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INVESTIGATION OF THERMAL PLASMA OF ARC DISCHARGE BETWEEN NOVEL COMPOSITE Cu-W MATERIALS

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In this work, the plasma emission of electric arc discharges between pairs of composite Cu-W electrodes was investigated by optical emission spectroscopy. Electrodes manufactured of Cu-W 50 vol.% composite materials by shock sintering technology at temperatures of 750, 850, 950, and 1050°C were used. The radial distributions of plasma temperature were determined by Boltzmann plot technique on the basis of the absolute values of intensity of both copper and tungsten spectral lines. The concentration of metal atoms of electrode origin (copper and tungsten) in the positive plasma column of electric arc discharges between studied electrodes manufactured of composite Cu-W materials was determined by the method of absolute intensities. The intensity of erosion of individual components of composite materials is estimated in an indirect way by comparing the radial distributions of atoms of materials of electrode origin for each type of the investigated arc discharge.

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INTRODUCTION

Tungsten-copper composite materials are used in the electrical and electronics industries as a medium- and heavy-duty electrical contacts, electrodes for resistance welding and electric discharge machining, in the production of microelectronic circuit boards [1-3], etc. Despite their wide popularity and widespread use, the attempt to improve the technology production of these materials is still relevant.

As is known, the manufacture of parts from the Cu-W composition requires their sintering in hydrogen at sufficiently high temperatures (≥1200°C) with exposure for ≥ 2 h. At the same time, the shock sintering (sintering with simultaneous high pressure shock pressing) method makes it possible to obtain high-density material at much lower temperatures and short exposure times [4]. As it was found in [5], it is possible to control the grain size of the samples and, as a result, the mechanical properties of copper material by varying the shock sintering temperature.

Since, composite Cu-W materials are used in the fabrication of varying types of contacts, their electrical properties, as well as erosion resistance to the thermal action of electric arc discharge which may occur during switching, are of the same great interest.

Thus, the investigation of the influence of the temperature of shock sintering, at which the electrodes were fabricated, on the erosion intensity of material under the interaction with thermal plasma of electric arc discharge is the main aim of this work.

1. EXPERIMENT

The vertically oriented free-burning arc was ignited in an air atmosphere between the end surfaces of un cooled composite electrodes manufactured on the basis of copper and tungsten (with a volume ratio of 1:1) by the shock sintering method at temperatures of 750, 850, 950, and 1050°C. Electrodes with a square cross-section (5×5 mm) were used. The discharge gap in all experimental studies was 8 mm, the discharge current was kept constant at 3.5 A.

A spectrograph with spatial resolution, optical scheme of which is shown in Fig. 1, was used for diagnostics of the plasma of arc discharges between different types of composite Cu-W electrodes by optical emission spectroscopy [6]. The implemented configuration of the experimental setup with an optical scheme based on a diffraction grating with a period of 600 g/mm allows simultaneous registration of the spatial distribution of radiation intensity in the spectral range of 430...650 nm.

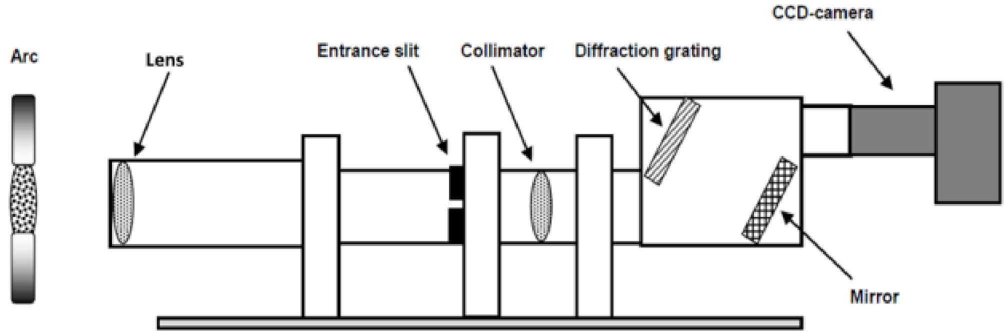


Fig. 1. Optical scheme of spectrograph provided the spectral and spatial resolution

The images of plasma radiation of electric arc discharges between each type of composite electrodes, registered with the RGB CCD matrix of the Nikon D7000 camera, were processed. In particular, the registered images obtained in *. NEF format (without compression and digital processing) with a resolution of 6036×4020 pixels were linearized in order to transform the distribution of colour tetrads of light filters (Bayer's pattern [7]) into a distribution of pixels with RGB components. The obtained images with a colour depth of 16 bits were converted into greyscale data. Thus, the emission spectra of such plasma with spatial resolution were obtained.

Radial distributions of plasma temperature and concentration of metal atoms of electrode origin (copper and tungsten) were determined by Boltzmann plots technique on the basis of the absolute values of the emission coefficients of both copper and tungsten atomic spectral lines. In turn, the radial distributions of the emission coefficients (radiation intensity) of the spectral lines were obtained from the observed values of the spectral radiance from the numerical solution of the Abel integral using the technique proposed by Bockasten [8].

The absolute values of spectral radiance (the energy that passes per time unit through an area unit within a unit solid angle perpendicular to the selected plane) were obtained, taking into account the spectral sensitivity of the registration device in energy units, determined preliminary using a band-lamp.

The profiles of each of the registered Cu I and W I spectral lines were approximated by the Voigt function at each of the 10 selected spatial points along the radius of the discharge channel to obtain the radial distributions of the integrated radiation of the spectral lines.

2. RESULTS AND DISCUSSIONS

The registered RGB images of the plasma radiation of electric arc discharges between composite Cu-W electrodes manufactured at temperatures of 750, 850, 950, and 1050°C are shown in Fig. 2. The exposure time of registration was 2.5 ms. One can see, that the spectrum of such a discharge plasma between each type of composite material is characterized by both line spectrum and continuous radiation. It can be concluded that the material of composites, in particular tungsten, injects to the discharge gap not only in the vapour phase, but also in the form of droplets of molten material.

Spectral lines Cu I 510.5, 515.3, 521.8, 578.2 nm and W I 468.1, 484.4, 488.7, 498.7, 500.6, 501.5, 522.5, and 551.5 nm were identified from the emission spectra. For each spectral line, the spatial limit of its radiation was determined. Thus, the ten points along the radius of the discharge channel were chosen. The contour of each of the presented spectral lines was approximated by the Voigt function to obtain integrated observed values of radiance at the corresponding spatial point in the radial direction from the axis of the arc discharge. Thus, the radial distributions of the radiance of each identified spectral line were obtained.

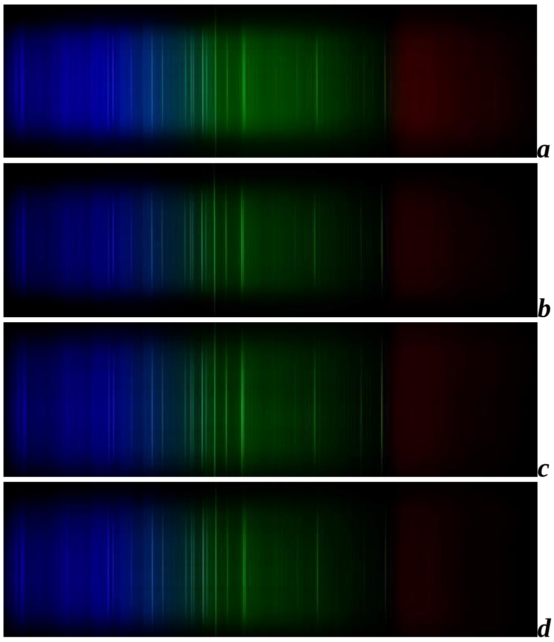


Fig. 2. Registered RGB images of the plasma radiation of electric arc discharges between composite Cu-W electrodes manufactured at temperatures of 750 (a), 850 (b), 950 (c) and 1050°C (d)

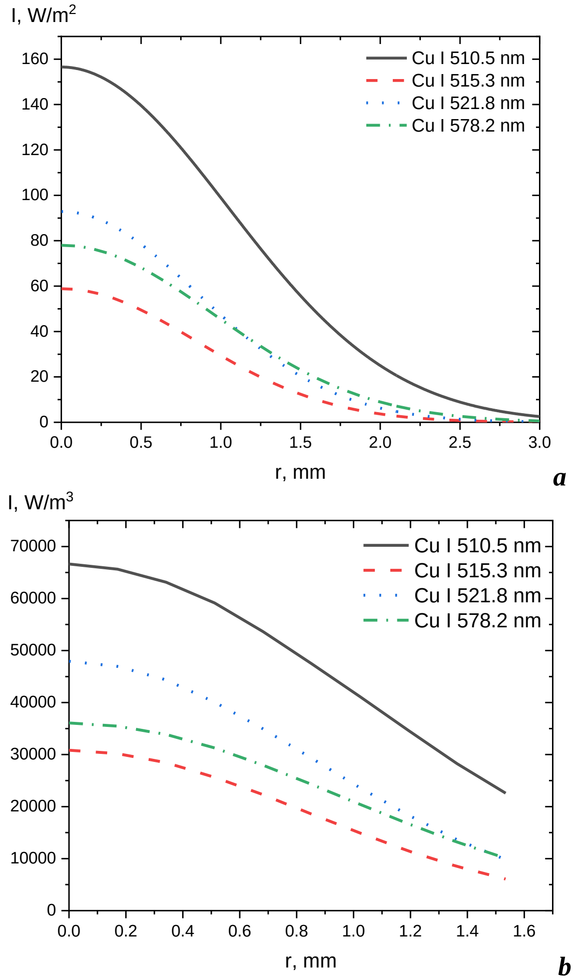
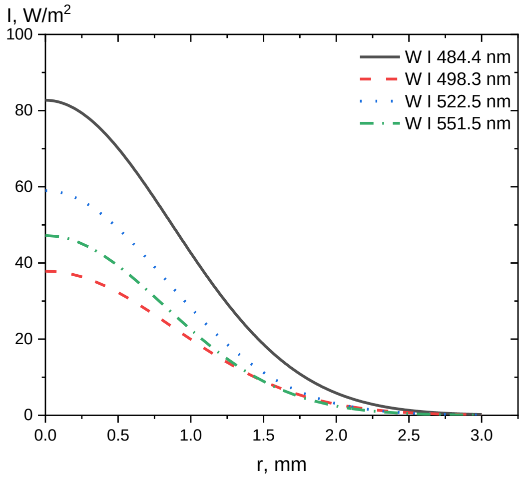


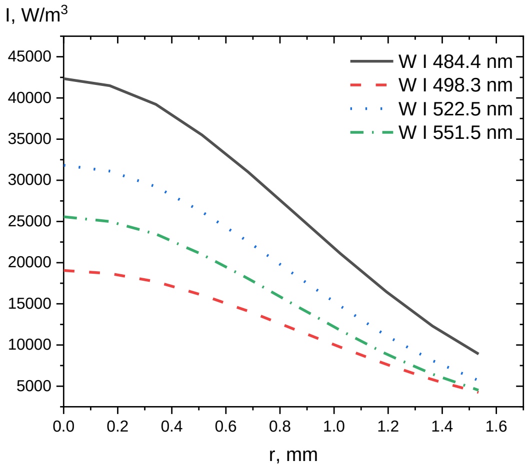
Fig. 3. Typical radial distributions of radiance and radiation intensity of copper spectral lines registered in plasma of arc discharge between Cu-W composites manufactured at 850°C

Radial distributions of radiance were transformed into radial distributions of the emission coefficients of the corresponding spectral lines using the Bockasten method [8].

Typical radial distributions of radiance and radiation intensity of spectral lines Cu I 510.5; 515.3; 521.8, and 578.2 nm in the positive column of the arc discharge plasma between the electrodes, which were manufactured at temperature 850°C are shown in Fig. 3. Typical radial distributions of radiance and radiation intensity of some spectral lines of tungsten (W I 484.4, 498.3, 522.5, and 551.5 nm) in the corresponding mode of arc discharge burning are shown in Fig 4.



a

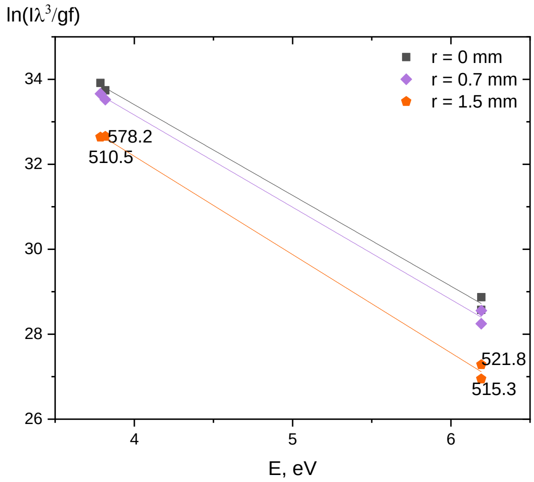


b

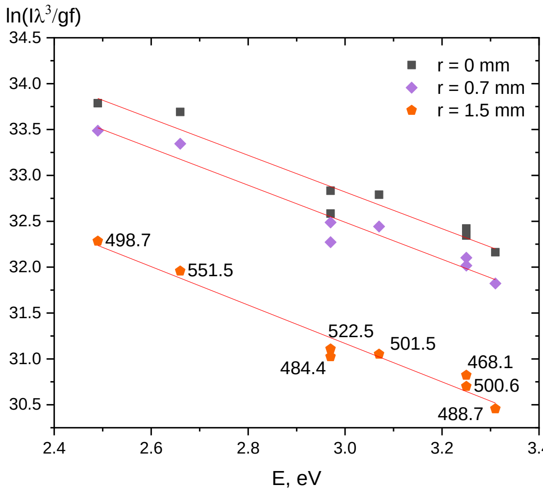
Fig. 4. Typical radial distributions of radiance and radiation intensity of tungsten spectral lines registered in plasma of arc discharge between Cu-W composites manufactured at 850°C

Radial distributions of radiation intensity of copper and tungsten spectral lines hown in Figs. 3 and 4,b were used to determine plasma temperature by Boltzmann plot technique. Typical Boltzmann plots on the basis of absolute values of radiation intensity of Cu I 510.5, 515.3, 521.8, 578.2 nm and W I 468.1, 484.4; 488.7; 498.7; 500.6; 501.5; 522.5, and 551.5 nm spectral lines, registered in the positive plasma column of arc discharges between composite Cu-W electrodes manufactured at temperatures 850°C are shown in Fig. 5.

Radial distributions of plasma temperature determined by Boltzmann plot technique on the basis of absolute radiation intensities both of Cu I and W I spectral lines (T_{Cu} and T_W, respectively) in the positive plasma column of arc discharges between composite Cu-W electrodes manufactured at temperatures of 750, 850, 950, and 1050°C is shown in Fig. 6. Radial distributions of concentrations of copper (n_{Cu}) and tungsten (n_W) atoms are shown in Fig. 7.



a



b

Fig. 5. Typical Boltzmann plots on the basis of absolute emission intensity of Cu I (a) and W I (b) spectral lines registered in plasma of electric arc discharge between Cu-W composites manufactured at 850°C

One can see from Figs. 6, 7 that the radial distributions of plasma temperature, determined by Boltzmann plot technique on the basis of both copper and tungsten spectral lines coincide within the measurement error along the entire radial direction of the positive plasma column. Due to this, it can be assumed that a local thermodynamic equilibrium is realized in the plasma with copper and tungsten vapours admixtures.

The number of copper atoms in the positive plasma column exceeds the number of tungsten atoms along the entire section from the axis to the periphery of the discharge channel, which indicates a more intense erosion of the copper component of composite electrodes. This phenomenon is inherent to the plasma of electric arc discharges between each investigated type of copper-tungsten composite material, which is natural, considering the higher melting point of tungsten as a refractory component of this material.

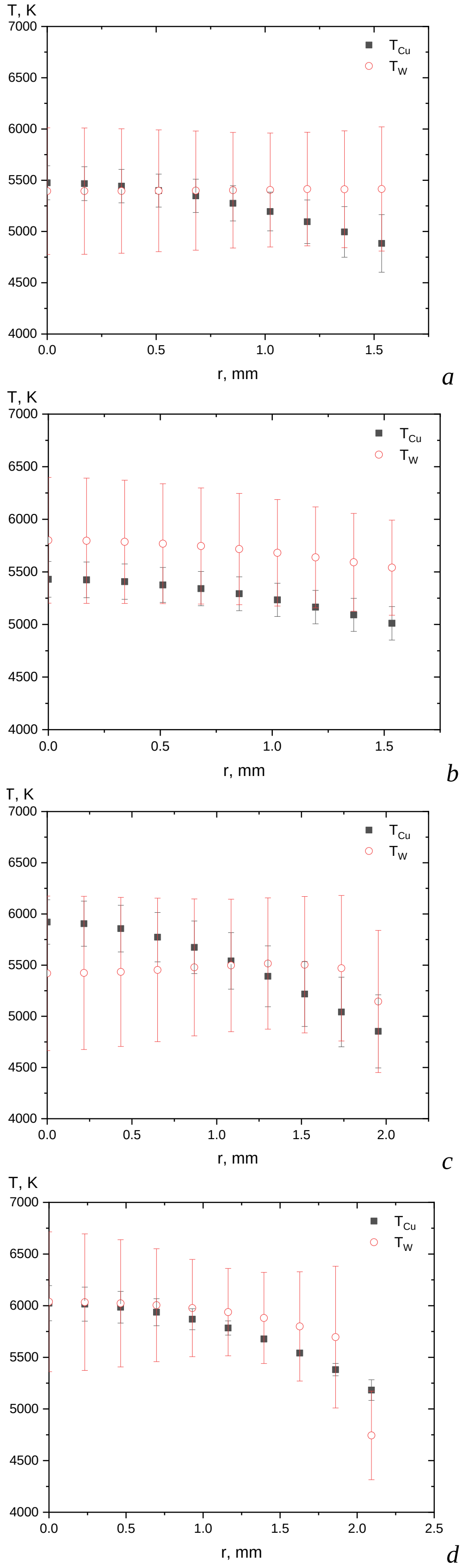


Fig. 6. Radial distributions of plasma temperature determined by Boltzmann plots on the basis of absolute radiation intensity of Cu I and W I spectral lines registered in plasma of electric arc discharge between Cu-W composites manufactured at 750(a), 850 (b), 950 (c), and 1050°C (d)

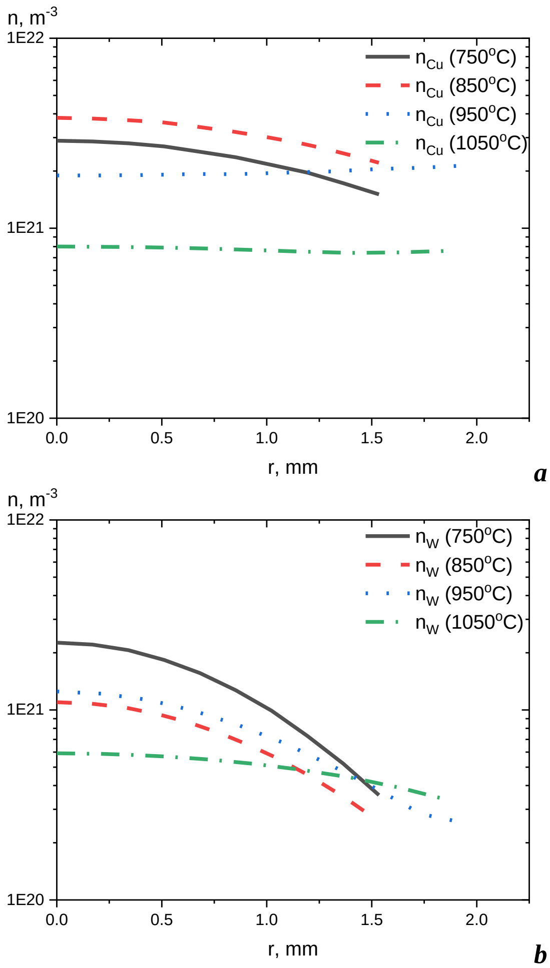


Fig. 7. Radial distributions of concentrations of copper (a) and tungsten (b) atoms obtained by method of absolute radiation intensities in plasma of electric arc discharge between different types of composite Cu-W electrodes

Moreover, the concentration of both copper and tungsten atoms is lower in the positive plasma column of the electric arc discharge between the electrodes that were manufactured at a temperature of 1050°C. The concentration of tungsten in the discharge gap between the electrodes, which were fabricated at a temperature of 750°C, is the highest. At the same time, the concentration of copper atoms in the positive column of the discharge between the electrodes, which were pressed at temperatures of 750, 850, 950°C, do not differ significantly. From this, it can be assumed that Cu-W electrodes, which were produced by shock sintering technology at a temperature of 1050°C, have better resistance to the thermal action of the arc discharge. The shock sintering temperature itself may also be the reason for this.

Since the melting temperature of copper is 1085°C, bringing the temperature, at which composite materials are manufactured, closer to this value can contribute to better diffusion of the copper component inside the tungsten skeleton. And this, in turn, can help increase the density and strength of the manufactured electrodes.

Thus, it can be concluded that there is a dependence of the intensity of erosion of the components of composite materials (copper and tungsten) on the manufacturing technology, in particular, on the shock sintering temperature. This dependence is observed, at least, when the manufacturing temperature increases to the value of the melting temperature of one composite`s component.

CONCLUSIONS

The plasma emission of electric arc discharges between pairs of Cu-W 50 vol.% composite electrodes, which were produced by shock sintering technology at temperatures of 750, 850, 950, and 1050°C, was investigated. In particular, the emission spectra in the positive column of the plasma of such discharges were registered and processed with spatial resolution. The radial distributions of the plasma temperature were determined by Boltzmann plot technique on the basis of the absolute values of radiation intensity of both copper and tungsten spectral lines. The concentration of metal atoms of electrode origin (copper and tungsten) in the positive plasma column of electric arc discharges between studied electrodes manufactured of composite Cu-W materials was determined by the method of absolute intensities.

It was found that there is a relationship between the intensity of erosion of the components of composite materials (copper and tungsten) and the manufacturing technology, in particular, the shock sintering temperature. This behaviour of erosion is observed, at least, when the shock sintering temperature increases to the value of the melting temperature of one composite`s component (copper in this case). In particular, the lowest concentration of metal atoms of electrode origin is observed in the positive plasma column of electric arc discharges between Cu-W composites produced at a temperature of shock sintering of 1050°C, which is as close as possible to the melting temperature of copper (1085°C).

The obtained results of this study require further calculations of the concentration of ions of the corresponding materials to determine the total content of metal vapours in the positive plasma column of the electric arc discharge between different types of composite Cu-W electrodes.

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ДОСЛІДЖЕННЯ ТЕРМІЧНОЇ ПЛАЗМИ ДУГОВОГО РОЗРЯДУ МІЖ НОВІТНІМИ КОМПОЗИТНИМИ Cu-W-МАТЕРІАЛАМИ

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

Методами оптичної емісійної спектроскопії досліджено випромінювання плазми електродугових розрядів між парами композитних Cu-W-електродів. Використано електроди, виготовлені з композитних матеріалів Cu-W 50 об.% за технологією ударного спікання при температурах 750, 850, 950 і 1050°C. Методом діаграм Больцмана із залученням абсолютних значень інтенсивності спектральних ліній як міді, так і вольфраму, визначено радіальні розподіли температури плазми електродугових розрядів. Методом абсолютних інтенсивностей визначено концентрацію атомів металів електродного походження (міді та вольфраму) в позитивному стовпі плазми електродугових розрядів між досліджуваними електродами з композитних матеріалів Cu-W. Інтенсивність ерозії окремих складових композитних матеріалів оцінена в непрямий спосіб із порівняння радіальних розподілів атомів матеріалів електродного походження для кожного типу досліджуваного дугового розряду.