ON THE INFLUENCE OF COPPER IMPURITIES ON THE TRANSPORT PROPERTIES OF THERMAL WATER PLASMA

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The influence of copper impurities on the transport properties of multicomponent thermal plasma is considered in the ambient atmosphere of water vapors. The calculations are carried out on the base of Grad's method, and it is shown that a small amount of metal causes the essential changes in the values of transport coefficients in comparison with the case of pure water plasma. It is considered the influence of the model of cross-section for electron collisions with atomic copper on transport properties.

PACS: 52.25.Fi, 52.25.Vy, 52.25.Ya, 52.27.Cm, 52.77.Fv, 52.50.Nr, 52.80.Mg

INTRODUCTION

Copper is widely used in plasma devices and industrial electronic plants. Sometimes they are doped with other materials to lower the work function of the cathode material. At operation the process of erosion leads to the evaporation of the metal impurities into the discharge region that causes the change of plasma properties. Also, the plasma created from water vapors is widely applied in applications. It is the thermal plasma mixture of both the copper and water vapors is considered below.

The improvement in controlling plasma processing needs for accurate numerical modeling. Transport properties are indispensable input data for the modeling. At weakly ionization the Lorentzian theory is suitable to calculate the properties of multicomponent thermal plasma [1]. But at increasing of ionization processes a number of collision processes are known to be included into consideration. Because of that it is the many processes are needed to take into account in the calculation procedure.

In this paper, the transport coefficients for multicomponent water plasma with copper impurities are calculated on the base of the Grad's method [2 - 4]. It is shown that the impurities have an influence on the transport properties of thermal plasma.

1. METHOD OF CALCULATION

It should be noted that the present state of the theory of gas mixtures, as well as multicomponent plasma, is characterized by the lack of a unified approach to the description of transport processes. The reason for this is a very complex nature of dependencies of the properties of gas mixtures and plasma on the properties of pure gases and concentrations of the components.

Thus, the coefficient of thermal conductivity is calculated as the sum

$$\lambda = \lambda_h + \lambda_e + \lambda_{\text{int}} + \lambda_{ri} + \lambda_{rd}, \qquad (1)$$

where λ_h is the translational thermal conductivity of heavy particles, λ_e is the thermal conductivity of electrons, λ_{int} is the thermal conductivity due to the transfer among the internal degrees of freedom, λ_{ri} is the reactive thermal conductivity due to ionization, λ_{rd} is the reactive thermal conductivity due to dissociation.

In turn, the coefficient of viscosity is calculated as the sum of additions from heavy particle η_h and electrons η_e:

$$\eta = \eta_h + \eta_e. \qquad (2)$$

It should be underlined that, now, the Grad's method of moments [2, 3] is an unique alternative in spite of the most developed Chapman-Enskog' method [4 - 8] to solve the kinetic Boltzmann equation. Both the methods are based on the formalism of Chapman-Cowling kinetic integrals

$$\Omega_{\alpha\beta}^{lr} = \left(\frac{kT}{2\pi\mu_{\alpha\beta}}\right)^{1/2} \int_0^\infty \varsigma^{2r+3} e^{-\varsigma^2} Q_{\alpha\beta}^{(l)}(\varsigma)\, d\varsigma, \qquad (3)$$

where k is Boltzmann constant, T is temperature, $\mu_{\alpha\beta}$ is a reduced mass of collided species of α and β, $\varsigma = \left(\mu_{\alpha\beta}/2kT\right)^{1/2} g$, g is the relative velocity, and transport cross-section of order l is determined as

$$Q_{\alpha\beta}^{l}(g) = 2\pi \int_0^\pi \sigma_{\alpha\beta}(g,\chi)\left(1-\cos^l \chi\right)\sin\chi\, d\chi,$$

where χ is scattering angle, $\sigma_{\alpha\beta}(g,\chi)$ is differential scattering cross-section.

In the 13-moments (13M) approximation of the Grad's method the translational transport coefficients are calculated as the sum of effective coefficients for each species

$$\eta_h = \sum_\alpha \eta_{h\alpha}, \qquad (4)$$

$$\lambda_h = \sum_\alpha \lambda_{h\alpha}. \qquad (5)$$

The effective coefficients are calculated on the base of combination of the Chapman-Cowling integrals (3).

The studies of electronic transport coefficients are known to need using of higher approximations. In that way for electronic viscosity, electrical conductivity σ, and electronic conductivity one can be write [3], respectively,

$$\eta_e = \frac{5}{2} n_e^2 \left(2\pi m_e kT\right)^{1/2} \frac{|p'|}{|p|}, \qquad (6)$$

$$\sigma = \frac{3}{2} n_e^2 e^2 \left(\frac{2\pi}{m_e kT}\right)^{1/2} \frac{|q'|}{|q|}, \qquad (7)$$

$$\lambda_e = \frac{75}{8} n_e^2 \left(\frac{2\pi kT}{m_e} \right)^{1/2} \frac{|q''|}{|q'|}. \qquad (8)$$

Here m_e is the mass of electron, n_e is electronic density, the elements of determinants p^{nk} and q^{nk} are the functions of the above pointed Chapman-Cowling integrals. Script denotes the absence of elements with indexes 0 and 1.

The peculiarity of the Grad' method is that the values have the same dimensions at all of stages in calculation procedure due to the control of calculation procedure may be improved.

2. RESULTS AND DISCUSSION

The calculations are carried out at assumption of local thermodynamic equilibrium, and the following 16 species have been taken into account: e^-, H_2O, H_2O^+, H_2, H_2^+, O_2, O_2^+, OH ,OH^+, H, H^+, O, O^+, Cu, Cu^+, Cu^{2+}. The results of calculation ns for the case of pure water are shown in Figs. 1-4.

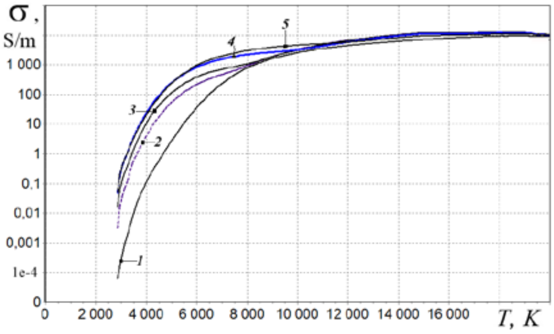

Fig. 1. Electrical conductivity of thermal plasma for the equimolar mixtures of water vapors with copper (pressure p *=1 bar). Curves 1 – pure water; 2 –* H_2O*-Cu (99.99:0.01); 3 –* H_2O*-Cu (99.7:0.3); 4 –* H_2O*-Cu (95:5); 5 –* H_2O*-Cu (70:30). The transport cross-section for* e^-*+Cu collision according to [5]*

One can see that the properties of multicomponent plasma have a pronounced non-monotone character with sharp pikes in certain temperature and pressure ranges. The pikes are appeared due to the dissociation, ionization and from others effects connected with metal impurities.

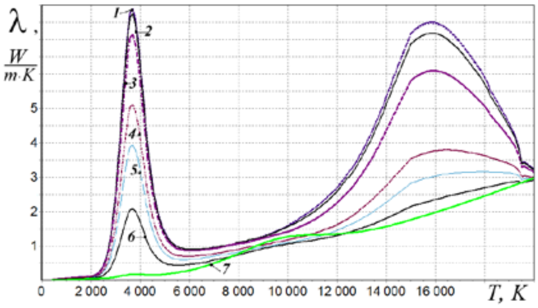

Fig. 2. Thermal conductivity of thermal plasma for the equimolar mixtures of water vapors with copper (p *=1 bar). Curves 1 – pure water; 2 –* H_2O*-Cu (99.9:0.1); 3 –* H_2O*-Cu (99.7:0.3); 4 –* H_2O*-Cu (99:1); 5 –* H_2O*-Cu (95:5); 6 –* H_2O*-Cu (70:30); 7 –* H_2O*-Cu (10:90). The transport cross-section for* e^-*+Cu collision according to [5]*

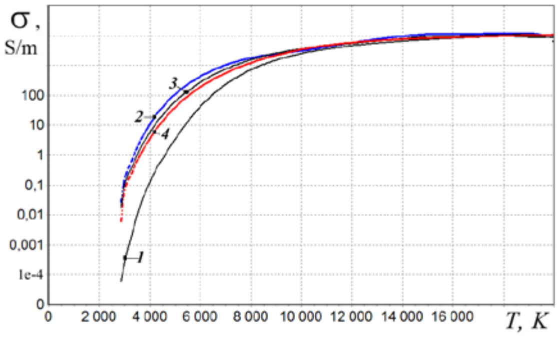

Fig. 3. Electrical conductivity of thermal plasma for the equimolar mixtures of water vapors with copper H_2O*-Cu (10:90) (* p *=1 bar). Curves 1 – pure water; 2 – the transport cross-section for* e^-*+Cu collision according to [6]; 3 – one is [5]; 4 – one is [7]*

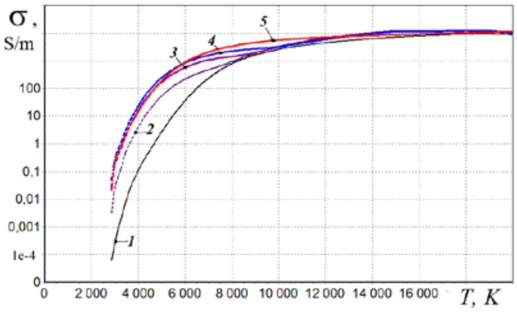

Fig. 4. Electrical conductivity of thermal plasma for the equimolar mixtures of water vapors with copper (p *=1 bar). Curves 1 – pure water; 2 –* H_2O*-Cu (99.99:0.01); 3 –* H_2O*-Cu (95:5); 4 –* H_2O*-Cu (95:5); 5 –* H_2O*-Cu (70:30). The transport cross-section for* e^-*+Cu collision according to [5]*

The appearance of copper impurities causes the essential changing of transport properties with comparison to the case of pure water. That is needed to take into account under studies of discharges with copper electrodes.

It should be noted that under scattering of electron on an atomic copper the various models are known to be exist (see for details [5 - 7]). The influence of the different cross-sections on the properties takes place with the strong character (see Figs. 3-4). Thus, the calculations based on the novel model [5] are very different from widely used one [6].

CONCLUSIONS

Thus, a small amount of copper causes the essential changes in the values of transport coefficients of thermal plasma in comparison with the case of pure water.

The properties of thermal plasma mixture are strongly depended on the character of electron-atom collision cross-sections.

Furthermore, the problem of inequality of transport properties calculation takes place for plasma mixtures containing copper due to the existing of various models describing the electron-atom collision cross section for copper.

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Article received 28.04.2015

О ВЛИЯНИИ ПРИМЕСЕЙ МЕДИ НА ТРАНСПОРТНЫЕ СВОЙСТВА ТЕРМИЧЕСКОЙ ВОДНОЙ ПЛАЗМЫ

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Рассмотрено влияние примесей меди на транспортные свойства многокомпонентной плазмы в атмосфере водяного пара. Проведенные расчеты основывались на методе моментов Грэда. Показано, что незначительное количество примесей металла может существенно изменить величины транспортных коэффициентов в сравнении со случаем чистого водяного пара. Рассмотрено влияние модели сечения столкновений электрона с атомом меди на транспортные свойства термической плазмы.

ПРО ВПЛИВ ДОМІШОК МІДІ НА ТРАНСПОРТНІ ВЛАСТИВОСТІ ТЕРМІЧНОЇ ВОДЯНОЇ ПЛАЗМИ

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Розглянуто вплив домішок міді на транспортні властивості багатокомпонентної плазми в атмосфері водяної пари. Проведені розрахунки ґрунтувалися на методі моментів Ґреда. Показано, що невелика кількість металевих домішок може суттєво змінити величини транспортних коефіцієнтів порівняно із випадком чистої водяної пари. Розглянуто вплив моделі перерізу зіткнень електрона з атомом міді на транспортні властивості термічної плазми.