

The Role of Secondary Electrons and Metastable Atoms in Electron-Beam Activation of Argon-Silane Mixtures

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Abstract. The role of metastable argon atoms and secondary electrons produced in low-pressure Ar-silane mixture under electron-beam activation is studied theoretically. The model includes consideration of the energy degradation of primary beam-electrons and production of fast secondary electrons. The influence of high-energy primary and secondary electrons on the direct ionization of gas mixture, formation of argon metastable atoms, and dissociation of silane molecules is analyzed for a wide range of electron beam energy, argon pressure, and silane concentration. The influence of metastable Ar_m on the dissociation of SiH₄ is studied on the basis of balance equation for metastable argon atoms, and ambipolar equations for ions and low-energy E-beam plasma electrons.

Keywords: Electron beams, energy degradation, secondary electrons, Boltzmann equation, argon-silane mixture.

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1. INTRODUCTION

Silane-argon mixtures have been intensively studied due to the importance of silane (SiH₄) in microelectronics and semiconductor industry [1]. Different methods of plasma chemical vapor deposition from discharges are used for production of amorphous silicon thin films. In the last decade, the method of electron-beam assisted deposition of silicon thin films from supersonic gas jets containing argon with silane addition is intensively used [2-4]. This method has some attractive features compared to conventional plasma enhanced chemical vapor deposition (PECVD) methods. In discharge plasma, the electron distribution function (EDF) for energies higher than the threshold of silane dissociation decreases very rapidly with the increase of energy. In contrast, in E-beam plasma EDF is formed due to degradation of secondary electrons produced by primary electrons under gas ionization, it decreases gradually with the increase of energy, and produces a more effective excitation and dissociation of silane molecules than in discharge plasma.

In different types of argon-silane discharges, argon is not simply a buffer gas but has an important influence on the dissociation rate in PECVD of amorphous silicon films due to the influence of metastable atoms [5-6]. Since metastable atoms are already in an excited state, it takes only a small amount of additional energy, typically a few eV, to ionize them (4.1 eV in the case of metastable argon). Moreover, collisions of metastable argon atoms with SiH₄ in argon-silane discharges cause dissociation of silane molecules with large rate constant [7].

Electron-beam plasma was studied with the help of Monte Carlo method [4,8]. Spatial-dependent aspects of electron degradation were considered. However, in these papers the role of metastable argon atoms was not studied. The aim of this work is to develop a comprehensive model of electron-beam activation of argon-silane mixtures on the basis of Boltzmann equation. The presented model includes the consideration of spatial-energy distribution functions of primary and secondary electrons, formation of metastable argon atoms, and their influence on dissociation of silane molecules diluted in argon.

2. DISTRIBUTION FUNCTION OF PRIMARY AND SECONDARY ELECTRONS

We will consider beam electrons moving initially in z-direction in the Ar-SiH₄ mixture (N_{Ar} is the density of argon and N_{SiH_4} is the density of silane addition). The energy losses for primary beam electrons can be considered in

one-dimensional approach for the highly anisotropic distribution function of primary electrons depending on the length of penetration z . In a small-angle-scattering approximation, distribution function was obtained from the Boltzmann equation as described in [9] in more details. High-energy secondary electrons play an important role due to specific energy dependencies of cross sections for the excitation of argon and silane by an electron impact. Distribution functions of high-energy secondary electrons can be determined on the basis of kinetic model presented in [9] and modified for the case of Ar-SiH₄ mixture.

The integral Boltzmann equation for isotropic part of distribution function $f(\mathbf{r}, e)$ in the Ar-SiH₄ mixture will be written in the form:

$$f_s(\mathbf{r}, e) = a \sum_g C_g \left\{ \int \frac{d^3 \mathbf{r}'}{4p} \frac{\exp(-a S_i(e) |\mathbf{r} - \mathbf{r}'|)}{|\mathbf{r} - \mathbf{r}'|^2} \left\{ c(\mathbf{r}') q_g(E_b, e) \chi_g + S_{el}^g(e) f_s(\mathbf{r}', e) + \right. \right. \\ \left. \left. + \sum_j S_j^g(e + e_j^g) f_s(\mathbf{r}', e + e_j^g) + \int_{e+I}^{2e+I} q_g(e, e - e - I_g) S_i^g(e) f_s(\mathbf{r}', e) de + \int_{2e+I}^{(E_b-I)/2} q_g(e, e) S_i^g(e) f_s(\mathbf{r}', e) de \right\} \right\} \quad (1)$$

where $\gamma = (\text{Ar}, \text{SiH}_4)$, $\sigma_j^\gamma(e)$ is cross section for j^{th} level of atom (molecule) of γ -sort by an electron impact, ε_j^γ is the excitation threshold (energy loss) in this process, $\sigma_i^\gamma(e)$ is the cross section of ionization by electron with energy e , I_γ is the ionization potential of molecule of γ -sort; $q_\gamma(E, e)$ is the spectrum of generation of secondary electron with energy ε in the ionization of γ -molecule by primary electron with energy E ; $\chi(r) = n_b(r)/n_b(0)$ is the dimensionless function of primary electron beam profile, $n_b(0)$ is a characteristic number density of primary electrons on the beam axis, $a = N_g b \sigma_0$, b is the characteristic radius of electron beam; $N_g = (N_{\text{Ar}} + N_{\text{SiH}_4})$ is the density of the mixture, $C_{\text{Ar}} = N_{\text{Ar}}/(N_{\text{Ar}} + N_{\text{SiH}_4})$ and $C_{\text{SiH}_4} = N_{\text{SiH}_4}/(N_{\text{Ar}} + N_{\text{SiH}_4})$ are the relative concentrations of Ar and SiH₄. Cross sections for energy excitation were taken from [10] for argon and from [11,12] for silane. Energy spectrum of secondary electrons produced in ionizing collisions was assigned as Lorentzian curve:

$$q_g(e, e) \approx \left[\bar{e} \arctg \frac{e - I_g}{2\bar{e}} \right]^{-1} \left(1 + \frac{e^2}{\bar{e}^2} \right)^{-1}, \quad (2)$$

where $\bar{e}_g \approx (0.8-1.0)I_\gamma$ (for argon, $\bar{e}_{\text{Ar}} \approx 12.5 \text{ eV}$, for silane $\bar{e}_{\text{SiH}_4} \approx 9.3 \text{ eV}$) and $\xi_{\text{Ar}}(e)$ and $\xi_{\text{SiH}_4}(e)$ are defined as

$$\xi_{\text{Ar}}(e) = \sigma_i^{\text{Ar}}(e) / [C_{\text{Ar}} \sigma_i^{\text{Ar}}(e) + C_{\text{SiH}_4} \sigma_i^{\text{Ar}}(e)], \quad \xi_{\text{SiH}_4}(e) = C_{\text{Ar}} \sigma_i^{\text{SiH}_4}(e) / [C_{\text{Ar}} \sigma_i^{\text{Ar}}(e) + C_{\text{SiH}_4} \sigma_i^{\text{SiH}_4}(e)], \quad (3)$$

The distribution function of secondary electrons in equation (1) is normalized as follows

$$S_i(E_b) \sqrt{E_b} \int_0^{E_m} f_s(\mathbf{r}, e) / \sqrt{e} de = n_e(\mathbf{r}) / n_b. \quad (4)$$

Then the excitation rate of j -th molecular state will be equal to

$$F_j^s(\mathbf{r}) / F_i^p(0) = \int_{e_j}^{E_m} f(\mathbf{r}, e) S_j(e) de, \quad (5)$$

where $F_i^p(0) = N_g n_b(0) v_b S_i(E_b)$ is the ionization rate by the primary electrons on beam axis.

With the help of Fourier-Bessel transformation $f(\mathbf{r}, e)$ can be presented in the form:

$$f_s(\mathbf{r}, e) = \int \frac{d^3 \mathbf{r}'}{4p} c(\mathbf{r}') G(|\mathbf{r} - \mathbf{r}'|, e), \quad G(|\mathbf{r} - \mathbf{r}'|, e) = \frac{2}{p} \int_{-\infty}^{\infty} dm \frac{\sin[n |\mathbf{r} - \mathbf{r}'|]}{|\mathbf{r} - \mathbf{r}'|} r(n, e). \quad (6)$$

where $G(|\mathbf{r} - \mathbf{r}'|, e)$ is the Green's function of the initial Boltzmann equation. The function $\rho(v, e)$ is the Fourier-Bessel image or a "spectral function" of the distribution function $f(\mathbf{r}, e)$ and must be determined from the equation

$$S_i(e) r(n, e) = A(n, e) \cdot \sum_g C_g \left\{ q_g(E_b, e) \chi_g + S_m^g(e) r(n, e) + \sum_j S_j^g(e + e_j^g) r(n, e + e_j^g) + \right. \\ \left. + \int_{e+I_g}^{2e+I_g} q(e, e - e - I_g) S_i^g(e) r(n, e) de + \int_{2e+I_g}^{(E_b-I_g)/2} q(e, e) S_i^g(e) r(n, e) de \right\}, \quad A(n, e) = \frac{a S_i(e)}{n} \arctg \frac{n}{a S_i(e)} \quad (7)$$

The expression (6) with the Green's function represents "exact" solution of the Boltzmann integral equation (1) and $\rho(v, e)$ is universal function for the given kind of gas-mixture.

In Fig.1 the dependence of the function $\rho(v=0, e)$ for secondary electrons is presented for different concentration of monosilane in argon. This function is equal to energy distribution function for secondary electrons averaged over radial direction. It is seen that the increase of silane concentration leads to reduction of secondary electron distribution function, especially in low-energy region. It is an obvious consequence of molecular addition to rare gas. In low-energy region, energy losses in molecular gases are higher than in noble gases due to dissociation and excitation of vibrational states.

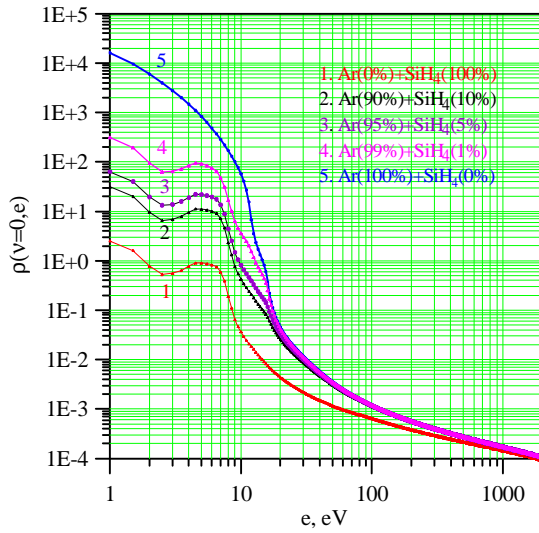


FIGURE 1. The function $\rho(v=0, e)$ for secondary electrons for different concentration of monosilane in argon.

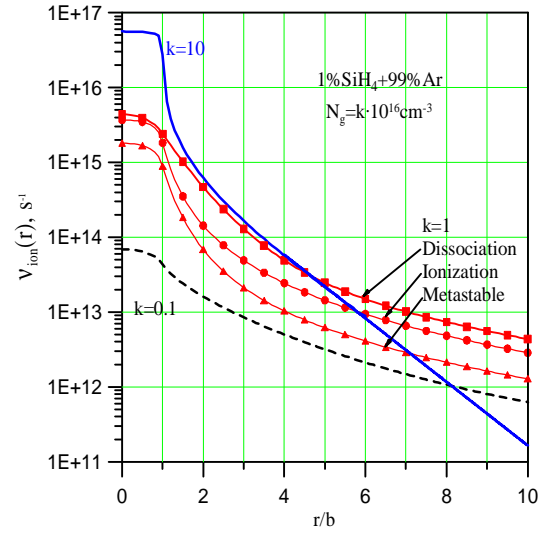


FIGURE 2. Radial distribution of frequencies of total ionization by secondary electrons in 1% SiH₄+99% Ar mixture at total gas density $N_g = 1 \cdot 10^{16} \text{ cm}^{-3}$: (—•—•—, $k=1$), solid line ($k=10$), dashed line ($k=0.1$); neutral dissociation of SiH₄ (—■—■—, $k=1$); Ar metastable production (—▲—▲—, $k=1$). Electron beam energy is 1 keV, beam current is 1 mA.

In Fig.2, the radial distribution of frequencies of total ionization, neutral dissociation of SiH₄, and Ar metastable production by secondary electrons in 1% SiH₄+99% Ar mixture are presented. It is seen that in E-beam plasma at total gas density $N_g = 1 \cdot 10^{16} \text{ cm}^{-3}$, dissociation frequency is higher than ionization frequency and the frequency of metastable argon atoms production. It should be stressed that in a low-temperature plasma of glow or RF discharges the rate of metastable argon atoms production is usually higher than ionization rate from the ground state of argon by direct electron impact.

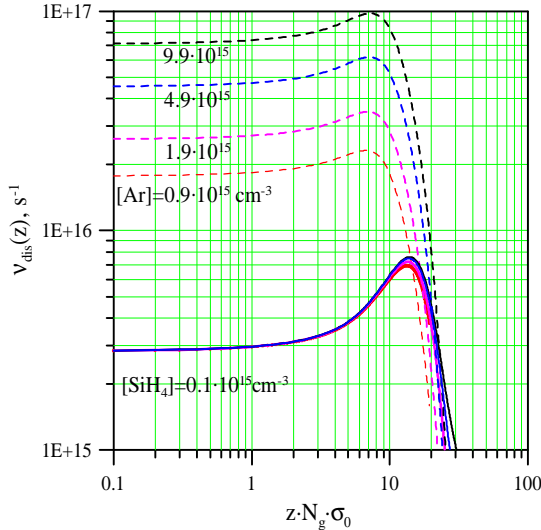


FIGURE 3. The frequency of SiH₄ dissociation by an electron impact depending on the dimensionless penetration length $zN_g\sigma_0$ for different additions of Ar: dashed lines – contribution of secondary electrons, solid lines – contribution of primary electrons.

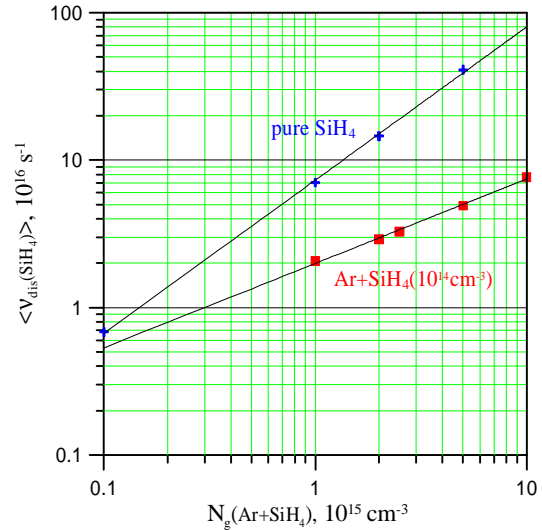


FIGURE 4. The dependence of frequency of SiH₄ dissociation on the gas pressure for $z=1 \text{ cm}$.

With the help of developed models for primary and high-energy secondary electrons, all electron-gas excitation rates can be obtained. In Fig.3, the dependence of dissociation frequency on the penetration length $zN_g\sigma_0$ is presented for constant density of SiH₄ with different additions of argon. It is seen that neutral dissociation by primary electrons is almost equal for different argon pressures, while dissociation by secondary electrons is increasing with the increase of argon pressure. It reflects the fact that the spectral function $\rho(v, e)$ for secondary electrons is higher for small concentrations of silane in Ar-SiH₄ mixture, especially in a low-energy region, see Fig.1. The dependence of total frequency of SiH₄ neutral dissociation by an

electron impact on the gas pressure for $z=1$ cm is presented. It should be stressed that almost all increase of neutral dissociation rate of silane at constant density is provided by secondary electrons only.

3. BALANCE EQUATIONS FOR METASTABLE ARGON, LOW-ENERGY SECONDARY ELECTRONS AND DISSOCIATION OF SILANE

Metastable levels of atoms serve as important intermediate states in many low-temperature plasmas. Argon atoms have two metastable levels lying closely to each other ($(3p^5 4s)^3P_2$ and $(3p^5 4s)^3P_0$ levels), at 11.55 and 11.72 eV above the ground state respectively. (Lifetimes of these levels are 38 and >1.3 s). The 3P_0 level is populated by a fraction of 10-20% of the 3P_2 level. Two resonant levels $(3p^5 4s)^3P_1$ and $(3p^5 4s)^1P_1$ are lying closely to the metastable levels at 11.62 and 11.83 eV, with lifetimes equal to 8.4 and 2.0 ns respectively. These levels can decay to the ground state by emission of radiation. However, due to reabsorption, these emissions are trapped in gas, and due to collisions, all these four levels are closely coupled with each other and can have a rather long effective common (collective) lifetime [5].

Thresholds of SiH_4 dissociative ionization and neutral dissociation are 11.6 and 8.4 eV, respectively. It means that collisions between argon metastable states and SiH_4 molecules can cause dissociative process of silane with high rate constants [6,7].

For determination of metastable argon atoms concentration and their influence on silane dissociation in argon-silane E-beam plasma, a fluid model for Ar^m and slow electrons was developed. The main processes in argon-silane plasma are listed in Table 1. Rate constants were taken from [7,13-16].

TABLE 1. Production and loss processes in argon-silane mixture under E-beam activation.			
	Processes	Name of process	Rate coefficients
1, 2	$\text{Ar} + e_f \rightarrow \text{Ar}^m + e_f$	Electron-impact excitation by fast electrons	Boltzmann equation
3	$\text{Ar}^+ + e_s \rightarrow \text{Ar}^m + h\nu$	Radiative recombination	$k_{\text{rad}} = 1 \cdot 10^{-11} \text{ cm}^3 \text{ s}^{-1}$ [13]
4	$\text{Ar}^m + e \rightarrow \text{Ar}^+ + 2e$	Electron-impact ionization	[14]
5	$\text{Ar}^m + e \rightarrow \text{Ar} + e_f$	Super-elastic collisions	[10]
6	$\text{Ar}^m + \text{Ar}^m \rightarrow \text{Ar}^+ + \text{Ar} + e$	Pooling ionization	$k_{\text{pool}} = 6.4 \cdot 10^{-10} \text{ cm}^3 \text{ s}^{-1}$ [13]
7	$\text{Ar}^m + \text{Ar} \rightarrow \text{Ar} + \text{Ar}$	Two-body collision	$k_{2B} = 2.3 \cdot 10^{-15} \text{ cm}^3 \text{ s}^{-1}$ [13]
8	$\text{Ar}^m + 2\text{Ar} \rightarrow \text{Ar}_2^+ + \text{Ar}$	Three-body collision	$k_{3B} = 1.4 \cdot 10^{-34} \text{ cm}^6 \text{ s}^{-1}$ [13]
9	Diffusion of Ar^m to the wall		$D_{\text{Ar}^m} = 54 \text{ cm}^2 \text{ s}^{-1}$ [13]
10	$\text{Ar}^+ + 2\text{Ar} \rightarrow \text{Ar}_2^+ + \text{Ar}$	Ion's conversion	[16]
11	$\text{Ar}_2^+ + e_s \rightarrow 2\text{Ar}$	Dissociative recombination	$9.1 \cdot 10^{-7} \cdot (300/T_e(\text{K}))^{0.61} \text{ cm}^3 \text{ s}^{-1}$ [15]
12	$\text{Ar}^+ + \text{SiH}_4 \rightarrow \text{Ar} + \text{SiH}_3^+$ $\rightarrow \text{SiH}_2^+ + 2\text{H}$ $\rightarrow \text{SiH}^+ + \text{H} + \text{H}_2$ $\rightarrow \text{Si}^+ + 2\text{H} + \text{H}_2$	Argon ions – silane reactions	$0.17 \cdot 10^{-10} \text{ cm}^3 \text{ s}^{-1}$ $0.39 \cdot 10^{-10} \text{ cm}^3 \text{ s}^{-1}$ $0.8 \cdot 10^{-10} \text{ cm}^3 \text{ s}^{-1}$ [7]
13	$\text{Ar}(^3P_2) + \text{SiH}_4 \rightarrow \text{Ar} + \text{SiH}_2^+ + 2\text{H}$ $\text{Ar}(^3P_0) + \text{SiH}_4 \rightarrow \text{Ar} + \text{SiH}^+ + \text{H} + \text{H}_2$ $\rightarrow \text{Ar} + \text{Si} + 2\text{H} + \text{H}_2$	Silane – Ar metastables reactions	$k_{\text{qu}} = 4.8 \cdot 10^{-10} \text{ cm}^3 \text{ s}^{-1}$; 94.7% $5.8 \cdot 10^{-10} \text{ cm}^3 \text{ s}^{-1}$; 4.9% 0.4% [7]
14	$\text{SiH}_4 + e_f \rightarrow \text{SiH}_3^+ + \text{H} + e_f + e_s$ $\rightarrow \text{SiH}_2^+ + 2\text{H} + e_f + e_s$ $\rightarrow \text{SiH}^+ + \text{H} + \text{H}_2 + e_f + e_s$	Dissociative ionization	[7]
15	$\text{SiH}_4 + e_f \rightarrow \text{SiH}_3 + \text{H} + e_f$ $\rightarrow \text{SiH}_2 + 2\text{H} + e_f$ $\rightarrow \text{SiH} + \text{H} + \text{H}_2 + e_f$ $\rightarrow \text{Si} + 2\text{H} + \text{H}_2 + e_f$	Dissociation into neutral fragments	Branching ratio $\approx 17\%$; 36% $\approx 83\%$; 43% $\approx 0\%$; 12% $\approx 0\%$; 9% [7]

The production rate for metastables is connected with the direct electron impact excitation from the ground-state argon atoms, including cascading from high-energy argon levels. It was obtained on the basis of integral Boltzmann equation (Table1, processes 1, 2). These rates are proportional to the electron beam current ($\sim J_b$), and were calculated with the help of electron distribution function obtained from the integral Boltzmann equation. Metastables

can be also produced via radiative recombination (process 3). The main mechanisms of argon metastable atom losses are the wall recombination (process 9), quenching in collisions with SiH₄ molecules (process 12), electron-impact ionization and excitation from the metastable levels (process 4), and argon metastables quenching into resonance argon levels by low-energy electrons (process 3), super-elastic collisions with electrons (process 5); polling ionization, two-body and three-body recombination (processes 6-8). The only metastables loss process, which is proportional to electron beam current, is process 12.

The kinetics of slow-electrons creation in E-beam plasma include energy degradation of high-energy secondary electrons, ambipolar diffusion to the chamber walls, and losses in recombination process. At high pressure conditions, the main mechanism of recombination is dissociative recombination of electrons in collision with Ar₂⁺ (process 10). The concentration of Ar₂⁺ is governed by the process of conversion, 2Ar+Ar⁺→Ar+Ar₂⁺ [16]. The process 11 is very important for the regulation of ionization degree in E-beam plasma at high pressures.

The dissociation of SiH₄ in silane-argon is governed by the processes listed in Table 1 (see, also [7]) which could be complimented by electron-silane attachment processes [7]. In this paper, we just calculate the total neutral dissociation rate.

In the paper, concentrations of argon metastable atoms were calculated for the electron beam passing along the axis of a cylindrical chamber (radius R=5-20 cm) with the help of balance equation including source terms for production, S_{prod}^m , and losses, S_{loss}^m (the processes are listed in Table 1):

$$-\frac{1}{r} \frac{\partial}{\partial r} \left(r D_m \frac{\partial n_m}{\partial r} \right) = S_{prod}^m - S_{loss}^m, \quad (8)$$

where $D_m=54/p(\text{Torr})\text{cm}^2\text{s}^{-1}$ is the coefficient of diffusion of argon metastable atoms, p is the gas pressure in Torr. For slow electrons and argon ions, the equation of ambipolar diffusion was used

$$-\frac{1}{r} \frac{\partial}{\partial r} \left(r D_a \frac{\partial n_e}{\partial r} \right) = S_{prod}^e - S_{loss}^e, \quad (9)$$

where $D_a \approx D_i T_e / T_g$, D_i is the diffusion coefficient for argon ions [16]. For simplicity, electron density was taken equal to argon ion's density, and slow electron temperature was $T_e=1\text{eV}$. In equation (9) at high gas pressures ($p \geq 1$ Torr) and high beam currents ($J_b \geq 100\text{mA}$), the dissociative recombination (process 11) was taken into account under the assumption that all argon ions are in the Ar₂⁺-form (separate equation for argon ions conversion was not considered), ions of silane were not taken into account due to small concentration ($\leq 10\%$) of silane.

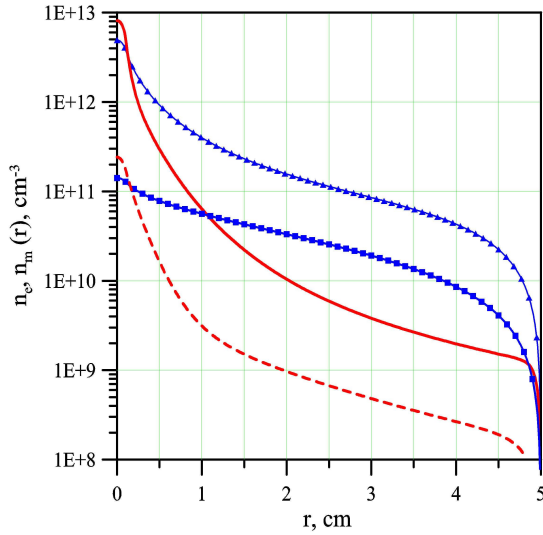


FIGURE 5. Radial distribution of density of slow electrons (-▲-▲-▲- $N_g=10^{15}$, -■-■-■- $N_g=10^{14}$) and argon metastables (solid line $N_g=10^{15}$, dashed line $N_g=10^{14}$), $E_b=1$ keV, $b=0.1$ cm, $R=5$ cm, 1% SiH₄.

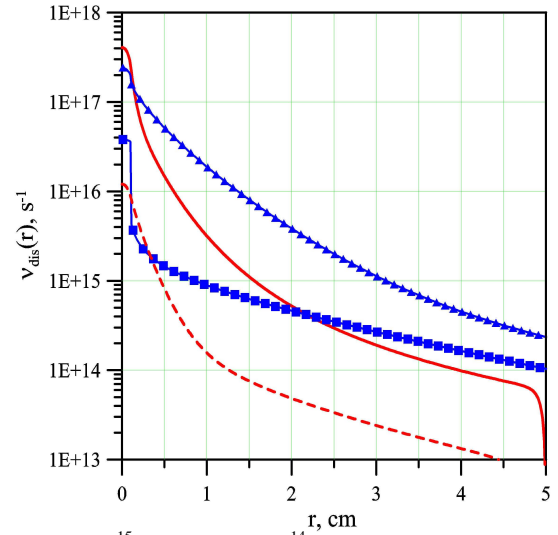


FIGURE 6. Radial distribution of silane dissociation frequency by an electron impact (-▲-▲-▲- $N_g=10^{15}$, -■-■-■- $N_g=10^{14}$) and by metastables (solid line $N_g=10^{15}$, dashed line $N_g=10^{14}$), $E_b=1$ keV, $b=0.1$ cm, $R=5$ cm, 1% SiH₄.

All balance equations are strongly coupled, source term of slow electron production is also coupled with the model of gas ionization (Boltzmann equations for primary and secondary electrons), and were considered self-

consistently by an iterative method. Equations (8, 9) were calculated with the help of double-swept method. As boundary conditions for densities of ions and argon metastable atoms zero values were chosen.

With the help of fluid model, the dissociation rate of silane by argon metastable atoms (process 13) was obtained. Numerical calculations were made for a wide range of gas pressures $p \sim 0.01$ -10 Torr, electron beam energies $E_b \sim 0.5$ -10 keV, and SiH_4 concentrations (1-10%). In Fig.5, the radial distributions of densities of slow electrons and argon metastables are presented for gas density $N_g = 10^{15}$, and $N_g = 10^{14} \text{ cm}^{-3}$ ($E_b = 1$ keV, $b = 0.1$ cm, $R = 5$ cm, 1% SiH_4). In Fig. 6, the radial distributions of neutral dissociation frequency of SiH_4 are presented for the same conditions. It is seen that in the region of narrow electron beam ($b \ll R$), the dissociation of SiH_4 by argon metastables can be comparable with (or even higher than) the direct dissociation of SiH_4 by an electron impact. However, outside the electron beam the density of metastable argon atoms decreases rapidly due to quenching by silane molecules (process 13), and the direct dissociation of SiH_4 by an electron impact is dominant.

3. DISCUSSION AND CONCLUSIONS

The model of argon-silane mixture activation by an electron beam was developed. The model includes consideration of the energy degradation of primary beam-electrons and production of fast secondary electrons based on the solution of Boltzmann equation, and the fluid model for argon metastable atoms and slow electrons. The model permits to obtain spatial and energy distribution functions of primary and secondary electrons, and frequencies of excitation, dissociation, and ionization produced in E-beam plasma by high-energy electrons, which are used in the fluid model as source (production) terms.

The influence of argon as a buffer gas on the neutral SiH_4 dissociation rate in argon-silane mixture was investigated. It was shown that under constant SiH_4 density, the dissociation rate of silane is increasing with the increase of argon density (for silane concentration in the range of 1-10%). Such an effect was observed in experiments and was explained previously by the influence of argon metastable atoms (in low-temperature RF discharge plasma [6]). In E-beam plasma, this effect is caused mainly due to secondary electrons impact. The distribution function of secondary electrons in Ar- SiH_4 mixture is re-arranged. With the dilution of silane by argon, the distribution function of secondary electrons decreases substantially in the region around the threshold of silane neutral dissociation.

The influence of metastable Ar_m on the dissociation of SiH_4 in argon-silane E-beam plasma is also studied. It was shown, that the dissociation of SiH_4 by argon metastables can be comparable with the direct dissociation of SiH_4 by an electron impact in the region of E-beam, however, outside the electron beam the density of metastable argon atoms decreases rapidly due to quenching by silane.

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REFERENCES

1. M.J. Kushner. *J. Appl. Phys.*, **63**, pp. 2532-2551. (1988).
2. A. E. Belikov, et al. In: *17th RGD*, edited by A. E. Beylich (VCH, Weinheim, Germany/VCH, New York, 1991, p. 1568.
3. R.G. Sharafutdinov et al. *J. Appl. Phys.* **79**, 7274 (1996).
4. A. V. Vasenkov, R. G. Sharafutdinov, and A. V. Skrinnikov. *J. Appl. Phys.* **83**, 3926-3928 (1998).
5. J.L. Delcroix, C.M. Ferreira, A. Ricard. In: *Principles of Laser Plasmas*, edited by G. Bekefi, New York: Wiley, 1976, p. 159.
6. L. Sansonnens et al. *J. Phys. D: Appl. Phys.* **27**, 1406-1411 (1994).
7. J. Perrin, O. Leroy, and M.C. Bordage. *Contrib. Plasma Phys.* **36**, 3-49 (1996).
8. A. V. Vasenkov. *J. Phys. D: Appl. Phys.*, **32**, 240-245 (1999).
9. G.I. Sukhinin, A.V. Fedoseev, *to be presented at RGD-2006*.
10. A. Yanguas-Gil, J. Cortino, and L.L. Alves. *J. Phys. D: Appl. Phys.* **38** 1588-1598 (2005).
11. W.L. Morgan. *Plasma Chemistry and Plasma Processing*. v. 12, No 4, pp. 477-493. (1992).
12. E. Krishnakumar and S.K. Srivastava. *Contrib. Plasma Phys.* **35**, 395-404 (1995).
13. N. Baguer, et al. *J. Appl. Phys.*, **97**, 123305(2005).
14. A.J. Dixon, M.F.A. Harrison, and A.C.H. Smith. *Contributed Papers, 8th ICPEAC*, Belgrade, 405 (1973).
15. Y.-J. Shiu, M.A. Biondi. *Phys. Rev. A*, **17**, 868-872, (1978).
16. E.W. McDaniel, E.A. Mason. "The mobility and diffusion of ions in gases". N.Y.: Willey&Sons, 1973.