PLASMA OF ELECTRIC ARC DISCHARGE BETWEEN Cu-Mo ELECTRODES

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The radial profiles of the plasma parameters of the electric arc between electrodes from composition materials on the base of cooper Cu-Mo are studied by optical spectroscopy techniques in the assumption of the local thermodynamic equilibrium (LTE). The occurrence of the secondary structure in electrodes' working layers under effect of the electric discharge was found by metallographic technique. The influence of the investigated electrode composition and its secondary structure nature on the plasma axial temperature and its radial distribution is shown.

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1. INTRODUCTION

A wide application of composition materials in the electrical device industry inspired a renewed interest in the investigation of plasma of an electric arc discharge between such material electrodes. A study of arc plasma parameters will be able to facilitate the optimization of various manufacturing equipments.

Electrical and thermophysical properties of composition materials on copper base predetermine the wide popularity of their application, especially, for contacts of switching devices. Processes occurred in free burning electric arc discharges can be serve as model of processes between contacts of switching devices.

The composition materials on the copper base Cu-Mo can be produced by various techniques. The first of them is the solid-phase sintering as a most often used the technique of powder metallurgy. However, the method of the electron-beam evaporation with the following condensation of the vapor stream on the rotating substrate is more economically sound. The composition material condensed from vaporous phase has gradient micro-layered and micro-dispersed structure.

In this paper the radial profiles of plasma parameters of the electric arc between electrodes from composition materials Cu-Mo with various structures are studied by optical spectroscopy. The condition of the electrode surface is studied by metallographic technique.

2. EXPERIMENTAL TECHNIQUE

The arc was ignited between the end surfaces of the non-cooled electrodes. The discharge gap l_{ak} was of 2, 4, 6 or 8 mm. The diameter of the rod electrodes was of 6 mm. To avoid the metal droplet appearing a pulsing mode was used: the current pulse up to 30 A was put on the "duty" weak-current (3.5 A) discharge. The pulse duration ranged up to 30 ms. A quasi-steady mode was investigated.

Because of the discharge spatial and temporal instability the method of the single tomographic recording of the spectral line emission was used. A CCD linear image sensor accomplished fast scanning of spatial distributions of radiation intensity. It allows the recording of the radial distributions of unsteady-state arc radiation intensity in arbitrary spatial sections simultaneously. The synchronization of operation of the CCD linear image sensor with the external electrical circuit is stipulated. The ISA interface slot of IBM PC in a control and data exchange is used. The hardware and software was especially designed for laboratory and industry plasma investigations [1].

3. RESULTS AND DISCUSSIONS

3.1 PLASMA INVESTIGATION OF THE ELECTRIC ARC DISCHARGE BETWEEN Cu-Mo ELECTRODES PRODUCED BY THE SOLID-PHASE SINTERING

We used composition materials Cu-Mo (50/50). The temperature profiles T(r) in electric arc between Cu-Mo electrodes were obtained from relative intensities of spectral lines CuI 521.8 and 510.5 nm. The radial profiles of electron densities $N_e(r)$ are obtained from width of spectral line CuI 515.3 nm in a case of prevail Stark broadening. The ratio of atom concentrations Cu and Mo in plasma was calculated from radial profiles of intensities of spectral lines CuI 521.8 and MoI 603.1 nm in the assumption of the equilibrium of the energy level population. In Fig. 1, 2 and 3 radial profiles T(r), $N_e(r)$ and N_{Cu}/N_{Mo} in the average cross section of the discharge gap l_{ak} = 8 mm are shown.

The obtained electron density and the temperature in plasma as initial parameters were used in the calculation of the plasma composition in LTE assumption. We used the Saha's equation for copper, nitrogen, oxygen and molybdenum atoms, dissociation equation for nitrogen and oxygen molecules, the equation of plasma electrical neutrality and Dalton's law as well. As an additional experimentally obtained parameter we used the ratio of atom concentrations Cu and Mo [1].

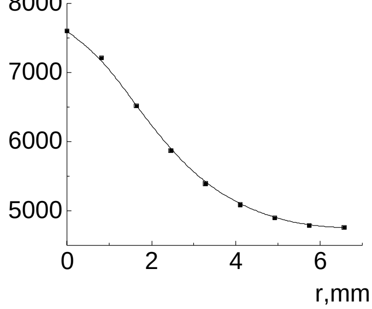


Fig.1. Radial profiles of temperature

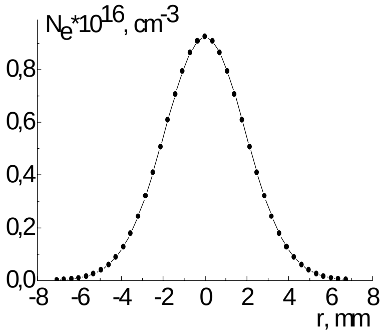


Fig.2. Radial profiles of electron density

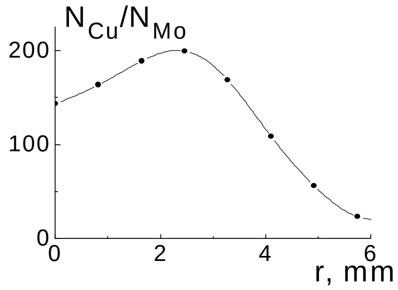


Fig.3. Radial distributions of atom concentration ratio of copper and molybdenum

In Fig. 4 equilibrium plasma composition is shown. It is possible to calculate the content of copper and molybdenum in plasma of the discharge gap. In Fig. 5 contents of Cu and Mo in plasma are shown. It is visible the content of copper is predominated by two orders of magnitude in plasma of the electric arc. The increasing of the content of metal vapors at the discharge periphery can be possible explained by the phenomenon of the ambipolar diffusion (demixing). The additionally confirmation of such assumption is the spatial separation of different plasma components according to their ionization energies [2, 3].

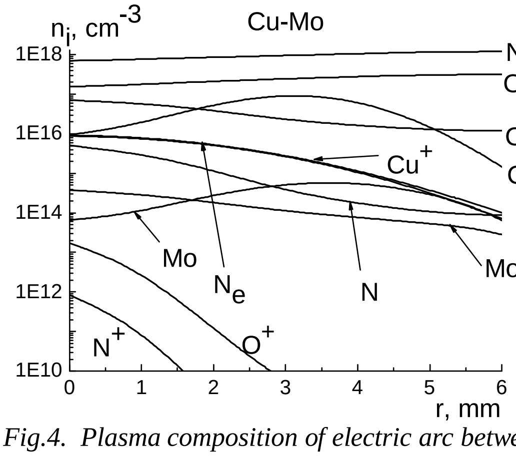


Fig.4. Plasma composition of electric arc between Cu-Mo electrodes

Furthermore as the pressure of saturated vapors of copper above the electrode surface some orders exceeds the pressure of molybdenum vapors the predominance of the copper atom concentrations in plasma is natural.

It is interesting to note that the content of copper in plasma of the electric arc between copper electrodes is about 0.6 % at the discharge axis [4]. In this case of Cu-Mo electrodes the content of copper prevails by the order of magnitude.

In paper [5] was found the working layer at Cu-Mo electrode surface is formed by the influence of the electric arc discharge. The structural changes in a working layer of electrode were studied by metallographic analysis of microvolumes of a working layer too. Such secondary modified surface of electrode has a capillary structure.

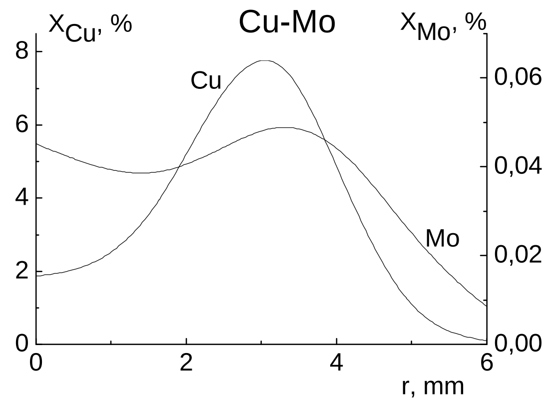


Fig. 5. Contents of copper and molybdenum in plasma

The low thermal conductivity of such modified surface of Cu-Mo electrodes in comparison with single-component Cu electrodes results in copper overheating and its rejection into the discharge gap. Such erosion mechanism can be makes for decreasing of plasma temperature of arc discharge caused by the intensive copper rejection.

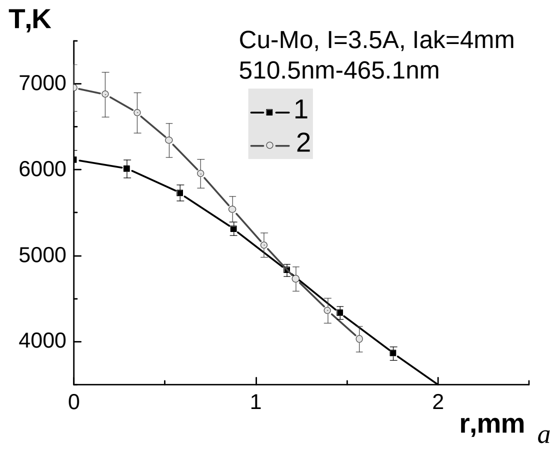
3.2 PLASMA INVESTIGATION OF THE ELECTRIC ARC DISCHARGE BETWEEN Cu-Mo ELECTRODES PRODUCED BY THE ELECTRON-BEAM EVAPORATION

We used electrodes produced by technique of electron-beam evaporation, which have a multilayered Cu and Mo structure [6]. These layers are normally located to the working surface of electrodes. The investigation was carried out at the arc current 3.5 A and discharge gaps l_{ak} of 4 mm. The temperature radial profiles were calculated from relative intensities of CuI spectral lines: 521.8, 515.3, 510.5 and 465.1 nm.

The examples of obtained temperature radial profiles in the average cross section of discharge gap are shown in Fig.6. The curve 1 corresponds to the case the electrode surface with secondary structure and curve 2 corresponds to another case without secondary structure. It is visible that secondary structure leads to the temperature decreasing at the discharge axis. The radial temperature gradient in this case is less significant as well. Probably this effect may be caused by destruction of the micro-layered structure of electrodes.

The temperature profiles obtained by different pairs of spectral lines are practically coincided at least within the experimental accuracy. It is possible to conclude that the Boltzmann law in level population of copper atoms is realized. Therefore, we can assume that LTE takes place in plasma.

The structural changes in a working surface of electrode were studied by metallographic analysis of microvolumes of this surface too. Such secondary modified surface of electrode has a complicated structure. Probably such working surface is characterized by different properties of copper and molybdenum erosion.



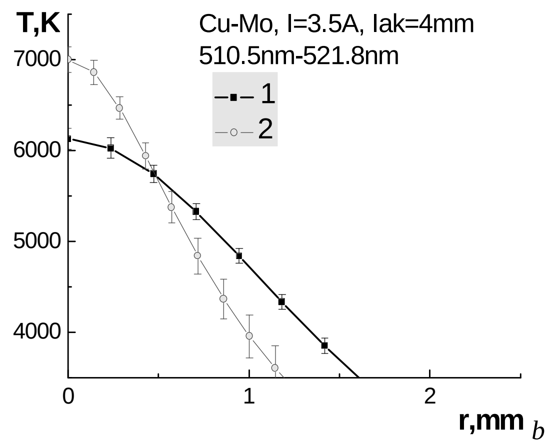


Fig. 6. Radial profiles of temperature

CONCLUSIONS

The radial profiles of temperature and electron densities in the plasma of electric arc discharge between composition Cu-Mo electrodes produced by various techniques were measured by optical spectroscopy techniques. On the base of this initial data the calculation of equilibrium composition of a plasma mixture was carried out in a case of Cu-Mo electrodes produced by the solid-phase sintering. The content of metal vapors in plasma is defined.

By metallographic analysis of microvolumes the structural changes in a working surface of electrode were studied. The processes occurred in the discharge gap are determined by erosion of the electrode material and condition of its surface.

The obtained results allow to make some conclusions concerning of processes of the electrode material erosion in arc. The spectroscopy techniques yield results, which are not at variance with metallographic technique results.

The further complex studies of composition materials will allow to optimize the contact and electrode content.

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ПЛАЗМА ЭЛЕКТРОДУГОВОГО РАЗРЯДА МЕЖДУ Cu-Mo ЭЛЕКТРОДАМИ

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Методами оптической спектроскопии в предположении локального термодинамического равновесия (ЛТР) исследованы радиальные профили параметров плазмы электрической дуги между электродами из композиционных материалов на основе меди Cu-Mo. Металлографическими методами установлено возникновение вторичной структуры в рабочем слое электродов под влиянием электрического разряда. Показано влияние структуры исследуемых электродов и их рабочих поверхностей на температуру плазмы на оси разряда и ее радиальное распределение.

ПЛАЗМА ЕЛЕКТРОДУГОВОГО РОЗРЯДУ МІЖ Cu-Mo ЕЛЕКТРОДАМИ

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Методами оптичної спектроскопії в припущенні локальної термодинамічної рівноваги (ЛТР) досліджено радіальні профілі параметрів плазми електричної дуги між електродами з композиційних матеріалів на основі міді Cu-Mo. Металографічними методами виявлено утворення вторинної структури у робочому шарі електродів під впливом електричного розряду. Показано вплив структури досліджуваних електродів та їх робочих поверхонь на температуру плазми на осі розряду та її радіальний розподіл.