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Conditions for The Deposition of Selenium Thin Films from the Plasma of an Overvoltaged Nanosecond Discharge

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Abstract

This paper presents the characteristics of an overvoltage nanosecond discharge in argon (p(Ar) = 101 kPa) and a distance between Se electrodes of 2 mm. Selenium vapors are introduced into the discharge gap during microexplosions of inhomogeneities on the working surfaces of the electrodes in a strong electric field. This creates conditions for obtaining thin films of selenium, which can be transferred to a solid dielectric substrate located near the discharge. The main excited components of a discharge plasma based on a mixture of argon and selenium were determined.

Electron energy distribution functions, mean energies, temperature, electron density in the plasma, specific discharge power losses for the main electronic processes and their rate constants depending on the value of the E/N parameter were calculated by solving the Boltzmann kinetic equation in a vapor-based discharge plasma selenium in argon. Key words: overvoltage nanosecond discharge, argon, selenium, pulse electric power of the discharge, radiation spectrum, numerical modeling, plasma parameters.

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Introduction

Selenium nanopowders and drugs made on their basis are widely used in agricultural and biomedicine [1-3]. Papers analyzed various applications of selenium nanoparticles in animal husbandry, where selenium nanoparticles (selenoproteins) can be used to regulate important physiological processes [3, 4]. It is also indicated here that the use of selenium in nanoform is promising due to significant bioavailability and low toxicity of such compounds. The synthesis of compounds based on nanoselenium was carried out mainly by biological and chemical methods [4-5]. Thus, the monograph analyzed environmentally friendly biotechnologies of "green" nanoselenium synthesis by using plants, bacteria, fungi, algae, and viruses; the significance of the factors regulating the biosynthesis of plants is considered, and the main properties of selenium nanoparticles from the point of view of their application in biology and agriculture are also established [4].

The paper reported on the preparation of selenium nanobiocomposite by chemical reduction of sodium selenite in solutions of alginate chitosan polyelectrolyte complexes. The selenium nanobiocomposite consisted of spherical nanoparticles about 40 nm in size [5]. The study of biological properties of selenium nanocomposites revealed an increase in the energy of germination and germination of certain varieties of pea and barley seeds and an increase in the mass of dry matter of the roots and the above-ground part at its concentration of 20 mg/l.

Along with the chemical and biological methods of synthesis of nanoselenium and compounds based on it in the form of thin films or finely dispersed powders, the method of deposition of micro-nanostructures of oxides of transition metals and silver sulfide from an overvoltage nanosecond discharge plasma (OND) may be promising) of atmospheric pressure between electrodes made of metals (Cu, Fe, Zn, Al) and a superionic conductor - silver sulfide (Ag2S) [6-8]. The solid dielectric substrate near the OND electrode system was covered with thin films, and a small amount of them was concentrated at the bottom of the dielectric discharge chamber. The introduction of the material took place at low temperatures of the chamber walls due to ex-

plosions of inhomogeneities of the electrode surface in a strong electric field [9]. The perspective of the synthesis of nanostructures using spark discharge and laser plasma was also indicated in the article [10].

For the synthesis of micro-nano-selenium thin films, it is important to optimize the operation of such a gas discharge reactor using argon as a buffer gas. The parameters and characteristics of the OND plasma between selenium electrodes at atmospheric pressure of argon, which can be used for the synthesis of thin selenium films and for the production of finely dispersed selenium powder, are presented in the article.

Conditions of the Experiment

The characteristics of the OND were studied using a discharge chamber and an experimental setup, which are given in [6,7]. The OND between the electrodes, which were made of selenium, ignited at an inter-electrode distance of 2 mm.

To ignite the discharge, high-voltage pulses with a duration of 50-150 ns and an amplitude of ± (20-40) kV were applied to the electrodes of the discharge chamber. The frequency of following voltage pulses was 35-80 Hz. Oscillograms of voltage pulses on the discharge gap and oscillograms of discharge current pulses were recorded using a broadband capacitive voltage divider, a Rogovsky coil and a 6LOR-04 oscilloscope. By graphically multiplying the current and voltage pulse oscillograms, the time distribution of the pulsed energy contribution to the plasma of the OND was obtained. Integrating the pulse power over time made it possible to determine the electrical energy introduced into the plasma during one sequence of voltage and current pulses.

A digital two-channel spectrometer with astigmatism compensation "SL-40-2-1024USB" was used to record plasma radiation spectra. Working range of the spectrometer: 190-1200 nm.

At an interelectrode distance of 2 mm, the discharge gap was overstressed, which created favorable conditions for the formation of a beam of high-energy "runaway electrons" that enter the mode of continuous acceleration and leave the discharge gap [11].

Under the action of a beam of "runaway electrons" and accompanying X-ray radiation, which perform the role of preionization, a fairly homogeneous discharge was formed in the discharge gaps, even with a non-uniform distribution of the electric field intensity.

The discharge chamber was evacuated with a forevacuum pump to a residual pressure of 10 Pa, and then argon was pumped into the chamber to a pressure of 101 kPa. The diameter of cylindrical selenium electrodes was 5 mm, and the radius of rounding of their working end surface was the same and equal to 3 mm. The volume of the discharge depended on the frequency of following voltage pulses. The "point discharge" mode was achieved only at repetition rates of voltage pulses in the range f = 35-150 Hz.

Characteristics of OND

Studies of time-averaged images of a discharge in the argon-selenium gas-vapor mixture at an argon pressure of p = 101 kPa, which were obtained with a time exposure of ≈ 1 s, showed that this discharge had the appearance of a bright sphere with a central part with a diameter of ≈ 2-4 mm.

The voltage and current oscillograms of the OND between electrodes made of selenium in argon (at d = 2 mm) were similar to those of the corresponding oscillograms for also the OND in argon between electrodes made of zinc or silver [7]. As a result of the inconsistency of the output resistance of the high-voltage modulator to the voltage pulse with the resistance of the OND plasma, the discharge had an oscillatory character with voltage and current maxima of different polarity lasting ≈ 25-35 ns.

The impulse power of the OND in the argon-selenium gas-vapor mixture and the corresponding contribution to the plasma are shown in Fig. 1.

The amplitude of the largest voltage drop of different polarity on the electrodes was ≈ +17 and -7 kV, and the current +100 and -70 A. The amplitude of the first positive maximum of the voltage pulse was reached at the time t = 120 ns, and the corresponding current maximum was delayed relative to this maximum voltage for 20-25 ns. The first maximum pulse power of the OND was reached at time t = 130-135 ns from the beginning of the development of discharge processes and was 1.5 MW in size. This provided an energy contribution for one discharge pulse to the plasma of about ≈ 63.3 mJ.

In Fig. 2. the radiation spectrum of the OND plasma in a gas-vapor mixture of atmospheric pressure "argon-selenium" is given, and in Table 1. the results of the identification of the spectral lines of this spectrum are given. The reference books were used for deciphering the radiation spectra [12-14].

In the radiation spectrum of the OND in the argon-selenium gas-vapor mixture, the spectral lines of the selenium atom in the far UV part of the spectrum (lines 1-3; Fig. 2.) and the Se I line (No. 4-8) were observed against the background of the continuum emitted by the plasma in the spectral range of 270-1000 nm. The presence of minor air impurities in the argon and the residual air pressure in the discharge chamber after it was pumped out by the forevacuum pump led to the appearance of the intense spectral line 656.28 nm Hα of the hydrogen atom in the radiation spectrum (line No. 9; Fig. 2). Spectral lines No. 10-26 in the spectrum (Fig. 2.) are the characteristic lines of the argon atom, which were emitted by the OND plasma based on atmospheric pressure argon between electrodes made of metals or silver sulfide [7].

Separate spectral emission lines of the selenium atom (488.7; 706.2; 769.7; 800.0; 844.0; 927.1 nm SeI) were observed from the pulse-periodic barrier discharge plasma in the gas-vapor mixture "Ar-Se" at the temperature discharge cuvette with selenium - 200 0C, argon pressure - 50 kPa, selenium vapor pressure - 133 Pa at the frequency of voltage pulses - 5 kHz, voltage amplitude - 3 kV and current amplitude - 0.2 A [15]. At low temperatures of the order of 100-300 0C, the mass spectra of selenium vapors are dominated by polyatomic molecules of the Se8-Se5 type [16]. Therefore, in order to explain the formation of excited selenium atoms in plasma, the mechanism of energy transfer from argon atoms, which were at metastable levels, to polyatomic selenium molecules was discussed in [15].

In the conditions of OND with an ectonic mechanism of introduction of selenium vapors during microexplosions of inhomogeneities of the surface of selenium electrodes and a discharge current amplitude of the order of 100 A, the temperature in the discharge gap is high enough for thermal dissociation of complex molecules into selenium atoms. As can be seen from Fig. 1, the pulse power of the OND has two maxima, the first of which can be used to destroy polyatomic selenium molecules, and the second to excite atoms and diatomic molecules of selenium with electrons. The issue of energy transfer from metastable argon atoms and molecules to selenium molecules requires additional study. Therefore, the emission spectra of the OND plasma differed from the spectra given in the work [15].

When a beam of sulfur, selenium, and tellurium molecules was excited by an electron beam with an energy of 30 eV in high vacuum conditions, continuums of chalcogens were also observed in the visible and near-UV parts of the spectrum [16]. A triplet of the selenium atom with λ = 473.1 was also observed against the background of the continuum in 473.9; 474.2 nm. In our experiments, the emission of these spectral lines of the selenium atom also appeared against the background of the continuum, but the resolution of our spectrophotometer and their low intensity did not allow them to be separated and reliably observed (Fig. 2) [16].

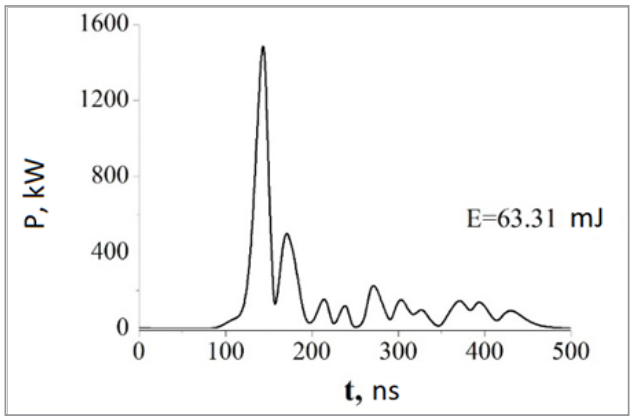

Figure 1: Pulsed power of the OND in a mixture of atmospheric argon and selenium vapor at f = 80 Hz, d = 2 mm.

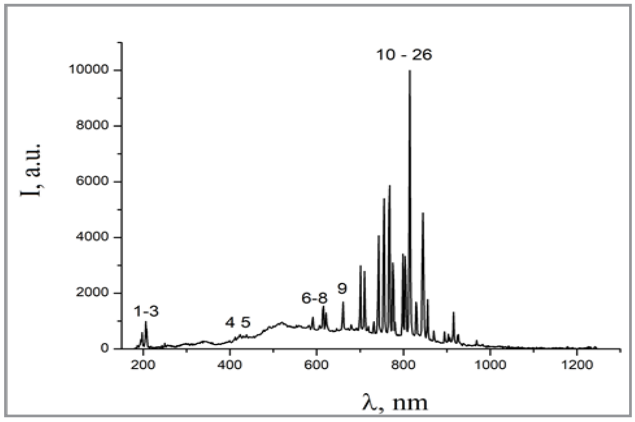

Figure 2: The emission spectrum of OND between selenium electrodes at atmospheric pressure of argon (f=80 Hz, d= 2 mm).

The selenium continuum in these experiments appeared in the spectral range of 300-550 nm. However, in our experiments with atmospheric pressure argon plasma, the brightness of the characteristic recombination continuum of argon probably significantly exceeded the brightness of the selenium continuum. Therefore, it was not possible to observe it in its pure form from the plasma of OND.

The nature of the continuum of argon plasma of the OND, which was ignited in argon and helium at atmospheric pressure between electrodes made of silver and silver sulfide, is illustrated by the radiation spectra shown in Fig. 3. As can be seen from Fig. 3, a wide continuum in the spectral range of 200-1100 nm is associated with thermal and recombination radiation of argon ions [20].

The continuum was practically absent in the radiation spectrum of the OND when replacing argon with helium under the same experimental conditions.

In work, based on the results of a study of the characteristics of a spark discharge in atmospheric pressure argon between metal electrodes (Al), an intense continuum in the wavelength range of 350-460 nm with a maximum at λ=420 nm was registered in the plasma radiation spectrum [21].

A decrease in the repetition frequency of pulses of the OND voltage from 80 to 35 Hz led to a decrease in the radiation intensity of all spectral lines. For example, the intensity of the 656.28 nm Hα spectral line decreased from 170 to 112 a.u.

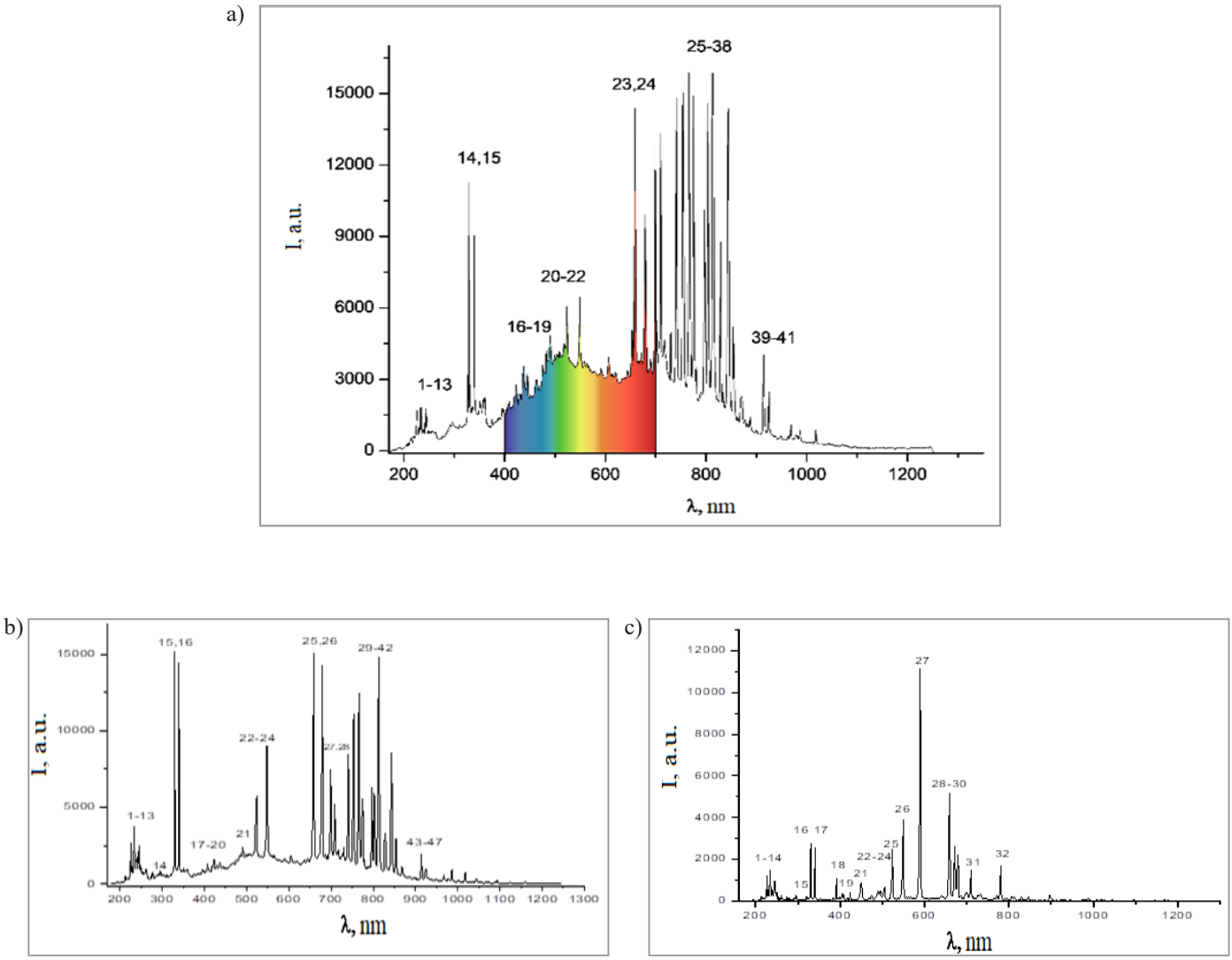

Figure 3: OND radiation spectra between electrodes made of silver (A) and silver sulfide (Ag2S) at p(Ar) = 101.3 kPa (B); p(No) = 101.3 kPa (C) f=1000 Hz, d=2mm [7].

Table 1: Results of identification of the radiation spectrum of the OND plasma between the selenium electrodes shown in Fig. 2.

№	λ tab, нм	I exp.,a.u. од.	Object
1	196.09	60	Se I
2	203.98	100	Se I
3	207.48	70	Se I
4	425.93	50	Ar I
5	433.11	51	Ar I
6	588.16	115	Se I
7	611.94	155	Se I
8	621.6	130	Se I
9	656.28	170	Hα

Parameters of the Plasma of OND

The parameters of the OND plasma in a mixture of argon with the addition of selenium vapor at atmospheric pressure (the ratio of components 101 : 0.3 kPa) were determined numerically and were calculated as total integrals of the electron energy distribution functions (EEDFs). EEDF were found numerically by solving the Boltzmann kinetic equation in the binomial approximation [22]. EEDF calculations were carried out using the program, where the effective cross sections for the interaction of electrons with selenium atoms are also included in the base of these effective cross sections [23]. Based on the obtained EEDF, a number of plasma parameters were determined depending on

the magnitude of the reduced electric field (the ratio of the electric field strength (E) to the total concentration of argon atoms and selenium vapor admixture (N)). The range of changes in the parameter E/N=1-1000 Td (1·10-17 - 1·10-15 V·cm2) included the values of the parameter E/N that were implemented in the experiment. These values of the E/N parameter were 326 and 153 Td for a time of 100 ns and 175 ns from the start of discharge ignition, respectively, at a total mixture pressure of 101300 Pa. The following processes are taken into account in the integral of collisions of electrons with atoms: elastic and inelastic scattering of electrons on selenium and argon atoms, dissociative excitation by electrons of energy levels of selenium atoms, from which radiation occurs at wavelengths (207.479 nm, 216.416 nm, 350.152 nm, 359.103 nm, 359.1 66 nm, 359.201 nm, 453.274 nm, 453.468 nm, 453.489 nm, 457.136 nm, 466.420 nm, 466.780 nm, 473.078 nm, 473.903 nm, 474.225 nm, 479.273 nm, 488.699 nm, 536.547 nm, 536.991 nm, 537.414 nm), ionization of selenium atoms (threshold energy 10.10 eV); excitation of the energy level of argon atoms (threshold energy 11.50 eV), ionization of argon atoms (threshold energy 15.80 eV), as well as electron-electron and electron-ion collisions [24, 25].

The selection of the effective excitation cross sections of selenium atoms based on work is due to the fact that this is currently the only article that contains the absolute values of the excitation cross sections of selenium atoms by low-energy electrons [24]. In only the relative measurements of such sections for individual spectral lines SeI, SeII at temperatures of selenium vapors in the range of 50-300 0C are given [20, 25]. As shown by the results of a mass spectrometric study of the composition of selenium vapors at a temperature of 200 0C the ratio of maxima I(Se+)/I(Se+2) = 0.7. Therefore, it is possible to assume that at temperatures higher than 300 0C, the composition of selenium vapors will be dominated by selenium atoms, with small impurities of diatomic selenium molecules [25]. Based on this, the effective excitation cross sections of selenium atoms given in can be considered to a large extent as the excitation cross sections of selenium atoms from the basic energy state of the selenium atom and to a lesser extent as the dissociative excitation of selenium atoms during the interaction of electrons with Se2 molecules [24]. According to the determination of the absolute cross sections of the excitation of selenium atoms was carried out at a temperature of 1230 0C, and it was stated that Se2 molecules predominate in selenium vapors at temperatures higher than 600-700 0C [24]. At the same time, the author referred to an article on mass spectroscopy of selenium vapors, published in 1982 [24]. However, these results contradict more recent results from mass spectroscopy of selenium vapors.

Fig. 4 shows the dependence of mean energy of electrons in a plasma on a mixture of argon with selenium vapors Ar : Se = 101000: 300 at a total pressure of p = 101300 Pa on the reduced electric field strength.

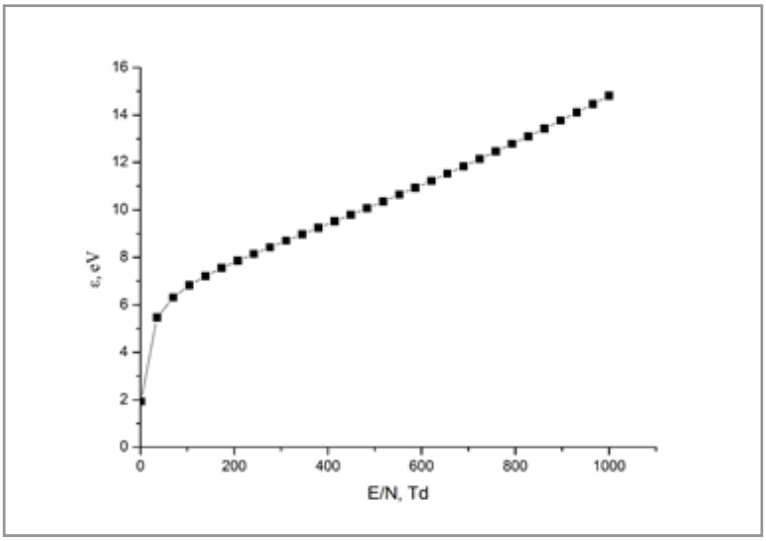

Figure 4: Dependency of the mean energy of electrons in the plasma of a vapor-gas mixture of Se-Ar=300 Pa – 101000 Pa on the reduced electric field strength.

The mean energy of the discharge electrons for the vapor-gas mixture of argon-selenium = Ar : Se = 101000 : 300 Pa increased from 1.936 to 14.81 eV with an increase in the reduced electric field strength from 1 to 1000 Td (Fig. 4). At the same time, an increase in the rate of its change was observed in the range of values of the parameter E/N = 1-35 Td. For a time of 100 ns and 175 ns from the start of the ignition of the discharge, the mean energies were 8.70 and 7.23 eV, respectively, which corresponded to their plasma temperatures of 100.92 0K and 83.86 0K (table 2).

Table 2. Transport characteristics of electrons (mean energy (ε), temperature (T0K), drift velocity (Vdr.) and concentration (Ne) of electrons) in a discharge in a mixture of argon with selenium vapors at a ratio of components of 101000 : 300 Pa for a time of 100 ns and 175 ns from the start of discharge ignition.

Table 2: Transport characteristics of electrons (mean energy (ε), temperature (T0K), drift velocity (Vdr.) and concentration (Ne) of electrons) in a discharge in a mixture of argon with selenium vapors at a ratio of components of 101000 : 300 Pa for a time of 100 ns and 175 ns from the start of discharge ignition.

τ, ns	E/N, Td	Mixture: Se-Ar=300 – 101000 Pa			
		ε, eV	T0, K	Vdr., m/s	Ne, m-3
100	326	8.70	100 920	2.2·105	1.45·1019
175	153	7.23	83 868	1.1·105	2.03·1020

The values of the electron drift velocity were 2.2·105 m/s for the plasma field strength of 8·106V/m and 1.1·105 m/s for the plasma field strength of 3.75·106 V/m, which was reached at the time of 100 ns from the start of the breakdown between the electrode gap (voltage pulse amplitude value of 16,000 V) and at the time 175 ns from the start of the breakdown of the interelectrode gap (voltage pulse amplitude value of 7.5,000 V), respectively. The value of the electron concentration was 1.45·1019 m-3 – 2.03·10 20 m-3 at a discharge current density in the range: (5.1 – 35.7) · 105 A / m2 on the surface of the electrodes (S = 0.196·10-4 m2) for the reduced electric field intensity E/N=326 Td, which existed on the discharge interval at the time of 100 ns and for the reduced electric field intensity E/N=153 Td, which existed on the discharge interval at the time of 175 ns.

In Fig. 5. the dependence of the specific losses of the discharge power on the processes of collisions of electrons with selenium and argon atoms on the value of the parameter E / N in the plasma based on the mixture Ar : Se = 101000 : 300 Pa is presented.

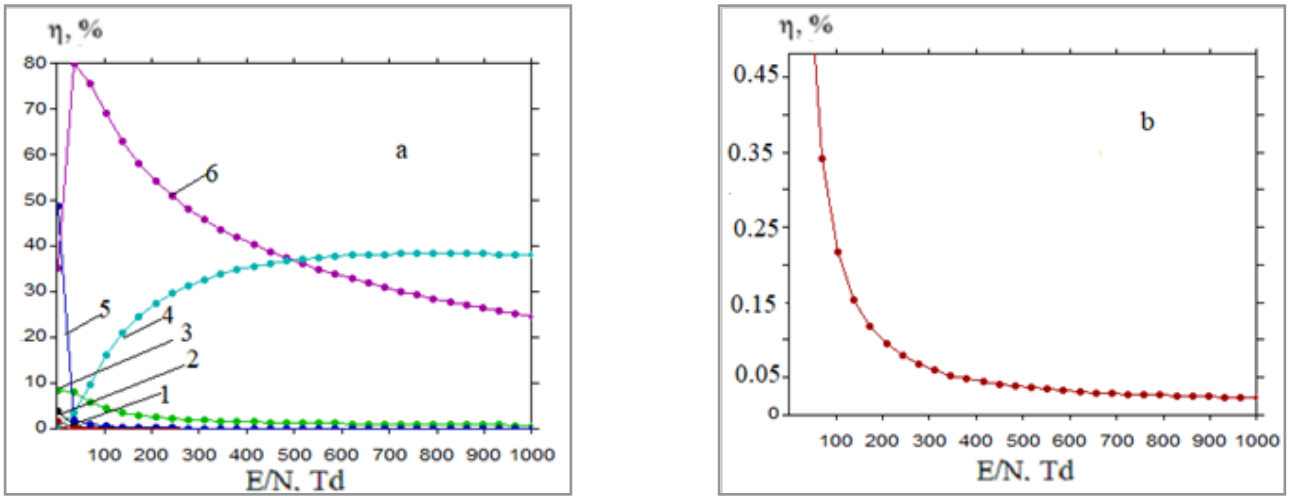

Figure 5: (a, b) Dependency of the specific discharge power losses on the processes of electron collisions with selenium and argon atoms on the reduced electric field strength in the plasma based on the mixture Se : Ar =300:101000 Pa: 1-excitation of the energy level of the selenium atom (threshold energy 6.48 eV), 2 - a, b-excitation of the energy level of a selenium atom (threshold energy 6.37 eV), 3- ionization of a selenium atom (threshold energy 10.10 eV), 4- ionization of an argon atom (threshold energy 15.80 eV), 5- elastic scattering of electrons on an argon atom, 6- excitation of the energy level of an argon atom (threshold energy 11.50 eV).

Specific discharge power losses in a mixture of selenium and argon vapors due to inelastic collision processes of electrons with the components of the mixture for a reduced electric field strength of 326 Td are maximal for excitation of the energy level of an argon atom (threshold energy of 11.50 eV) and ionization of an argon atom with a threshold energy of 15.8 eV (Fig. 5., curves 6 and 4) and reached 45.7% and 32.7%, respectively. And for the reduced field strength E/N=153 Td, which appeared at time t = 175 ns from the beginning of the breakdown of the plasma gap, they did not exceed 63.0% and 20.8%, respectively.

For selenium atoms, the maximum specific discharge power loss (3.9%) was observed for the excitation of the term 4S 5s 5S2 from which radiation at a wavelength of 207.48 nm was observed (Table 1) at a reduced electric field strength of 1 Td, and for reduced electric field strengths of 326 Td and 153 Td 0.06% and 0.15% (Fig. 5. a, b).

As the value of the E/N parameter increased to 1000 Td, the specific losses of the discharge power in the mixture decreased, except for the losses due to ionization of atoms (Fig. 5, curve 4). The rate of rise and fall of discharge power losses due to the processes of excitation of electronic states and ionization and its magnitude are related to the nature of the dependence of the effective cross sections of inelastic processes of collisions of electrons with the components of the mixture on the energies of electrons, their absolute values, with the dependence of the electron distribution function on the values of the reduced field strength and threshold energy values of the process [6].

The total losses of the specific power of the discharge due to the inelastic processes of electron collisions with argon and se-

lenium atoms were 5.176·10-14 eV m3/s and 1.267·10-14 eV m3/s for E/N = 326 Td and 153 Td, respectively, and they were larger by approximately three orders of magnitude compared to elastic losses (table 3,fig.6).

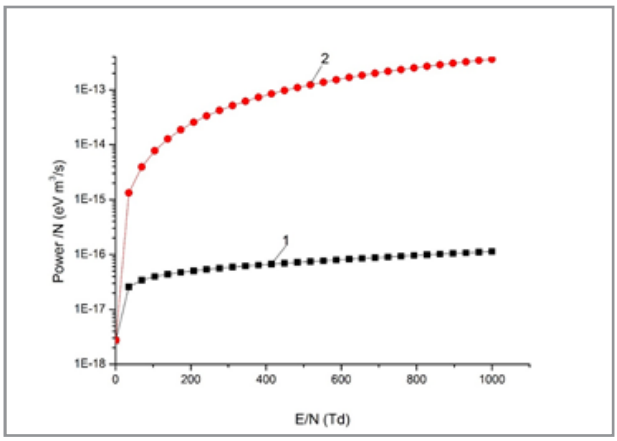

Figure 6: Dependency of the specific discharge power losses on elastic (1) and inelastic (2) processes on the reduced electric field strength of the discharge on the mixture: Se-Ar=300 - 101000 Pa.

Table 3: The value of the specific power of discharge losses due to elastic and inelastic processes of electron collisions with argon and selenium atoms from the reduced electric field strength in the plasma of the vapor-gas mixture Ar– Se =101000: 300 Pa for the reduced electric field strength of 326 Td and 153 Td.

Mixture: Se-Ar=300 Pa - 101000 Pa		
E/N, Td	**Elastic, Power /N (eV m3/s)**	**Inelastic, Power /N (eV m3/s)**
326	0.5900E-16	0.5176E-13
153	0.4378E-16	0.1267E-13

In fig. 7. the results of the numerical calculation of the dependence of the rate constants of collisions of electrons with argon and selenium atoms on the value of the E/N parameter in the mixture of argon and selenium vapor for the ratio of partial pressures in the mixture of 101000: 300 Pa are presented. The rate constants varied in the range of k≈1.7·10-21 – 3.4·10-12 m3/c, which is related to the values of the absolute effective cross sections of the respective processes. For selenium atoms (Fig. 7 b), they vary in the range of 1.1291·10-17 – 6.8 ·10-15 m3/s for the reduced electric field strength E/N=1 -1000 Td. And for the reduced electric field strength E/N=326 Td, which existed on the discharge interval at the time instant of 100 ns, and for the reduced electric field intensity E/N=153 Td, which existed on the discharge interval at the time instant of 175 ns, the rate constants excitation of the upper term of selenium (4S 5s5S2) had values of 2.028·10-15 m3/s and 1.351·10-15 m3/s, respectively (table 4).

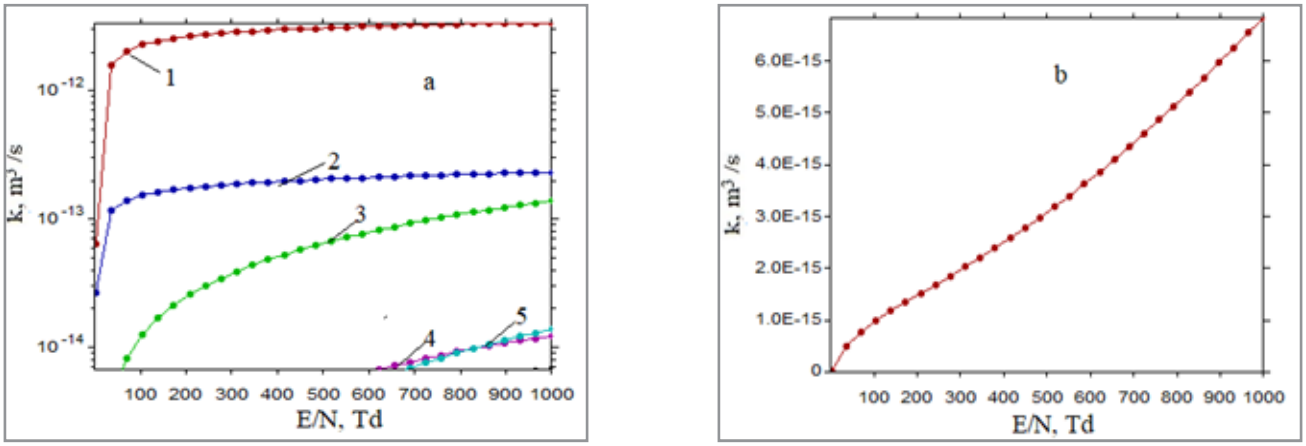

Figure 7: Dependency of the rate constants of collisions of electrons with selenium and argon atoms on the reduced electric field strength in the plasma on a mixture of selenium and argon vapors 300 - 101000 Pa: 1- elastic scattering of electrons on selenium atoms, 2 - elastic scattering of electrons on argon atoms, 3- ionization of atoms selenium (threshold energy 10.10 eV), 4- excitation of the energy level of argon atoms (threshold energy 11.50 eV), 5- ionization of argon atoms (threshold energy 15.80 eV).

Table 3: The value of the specific power of discharge losses due to elastic and inelastic processes of electron collisions with argon and selenium atoms from the reduced electric field strength in the plasma of the vapor-gas mixture Ar– Se =101000: 300 Pa for the reduced electric field strength of 326 Td and 153 Td.

E/N, Td	kSe*·10+15 m3/s ʎ=207nm	kSe+·10+14m3/s	krSe ·10+12 m3/s	krAr·10+13 m3/s	kAr+·10+16 m3/s
326	2.028	3.912	2.850	1.872	3.381
153	1.351	2.135	2.558	1.686	13.35

Conclusions

The study of the characteristics of the OND in a gas-vapor mixture of atmospheric pressure "argon-selenium" showed that when the distance between the selenium electrodes was 2 mm, a uniform spherical discharge with a diameter of 2-3 mm was ignited; the maximum pulsed power of the discharge reached 1.5 MW (at t = 130-135 ns), and the energy contribution to the plasma for one discharge pulse was equal to ≈ 63.3 mJ; in the radiation spectrum of OND, the radiation of selenium atoms prevailed against the background of the recombination and thermal continuum of argon; provided that a spectrophotometer with increased resolution or an interferometer is used, the intense spectral line of the hydrogen atom with λ=656.28 Hα can be used to estimate the concentration of electrons in the discharge; under the conditions of this experiment, the synthesis of thin films or finely dispersed selenium powder is possible.

The study of the transport characteristics of electrons, the power of discharge losses on the elastic and inelastic processes of electron collisions with the components of the vapor-gas mixture of argon and selenium established that the average energy of discharge electrons for the steam-gas mixture of argon-selenium = Ar : Se = 101000 : 300 increased from 1.936 to 14.81 eV with an increase in the reduced electric field intensity from 1 to 1000 Td. For times t = 100 and 175 ns from the start of discharge ignition, the average energies were 8.70 and 7.23 eV, respectively. The power of discharge losses due to the elastic and inelastic processes of collisions of electrons with the components of vapor-gas mixtures also increased with an increase in the reduced electric field strength in the range of 1-1000Td. They had larger values for the inelastic processes of electron collisions with the components of the vapor-gas mixture and were three orders of magnitude higher compared to elastic losses. For the reduced electric field strength of 326 Td, the value of the power loss of the discharge due to inelastic processes is 5.176·10-14 eV m3/s. An increase in the rate constants of excitation of the spectral lines of selenium atoms with an increase in the reduced electric field intensity was also characteristic. For the reduced electric field strength E/N=326 Td that existed on the discharge interval at the time t=100 ns and for the reduced electric field strength E/N=153 Td that existed on the discharge interval at the time t=175 ns the rate constants the excitation of the upper term of selenium (4S 5s5S2), from which radiation at a wavelength of 207.48 nm was observed, had values of 2.028·10-15 m3/s and 1.351·10-15 m3/s, respectively, which provided sufficient intensity of discharge to be used in diagnostics during sputtering of selenium-based films.

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