PLASMA DIAGNOSTICS

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DIAGNOSTICS OF PLASMA OF ELECTRIC ARC DISCHARGE BETWEEN ASYMMETRIC SINGLE-COMPONENT Cu AND Ni ELECTRODES

A. Murmantsev, A. Veklich, V. Boretskij, S. Fesenko, M. Kleshych

Taras Shevchenko National University of Kyiv, Kyiv, Ukraine

E-mail: murmantsev.aleksandr@gmail.com

In this work, the radial distributions of parameters of plasma with copper and nickel vapours admixtures in positive column of electric arc discharge were investigated by optical emission spectroscopy. The plasma temperature was determined by the Boltzmann plot technique on the basis of absolute values of radiation intensity of both copper and nickel atomic spectral lines. Concentrations of both kinds of metal atoms of electrode origin were determined by the method of absolute intensities of the corresponding spectral lines of radiation of such plasma.

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INTRODUCTION

The copper composites and alloys have played an important role in developing switching contacts, electrodes for electrical discharge machining, welding electrodes, sliding contacts, integrated circuits, materials for load resistance, diverter plates in fusion reactors, high-temperature erosive material [1-5], etc.

Nickel and its alloys are suitable for a wide range of applications, some of which need corrosion protection, as well as heat resistance [6]. It is widespread as a special substrate for metal platings such as tin, silver, and gold. Nickel-base alloys are used in applications, in which low-expansion, electrical resistance, soft magnetic and shape-memory are necessary, as well. The usage of nickel with copper in a cladding composite can provide material with very well-controlled expansion characteristics. Nickel alloys with given electrical resistance are commonly used in instrumentation and control equipment to measure and regulate electrical characteristics or to generate heat in furnaces and appliances. According to [6] the most common materials in this form of alloys or composites are Cu–Ni (2...45 % Ni), Ni–Cr–Al (35....95 % Ni), and Ni–Cr–Si (70...80 % Ni). As author states, the permeability properties of soft magnetic nickel-iron alloys are used in switchgear and direct current motor and generator designs. The lower-nickel alloys (<50 % Ni) with a fairly constant permeability over a narrow range of flux densities are primarily used in the rotors, armatures and low level transformers. High-nickel alloys (~77% Ni) are used for applications in which power requirements must be minimized such as transformers, inductors, magnetic amplifiers and shields, memory storage devices and tape recorder heads [6].

In addition, nickel seems to be the most useful coating material in terms of both cost and notable advancements in the metallurgical and contact characteristics of electrical connectors. In many electrical and electronic devices where diffusion between the coating and substrate base constitutes a serious issue, nickel's resistance to forming inter metallic phases with copper, aluminium, and other metals makes it a very efficient diffusion barrier. Nickel has been successfully used in recent years to coat aluminium conductors and power connectors [6].

Cu-Ni alloys have outstanding anti-fouling and anticorrosion properties in seawater and thus have been extensively used in marine applications such as heat exchanger tubes, ship pipes, boiler parts, pump impellers, conduits, pump bodies and components, boat hulls, valve bodies, seawater condensers, pipe fittings, oil rigs and platforms, seawater intake screens, fish farming cages, and other ship hardware [7, 8].

The main aim of this study is to carry out the diagnostics of plasma of electric arc discharge between asymmetric pair of single-component copper and nickel electrodes in order to investigate the behaviour of separate components of aforementioned composites or alloys in conditions close to real. In particular, this work is focused on the estimation of the concentration of metal atoms of electrode origin (copper and nickel) in a positive plasma column by the method of absolute radiation intensities of spectral lines.

1. EXPERIMENT

The spectroscopic diagnostics of thermal plasma in the midsection of arc discharges between single-component Cu and Ni electrodes (arc current of 3.5 A, discharge gap of 8 mm) were carried out by experimental setup on the basis of the spectrograph with 600 g/mm diffraction grating [9]. Such configuration allows simultaneous registration of the spatial distribution of spectral radiance in the wavelength range of 430...650 nm.

Plasma radiation was registered in two different configurations of the electrode assembly: when the copper electrode was the cathode, and the nickel electrode was the anode, and vice versa. It should be noted that the electrode spatially located in the upper position was used as the cathode in these experimental studies.

The spectral radiation of the plasma with admixtures of metal vapours was registered by an RGB CCD camera. Spectral distributions at a distance of ten points along the radius, starting from the axial one, were chosen for further processing. The spectral sensitivity of the spectrograph was previously determined in energy units using a tungsten band-lamp to obtain absolute radiance and, as a result, absolute radiation intensity.

The contours of the selected Cu I and Ni I spectral lines were approximated by the Gaussian function in order to obtain the observed values of their radiance. The method proposed by Bockasten [10] was used to transform the observed radiance units into local radiation intensity units. The obtained absolute radiation intensity of the atomic spectral lines of metals were used to determine the plasma temperature and further calculate the concentration of their atoms.

The dependence of the radiation intensity of the spectral lines I on the temperature T and the concentration of atoms of the emitting element n is determined from the equation [11]:

$$I = \frac{2\pi e^2 h}{m_e \lambda^3} \frac{f_{ik} g_i}{\Sigma_a} n e^{-\frac{E_k}{k_b T}}, \quad (1)$$

where h is Planck's constant, e is the charge of the electron, m_e is the mass of the electron, λ is the wavelength in the centre of the spectral line, f_{ik} is the oscillator strength, g_i is the statistical weight of the i^{th} energy level, Σ_a is the partition function of atoms of the emitting material, E_k is the energy k^{th} energy level, k_b is the Boltzmann constant. Linearization of equation (1) gives equation (2):

$$ln\left(\frac{I\lambda^3}{f_{ik} g_i}\right) = -\frac{E_k}{k_b T} + ln\left(\frac{2\pi e^2 h}{m_e} \frac{n}{\Sigma_a}\right), \quad (2)$$

the equation of a straight line $y = ax + b$, where, $y = ln\left(\frac{I\lambda^3}{f_{ik} g_i}\right)$, $x = E_k$, $a = -\frac{1}{k_b T}$, $b = ln\left(\frac{2\pi e^2 h}{m_e} \frac{n}{\Sigma_a}\right)$.

Then, the excitation temperature can be determined by the Boltzmann plots technique on the basis of the intensity of at least two spectral lines as:

$$T = -\frac{1}{k_b a}. \quad (3)$$

Calculating the temperature from equation (3) and taking into account equation (4), which describes the temperature dependence of the partition function of atoms:

$$\Sigma_a = \sum_m g_m e^{-\frac{E_m}{k_b T}}, \quad (4)$$

it is possible to calculate the concentration of particles of the emitting element according to the equation (5):

$$n = \frac{e^b m_e \Sigma_a}{2\pi e^2 h}. \quad (5)$$

2. RESULTS AND DISCUSSIONS

The registered RGB images of plasma radiation with copper and nickel vapour sad mixtures, as well as emission spectra with spatial resolution for two different spatial configurations of electrodes are shown in Figs. 1 and 2, respectively. In Fig. 1 the vertical corresponds to the spatial coordinate x, and the horizontal corresponds to the spectral coordinate λ.

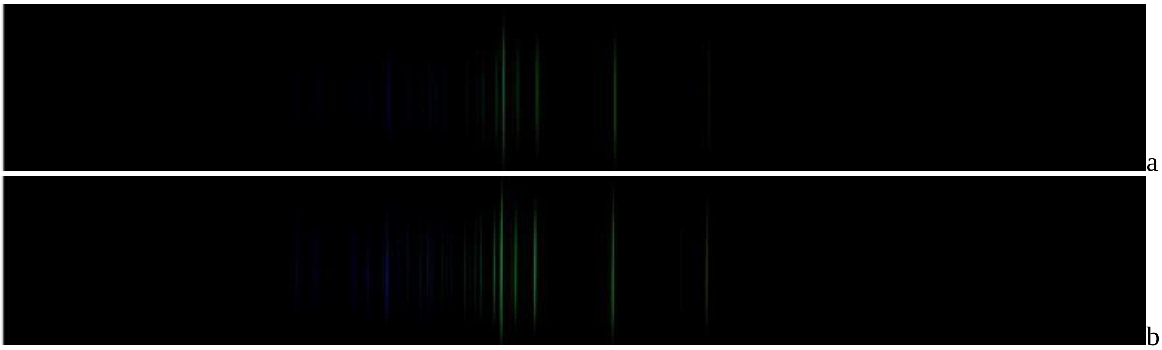

Fig. 1. RGB images of plasma radiation registered in arc discharge between copper cathode and nickel anode (a), nickel cathode and copper anode (b)

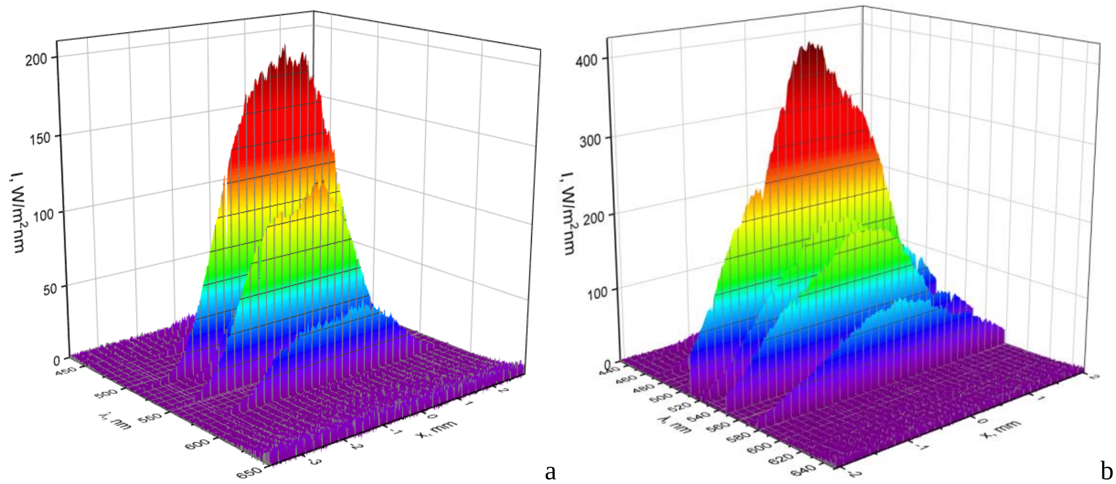

Fig. 2. Spatial distributions of emission spectra of plasma of electric arc discharge between copper cathode and nickel anode (a), nickel cathode and copper anode (b)

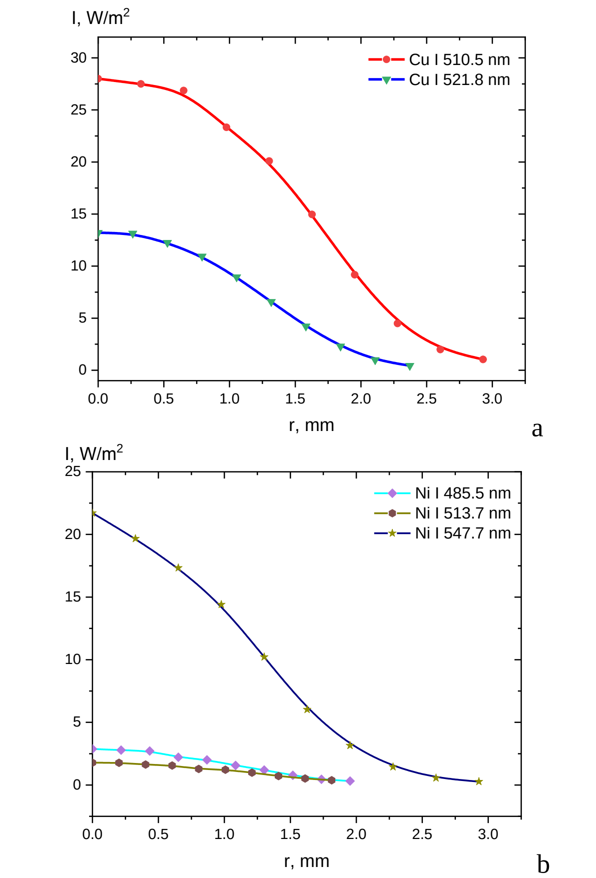

Fig. 3. Radial distributions of radiance of Cu I (a) and Ni I (b) spectral lines registered in electric arc discharge between copper cathode and nickel anode

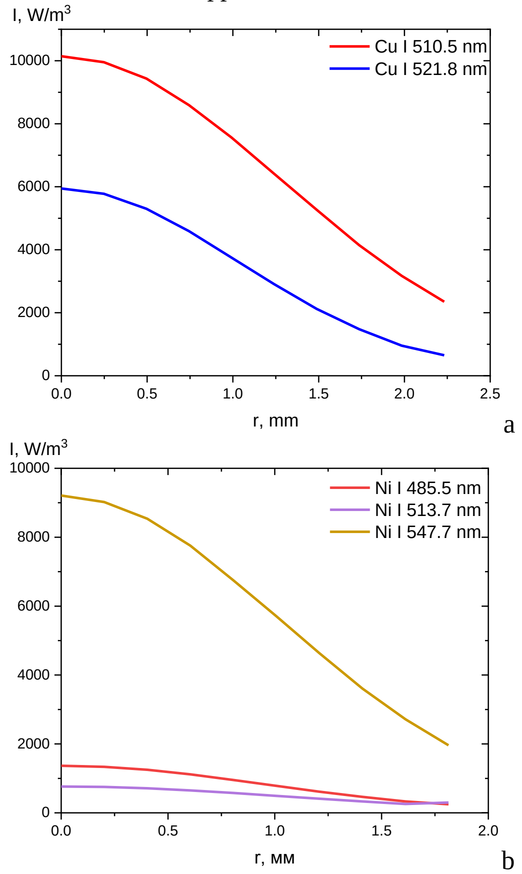

Fig. 4. Radial distributions of radiation intensity of Cu I (a) and Ni I (b) spectral lines registered in electric arc discharge between copper cathode and nickel anode

The spatial distributions of the radiance of spectral lines integrated along the line of sight of both copper and nickel atoms, which are sufficiently intense and do not overlap with each other, were chosen for further spectroscopic treatment. Namely, the spatial profiles of radiance of the Cu I 510.5, 521.8, 578.2 nm and Ni I 478.7, 485.5, 490.4, 503.5, 513.7, and 547.7 nm spectral lines were used. Typical radial distributions of radiance of Cu I 510.5, 521.8 nm and Ni I 485.5, 513.7, and 547.7 nm spectral lines are shown in Fig. 3.

Having determined the radiance of all the spectral lines selected for diagnostics at each investigated point along the radius of the arc discharge, the radial distributions of the absolute values of the radiation intensity of both copper and nickel spectral lines were obtained (Fig. 4).

The obtained absolute values of the radiation intensity of Cu I and Ni I spectral lines were used to determine the plasma temperature by Boltzmann plots technique. Typical Boltzmann plots constructed for some points along the radius of the positive plasma column on the basis of radiation intensity of Cu I 510.5,521.8. 578.2 nm and Ni I 478.7; 485.5; 490.4; 503.5; 513.7, and 547.7 nm spectral lines are shown in Fig. 5.

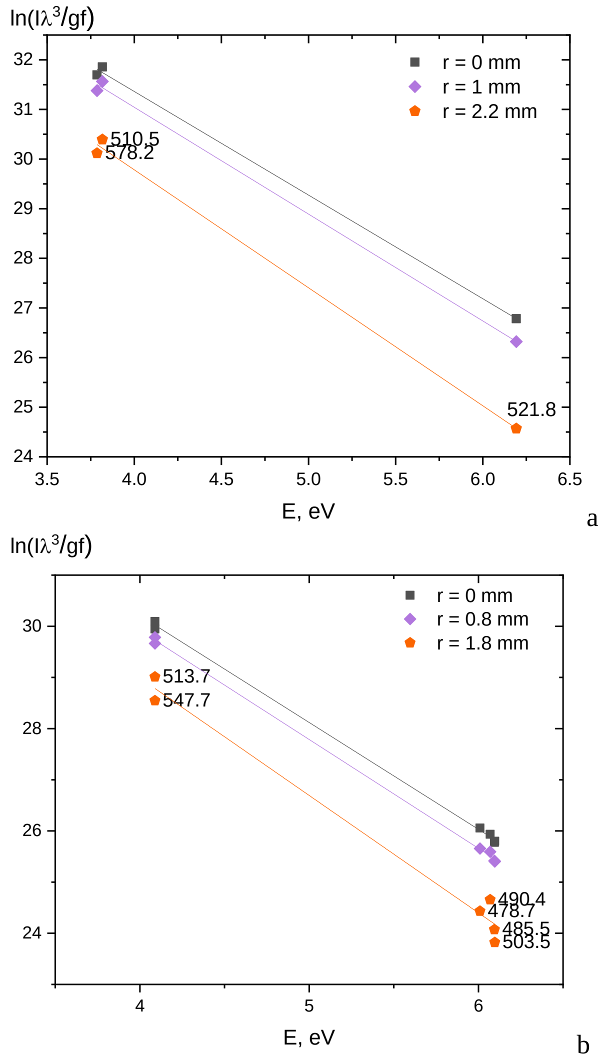

Fig. 5. Typical Boltzmann plots on the basis of absolute values of radiation intensity of Cu I (a) and Ni I (b) spectral lines registered in electric arc discharge between copper cathode and nickel anode

Radial distributions of the plasma temperature, determinedby Boltzmann plot techniqueon the basis of absolute radiation intensity of both Cu I and Ni I spectral lines (T_{Cu}, T_{Ni}, respectively) at different spatial configurations of the electrodes are shown in Fig. 6.

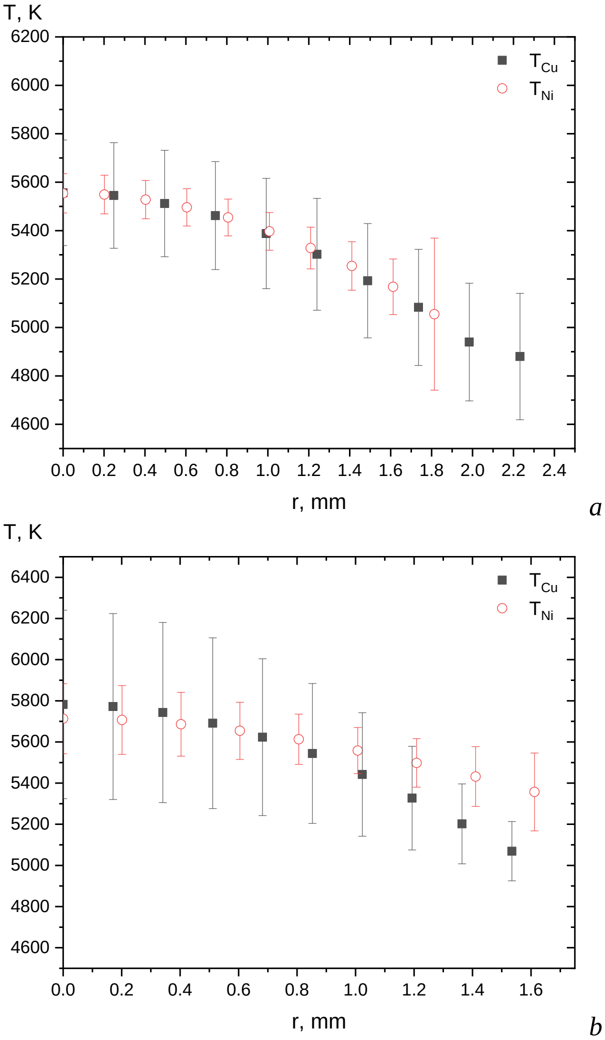

Fig. 6. Radial distributions of plasma temperature of electric arc discharge between copper cathode and nickel anode (a), nickel cathode and copper anode (b)

One can see from Fig. 6, that the radial distributions of the plasma temperature, determined on the basis of both copper and nickel spectral lines, coincide within the margin of error over the entire section from the axis of the positive column of electric arc discharges to its periphery in both spatial configurations of the electrodes. This allows to assume that local thermodynamic equilibrium is realized in the midsection of arc discharge plasma with admixtures of copper and nickel vapours.

Thus, the radial distributions of the concentration of copper (n_{Cu}) and nickel (n_{Ni}) atoms in the plasma of the positive discharge column between the copper and nickel electrodes in both spatial configurations of the electrodes were calculated assuming the energy levels are populated according to the Boltzmann distribution with the involvement of experimentally determined radial distributions of temperature and absolute values of the radiation intensity of spectral lines (Fig. 7).

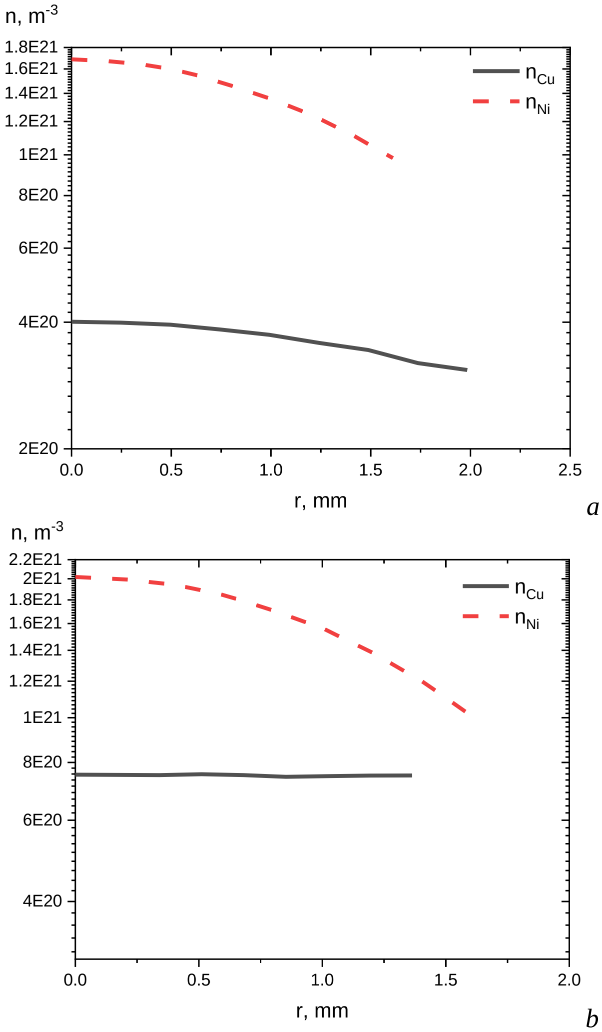

Fig. 7. Radial distributions of metal atoms concentrations in plasma of electric arc discharge between copper cathode and nickel anode (a), nickel cathode and copper anode (b)

As one can see, the concentration of nickel atoms is higher compared to the concentration of copper atoms. This tendency is observed for both spatial configurations of asymmetric electrodes. In addition, it can be seen that the concentration of both copper and nickel atoms is higher in the case of the configuration with a nickel cathode. This fact contradicts the results of previous works [12, 13], in which it was found that the concentration of the material from which the cathode is fabricated is higher in the discharge gap.

However, these results require further calculations of the concentration of ions of the corresponding materials in order to obtain the radial distribution of the total content of metal vapours in the positive plasma column of the electric arc discharge between different configurations of single-component copper and nickel electrodes.

CONCLUSIONS

The radial distributions of plasma parameters with copper and nickel vapours admixtures were investigated by optical emission spectroscopy. The plasma temperature was determined by the Boltzmann plot technique on the basis of the absolute radiation intensity of spectral lines of both copper and nickel atoms. Concentrations of various metal atoms of electrode origin were determined by the method of absolute intensities of the corresponding spectral lines of such plasma radiation.

It was found that the concentration of nickel atoms is higher in comparison with the concentration of copper atoms in both studied spatial configurations of asymmetric electrodes. In addition, the concentration of both copper and nickel atoms is higher in the case of the configuration with a nickel cathode. These results require further calculations of the concentration of ions of the corresponding materials in order to obtain the radial distribution of the total content of metal vapours in the positive plasma column of the electric arc discharge between different configurations of single-component copper and nickel electrodes.

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ДІАГНОСТИКА ПЛАЗМИ ЕЛЕКТРОДУГОВОГО РОЗРЯДУ МІЖ АСИМЕТРИЧНИМИ ОДНОКОМПОНЕНТНИМИ Cu- ТА Ni-ЕЛЕКТРОДАМИ

О. Мурманцев, А. Веклич, В. Борецький, С. Фесенко, М. Клешич

Методами оптичної емісійної спектроскопії досліджено радіальні розподіли параметрів плазми з домішками парів міді та нікелю в позитивному стовпі дугового розряду. Температура плазми визначалась методом діаграм Больцмана із залученням абсолютних значень інтенсивності випромінювання спектральних ліній як атомів міді, так і нікелю. Концентрації обох сортів атомів металів електродного походження визначались методом абсолютних інтенсивностей відповідних спектральних ліній випромінювання такої плазми.