DIAGNOSTICS OF MULTICOMPONENT ELECTRIC ARC PLASMA

A.I. Cheredarchuk, V.F. Boretskij, A.N. Veklich
Taras Shevchenko Kiev National University, Kiev, Ukraine
E-mail: anri@univ.kiev.ua

The plasma parameters of electric arc discharge in a gas flow between copper electrodes were investigated. The electrical conductivity of copper-argon and copper-carbon dioxide plasma was calculated. It was found that at low temperatures (5000 K<T<9000 K) the electrical conductivity considerably depends on the amount of copper in plasma.
PACS: 51.20.d

1. INTRODUCTION

The electric arc between evaporated electrodes has diverse technological applications. It is well known that electrode vapours have a determining influence on properties of arc plasma. The insignificant impurity (about 1 %) of electrode metal vapour appreciably changes plasma parameters of the discharge in a rather wide temperature range [1]. Unfortunately the influence of metal impurity on the plasma of free burning electric arc discharge in different working gases is not experimentally investigated in detail yet.

The main aim of this study is a development of complex diagnostics techniques of determination of plasma parameters of electric arc discharge in a gas flow between copper electrodes.

2. TRANSPORT PROPERTIES OF THERMAL PLASMA

In calculations of the transport properties of thermal plasma it is necessary to know the proportion between plasma components at a constant pressure. The method of calculation of $CO_2 - Cu$ (or $Ar - Cu$) plasma composition was discussed earlier [2]. The content of copper we determined as $X_{Cu}=(N_{Cu}+N_{Cu+})/N_{all}$. As examples in Fig. 1-2 the compositions of CO_2 plasma as well as plasma mixture CO_2-10% Cu are shown. One can see that copper vapours play key role in ionization processes in wide temperature range.

At the next stage we can determine the electrical conductivity σ_e of such plasma mixtures. It can be obtained according to Grad's expression [3-4]:

$$\sigma_e = \frac{n_e e^2 < \upsilon^2 >}{m_e < \upsilon^2 \nu >}. \quad (1)$$

For argon and argon-copper mixture the Frost's expression [5] for electrical conductivity was also used:

$$\sigma^F = \frac{4\pi n_e e^2}{3k_b T} \int_0^\infty \left(\frac{\upsilon^4 f_M}{\nu^F} \right) d\upsilon, \quad (2)$$

where f_M – distribution function, ν^F – function of collisions electron with heavy particles.

3. EXPERIMENT

The arc was ignited in argon or carbon dioxide flow of 6 slpm between the end surfaces of non-cooled copper electrodes. The diameter of rod electrodes was of 6 mm, the discharge gap was of 8 mm, and the arc current was 3.5 and 30 A. The radial temperature profiles T(r) in plasma were obtained from intensities of *CuI* spectral lines by the Boltzmann plot techniques using previously selected spectroscopic data. The radial profiles of electron densities N_e(r) in discharge at 30 A were obtained from width of spectral lines *CuI* 448.0 nm, broadened due to the quadratic Stark effect. In the case of low current (3.5 A) absolute intensity of *CuI* 465.1 nm spectral line was used.

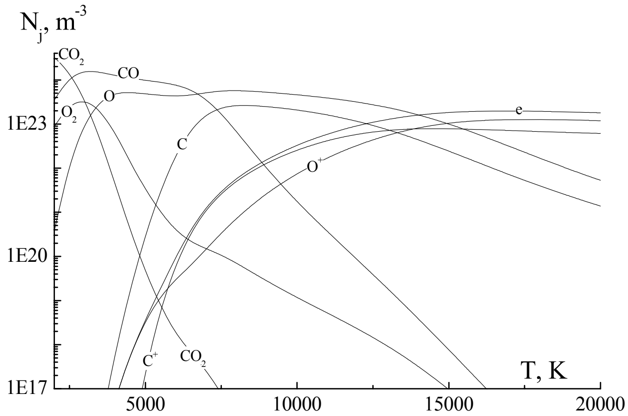


Fig. 1. CO_2 plasma composition

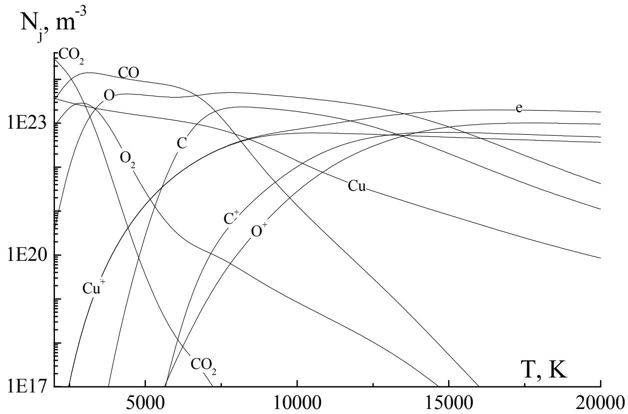
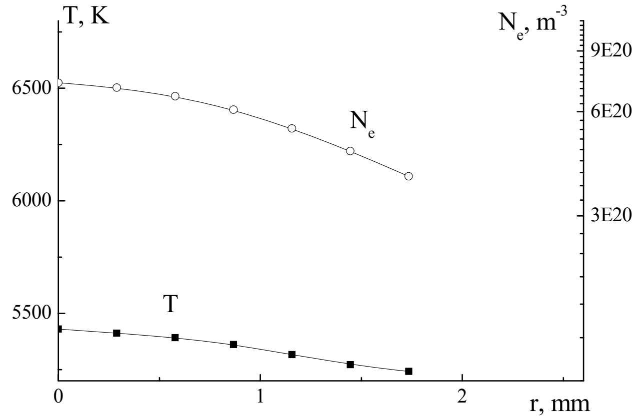


Fig. 2. Plasma composition of CO_2 and 10% Cu mixture

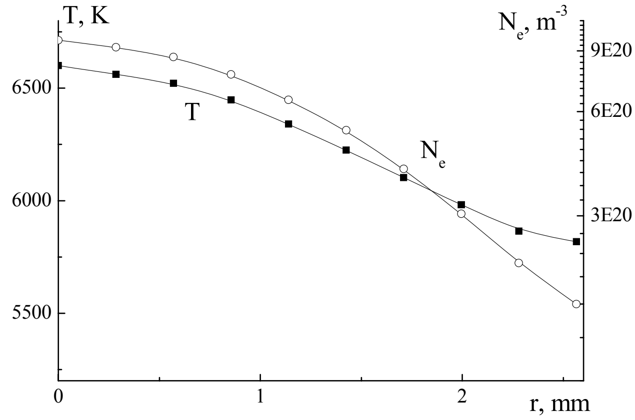
In Fig. 3 the radial distributions of temperature and electron density in argon arc discharge are shown. Two essentially different modes of arc operation are observed at arc current 3.5 A (see Fig. 3, a and Fig. 3, b).

The obtained electron density and temperature in plasma as initial data were used in the calculation of plasma composition in the assumption of local thermodynamic equilibrium (LTE). In Fig. 4 the radial distributions of plasma component in argon arc discharge are shown. One can see that two modes of arc operation at arc current 3.5 A (see Fig. 4, a and Fig. 4, b) differ considerably by copper concentration in discharge gap. In Fig. 5 the radial distributions of copper content in such discharges and electrical conductivity obtained according to expression (1) or (2) are shown.

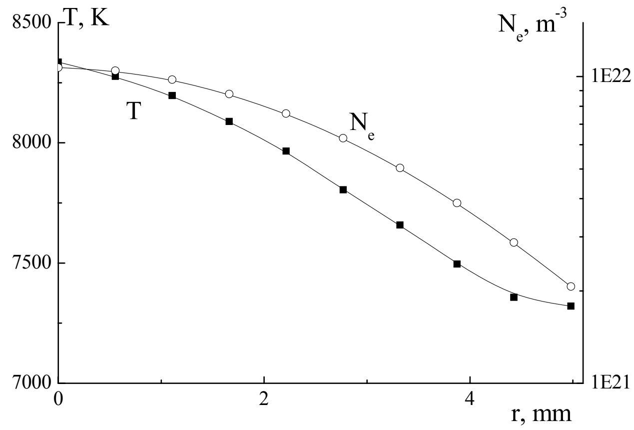
We should note that electrical conductivity essentially depends on plasma temperature. It is natural that this conductivity is raised with a current increasing up to 30 A. One can see that the temperature growth is noticeable in such arc discharge (see Fig. 3, c). Similar behavior of electrical conductivity is observed in two modes of arc operation at arc current 3.5 A. The decreasing of copper content (see Fig. 5, b) naturally leads to the temperature growth (see Fig. 3, b) in the arc discharge. Therefore we observe in this case the not considerable increasing of electrical conductivity obtained by both Grad's and Frost's methods as well (see Fig. 5, a and Fig. 5, b). So, we must note once again that copper vapours play key role in this plasma source.



a



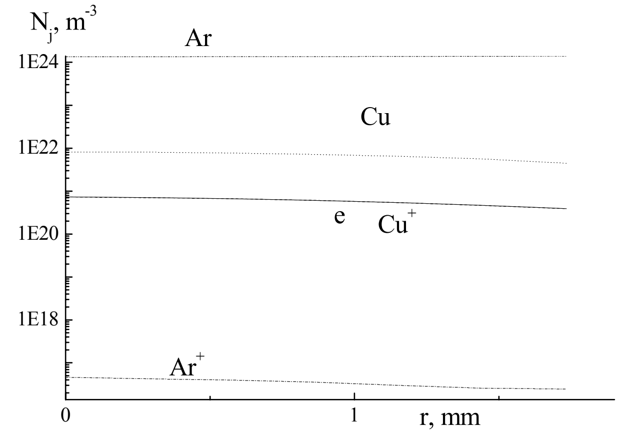
b



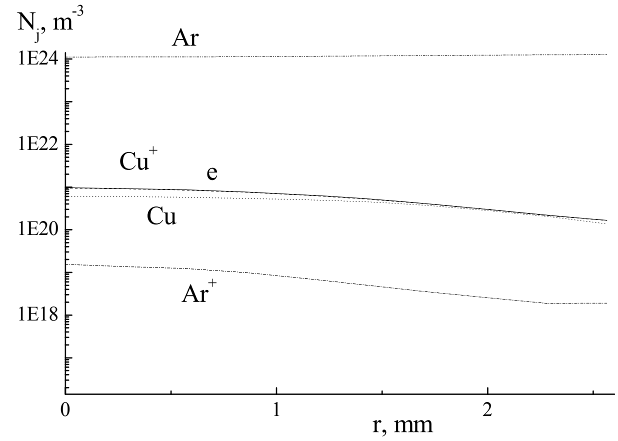
c

Fig. 3. Radial profiles of temperature and electron density in discharge in argon flow at arc currents 3.5 A (a, b – two modes of arc operation) and 30 A (c)

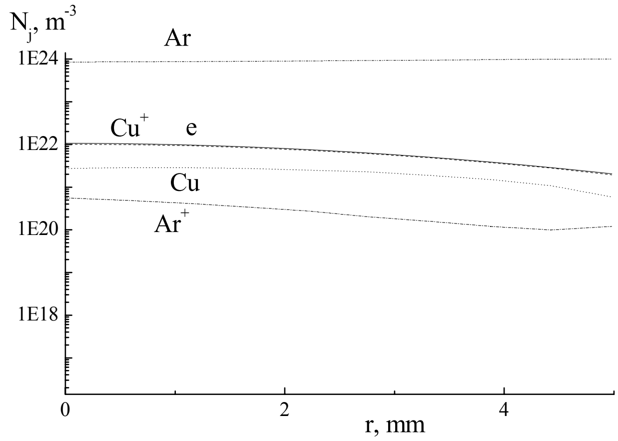
We studied plasma of arc discharge in carbon dioxide flow too (Fig. 6). In Fig. 7 the radial distributions of copper content in such discharges and electrical conductivity obtained by Grad's method (1) are shown. It was found in our previous investigations that plasma discharge in carbon dioxide flow at arc current 30 A is not in equilibrium [2]. We developed the calculation technique of the non-LTE plasma composition. But the detail consideration of this problem is out of the frame of this work.



a

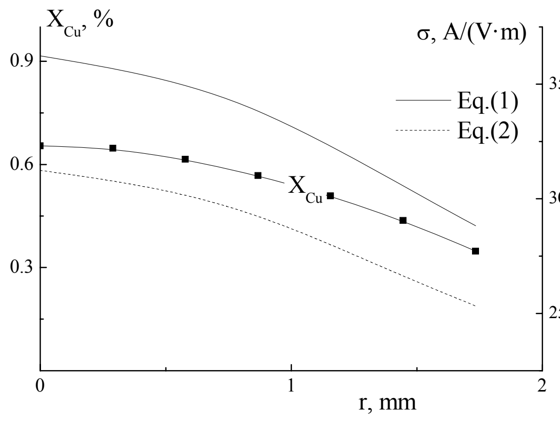


b

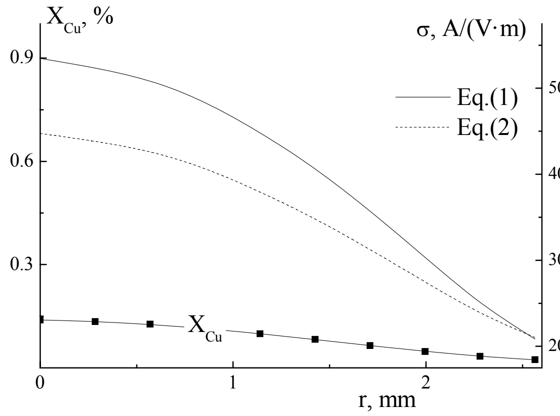


c

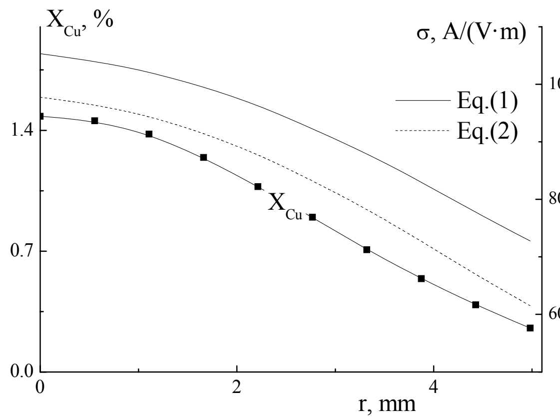
Fig. 4. Radial profiles of plasma components in discharge gap in argon flow at arc currents 3.5 A (a, b – two modes of arc operation) and 30 A (c)



a



b



c

Fig. 5. Radial profiles of copper content and electrical conductivity in discharge gap in argon flow at arc currents 3.5 A (a, b – two modes of arc operation) and 30 A (c)

CONCLUSIONS

The complex diagnostics technique of determination of plasma parameters of electric arc discharge in a gas flow between copper electrodes was developed. The electrical conductivity of copper-argon and copper-carbon dioxide plasma was calculated. It was found that at low temperatures (5000 K< T <9000 K) the electrical conductivity considerably depends on the amount of copper in plasma.

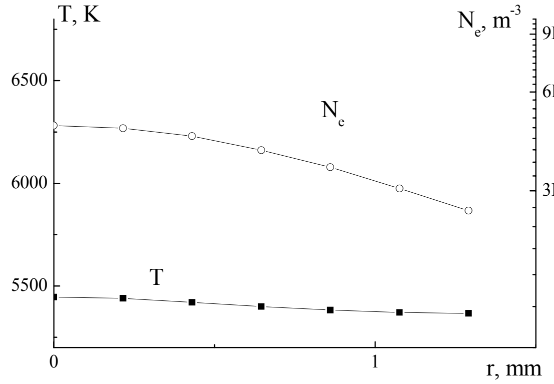


Fig. 6. Radial profiles of temperature and electron density in discharge in carbon dioxide flow at arc current 3.5 A

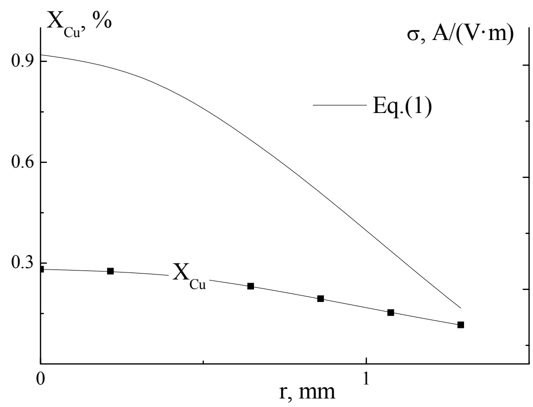


Fig. 7. Radial profiles of copper content and electrical conductivity in discharge gap in carbon dioxide flow at arc current 3.5 A

REFERENCES

1. A. Gleizes, J.J. Gonzalez and P. Freton // *J. Phys. D: Appl. Phys*. 2005, v. 38, p. R153–R183.
2. I. L. Babich, V.F. Boretskij, A.N. Veklich // *Problems of Atomic Science and Technology. Series “Plasma Physics” (14)*. 2008, N 6, p. 171-173.
3. V.M. Zhdanov. *Transport phenomena in multicomponent plasma*. M: “Energoatomizdat”, 1982 (in Russian).
4. S.S. Mankut, A.M. Veklich, P.V. Porytskyy //*Bull. of the Univ. of Kiev. Ser. “Phys.&Math”*. 2006, N 3, p. 358-365.
5. M. Mitchner, Ch. Kruger. *Partially ionized gases*. M: “Mir”, 1976 (Russian translation).

Article received 01.10.10

ДИАГНОСТИКА МНОГОКОМПОНЕНТНОЙ ЭЛЕКТРОДУГОВОЙ ПЛАЗМЫ

А.И. Чередарчук, В.Ф. Борецкий, А.Н. Веклич

Исследовались параметры плазмы электродугового разряда в потоке газа между медными электродами. Рассчитана электропроводность плазмы медь-аргон и медь-углекислый газ. Установлено, что при низких температурах (5000 K < T < 9000 K) электропроводность существенно зависит от количества меди в плазме.

ДІАГНОСТИКА БАГАТОКОМПОНЕНТНОЇ ЕЛЕКТРОДУГОВОЇ ПЛАЗМИ

А.І. Чередарчук, В.Ф. Борецький, А.М. Веклич

Досліджувалися параметри плазми електродугового розряду у потоці газу між мідними електродами. Розраховано електропровідність плазми мідь-аргон та мідь-вуглекислий газ. Встановлено, що при низьких температурах (5000 K < T < 9000 K) електропровідність суттєво залежить від кількості міді в плазмі.