

INVESTIGATIONS OF THERMAL PLASMA WITH METAL IMPURITIES.

PART I: THE INFLUENCE OF ELECTRODES COMPOSITION ON PLASMA PROPERTIES

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Present paper deals with spectroscopic investigations of electric arc discharge plasma in argon flow between Cu-Mo and Cu-Mo-LaB₆ composite electrodes. Obtained profiles of temperature and electron density were used for calculation of plasma composition and metals' content in assumption of local thermodynamic equilibrium (LTE). Significant influence of LaB₆ admixture on plasma properties was found.

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INTRODUCTION

Composite materials on copper base are widely used for contacts and electrodes in switching devices for the electrical engineering industry [1,2]. Exploitation efficiency of switching devices is determined by mass transfer of electrode's materials inside discharge gap. Amount of metal vapours in discharge gap affected by mutual interaction between electrode's material and electric arc plasma, which appeared during switching. Therefore, investigations of such plasma can be useful for optimization of new composite materials, their composition and fabricating technologies.

Plasma of electric arc discharge between Cu-Mo and Cu-Mo-LaB₆ composite electrodes were studied by optical emission spectroscopy. Obtained values of temperature and electron density were used for calculation of plasma compositions for both electrodes' types in assumption of LTE.

Such approach allows identify the influence of LaB₆ admixture on plasma composition, and, consequently on erosion properties of studied materials.

It must be mentioned, that gas (vapour) phase mass transfer of metal is dominated in case of electric arc discharge between composite Cu-Mo electrodes [3].

1. EXPERIMENT

The arc was ignited in argon flow 6.4 slpm between the end surfaces of Cu-Mo or Cu-Mo-LaB₆ non-cooled electrodes. The diameter of the rod electrodes was 6 mm, the discharge gap was 8 mm, arc current was 3.5 or 30 A. To avoid the metal droplet appearing, a pulsing high current mode was used: the current pulse 30 A was put on the "duty" low-current (3.5 A) discharge. The high-current pulse duration was 30 ms.

Cu-Mo and Cu-Mo-LaB₆ composite electrodes were fabricated by powder metallurgy, particularly, by copper infiltration of the high-melting component. Ratio of copper and molybdenum contents in these electrodes was 50%:50%. Admixture of LaB₆ in Cu-Mo-LaB₆ electrodes was less than 1 %.

Technique of one-pass tomographic recording of the spatial distribution of spectral line intensities was used [4]. Monochromator MDR-12 with 3000-pixels CCD linear image sensor (B/W) Sony ILX526A accomplished fast scanning of spatial distribution of radial intensity. Due to the instability of the discharge, statistical averaging of the recorded spatial distributions of the radiation characteristics was carried out.

Selection of CuI spectral lines and analysis of their spectroscopic data was previously carried out in [5]. It was found in preliminary investigations that CuI lines 427.5 nm and 465.1 nm are overlapped by MoI lines 427.6 nm and 465.2 nm during arcing [6]. These lines were withdrawn from further consideration. So, CuI spectral lines 510.5, 515.3, 521.8, 570.0, 578.2, 793.3 and 809.3 nm were used for plasma diagnostic in present work. Boltzmann plot method was applied for plasma temperature determination.

For registration of spectral line profiles in case of 30 A was used spectral device combined with Fabry-Perot interferometer in etalon mode [7]. Electron density was obtained from half-width of spectral line CuI 515.3 nm in assumption of dominated quadratic Stark effect.

Unfortunately, such Fabry-Perot interferometer can't be used for half-width determination in case 3.5 A current. So, electron density in this case was calculated by algorithm based on previously obtained plasma parameters, namely: temperatures distributions for 3.5 and 30 A, electron density for 30 A, intensities ratio of CuI and MoI spectral lines. Comprehensive description of the algorithm has place in work [5].

Plasma of electric arc discharge between Cu-Mo or Cu-Mo-LaB₆ in argon flow generally contains atoms and ions of copper, molybdenum and argon. Plasma in state of local thermodynamic equilibrium can be described by equations set, which consist of Saha equations for each plasma component, equation of charge neutrality, perfect gas law. Additionally, expression for ratio of Cu and Mo atoms' content in plasma volume were included into equations set. This expression can be obtained from ratio of CuI and MoI spectral lines intensities.

2. RESULTS AND DISCUSSIONS

Radial temperature profiles of electric arc discharge are shown in Fig. 1. Profiles for 3.5 A are almost the same within measurement error for both types of electrodes. In contrast, at 30 A significant difference between temperature profiles for Cu-Mo and Cu-Mo-LaB₆ has place - in case of Cu-Mo-LaB₆ electrodes temperature are higher.

It is well known that increasing of metallic vapour content in plasma volume leads to temperature decreasing. So, lower content of metallic vapour (copper and/or molybdenum) in plasma can be assumed in case of Cu-Mo-LaB₆ electrodes at 30 A current.

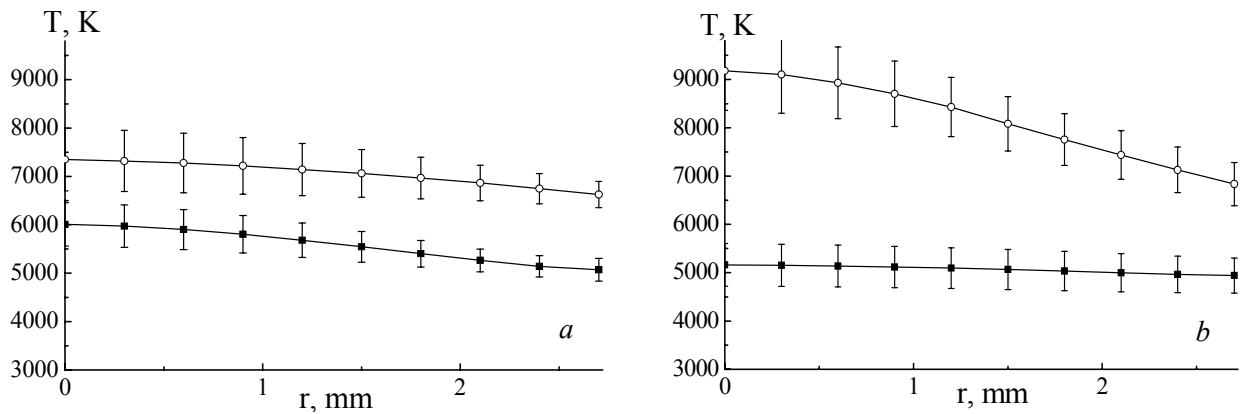


Fig. 1. Radial temperature profiles of electric arc discharge between Cu-Mo (a) and Cu-Mo-LaB₆ (b) electrodes at current 3.5 (■) and 30 A (○)

Calculated plasma compositions of electric arc discharge between Cu-Mo and Cu-Mo-LaB₆ for 3.5 and 30 A currents are shown in Fig. 2 and Fig. 3.

One can see, that electric conductivity of plasma channel mainly supports by copper ionization. Naturally, in contrast to high-melting molybdenum, the amount of copper vapour in plasma volume is dominant.

In case of 3.5 A current contents of copper and molybdenum are in reasonable agreement for both types of electrodes.

Discrepancy in metallic vapour amount for Cu-Mo and Cu-Mo-LaB₆ electrodes has place in case of 30 A.

In the next step, the radial distributions of copper atoms and ions ($X_{Cu}, \% = (N_{Cu} + N_{Cu+}) * 100 / \sum N_i$) and molybdenum ($X_{Mo}, \% = (N_{Mo} + N_{Mo+}) * 100 / \sum N_i$) content for both types of electrodes at 30 A current are calculated (see Fig. 5).

One can see, that contents of copper are in good agreement for both electrodes' types, while content of molybdenum are significantly lower for electrodes with LaB₆ admixture. It leads to temperature increasing for Cu-Mo-LaB₆ in comparison to Cu-Mo electrodes at 30 A current.

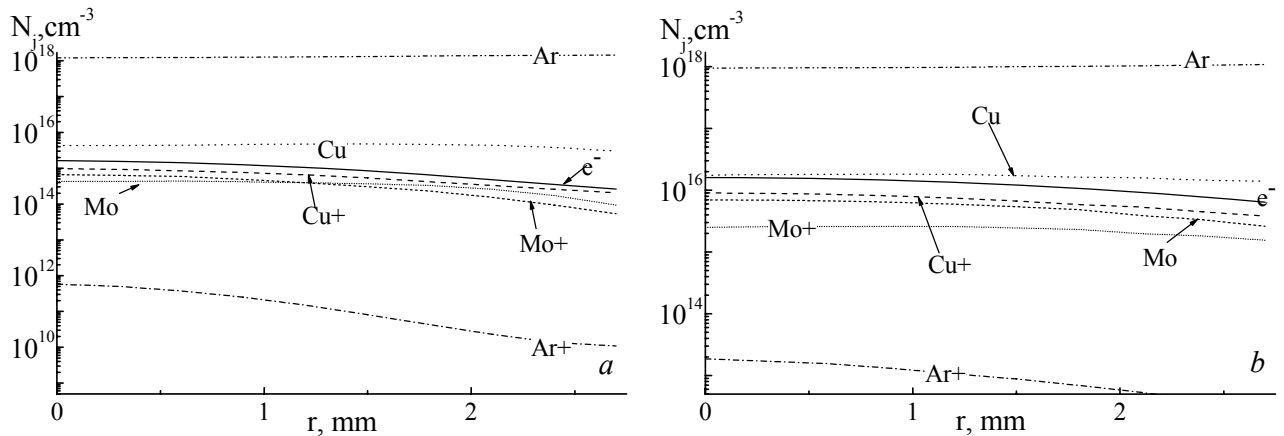


Fig. 2. Plasma composition of electric arc discharge between Cu-Mo electrodes at 3.5 (a) and 30 A (b)

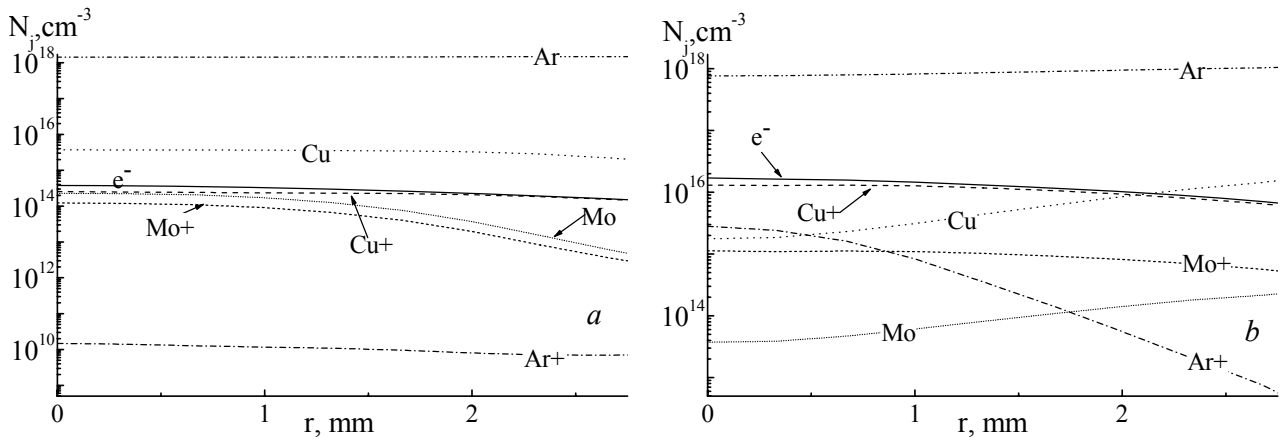


Fig. 3. Plasma composition of electric arc discharge between Cu-Mo-LaB₆ electrodes at 3.5 (a) and 30 A (b)

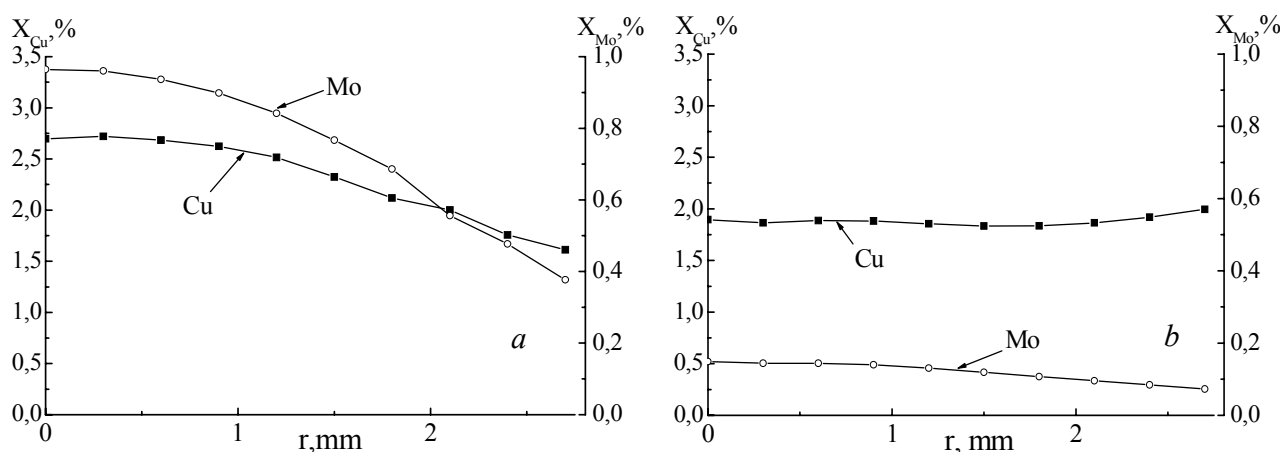


Fig. 4. Content of copper and molybdenum in plasma of electric arc discharge between Cu-Mo (a) and Cu-Mo-LaB₆ (b) electrodes at 30 A

CONCLUSIONS

Electric conductivity of electric arc discharge between Cu-Mo and Cu-Mo-LaB₆ composite electrodes mainly supports by copper ionization. Plasma composition and consequently erosion properties of both electrodes types in 3.5 A current mode are in good agreement. However, presence of LaB₆ admixture causes plasma temperature rising and decreasing of molybdenum content in case of 30 A. This effect can be caused by qualitative changes in plasma-surface interaction at power input increasing.

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ИССЛЕДОВАНИЯ ТЕРМИЧЕСКОЙ ПЛАЗМЫ С ПРИМЕСЯМИ МЕТАЛЛОВ. ЧАСТЬ I: ВЛИЯНИЕ СОСТАВА ЭЛЕКТРОДОВ НА СВОЙСТВА ПЛАЗМЫ

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Работа посвящена спектроскопическим исследованиям плазмы электродугового разряда между Cu-Mo и Cu-Mo-LaB₆ композитными электродами в потоке аргона. Полученные распределения температуры и электронной концентрации использованы для расчета состава плазмы и содержания металлов в предположении состояния локального термодинамического равновесия. Установлено существенное влияние примеси LaB₆ на свойства плазмы.

ДОСЛІДЖЕННЯ ТЕРМІЧНОЇ ПЛАЗМИ З ДОМІШКАМИ МЕТАЛІВ. ЧАСТИНА I: ВПЛИВ СКЛАДУ ЕЛЕКТРОДІВ НА ВЛАСТИВОСТІ ПЛАЗМИ

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Робота присвячена спектроскопічним дослідженням плазми электродугового розряду між композитними Cu-Mo та Cu-Mo-LaB₆ композитними електродами в потоці аргону. Отримані розподіли температури та електронної концентрації використано для розрахунку складу плазми та вмісту металів у припущенні стану локальної термодинамічної рівноваги. Встановлено суттєвий вплив домішки LaB₆ на властивості плазми.