NON-EQUILIBRIUM PLASMA PROPERTIES OF ELECTRIC ARC DISCHARGE IN AIR BETWEEN COPPER ELECTRODES

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Spectroscopy investigations of plasma of free burning electric arc discharge as well as discharge in air flow of 6.45 slpm at currents 3.5, 30, 50 and 100 A were carried out. Plasma state deviation from thermodynamic equilibrium was found at arc current 100 A. Two-temperatures model was used to estimate plasma composition at arc current 100 A.

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INTRODUCTION

There are many applications of electric discharges in molecular gases: plasma chemistry, physics and chemistry of lasers, welding or cutting etc. The remarkable property of such type plasma is that the translational T and vibrational T_v temperatures are not the same [1, 2]. So, in this case the deviation from local thermodynamic equilibrium of plasma state is realized. Situations characterized by strong deviations from equilibrium at low gas temperatures and low pressures, in which considerable amounts of energy are stocked in vibrational levels (T_v>T), are of great practical interest for plasma chemistry or laser chemistry and physics [1-3]. The reason of this kind plasma behavior is the essential time of vibrational-translational energy exchanges (V-T processes) in comparison with the vibrational relaxation (V-V processes) time. It is generally accepted that in thermal plasma of electric arc discharges (welding or cutting etc.) in molecular gases at atmospheric pressure these temperatures are equal (T_v=T) because of comparable time of V-T and V-V relaxation. But if the input power into arc is essential a Boltzmann distribution of vibrational levels with temperature T_v<T is realized due to thermal dissociation in plasma. This phenomenon is responsible for nonequilibrium depletion of vibrational levels in comparison with equilibrium population and has threshold nature at the input energy kT>0.05 D, where D is the dissociation energy [2, 3]. In this case chemically nonequilibrium plasma takes place, i.e. mass action low is not implemented. We observed such type nonequilibrium in plasma of electric arc discharges in CO_2 flow at arc current which exceeds 3.5 A (namely, 30 A) [4]. Similar behavior of nitrogen molecule temperatures (T_v<T) was observed in experiments of physics of the upper atmosphere [3], where authors discussed in detail vibrational and chemical kinetics during space shuttle "Buran" reentry.

The aim of this study is the investigation of the peculiarity of thermal dissociation in electric arc discharge in molecular gas atmosphere of air.

1. PECULIARITIES OF INVESTIGATIONS

The experimental investigations of plasma parameters of free burning discharge as well as discharge in air flow of 6.45 slpm at arc currents 3.5, 30, 50 and 100 A were carried out by optical emission spectroscopy. Electrode assembly and optical system, which were used in experiments, are in detail described in [4]. Plasma temperatures were calculated by Boltzmann plot method using spectroscopic data from [5]. Electron density was obtained from the width of CuI 448.0 nm spectral line using spectroscopic data from [6].

Thermal conductivities for different copper content were obtained from the Chapman–Enskog method [7, 8] based on the solution of Boltzmann's integro-differential equation.

2. RESULTS AND DISCUSSIONS

Experimentally obtained radial distributions of plasma temperature in free burning electric arc discharge and discharge in air flow are shown in Fig. 1. One can see that radial temperature gradient is more noticeable at arc currents 3.5 and 100 A. For the first one such effect is natural because of peak of thermal conductivity in the experimental temperature range (5-7 kK) (see Fig. 2) which mainly corresponds to reaction part, actually, to dissociation process of N_2 molecule [8]. But in the case of arc current 100 A the existence of such temperature gradient is not so clear – there is no any peak of thermal conductivity for the temperatures 8…11 kK.

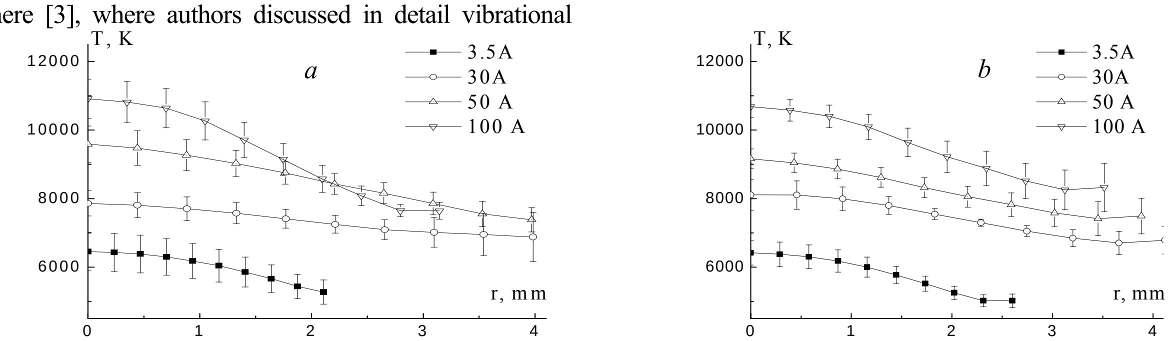

Fig. 1. Radial distributions of plasma temperature in free burning electric arc discharge (a) and discharge in air flow (b.

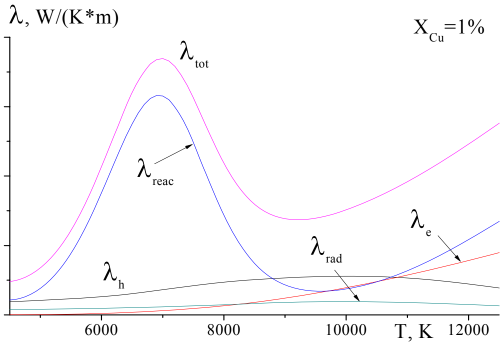

Fig. 2. Components of total thermal conductivity.

Therefore plasma at arc current 100 A is of particular interest and must be studied in detail to understand this effect. Experimentally obtained radial distributions of plasma temperature (Fig. 2) and electron density (Fig. 3) were used in calculation of plasma equilibrium compo-sition. The technique of calculation described in detail in [5].

Some results of these calculations for free burning discharge are shown in Fig. 4. As one can see in Fig. 4, b the results of calculation showed that plasma state is not in LTE (local thermodynamic equilibrium) in the central part of the discharge channel at arc current 100 A.

As was early suggested [9] the main reason of plasma state deviation from LTE is aforementioned nonequilib-rium dissociation. To estimate composition of such non-equilibrium plasma the two-temperature technique was proposed for the first time in [4]. This technique requires knowledge of the copper atom concentration which can be estimated by extrapolating of data calculated by traditional approach [5] as was shown in Fig. 5. The results of such kind two-temperature calculation were used to obtain so called effective temperatures of N_2 molecule dissociation (Fig. 6) and plasma component concentrations in the case when plasma state is not in LTE (Fig. 7). As one can see, for the plasma temperatures more than 9 kK the dissociation temperatures significantly lower. We assume that it caused by lower dissociation rate constant in coSSmparison with its equilibrium value [10]. This effect leads to the modifying of the total thermal conductivity of such non-equilibrium plasma due to additional contribution of reaction component of conductivity at the temperatures 8…11 kK.

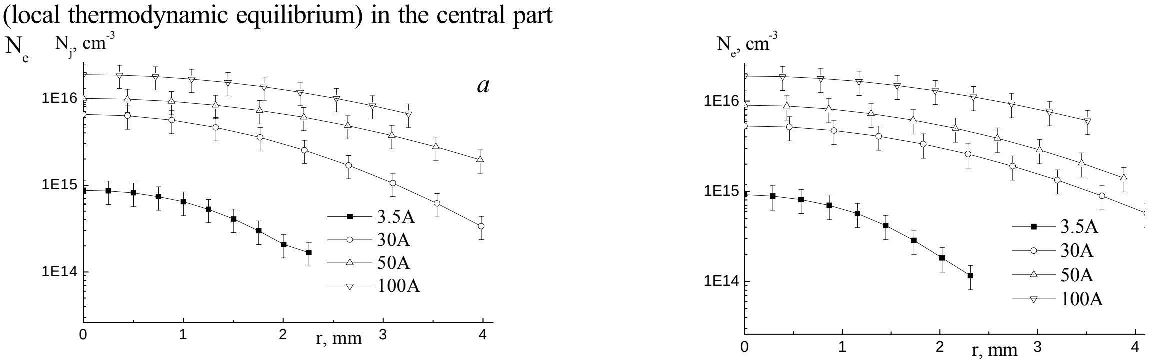

Fig. 3. Radial distributions of the electron density: (a) - free burning electric arc discharge, (b) - discharge in air flow

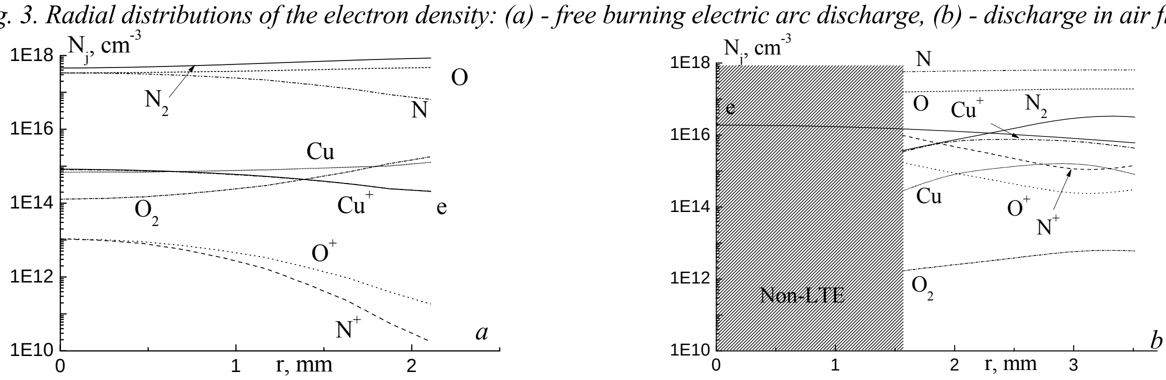

Fig. 4. Radial distributions of the plasma components of free burning discharge at currents 3.5 (a) and 100 A (b)

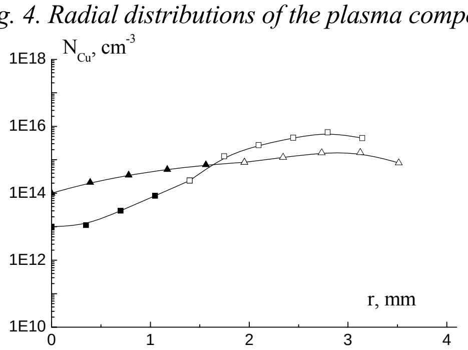

Fig. 5. Copper atom concentration in the plasma of free burning electric arc discharge (squares) and discharge in air flow (triangles) at arc current 100 A. Empty symbols – calculated data, filled symbols – extrapolation

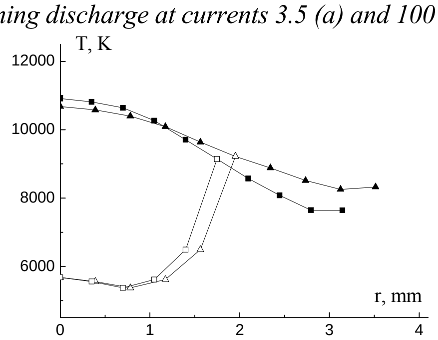

Fig. 6. Temperatures in the plasma of free burning electric arc discharge (squares) and discharge in air flow (triangles) at arc current 100 A. Empty symbols – effective temperatures of dissociation, filled symbols – plasma temperatures

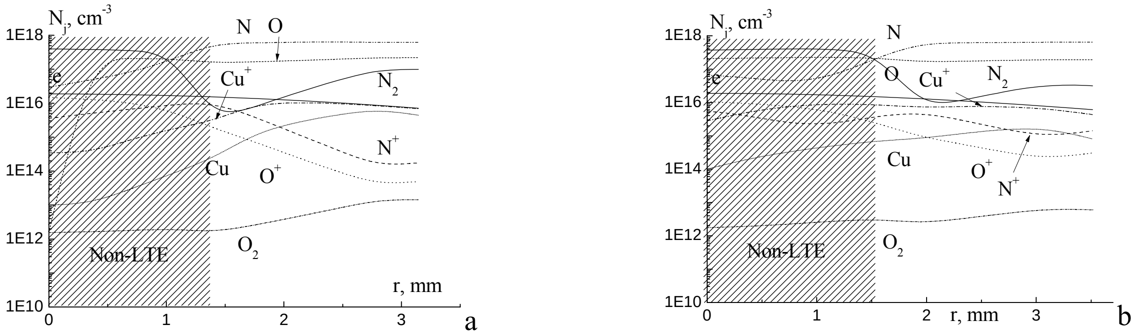

Fig. 7. Radial distributions of plasma components of free burning electric arc discharge (a) and discharge in air flow (b) at arc current 100 A

Such modifying of the thermal conductivity can explain the observed behavior of radial temperature gradient at arc current 100 A.

CONCLUSIONS

It was found that plasma of electric arc discharge in air at arc current 100 A is not in chemical equilibrium. We assume that the main reason of such non-equilibrium property is thermal dissociation of N_2 molecule at plasma temperatures more than 9 kK. This phenomenon can lead to decreasing of vibrational temperature in comparison with translational one and, finally, as a result, to decreasing of the dissociation rate constant. We used two temperatures model in estimation of density components in such chemically non-equilibrium plasma. It was found that in the discharge axis the dissociation processes occurs at effective temperatures 6000-7000K in this mode of arc operation. Taking into account the additional contribution of the non-equilibrium thermal dissociation to the total thermal conductivity we suggested the explanation of radial plasma temperature behavior.

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НЕРАВНОВЕСНЫЕ СВОЙСТВА ПЛАЗМЫ ЭЛЕКТРОДУГОВОГО РАЗРЯДА В ВОЗДУХЕ МЕЖДУ МЕДНЫМИ ЭЛЕКТРОДАМИ

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Выполнены спектроскопические исследования плазмы свободно горящего электродугового разряда, а также разряда в потоке воздуха 6,45 л/мин при силах тока 3,5, 30, 50 и 100 А. Установлено отклонение состояния плазмы от термодинамического равновесия при силе тока 100 А. Использована двух-температурная модель для оценки состава плазмы при силе тока 100 А.

НЕРІВНОВАЖНІ ВЛАСТИВОСТІ ПЛАЗМИ ЕЛЕКТРОДУГОВОГО РОЗРЯДУ В ПОВІТРІ МІЖ МІДНИМИ ЕЛЕКТРОДАМИ

В. Борецький, А. Веклич, Y. Cressault, A. Gleizes, Ph. Teulet

Виконані спектроскопічні дослідження плазми вільно існуючого електродугового розряду, а також, розряду в потоці повітря 6,45 л/хв при силах струму 3,5, 30, 50 и 100 А. Встановлено відхилення стану плазми від термодинамічної рівноваги при силі струму 100 А. Використано двотемпературну модель для оцінки складу плазми при силі струму 100 А.