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DIAGNOSTICS OF THERMAL PLASMA WITH Cu AND Ni VAPOUR ADMIXTURES

A. Murmantsev[1], A. Veklich[1], V. Boretskij[1], S. Fesenko[1], M. Kleshych[1], V. Ninyovskij[1], Y. Cressault[2]

[1]Taras Shevchenko National University of Kyiv, Kyiv, Ukraine;
[2]Université de Toulouse; UPS, INPT; LAPLACE, France

E-mail: murmantsev.aleksandr@gmail.com

This work is devoted to diagnostics of thermal electric arc discharge plasma with copper and nickel vapour admixtures by optical emission spectroscopy and possibility of its usage for investigation of plasma regions near-electrodes surfaces. The spectra of plasma emission from such areas were obtained by registration device with spatial and spectral resolution. The Boltzmann plot technique was used to determine the radial distribution of plasma temperature of arc discharge channel in different cross-sections. Namely, the regions of arc discharge plasma in the vicinity of cathode and anode surfaces in the two different configuration of electrodes assembly (copper as a cathode, nickel as an anode and vice versa) were investigated.

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INTRODUCTION

Electrodes, fabricated of composites or alloys based on copper or nickel, are widely used as contact materials in switching devices of power networks.

Copper is used in the fabrication of a large number of various composite materials due to their excellent electrical and thermal conductivity, relatively cheap and widespread. For example, these are Cu-Cr composites with low ten dency to welding, high strength, good vacuum getter property, etc. [1-3]; Cu-W material, which are used in arc resistance electrodes, electrical contacts, electrodes for electrical discharging machining and heat-sink materials for high density integrated circuits, etc. [4]; Cu-C composites for sliding contacts with good mechanical and antifriction properties, low resistivity and transient electrical resistance, high resistance to electrical erosion [5]; etc.

In turn, nickel is a very common additive for variable composite materials since. First of all, it has a very slight solubility in tungsten and silver at near 1000 °C temperatures, and nickel increases the self-diffusivity of tungsten [6]. Nickel addition does not decrease the conductivity of the silver phase of silver-tungsten (Ag-W) contact since it is not soluble in silver [7]. Moreover, small amounts of Ni sufficiently increase the wettability of copper, which makes it a very useful material during Cu-W composite manufacturing [4]. Another analog of these materials is a composite Ag-Ni, which is a very popular type of contact material used worldwide, especially in Europe [8].

It should be noted, that the erosive properties of the aforementioned contact materials play a key role in its efficiency due to the thermal action of arc discharge occurred during the contact switching. For a deeper understanding of the processes occurring in the plasma of discharge between such composites, it is necessary to investigate the behaviour of separate components of such electrodes.

Thus, 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 particular, this work is focused on elucidating the possibility of using optical emission spectroscopy for studying the near-electrode`s regions of arc discharge plasma with copper and nickel vapours admixtures.

1. EXPERIMENT

The vertically oriented free-burning arc was ignited in air between the end surfaces of asymmetric single-component nickel and copper non-cooled electrodes.

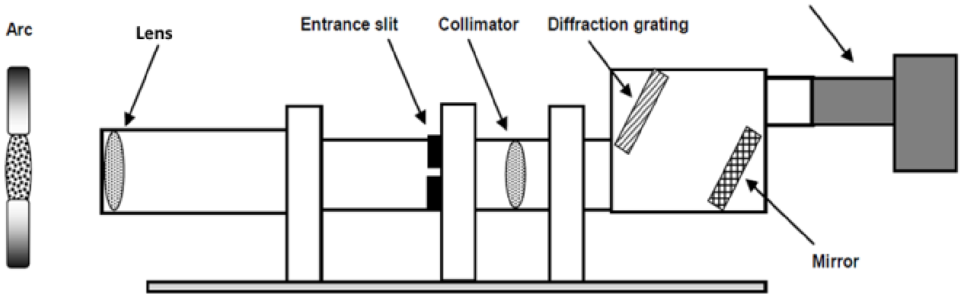


Fig. 1. Optical scheme of registration device with spatial and spectral resolution

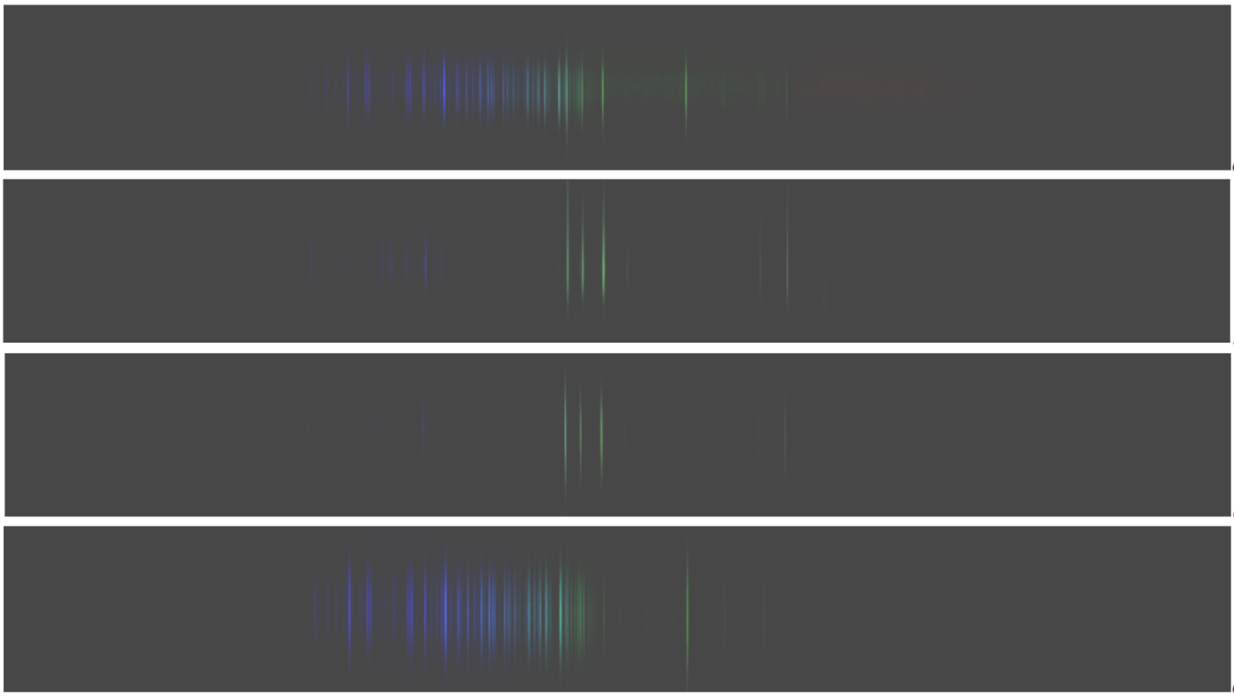
The diameter of the rod electrodes was 6 mm, the discharge gap was 8 mm and DC current was 3.5 A.

The optical scheme of experimental setup shown in Fig. 1 was proposed for diagnostics of thermal plasma with Cu and Ni vapour admixtures by optical emission spectroscopy technique. The realized configuration of experimental setup with optical scheme on the basis of diffraction grating 600 g/mm permits simultaneous registration of spatial intensity distribution in spectral range 420...620 nm.

The arc discharge and entrance slit of the registration device were placed on both sides of the lens at a distance of double focus. Thus, an image of the arc discharge channel with a magnification of 1 was formed at the entrance slit. Since the slit was oriented horizontally with respect to the arc it was possible to choose any cross-section of the channel along the axis of discharge by moving the optical scheme up or down. The cross-sections in the vicinity of anode and cathode surfaces were investigated in this work. Measurements were carried out for two different configurations of electrodes assembly: when copper electrode was as the cathode and nickel as the anode and vice versa. It should be noted, that the cathode was in upper position within these experiments.

Ten radial points, starting from the axial one, were chosen from the spectra registered by the RGB CCD camera for further treatment with taking into account the spectral sensitivity of spectral device. The spectral profiles of selected Cu I and Ni I spectral lines were approximated by the Voigt function in order to obtain the observed values of emission intensity of each from these lines.

The technique, proposed by Bockasten [9], was used to transform the observed radiances into the local values of emission intensity. The obtained local values intensity of emission of aforementioned spectral lines were used to determine the plasma temperature by Boltzmann plot technique [10].



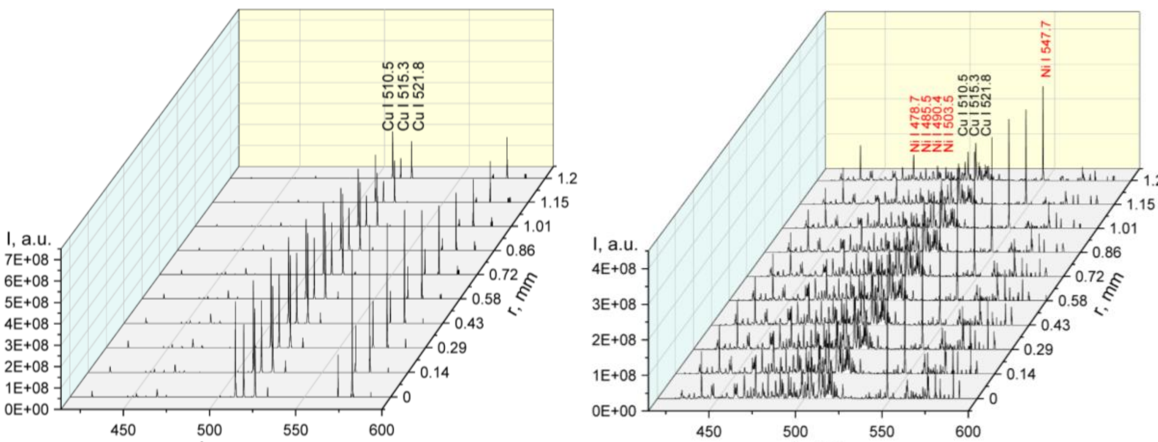
a

b

c

d

Fig. 2. Emission spectra with spatial and spectral resolution registered in the vicinity of: nickel anode (a), copper cathode (b), copper anode (c) and nickel cathode (d)



a

b

Fig. 3. Emission spectra obtained at different radial points of plasma channel in the vicinity of: copper anode (a) and nickel cathode (b)

2. RESULTS AND DISCUSSIONS

The emission spectra (Fig. 2) were obtained by registration of image on the diffraction grating surface by RGB CCD camera. Each image was converted to grayscale data. Thus, each radial point of the cross-sections, which contains the spectral distribution of the emission intensity, was obtained in the vicinity of cathode or anode surface. The emission spectra at ten chosen radial points of theplasma channel in the vicinity of copper anode and nickel cathode surface on the distance 0; 0.14; 0.29; 0.43; 0.58; 0.72; 0.86; 1.01; 1.15; 1.2 mm from the arc axis are shown in Fig. 3. As one can see, the spectra observed in the vicinity of copper surfaces (regardless of whether it was the cathode or the anode) contain just the Cu spectral lines, while the spectra obtained in the vicinity of nickel surfaces contain both the Ni I and Cu I spectral lines (see Figs. 2, 3).

This phenomenon can be associated with the nature of nickel erosion [11]. In fact, the erosion of nickel electrode is characterized by a creation of a melting pool (on the cathode surface) or drop (on the anode surface), which indicates the presence of a liquid phase of nickel when interacting with thermal plasma. Due to its high surface tension (1.76 J/m^2 compared to 1.29 J/m^2 for copper [8]), most part of the nickel material reaches opposite electrode not in atomic form, but in the form of droplets, while the atoms disperse in the discharge gap.

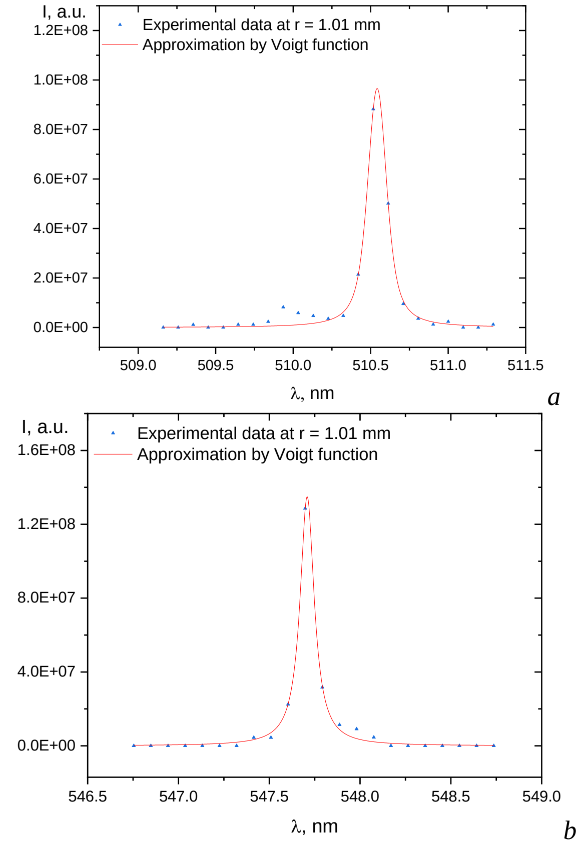


Fig. 4. Typical approximations of spectral profile of Cu I 510.5 nm (a) and Ni I 547.7 nm (b) lines by Voigt function

The spectral profiles of Cu I 510.5, 515.3, 521.8 nm [12] and Ni I 478.7, 485.5, 490.4, 503.5, 547.7 nm [13] (see Fig. 3) were approximated by Voigt function in order to obtain the observed values of emission intensity of each from these lines. The typical approximations of spectral line profiles by Voigt function are shown in Fig. 4.

The observed values of emission intensity obtained in each of the ten radial points were transformed into local values of intensity. These values were used in the Boltzmann plots as shown in Fig. 5.

One can see, the temperature obtained by the Boltzmann plot on the basis of nickel atomic line intensity is calculated with error not exceeding 5 %. This is indicated by the coincidence of the approximating straight line with points on the plot, which correspond to emission intensity of marked Ni I spectral lines. At the same time the Boltzmann plot on the basis of Cu I spectral lines gives a lower accuracy of plasma temperature determination (~ 15 %). This is due to overlapping of the selected Cu I spectral lines with some Ni I lines, namely 501.8 and 515.6 nm. This overlapping can lead to overestimation of the observed emission intensity of spectral lines, which consequently affects the determination of the local values of line`s intensity.

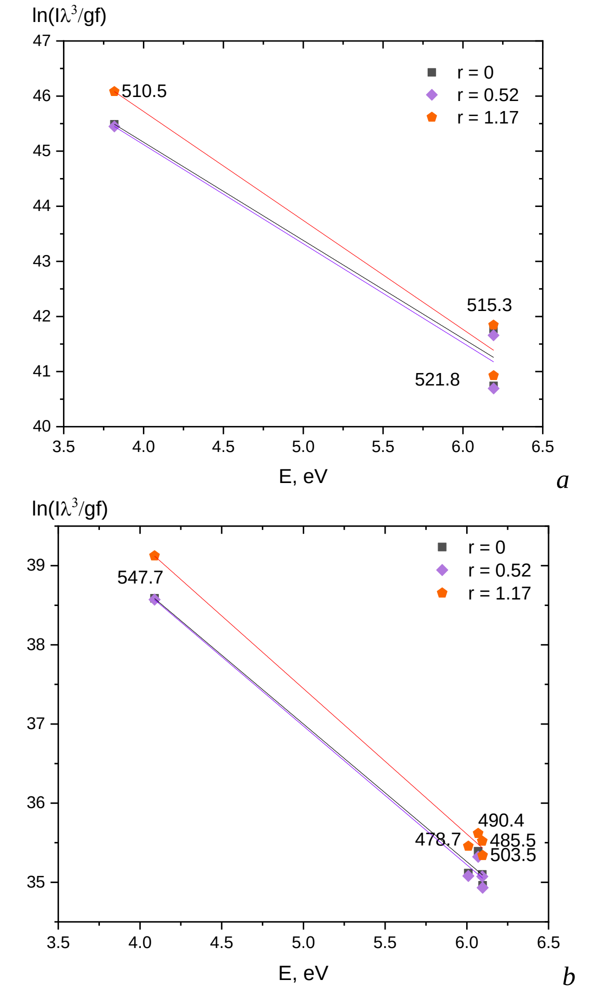


Fig. 5. Typical Boltzmann plots on the basis of emission intensity of Cu I 510.5, 515.3, 521.8 nm (a) and Ni I 478.7, 485.5, 490.4 and 547.7 nm (b) spectral lines (spectra registered in the vicinity of nickel cathode)

The radial distributions of plasma temperature, determined on the basis of Cu I (for cross-sections in the vicinity of copper surfaces) and both Cu I and Ni I spectral lines (for cross-sections in the vicinity of nickel surfaces), are shown in Figs. 6, 7.

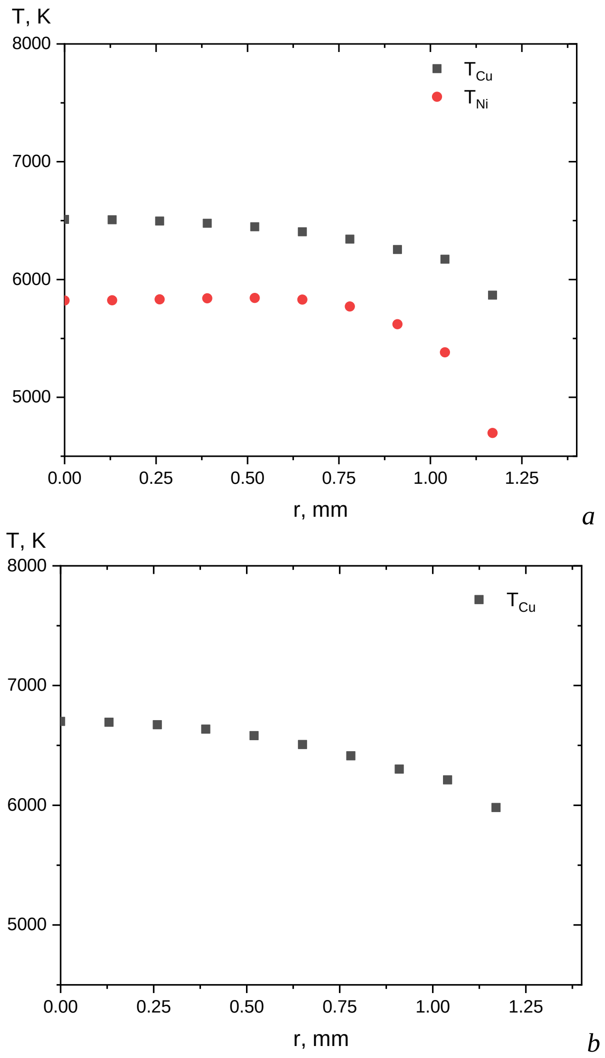


Fig. 6. Radial distributions of plasma temperature, obtained by Boltzmann plot technique on the basis of Cu I 510.5, 515.3, 521.8 nm and Ni I 478.7, 485.5, 490.4, 503.5, 547.7 nm spectral lines registered in the vicinity of: nickel anode (a), copper cathode (b)

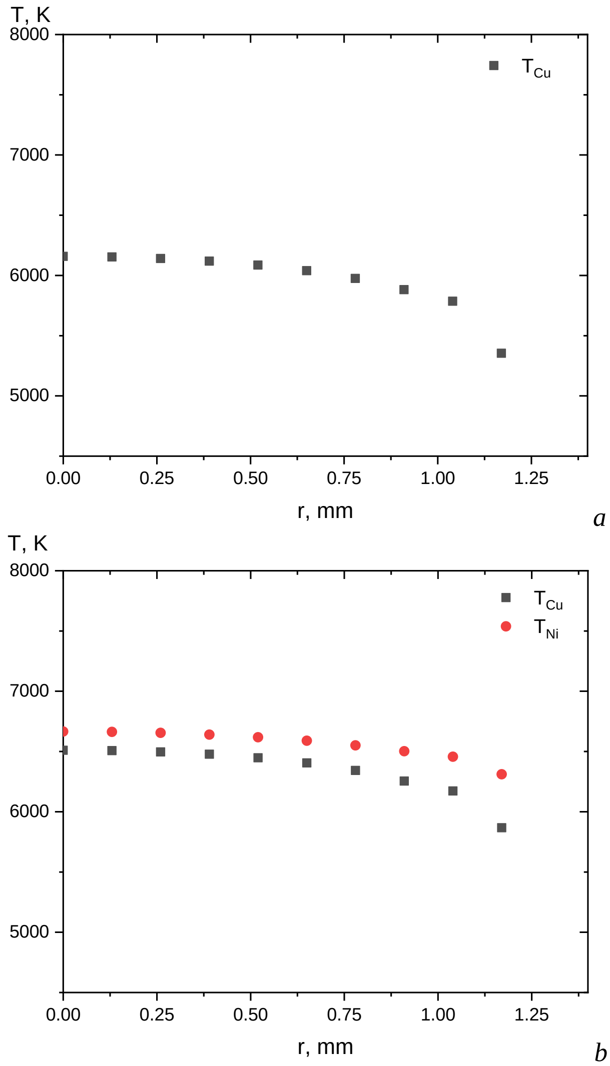


Fig. 7. Radial distributions of plasma temperature, obtained by Boltzmann plot technique on the basis of Cu I 510.5, 515.3, 521.8 nm and Ni I 478.7, 485.5, 490.4, 503.5, 547.7 nm spectral lines registered in the vicinity of: copper anode (a) and nickel cathode (b)

One can see, the radial distributions of temperatures, obtained from both Cu I and Ni I spectral lines, coincide within the measurement accuracy. It can be assumed that local thermodynamic equilibrium (LTE) can realize in plasma with copper and nickel vapour admixtures even in discharge areas in the vicinity of electrodes surfaces. However, this can only be asserted for the results obtained in the near-electrode region of nickel due to the impossibility of determining the plasma temperature on the basis of emission of the spectral lines of this material in the vicinity of the copper surface. Moreover, the results, obtained in the vicinity of nickel surfaces need additional clarification, namely the separating the Cu I and Ni I spectral lines in order to avoid overestimating the emission intensity. Nonetheless, it can be supposed that plasma with copper and nickel vapour admixtures in the near-electrodes surface is close to the state of LTE at least.

This fact allows us to carry out further investigation of plasma of electric arc discharge between asymmetric pairs of single-component Cu and Ni electrodes in the near-cathode and near-anode regions.

Namely, the equilibrium composition of such plasma and metal vapours contents in such regions can be determined.

CONCLUSIONS

The diagnostics of thermal plasma of arc discharge between asymmetric pair of single-component copper and nickel electrodes were investigated in different plasma regions: in the vicinity of copper cathode, nickel anode, nickel cathode, and copper anode surfaces.

As a result, the radial distributions of plasma temperature were determined by the Boltzmann plot technique on the basis of Cu I (in cross-sections in the vicinity of copper surfaces) and both Cu I and Ni I spectral lines (in cross-sections in the vicinity of nickel surface).

It was found, that local thermodynamic equilibrium can realize in plasma with copper and nickel vapour admixtures even in discharge areas in the vicinity of electrodes surfaces (at least in the vicinity of nickel electrodes surface).

This is indicated by the coincidence of the radial distributions of temperatures, obtained from both Cu I and Ni I spectral lines, within the measurement accuracy.

Thus, optical emission spectroscopy can be used for diagnostics of similar plasma of electric arc discharges in regions in the vicinity of electrodes surfaces.

The results obtained in this investigation allows us to carry out further studies of plasma with Cu and Ni vapours admixtures focused on determination of plasma equilibrium composition and investigation of behaviour of metal component in near-electrodes regions.

ACKNOWLEDGEMENTS

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ДІАГНОСТИКА ТЕРМІЧНОЇ ПЛАЗМИ З ДОМІШКАМИ ПАРІВ Cu ТА Ni

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

Присвячено діагностиці термічної плазми електродугового розряду з домішками парів міді та нікелю методами оптичної емісійної спектроскопії та можливості застосування цих методів для дослідження областей плазми поблизу поверхонь електродів. Спектри випромінювання плазми з таких ділянок отримані із застосуванням оптичної схеми з просторовою та спектральною роздільними здатностями. Для визначення радіальних розподілів температури плазми в каналі дугового розряду в різних поперечних перерізах використовувався метод діаграм Больцмана. Зокрема, досліджено області плазми дугового розряду поблизу поверхонь катода та анода у двох різних конфігураціях електродного вузла (мідний катод, нікелевий анод і навпаки).