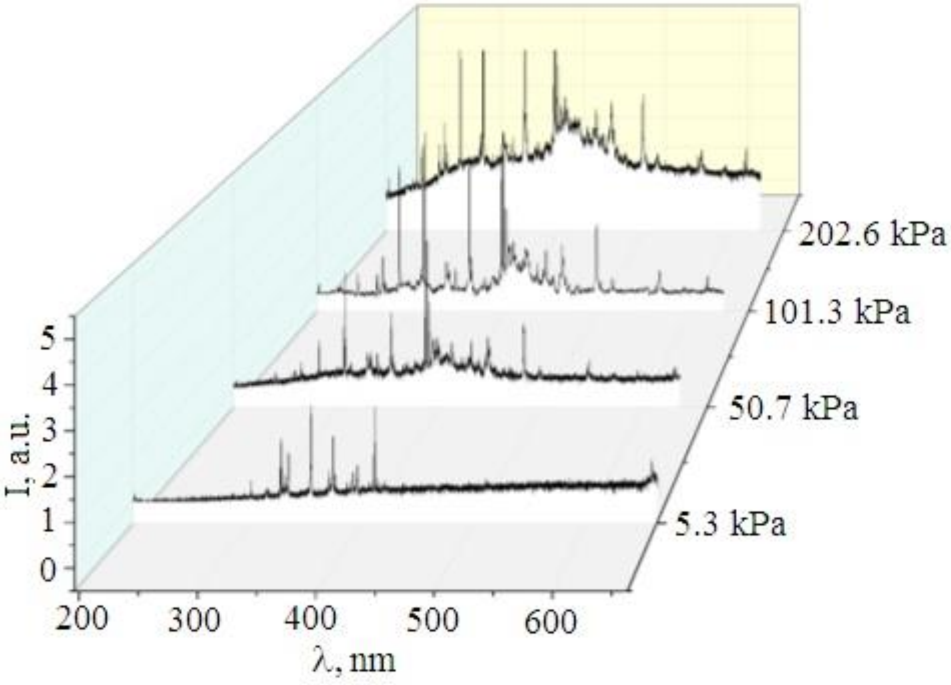

Fig.1. Emission plasma spectra of an overstressed nanosecond discharge at different air pressures (5.3; 50.7; 101.3 and 202.6 kPa).

In a discharge in air mixtures with a small admixture of aluminum vapor in the emission spectra (Fig. 1), broad emission bands with maxima in the spectral ranges of 410–420 nm and 300–390 nm are recorded. The highest radiation intensity of these bands was obtained at a maximum air pressure of 202 kPa. In argon-based mixtures, these bands are absent in the discharge emission spectra.

It was noted in [4] that a wide emission band was observed with a maximum at a wavelength of 415 nm in the photoluminescence spectrum of anion-defective single crystals of nanostructured ceramics based on alumina when the corresponding samples were excited by radiation with a wavelength of 205 nm. This band coincides with that obtained in the present experiment. It is interpreted as the luminescence band of F centers (the transition is 1S - 3P with the maximum of the emission spectrum at an energy of 3.0 eV and a decay time constant of 36–40 ms).

The transmission spectrum of a film based on aluminum oxide nanostructures synthesized at room temperature on a glass substrate in the visible region of the spectrum has been studied and it is shown in Fig.2.

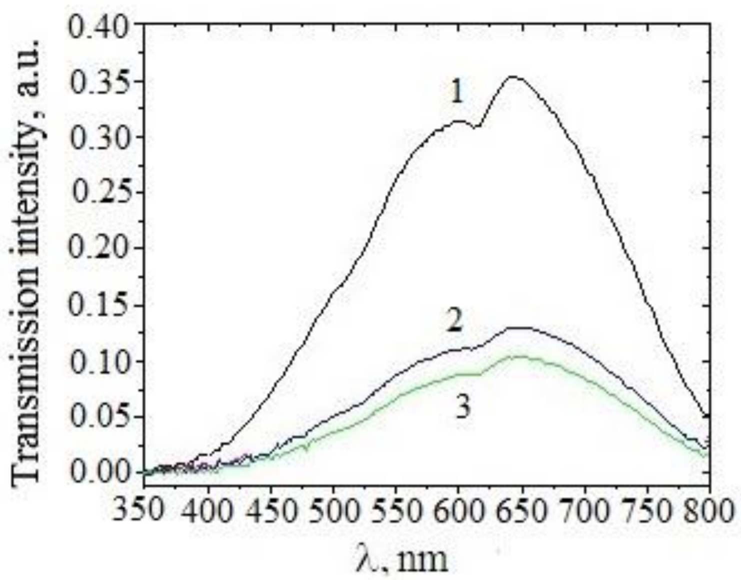

Fig.6. The transmission spectra of a nanostructured alumina film on a glass substrate in the spectral region of 350-800 nm (band lamp): 1 is pure glass, 2 is a film obtained by sputtering aluminum electrodes in air at a pressure of 101 kPa, a current pulse repetition rate of 40 Hz and a sputtering time of 3 hours, 3 is a film synthesized by replacing aluminum electrodes with chalcopyrite-$CuInSe_2$ electrodes synthesized under the same conditions as and film 2.

The obtained film was characterized by a weak transmission of radiation in the visible wavelength region, comparable with the transmission of radiation by a chalcopyrite film (which is such as a result of strong light absorption by chalcopyrite [13]). As is known, chalcopyrite films are used in photovoltaic devices (solar cells) and are effective converters of light into electricity [14]. According to [5], films based on nanostructured alumina ceramics are practically not transparent to the visible region of the spectrum; their transmission begins to increase in the spectral range of 0.8–2.0 μm from 1-3 to 25%.

Conclusions. Thus, it was found that the plasma of an overstressed nanosecond discharge, formed under the action of a packet of 5-10 ns voltage pulses with a total duration of 100-120 ns, between aluminum electrodes at air pressures of 50-202 kPa, pulse discharge power of 3-6.5 MW and the energy input per pulse 110-153 mJ is a source of luminescence of aluminum oxide nanoparticles in the form of a wide band, which is in the spectral range 300-430 nm. The detected broad luminescence bands from a nanosecond discharge plasma are assigned to the radiation of the F - and F + centers of oxygen vacancies in nanostructured alumina ceramics. Upon deposition of degradation products of electrodes and air molecules in a plasma on a glass substrate, films based on aluminum oxides were obtained, which are characterized by low transparency in the visible region of the spectrum.

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