ON THE INFLUENCE OF BERYLLIUM IMPURITIES ON THE TRANSPORT PROPERTIES OF MULTICOMPONENT ARC PLASMA

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The influence of beryllium impurities on the transport properties of multicomponent arc plasma is considered in the ambient atmosphere of argon and carbon dioxide. 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 gaseous mixtures. It is revealed that the influence of the Ramsauer effect on transport properties can be neutralized by additions of metal into ambient argon.

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INTRODUCTION

Beryllium 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.

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 plasma with tungsten impurities are calculated on the base of the Grad’s method [2, 3]. 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

$$\lambda = \lambda_h + \lambda_e + \lambda_{\text{int}} + \lambda_{ri} + \lambda_{rd} \ , \qquad (1.1)$$

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:

$$\eta = \eta_h + \eta_e \ . \qquad (1.2)$$

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

$$\Omega^{lr}_{\alpha\beta} = \left(\frac{kT}{2\pi\mu_{\alpha\beta}}\right)^{1/2} \int_0^\infty \varsigma^{2r+3} e^{-\varsigma^2} Q^{(l)}_{\alpha\beta}(\varsigma)\, d\varsigma \ , \qquad (1.3)$$

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

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

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

$$\eta_h = \sum_\alpha \eta_{h\alpha} \ , \qquad (1.4)$$

$$\lambda_h = \sum_\alpha \lambda_{h\alpha} \ . \qquad (1.5)$$

The effective coefficients are calculated on the base of combination of the Chapman-Cowling integrals (1.3).

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,

$$\eta_e = \frac{5}{2} n_e^2 \left(2\pi m_e kT\right)^{1/2} \frac{|p'|}{|p|}, \tag{1.6}$$

$$\sigma = \frac{3}{2} n_e^2 e^2 \left(\frac{2\pi}{m_e kT}\right)^{1/2} \frac{|q'|}{|q|}, \tag{1.7}$$

$$\lambda_e = \frac{75}{8} n_e^2 \left(\frac{2\pi kT}{m_e}\right)^{1/2} \frac{|q''|}{|q'|}. \tag{1.8}$$

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 (see for details [3-8]).

Others coefficients are calculated according to the Lorentzian theory [2].

2. RESULTS AND DISCUSSION

The calculations are carried out at assumption of local thermodynamic equilibrium, and the following 8 species have been taken into account: *e^-, Ar, Ar^+, Be, Be^+, Be^{2+}, Be^{3+}, Be_2, Be_2^+* and others analogous mixtures. The results of calculations for the case of nickel are shown in Figs.1-4. The obtained values are in a good agreement with the data obtained by Chapman-Enskog method (see Figs. 1, 2).

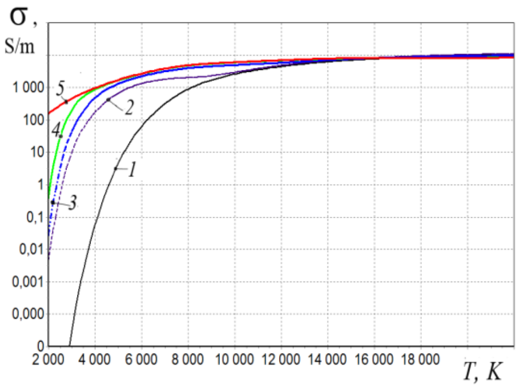

Fig. 1. Electrical conductivity of thermal plasma (p =1 atm) for pure argon and the equimolar mixtures of argon with beryllium. Curves 1 – pure Ar (this work calculations); 2 – Ar–Be (99:1); 3 – Ar–Be (90:10); 4 – Ar-Be (75:25); 5 – pure Be

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. Thus, the viscosity peaks (see Fig.4) are caused by the minor additions of ions in gases at weakly ionization.

It should be noted that under scattering of electrons on argon the Ramsauer effect takes place that is determined the properties of pure argon. However this influence can be neutralized by metal additions in plasma.

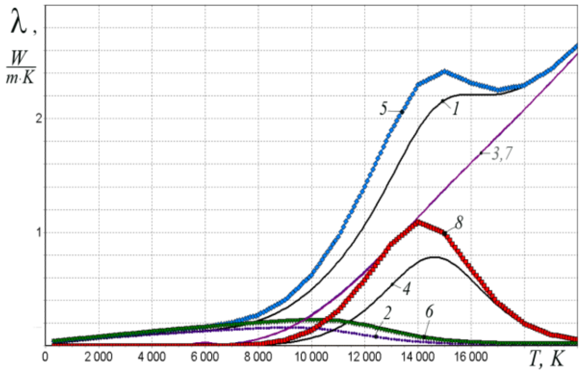

Fig. 2. Thermal conductivity of thermal plasma for pure argon (p =1 atm). Curves 1,5 are total conductivities, 2,6 are gaseous ones, 3,7 are electronic ones, 4,8 are ionization ones. Curves 1,2,3,4 are presented calculations, 5,6,7,8 are the data from [8]

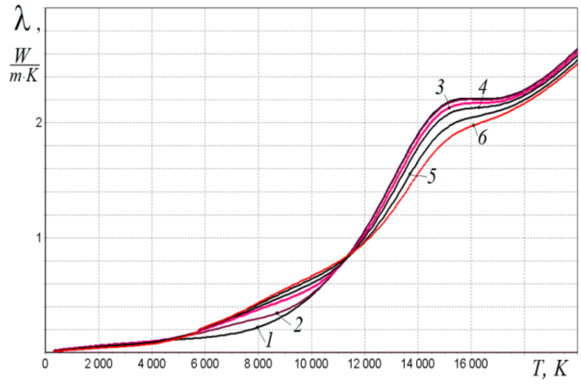

Fig. 3. Thermal conductivity of thermal plasma (p =1 atm) for pure argon and the equimolar mixtures of argon with beryllium. Curves 1 – Ar (this work calculations); 2 – Ar–Be (99.9:0.1); 3 – Ar –Be (95:5); 4 – Ar-Be (90:10); 5 – Ar–Be (80:20); 6 – Ar–Be (70:30)

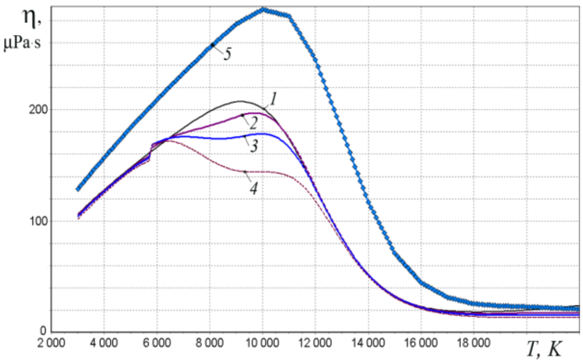

Fig. 4. Viscosity of thermal plasma (p =1 atm) for pure argon and the equimolar mixtures of argon with beryllium. Curves 1 – Ar (this work calculations); 2 – Ar–Be (95:5); 3 – Ar–Be (90:10); 4 – Ar-Be (80:20); 5 – Ar (data from [8])

Also, one can see that the appearance of beryllium impurities causes the essential changing of transport properties with comparison to the case of pure argon. That is needed to take into account under studies of discharges with tungsten electrodes.

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.

CONCLUSIONS

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

The calculations of transport properties on the base of Grad's method have a good agreement with the recent calculations based on Chapman-Enskog method.

The influence of the Ramsauer effect on the transport coefficients can be neutralized by metal additions in plasma.

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О ВЛИЯНИИ ПРИМЕСЕЙ БЕРИЛЛИЯ НА ТРАНСПОРТНЫЕ СВОЙСТВА МНОГОКОМПОНЕНТНОЙ ДУГОВОЙ ПЛАЗМЫ

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Рассмотрено влияние примесей бериллия на транспортные свойства многокомпонентной дуговой плазмы в атмосфере смесей аргона и диоксида углерода. Проведенные расчеты основывались на методе моментов Грэда. Показано, что незначительное количество примесей металла может существенно изменить величины транспортных коэффициентов в сравнении со случаем чистого аргона. Показана возможность нейтрализации влияния эффекта Рамзауэра на свойства плазмы путем добавки металлических примесей.

ПРО ВПЛИВ ДОМІШОК БЕРИЛІЮ НА ТРАНСПОРТНІ ВЛАСТИВОСТІ БАГАТОКОМПОНЕНТНОЇ ДУГОВОЇ ПЛАЗМИ

П.В. Порицький

Розглянуто вплив домішок берилію на транспортні властивості багатокомпонентної плазми в атмосфері сумішей аргону та диоксиду вуглецю. Проведені розрахунки ґрунтувалися на методі моментів Ґреда. Показано, що невелика кількість металевих домішок може суттєво змінити величини транспортних коефіцієнтів порівняно із випадком чистого аргону. Висвітлено можливість нейтралізації впливу ефекту Рамзауера на властивості плазми шляхом додавання металевих домішок.