PLASMA, GASES

IONIZATION EQUILIBRIUM IN A THERMAL PLASMA—SOLID CONTACT

V.I. VISHNYAKOV, G.S. DRAGAN

Mechnikov Odessa National University

(2, Dvoryanskaya Str., Odessa 65026, Ukraine; e-mail: pipeaes@te.net.ua)

Dependence of the ionization degree of a thermal smoky plasma on properties of a solid contacting with the plasma is studied. The interphase exchange by electrons in a direct way and as a result of the ionization of atoms and the recombination of ions on the solid surface is researched. The parameter describing the ionization nonequilibrium of the plasma in the cases of its contact with a metal surface or a semiconductor surface in the presence or absence of the surface states on the interface is derived. The possibility to apply the obtained results to the interpretation of voltage-current characteristics measured upon a probing is considered.

Introduction

A thermal smoky plasma is a high-temperature system which is formed in a combustion flame of fuel mixtures at atmospheric pressure and, as a rule, contains an easily ionizable admixture of alkali metals atoms. Practically in all the cases, there is a condensed disperse phase in plasma as a result of the condensation of combustion products (smoke grains). The interphase interaction in plasma with a condensed phase gives rise to new effects such as a displacement of the ionization equilibrium in the gas phase [1,2], the origin of ordered structures of smoke grains [3], long-range interaction between charged grains [4], and, at last, the formation of plasma-crystalline structures of dust grains in a discharge plasma [5—7].

The last fact induced a considerable increase in the number of papers researching a dusty plasma [8] which, as well as a thermal smoky plasma, is a variety of plasma with condensed disperse phase [4]. Alongside with that, mechanisms of interaction of plasma with the surface of grains are investigated insufficiently till now, in particular, ionization — recombination processes on the interface are not always taken into account. It does not allow constructing an adequate model of equilibrium plasma with condensed phase which would explain the observed effects. In addition, the construction of such a model would promote the interpretation of probe voltage-current characteristics of a thermal smoky plasma, which remains an unsolved problem till now.

1. Statement of the Problem

Let us assume that a thermal plasma with macroscopic smoke grains is in a state of thermodynamic equilibrium. As a result of the interphase interaction between the gas and condensed phases, the grains acquire a surface charge, and the volumetric charge depending on the value and sign of the grain charges is formed in the gas phase. The presence of charged grains and, accordingly, a volumetric charge in the gas phase leads the latter to a new ionization equilibrium distinct from the equilibrium in a similar gas plasma without grains. This effect called the displacement of ionization equilibrium in plasma with condensed phase is characterized by the nonequilibrium parameter which is defined by both the surface characteristics of grains and a state of the gas phase of plasma. Therefore, for the analysis of ionization equilibrium in plasma with condensed phase, it is necessary to describe the ionization of the gas phase and the processes of interphase exchange by charges on the surfaces of grains with regard for their surface properties.

Ionization equilibrium in a thermal gas plasma is featured by the Saha equation

$$\frac{n_{e0}n_{i0}}{n_{a0}} = 2\frac{g_i}{g_a}\left(\frac{m_e kT}{2\pi\hbar^2}\right)^{3/2}\exp\left(-\frac{I}{kT}\right) \equiv K_{\mathrm{S}}, \qquad (1)$$

where n_{e0} is the electron number density, n_{i0} is the ion number density, n_{a0} is the atom number density, g_i is the statistical weight of ions, g_a is the statistical weight of atoms, m_e is the electron mass, T is the Kelvin temperature, k is the Boltzmann constant, $\hbar$ is the Planck constant, I is the ionization potential of an easily ionized admixture, and K_{S} is the Saha constant. The coefficient 0 means that plasma does not contain grains and, in any area of plasma, the requirement of electroneutrality is satisfied:

$$n_{e0} = n_{i0} = n_0. \qquad (2)$$

Here, n_0 is the unperturbed number density.

The interaction of the condensed grains with plasma induces the appearance of a charge on their surface. Therefore, the requirement of electroneutrality becomes

$$\bar{n}_i - \bar{n}_e + \bar{Z}_g n_g = 0, \qquad (3)$$

where Z_g is the charge number of grains and n_g is the grain number density.

It follows from Eq. (3) that the number density disequilibrium in the gas phase, i.e. a volumetric charge which causes a displacement of the ionization equilibrium in the gas phase of plasma with condensed grains relative to a similar gas plasma, arises as a result of charging the grains. This is explained by the appearance of additional electron and ion sources stipulated by the surface processes. Then ionization equilibrium can be described by the transformed Saha equation [1, 2, 9, 10]

$$\frac{n_q^2}{n_a} = 2\frac{g_i}{g_a}\left(\frac{m_e kT}{2\pi\hbar^2}\right)^{3/2}\exp\frac{-I+\psi}{kT} = K_{\mathrm{S}}\exp\frac{\psi}{kT}, \qquad (4)$$

where $n_q = \sqrt{n_e n_i}$ is the quasi-unperturbed number density of charge carriers in the gas phase and ψ is the nonequilibrium parameter. According to work [9], the latter is defined by the potential of plasma ϕ_{pl} which characterizes a deviation of the gas phase from electroneutrality and is defined, in turn, by the energy of an electric field $\psi \cong -e\phi_{\mathrm{pl}}$. Accordingly, the quasi-unperturbed number density of free charges in thermal plasma is $n_q = n_0\exp(\psi/2kT)$.

Equation (4) describes a change of the ionization degree of plasma owing to the appearance of a volumetric charge of the gas phase. We note that the value of ψ is defined not only by the charge of the gas phase, but also by the processes running on the grains surface.

We consider the "metal grain — plasma" contact in the approximation of an even surface. This means that the free path of gas particles of plasma (electrons, ions, and atoms) is much less than the radius of condensed grains.

Equilibrium on the grain — plasma boundary is reduced to the balance of the following streams of electrons, ions, and atoms.

(i) Richardson—Dushman stream of thermionic emission from grain surfaces:

$$j_e^T = -\frac{4\pi e m_e k^2 T^2}{(2\pi\hbar)^3}\exp\left(-\frac{W}{kT}\right), \qquad (5)$$

where j is the density of electric current in the direction from a grain to plasma, W is the work function of an electron from a grain to plasma which differs from the work function from metal to vacuum by a value of the potential barrier in plasma on the plasma — vacuum boundary. The value of the potential barrier can be found from the expression [9]

$$e\phi_v = -\frac{1}{4}kT\ln\frac{m_i}{m_e}. \qquad (6)$$

Hence, if the work function from metal to vacuum is W_g, then the work function from metal to plasma is $W = W_g - \frac{1}{4}kT\ln(m_i/m_e)$.

(ii) Backflow of electrons absorbed by the surface of a grain is

$$j_e^{\mathrm{abs}} = \frac{1}{4}en_{es}\bar{C}_e, \qquad (7)$$

where $\bar{C}_e = \sqrt{8kT/\pi m_e}$ is the thermal velocity of electrons and n_{es} is the electron number density at the surface of the grain.

The sum of streams (5) and (7) allows one to calculate the surface electron number density

$$n_{es} = 2\left(\frac{m_e kT}{2\pi\hbar^2}\right)^{3/2}\exp\left(\frac{-W}{kT}\right) \equiv \nu_e\exp\left(\frac{-W}{kT}\right) \qquad (8)$$

which can considerably exceed the equilibrium value in volume.

Together with streams (5) and (7), it is necessary to take into account the processes of ionization of atoms and recombination of ions on the grain surface.

(iii) Current density of the surface recombination of ions is

$$j_i^{\mathrm{rec}} = -\frac{1}{4}\gamma_s en_{is}\bar{C}_i, \qquad (9)$$

where $\bar{C}_i$ is the thermal velocity of ions, n_{is} is the surface number density of ions, and γ_s is the surface recombination coefficient.

(iv) Current density of the surface ionization of atoms is

$$j_a^{\text{ion}} = \frac{1}{4}\beta_s e n_{as} \bar{C}_a, \tag{10}$$

where $\bar{C}_a$ is the thermal velocity of atoms ($\bar{C}_i \cong \bar{C}_a$), $n_{as} = N_A - n_{is}$ is the surface number density of atoms, and β_s is the surface ionization coefficient.

Thus, while studying the plasma—solid contact, we take into account the interphase exchange of charges, which is defined expressions (5), (7), (9), and (10), and features of surface characteristics of a solid.

2. A Thermal Plasma — Metal Contact

The energy diagram of a metal — plasma contact in view of the ionization nonequilibrium parameter ψ is given in Fig. 1. Energy levels E_0 and E_a mean the lower boundary of an energy distribution of free electrons and ions (the level of a valence electron of an atom), accordingly. The equilibrium in the contact means the equality of the level of the electrochemical potential of plasma $\tilde{\mu}$ and the Fermi level of metal F_m. The difference between the levels E_0 and $\tilde{\mu}$ is defined by the chemical potential of electrons of plasma μ_e.

As the interaction act of an ion or an atom with the grain surface, we consider their adsorption on the surface, transport of an electron in some direction, and the subsequent desorption, because the necessary condition for ionization equilibrium is the recovery of a gas particle to plasma.

As seen from the diagram, the process of ionization of the atoms of an easily ionizable admixture means the transition of a valence electron from the level E_a to the Fermi level of metal, for that $E_s^{\text{ion}} = I - \psi + \mu_e + e\phi_s = I - \psi - W$ is the required energy of the electron. Accordingly, the surface ionization coefficient defining the probability of ionization of atoms on the metal surface is

$$\beta_s = \frac{(g_i/g_a)\exp\left(-E_s^{\text{ion}}/kT\right)}{1 + (g_i/g_a)\exp\left(-E_s^{\text{ion}}/kT\right)}\exp\frac{-\varepsilon_i}{kT}, \tag{11}$$

where g_i, g_a are the statistical weights of ions and atoms, accordingly, and ε_i is the activation energy of desorption of an ion.

The process of ion recombination on the grain surface is associated with the electron transition from the Fermi level of metal to the vacant level of the valence electron
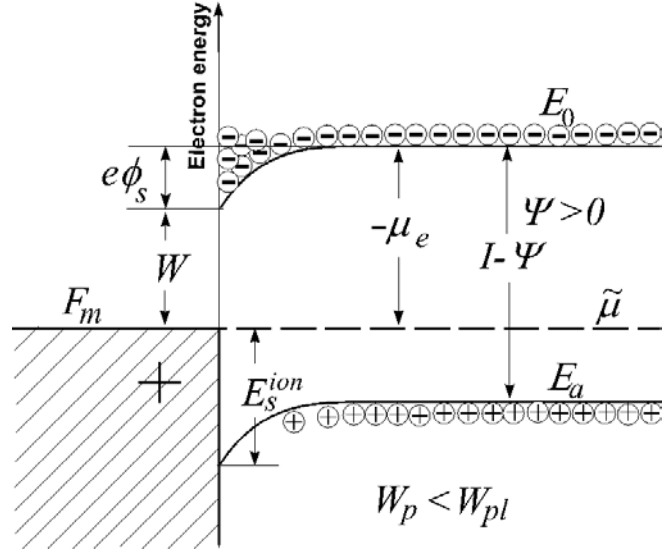

Fig. 1. Energy diagram of the "metal—plasma" contact

of an ion, i.e. the recombination energy is $-E_s^{\text{ion}}$. Accordingly, the surface recombination coefficient is

$$\gamma_s = \frac{(g_a/g_i)\exp\left(E_s^{\text{ion}}/kT\right)}{1 + (g_a/g_i)\exp\left(E_s^{\text{ion}}/kT\right)}\exp\frac{-\varepsilon_a}{kT} =$$

$$= \frac{1}{1 + (g_i/g_a)\exp\left(-E_s^{\text{ion}}/kT\right)}\exp\frac{-\varepsilon_a}{kT}, \tag{12}$$

where ε_a is the activation energy of desorption of an atom.

The sum of streams (9) and (10) defines the ionization degree of atoms of an admixture near the grain surface (the well-known Saha—Langmuir equation):

$$\frac{n_{is}}{n_{as}} = \frac{g_i}{g_a}\exp\left(\frac{W - I + \psi}{kT}\right)\exp\left(\frac{\varepsilon_a - \varepsilon_i}{kT}\right). \tag{13}$$

Then, Eqs. (4), (8) and (13) yield the expression for equilibrium surface ionization:

$$\frac{n_{es}n_{is}}{n_{as}} = K_S\exp\left(\frac{\psi + \varepsilon_a - \varepsilon_i}{kT}\right). \tag{14}$$

To determine the coefficients of surface ionization and recombination, it is necessary to know values of the activation energies of desorption of an ion ε_i and an atom ε_a from the grain surface which are not available. Therefore, we determine the difference in the activation energies of desorption. Since an ion differs from an admixture atom by only the presence of a charge, the difference in the activation energies of desorption is defined by the potential barrier on the grain - plasma boundary, $\varepsilon_a - \varepsilon_i = e\phi_s$.
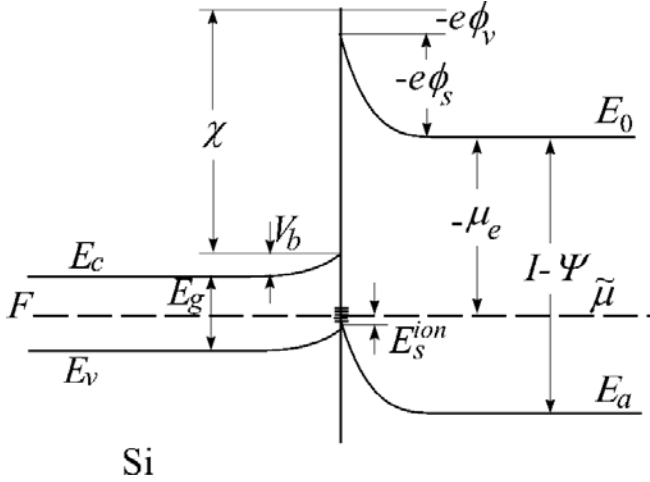
Fig. 2. Energy diagram of the "semiconductor—plasma" contact (charge exchange occurs via surface states)

Then the ionization equilibrium equation (4) can be presented as follows:

$$\frac{n_{es}n_{is}}{n_{as}} = K_S \exp\left(\frac{\psi + e\phi_s}{kT}\right) \equiv K_S \exp\frac{\psi_s}{kT}, \qquad (15)$$

where the parameter ψ_s characterizes a displacement of the ionization equilibrium near the grain surface due to both the influence of a volumetric charge of plasma in the surface layer ($\psi = -e\phi_{pl}$) and the interface properties: $e\phi_s$.

We express the surface value of the potential of plasma ϕ_{pl} via the energy of the electric field in the space charge layer near the grain surface of radius a:

$$(\phi_{pl}) \int_a^{a+4D} r^2 \left(en_i - en_e\right) dr = \varepsilon_0 \int_a^{a+4D} r^2 E^2 dr, \qquad (16)$$

where E is the electric field intensity, and the electron and ion number densities are defined by the Boltzmann distribution law: $n_e = n_q \exp(e\phi/kT)$, $n_i = n_q \exp(-e\phi/kT)$; and $D = \sqrt{\varepsilon_0 kT/2e^2 n_q}$ is the shielding distance.

The upper limit of integration in Eq. (16) is defined by that the grain field is concentrated in a layer with thickness which does not exceed $4D$ [11] counting from the grain surface. In this case, the inequality $e\phi(a + 4D) \leq 0.1kT$ is satisfied.

For the potential distribution, we use the Debye approximation:

$$\phi(r) = \phi_s \frac{a}{r} \exp\left(\frac{a-r}{D}\right).$$

Then, by performing the relevant evaluations in Eq. (16), we obtain

$$\psi = -e\phi_{pl} = e\phi_s \frac{a+2D}{2(a+D)}. \qquad (17)$$

Hence, the surface value of the nonequilibrium parameter is equal to

$$\psi_s = e\phi_s(3a + 4D)/2(a + D). \qquad (18)$$

A value of the nonequilibrium parameter ψ_s defines the surface value of the quasi-unperturbed number density $n_{qs} = n_0 \exp(\psi_s/2kT)$. Accordingly, the surface value of the electron density is $n_{es} = n_{qs}\exp(e\phi_s/kT)$. Then Eq. (18) can be transformed to the form

$$n_{qs}^{2+(3a+4D)/2(a+D)} = n_0^2 n_{es}^{(3a+4D)/2(a+D)}.$$

In the case of submicronic grains where $a << D$, this equation can be simplified to a simple expression $n_{qs} = \sqrt{n_0 n_{es}}$. It is seen that the quasi-unperturbed density can be both less or more than the equilibrium value n_0, which is defined by the equilibrium electron density at the grain surface. If values of the work function and the ionization potential are such that Eq. (8) yields the same value of the density as the Saha equation (1), then $n_{qs} = n_0$. Almost such a situation is realized for grains of Al in a Cs plasma at a temperature 2200 K. The work function of an electron from Al to vacuum is equal to 3.74 eV. The correction for a potential barrier on the plasma—vacuum boundary defined by expression (7) is equal to 0.6 eV for Cs. Therefore, the work function from Al to plasma is $W = 3.14$ eV. Finally, Eq. (8) yields the surface electron density $n_{es} = 2.9 \cdot 10^{19} \text{m}^{-3}$. The Saha equation (1) yields the unperturbed density $n_0 = 2.6 \cdot 10^{19} \text{m}^{-3}$ which slightly differs from the quasi-unperturbed density calculated by formula (15), $n_{qs} = 2.7 \cdot 10^{19} \text{m}^{-3}$. Thus, the cases are possible where grains perturb plasma a little if their parameters correspond to an equilibrium state of plasma are possible.

3. A Thermal Plasma — Semiconductor Contact

Equations (15) and (18) allow us to determine a displacement of the ionization equilibrium of plasma in the layer of space charge at the surface of a metal grain. An actual plasma of combustion products contains a great amount of the condensed oxides which are referred to semiconductors. In experiments carried out in [1], the fuel compositions containing particles of Si were used.

Therefore, we consider the interaction of plasma with semiconductor grains by the example of Si.

In Figs. 2 and 3, the energy diagrams of the silicon — plasma and silicon — silicon dioxide — plasma contacts are presented.

As many other semiconductors with covalent binding, silicon has the large density ($N_S > 10^{17}\mathrm{m}^{-2}$) of surface states which form a narrow band in a gap of the semiconductor [12]. The band of surface states is located at the depth $\frac{2}{3}E_g$ from the conduction band bottom (E_g is the gap width). As the surface states take the major participation in the charge exchange, the Fermi level of the semiconductor is anchored on the band of surface states and does not change its position with a change in properties of the contacting medium. This leads to that the barrier in the layer of space charge of the semiconductor V_b remains invariable at a change of the grain charge. At the temperature of existence of the plasma, the Fermi level of the semiconductor is positioned in the middle of the gap for any type of conduction, therefore $-V_b = \frac{1}{2}E_g - \frac{2}{3}E_g = -E_g/6$.

The gap width depends on temperature. For silicon, this dependence is expressed as $E_g(T) = 1.21 - 4.1 \cdot 10^{-4}T$, eV (temperature is in K). Accordingly, the electron number density and the hole number density in volume of natural silicon are $n_{\mathrm{sem}V} = p_{\mathrm{sem}V} = 2(m^*kT/2\pi\hbar^2)^{3/2}\exp(-E_g/2kT)$, where m^* is the effective electron mass.

This case reminds the metal — plasma contact, because electrons make transition to the Fermi level of the semiconductor. The difference consists in that the number of electrons in the surface states is much less of that of free electrons in metal. Therefore, a change of the grain charge can affect the exchange processes.

Let us introduce a variable δ equal to the ratio of the number of filled surface states to their total number. The electron number density for the surface states of a silicon grain is defined by a layer of space charge inside the grain and the charge exchange between the grain and plasma. The number of electrons passed from the semiconductor volume into the surface states is calculated by integration over the layer of a volumetric charge:

$$N_{es} = 4\pi a^2 n_{\mathrm{sem}V} \int\limits_0^\infty \frac{V_b}{kT} \exp\frac{-x}{D_{\mathrm{sem}}}dx =$$

$$= 4\pi a^2 n_{\mathrm{sem}V}\frac{V_b}{kT}D_{\mathrm{sem}}, \qquad (19)$$

where $D_{\mathrm{sem}} = \sqrt{\varepsilon\varepsilon_0 kT/2e^2 n_{\mathrm{sem}V}}$ is the shielding distance in the semiconductor.
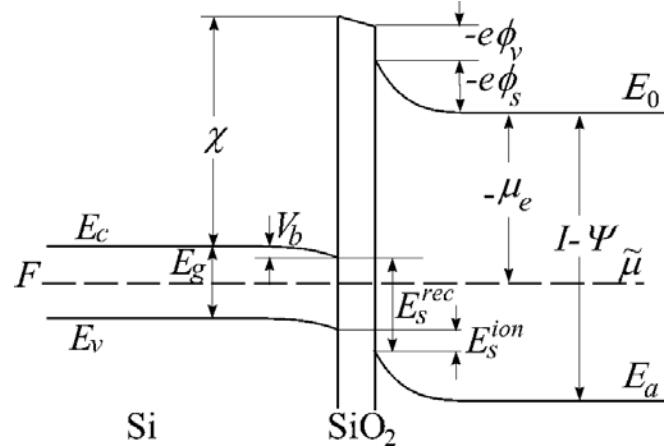

Fig. 3. Energy diagram of the "semiconductor—dielectric—plasma" contact (surface states are absent)

Accordingly, the volume electron number density for the surface states of the grain is $n_{\mathrm{sem}S} = n_{\mathrm{sem}V}V_b/kT$. As a result, the filling of the surface states is

$$\delta = (D_{\mathrm{sem}}n_{\mathrm{sem}S} - Z_g/4\pi a^2)/N_S. \qquad (20)$$

Thus, if n_{as} atoms are adsorbed on the grain surface, then $n_{as}(1-\delta)$ atoms has the opportunity to be ionized. For the ionization of atom, it is necessary that an electron make transition into the semiconductor surface states. That is, we meet a situation similar to the case of the plasma — metal contact: the ionization energy $E_s^{\mathrm{ion}} = I - \psi - W$. Then the work function of an electron from the grain is defined by both the barrier height (6) and the Fermi level position: $W = \chi + e\phi_v + \frac{2}{3}E_g$. Accordingly, the coefficients of surface ionization β_{Si} and recombination γ_{Si} are defined as

$$\beta_{\mathrm{Si}} = (1-\delta)\beta_{\mathrm{s}}, \quad \gamma_{\mathrm{Si}} = \delta\gamma_{\mathrm{s}}.$$

In this case, the ionization equilibrium is described by the formula similar to Eq. (15) taking into account the filling of the surface states of a silicon grain:

$$\frac{n_{es}n_{is}}{n_{as}} = K_{\mathrm{S}}\exp\left(\frac{-e\phi_{\mathrm{pl}} + e\phi_{\mathrm{s}}}{kT}\right)\frac{1-\delta}{\delta}, \qquad (21)$$

where ϕ_{pl} is defined by Eq. (17).

Then the surface value of the parameter ψ_{s} for a silicon grain is will

$$\psi_{\mathrm{s}} = e\phi_{\mathrm{s}}\frac{3a+4D}{2(a+D)} + kT\ln\frac{1-\delta}{\delta}. \qquad (22)$$

It is natural to assume that the silicon grains in plasma are covered with a layer of oxide. In this case, the surface states do not play a defining role and the barrier height in the semiconductor depends on properties of the contacting medium (Fig. 3).

Between the media, there occurs the exchange of electrons whose direction depends on the ratio of the work function of an electron from the semiconductor to vacuum to that from plasma to vacuum. The work function of an electron from the semiconductor to plasma is

$$W = \chi + e\phi_v + \frac{1}{2}E_g - V_b. \qquad (23)$$

The barrier height in the semiconductor V_b is defined by the excess or the deficiency of electrons in the layer of space charge of the semiconductor and, as follows from Eq. (19), may be expressed through the grain charge as

$$V_b = -Z_g kT/4\pi a^2 n_{semV} D_{sem}. \qquad (24)$$

Because the grain charge in the Debye approximation is connected with the surface grain potential [13] by the expression $eZ_g = 4\pi\varepsilon_0 a\phi_s(1 + a/D)$, Eq. (24) can be represented as

$$V_b = -\frac{\varepsilon_0 kT\phi_s}{en_{semV} D_{semV}} \left(\frac{1}{a} + \frac{1}{D} \right). \qquad (25)$$

Let us take into account the processes of surface ionization and recombination. An atom adsorbed on the grain surface donates an electron on a vacancy of the valence band with a great probability, which corresponds to the emission of holes. In this case, the ionization energy of the atom is

$$E_s^{ion} = (I - \psi) - (\chi + E_g + e\phi_v). \qquad (26)$$

The adion takes away an electron from the conduction band of the semiconductor, therefore the recombination energy is

$$E_s^{rec} = -(I - \psi) + (\chi + e\phi_v). \qquad (27)$$

The ionization energy of atoms of the admixture of plasma turns out to be less than the recombination energy of ions by the semiconductor gap width.

We substitute Eq. (23) in Eqs. (26) and (27). Then, taking into account Eqs. (1) and (8), we get the expressions for the coefficients of surface ionization and recombination:

$$\beta_s = \frac{\exp(-\varepsilon_i/kT)}{1 + n_{es}/K_S \cdot \exp[(-\psi - V_b - E_g/2)/kT]}, \qquad (28)$$

$$\gamma_s = \frac{\exp(-\varepsilon_a/kT)}{1 + K_S/n_{es} \cdot \exp[(\psi + V_b - E_g/2)/kT]}. \qquad (29)$$

Calculations show that, for the case of plasma with an admixture of atoms K ($I = 4.3$ eV), the denominator in Eq. (28) is of the order of 1, whereas the denominator in Eq. (29) is much greater than 1. Therefore, for the silicon — silicon oxide — potassium plasma contact, the ionization equilibrium at the grain surface is described by the approximate relation

$$\frac{n_{es}n_{is}}{n_{as}} \cong K_S \exp\left(\frac{\psi + e\phi_s + V_b + E_g/2}{kT} \right), \qquad (30)$$

where, according to Eq. (17), $\psi = -e\phi_{pl} = e\phi_s(a + 2D)/2(a + D)$.

Thus, the surface value of the nonequilibrium parameter for a silicon grain which is covered with a layer of oxide and is positioned in a potassium plasma is defined as

$$\psi_s = e\phi_s(3a + 4D)/2(a + D) + V_b + E_g/2. \qquad (31)$$

Expression (31) differs from that for the metal — plasma contact only by the presence of two additional terms: the barrier height in the semiconductor and the gap half-width of the semiconductor.

Conclusions

In conclusion, we note that the interphase exchange of charges on the interface leads to a change of the ionization degree of the plasma containing condensed grains. In this case, the exchange of electrons on the grain surface can be realized by means of electron emission and collisions directly with the surface and due to the processes of surface ionization of atoms and surface recombination of ions. A change of the ionization degree of plasma is described by the nonequilibrium parameter which depends both on volumetric processes and properties of the interface.

Grains influence the gas phase of plasma not only at the expense of a change of its charge state, but also by directly changing the ionization degree at the surface. Thus, a change of the ionization degree is the natural response of plasma to the perturbations introduced by grains.

The above-mentioned concerns equally the interaction of a probe with plasma. The balance of streams (5), (7) and (9), (10) defines a value of the floating potential of an isolated probe ϕ_{s0}. The transmission of an electric current through the probe - plasma contact gives rise to a change of the potential

barrier $\phi_s = \phi_{s0} + \delta\phi$. Then the dependence of the density of a current passing through the contact on a change of the potential barrier can be presented as

$$j_c = j_e^T \left(1 - \exp\frac{e\delta\varphi}{kT}\right) + j_{a0}^{\text{ion}} \left(1 + \frac{\beta_s}{\gamma_s}\right)\left(1 - \exp\frac{-e\delta\varphi}{kT}\right),$$

where j_{a0}^{ion} is the ionization current density of atoms on the surface of an isolated probe, i.e. without current in the external circuit.

It follows from expression (18) that a change of the potential barrier induces a change of the ionization degree of plasma near a probe. This effect should be necessarily taken into account in the interpretation of the probe measurements in a thermal plasma at atmospheric pressure.

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ІОНІЗАЦІЙНА РІВНОВАГА В КОНТАКТІ ТЕРМІЧНА ПЛАЗМА — ТВЕРДЕ ТІЛО

В. І. Вишняков, Г. С. Драган

Р е з ю м е

Досліджено залежність ступеня іонізації термічної запорошеної плазми від властивостей твердого тіла, що контактує з нею. Розглянуто як безпосередній обмін електронами, так і обмін, що відбувається внаслідок іонізації атомів і рекомбінації іонів на поверхні твердого тіла. Виведено параметр, що описує стан іонізаційної рівноваги в плазмі, для випадків контакту плазми з металічною та з напівпровідниковою поверхнею за наявності та у відсутності поверхневих станів на межі поділу фаз. Розглянуто можливість застосування отриманих у роботі результатів для інтерпретації вольт-амперних характеристик у зондових вимірюваннях.