# INVESTIGATION OF ELECTRIC ARC DISCHARGE PLASMA BETWEEN ONE-COMPONENT Cu AND Ni AND COMPOSITE Ag-Ni ELECTRODES

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Plasma of electric arc between one-component Cu and Ni and composite Ag-Ni electrodes was studied by means of optical emission spectroscopy. Radial temperature profiles of plasma column were obtained using Boltzmann plot techniques at arc currents of 3.5 and 30 A. Radial distributions of plasma electron density of electric arc discharge between Cu and Ni and Ag-Ni electrodes were measured as well at currents 3.5 and 30 A. Equilibrium of plasma composition was calculated. The properties of material erosion processes on the electrodes' surface are studied.

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## INTRODUCTION

Nowadays, composite Ag–Ni materials are widely used in fabrication of electrodes or contacts of switching devices in the electric and electronics industry. The advantage of such materials is a combination of high erosion resistance, high thermal conductivity and electrical conductivity. High melting nickel component of such materials defined attractive erosion properties of this composition [1-4]. The required electrical and thermal conductivities are provided by low melting silver component.

It should be noted, that to reduce the development time and to optimize the composition and fabrication technology of composite materials, it is necessary to have a set of diagnostic tools to determine the parameters of electrical contacts.

Papers [5, 6] proposed the techniques of erosion resistance studies of composite electrode materials under influence of arc discharge thermal plasma. The radial distributions of plasma temperature and electron density, measured by methods of optical spectroscopy, were used to calculate the plasma composition. So, the amount of electrode impurities in the discharge gap can be determined. In such indirect way, the intensity of erosion on the surface of the composite electrodes was rated [6, 7].

The main aim of this paper is the development of the diagnostics techniques on the base of optical emission spectroscopy. The electric field measurements also were fulfilled for study of the radial distributions of plasma parameters in positive column of arc discharge with copper, nickel and silver vapours. The measurements of the temperature, electron density and content of metal vapors in discharge gap are carried out in this research. The erosion properties of materials of one-component Cu and Ni and composite Ag–Ni electrodes could be as well investigated.

## 1. EXPERIMENTAL INVESTIGATIONS

At the first stage of investigation the erosion properties of composite materials on the base of silver with nickel admixture (Ag-Ni) was carried out in the electric arc between one-component copper and nickel electrodes (Cu and Ni). It should be mentioned, the techniques of optical emission spectroscopy of plasma in positive column of arc discharge with copper and nickel vapours previously was developed [8]. It can be useful at the next stage of investigation. The initially selected Ni I spectral lines were utilized for plasma optical diagnostics of arc discharge between composite Ag–Ni electrodes.

### 1.1. ARC DISCHARGE ARRANGEMENT

The free burning electric arc was ignited in air between the end surfaces of the non-cooled electrodes [6-8]. The diameter of the rod electrodes was 6 mm. The discharge gap was 8 mm. Currents of arc were 3.5 and 30 A. Electrodes are positioned vertically: upper electrode as cathode – Ni and the bottom electrode as anode – Cu (signed as one-component Cu and Ni electrodes) or both composite Ag-Ni electrodes are used.

A pulsed mode of high current was used for avoid the appearance of metal droplets. Namely, the current pulse up to 30 A was combined with stationary low-current (3.5 A) discharge. The duration of this high-current pulse achieved of 30 ms. The registration of arc plasma radiation was performed at 7 ms after current pulse rise i.e. when a steady-state mode of electric arc discharge was realized.

### 1.2. MEASUREMENTS OF TEMPERATURE

The radial distributions of plasma temperature were determined in the middle section of discharge gap. The techniques of Boltzmann plot and/or relative intensities of spectral lines in the assumption of local thermodynamic equilibrium (LTE) were applied. In this study spectral lines Cu I 510.5, 515.3, 521.8, 578.2 nm, and Ag I 405.5, 447.6, 520.9, 546.5, 547.2, 768.8, 827.4 nm, and Ni I 508, 508.1, 508.4 nm were used [5-8].

As an example, the radial distributions of plasma temperature of electric arc discharge between one-component Cu and Ni electrodes at current 3.5 A, obtained with using of Cu I and Ni I spectral lines, are shown in Fig. 1. One can see that both radial profiles are coincide within error bars. It can be concluded, that assumption of LTE is reasonable in the investigation of such kind plasma.

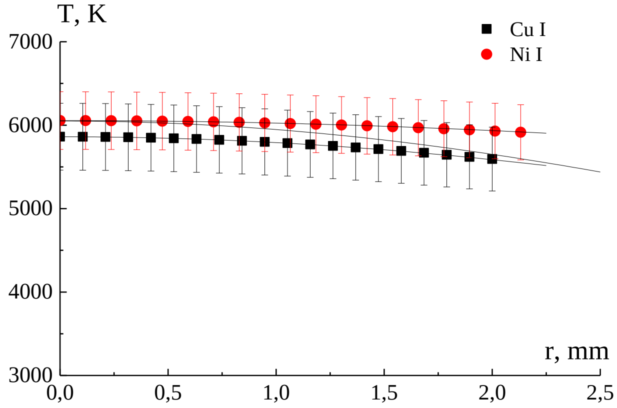


*Fig. 1. Radial distributions of plasma temperature of arc discharge between one-component Cu and Ni electrodes at current 3.5 A, obtained with using Cu I and Ni I spectral lines*

### 1.3. ELECTRON DENSITY MEASUREMENTS

Two techniques of electron density determination were used in the frame of this study. First of them the electron densities were obtained from the half-width of spectral lines Cu I 515.3 nm and Ag I 447.6 nm, 466.8 nm in an assumption of dominating quadratic Stark effect at arc current 30 A [5-7]. The spectral device is combined with Fabry–Perot interferometer (FPI) in etalon mode is used for registration of spectral line profiles with spatial resolution. As the examples, Fig. 2 shows the interferograms of copper and silver spectral lines. In spite of proximity of wave lengths Cu I 515.3 nm and Ni I 515.5 nm in the free spectral range of FPI (see Fig. 2,a), the contribution of nickel spectral line into determination of half-width of copper spectral line is negligible. The radial distributions of electron density of plasma of electric arc discharges between one-component Cu and Ni and composite Ag-Ni electrodes at current 30 A are shown in Fig. 3.

In the second technique, the electron density is obtained from electric conductivity, which can be calculated by solution of energy balance equation (Elenbaas-Heller) in assumption of LTE in plasma [9]. Previously, the measurement of electric field has been carried out in positive plasma column of arc discharge. As an example, the radial profile of electron density of electric arc discharge between one-component Cu and Ni electrodes at current 3.5 A is shown in Fig. 4.

## 2. RESULTS AND DISCUSSION

### 2.1. ESTIMATIONS OF METAL VAPOURS' CONTENT IN PLASMA

Experimentally obtained data of electron densities and temperature can be plotted on the diagram in the coordinates $N_e$ and T. Additionally, the curves of electron density in air plasma with different contents of metal vapours as a function of temperature can be plotted as well in this figure. Such curves are obtained by calculation of equilibrium plasma composition of air-metal vapours mixtures.

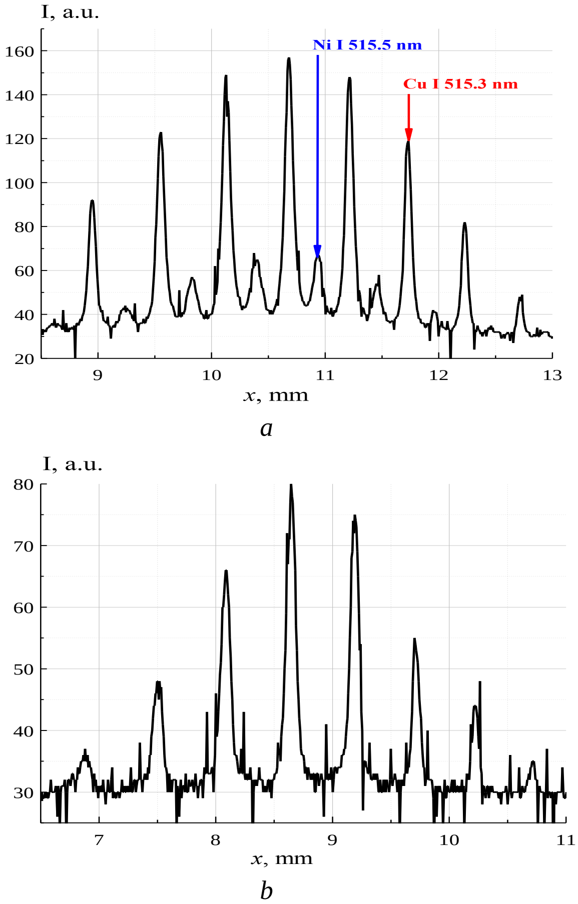


*Fig. 2. Interferograms of spectral lines Cu I 515.3 nm (a) and Ag I 447.6 nm (b); discharges between Cu and Ni (a) and Ag-Ni (b) electrodes at arc current 30 A*

In Fig. 5 such diagram with experimentally obtained data and calculated electron density within temperature range of 4000…6500 K is shown. This figure is plotted for air plasma with copper and nickel vapours of arc discharge between one-component Cu and Ni electrodes at arc current of 3.5 A.

As one can see, that experimental data are in region between curve of pure air plasma (air/Cu/Ni(100/0/0)) and curve of air-metal vapours plasma mixture (air/Cu/Ni(99/1/0)). It means, that content of metal vapours in plasma does not exceed 1 %.

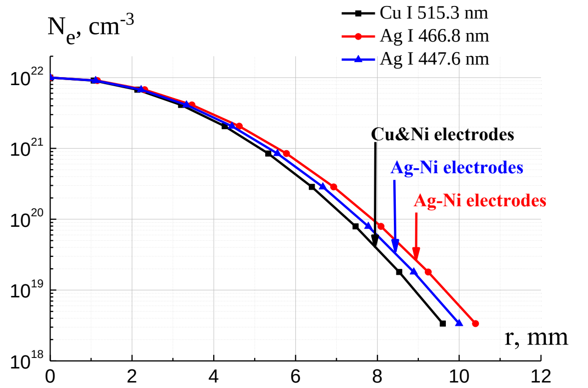


*Fig. 3. Radial distributions of electron density of plasma of electric arc discharges between one-component Cu and Ni and composite Ag-Ni electrodes at current 30 A*

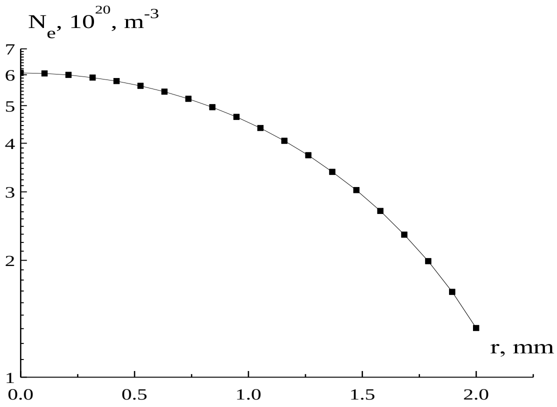


*Fig. 4. Radial distribution of electron density of plasma of electric arc discharge between one-component Cu and Ni electrodes at current 3.5 A*

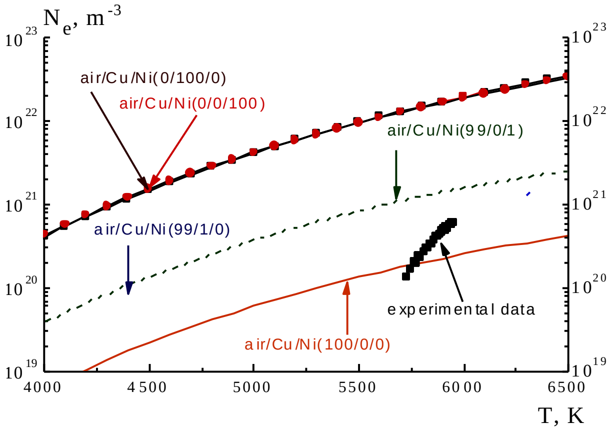


*Fig. 5. The dependence of electron density from temperature for plasma of electric arc discharge between one-component Cu and Ni electrodes at current 3.5 A*

It should be noted, that experimental data below temperature 5750 K do not correspond even plasma of pure air. It means, that plasma is not in equilibrium in this region (namely, in the arc periphery).

Fig. 6 shows the diagram with experimentally obtained data and calculated electron density within temperature range of 3500…4500 K. This figure is plotted for air plasma with silver and nickel vapours of arc discharge between composite Ag-Ni electrodes at arc current of 3.5 A. One can conclude, that content of metal vapours in plasma of considered arc between Ag-Ni electrodes also does not exceed 1 %.

So, we proposed in this stage of investigation the technique of rough estimation of metal vapours' content in plasma and, respectively, the properties of material erosion processes on the electrodes' surface.

## 2.2. MEASUREMENTS OF METAL VAPOURS' CONTENT IN PLASMA

In this part of investigation the extended techniques of quantitative determination of metal vapours' content in plasma is considered. It is well known [5-7], that plasma in a state of LTE can be described by the equation set, which primarily depends on the type of particles in its volume. Molecules, atoms and ions of nitrogen and oxygen must be taken into account in plasma of the free burning arc discharge in air between Ag-Ni electrodes. In addition, atoms and ions of silver and nickel will be present in the plasma due to the heating of the electrodes in discharge. The composition of air-silver-nickel plasma mixture can be calculated on the base of experimentally measured temperature and electron density. Only one additional parameter is required for this calculation. Namely, the ratio between silver and nickel atom concentration must be used. Such parameter can be defined from the intensity ratio of Ag I 520.9 nm and Ni I 547.6 nm spectral lines in an assumption of LTE.

So, solution of an equation set, which describes the plasma in LTE, allows to calculate the content of silver ($X_{Ag}$) and nickel ($X_{Ni}$) vapours in air plasma (Fig. 7). Such approach provides the quantitative determination of radial profiles of metal vapours in the discharge gap.

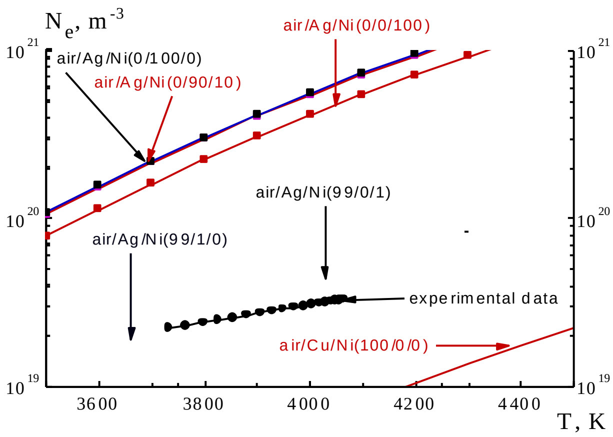


*Fig. 6. The dependence of electron density from temperature for plasma of electric arc discharge between composite Ag-Ni electrodes at current 3.5 A*

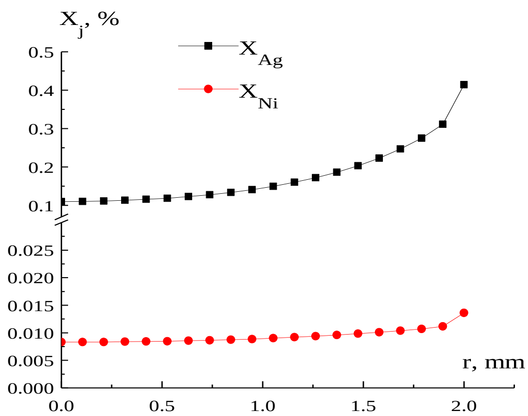


*Fig. 7. The radial distributions of silver and nickel vapours contents in plasma of electric arc discharge between composite Ag-Ni electrodes at current 3.5 A*

One can conclude that, really, nickel plays role of a high melting component in Ag-Ni composite material as it follows from analysis of radial distributions of different kind of metal component in arc discharge plasma. Its erosion intensity is less in comparison with silver. Nevertheless, the thermal and electrical conductivities are provided mainly by silver in this composition, obviously.

So, the proposed technique of quantitative determination of metal content in plasma can be used as well for estimation of the erosion properties of different materials.

## CONCLUSIONS

Plasma of free burning arc discharge in air between one-component Cu and Ni and Ag-Ni composite electrodes was investigated in various modes of arc. Radial distributions of temperature and electron density were determined in the average cross section of arc discharge plasma column.

Compositions of air-metal plasma mixture were calculated in assumption of local thermodynamic equilibrium.

It was found that, the-content of metal vapours does not exceed 1% in plasma of arc discharges between Cu and Ni and Ag-Ni electrodes at current 3.5 A. The realized techniques of quantitative determination of metal content in plasma can be recommended in estimations of the erosion properties of the material on the electrodes' surface.

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### ИССЛЕДОВАНИЕ ПЛАЗМЫ ЭЛЕКТРОДУГОВОГО РАЗРЯДА МЕЖДУ ОДНОКОМПОНЕНТНЫМИ Cu И Ni И КОМПОЗИТНЫМИ Ag-Ni-ЭЛЕКТРОДАМИ

***А. Веклич, М. Клешич, С. Фесенко, В. Борецкий, Y. Cressault, Ph. Teulet***

Методами оптической спектроскопии исследована плазма электродугового разряда между однокомпонентными Cu и Ni и композитными Ag-Ni-электродами. С помощью диаграмм Больцмана получены радиальные распределения плазменного столба для дуги током 3,5 и 30 А. Проведены измерения радиальных распределений электронной концентрации плазмы дугового разряда током 3,5 и 30 А между Cu и Ni и Ag-Ni-электродами. Рассчитан равновесный состав плазмы. Исследованы свойства эрозионных процессов материала на поверхности электродов.

### ДОСЛІДЖЕННЯ ПЛАЗМИ ЕЛЕКТРОДУГОВОГО РОЗРЯДУ МІЖ ОДНОКОМПОНЕНТНИМИ Cu ТА Ni І КОМПОЗИТНИМИ Ag-Ni-ЕЛЕКТРОДАМИ

***А. Веклич, М. Клешич, С. Фесенко, В. Борецький, Y. Cressault, Ph. Teulet***

Методами оптичної емісійної спектроскопії досліджена плазма електродугового розряду між однокомпонентними Cu та Ni і композитними Ag-Ni електродами. Радіальні розподіли температури плазмового стовпа отримані з діаграм Больцмана для дуги струмом 3,5 та 30 А. Виміряні радіальні розподіли електронної концентрації плазми дугового розряду струмом 3,5 та 30 А між Cu та Ni and Ag-Ni-електродами. Розрахований рівноважний склад плазми. Досліджені властивості ерозійних процесів матеріалу на поверхні електродів.