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INFLUENCE OF TARGET ORIENTATION ON THE ENERGY ACCOMMODATION COEFFICIENT FOR NITROGEN IONS

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The energy accommodation coefficient is one of the most important parameters describing interaction of particles of an incident stream with a body surface. Knowledge of this parameter is a basic requirement in determining the aerodynamic characteristics of, and of the heat transfer to bodies in free-molecular flow. Data is sparse for the energy accommodation coefficients of particles in the energy range ∿1—100 eV [1], and therefore α_i is often assumed to be near 1, although this condition does not hold in practice for most working gases. Also missing in the literature is the required volume of information on accommodation coefficient as a function of the orientation of the exposed surface relative to the velocity vector of the incident stream.

The present article presents α_i as a function of the orientation of some target materials in a high-speed (u_∞ = 10 km/sec) stream of partially ionized nitrogen. The experimental investigations were conducted in a gasdynamic plasma facility in a flow of rarefied plasma, generated in an accelerator with ionization of the working substance by means of an electron beam. A schematic diagram of a source of this type was given in [2].

The accelerated stream of ions of intensity $j_\infty \approx 10^{15}$—10^{17} ions/cm^2·sec was directed into the working chamber in which the residual gas pressure was ∿$7\cdot10^{-7}$—$1\cdot10^{-6}$ torr. The measurements were made with a working chamber pressure of ∿(0.87-1.6) 10^{-5} torr.

The energy accommodation coefficient of the nitrogen ions was measured with a planar hot wire anemometer probe, in the form of a disk δ = 0.12 mm with a working surface of diameter 3.5 mm, to the back face of which were attached the current leads and a thermocouple. The lateral surface of the sensor, the thermocouple, and the current leads were insulated from contact with the plasma by means of a ceramic tube.

The volt—ampere characteristics $\log \dot{I}_e = f(V)$ had a sharply pronounced straight-line section. This allowed us to determine the electron temperature to be T_e = 3.5—4.7 eV by the conventional method [3].

The plasma potential φ_0 was determined by the second derivative method, and also from the electronic part of the probe characteristic, drawn on a semilogarithmic scale. This gave quite high accuracy in measurement of the energy W_i of ions of the stream transferred by the particles to the plasma—layer interface. The values obtained agree satisfactorily with values of W_i calculated on the assumption that the accelerating potential is equal to

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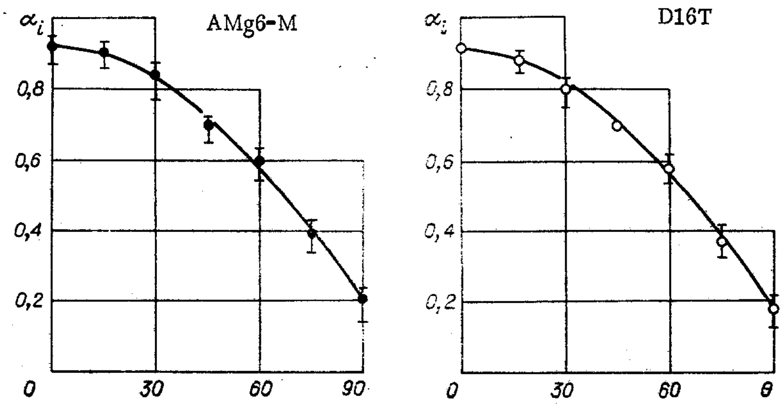

Fig. 1

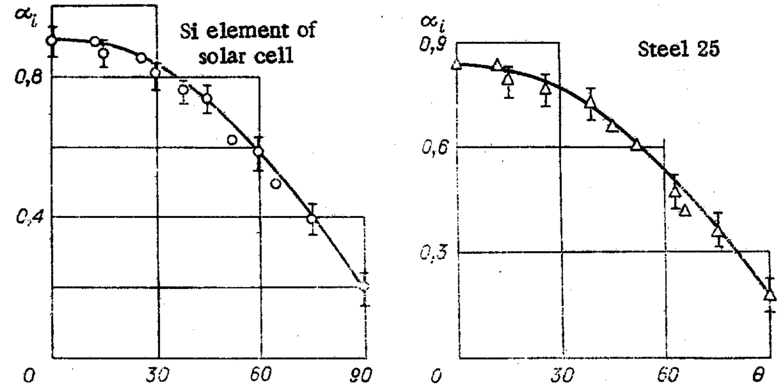

Fig. 2

the difference between the source anode potential and the local plasma potential. The scatter in the values of W_i obtained did not exceed ± 4.5%.

A rake of sensors with working surfaces made of different materials was located in a high-speed stream of low-density, partially ionized nitrogen. To monitor the local stream operating parameters and the orientation of the sensors relative to the velocity vector u_∞ we used a thin cylindrical probe made of molybdenum wire of diameter 0.09 and length 4 mm. The peak ion current measured by this probe when rotated around horizontal and vertical axes corresponds to the probe flow being oriented along the flow [4], and gives an estimate of the ion stream temperature $T_i \approx 0.35$–0.51 eV.

The probes were made of aluminum alloys AMg6-M, D16T, steel 25 and the silicon element of solar cell panels. The probe surfaces corresponded to the operating state of surfaces of these materials [5]. Immediately prior to the measurements the probe working surfaces were irradiated by a stream of plasma, and they were also subjected, for 15-20 min, to forced bombardment by electrons at high positive probe potentials and heating up to temperatures at which no breakdown of the probe material occurred. To monitor the surface temperature of the probes during the measurement of α_i, the sensors were calibrated beforehand in a thermostat, prior to the experiments; the relationship $T_w = T_w(E)$ was determined, where E is the thermocouple emf.

The accommodation coefficients α_i were determined, using the method of [6], from the relation

$$\frac{\dot{I}_i^A}{e}\{\xi+\alpha_i(W_i+e|V^A|)-\gamma_i\varkappa\}+\frac{\dot{I}_e^A}{e}(W_e+\varkappa)=\frac{\dot{I}_e^B}{e}(W_e+\varkappa+e|V^B|),$$

obtained from the energy balance equation for points on the temperature characteristic with equal temperatures at different probe potentials $T_w^A(V<0) = T_w^B(V>0)$. Here $\xi = h_i - \varkappa$ is the difference between the ionization energy and the work function; γ_i, secondary emission coefficient; V, difference in potentials through which particles in the near-electrode layer pass; $\dot{I}_{i,e}$, probe current; and $W_{i,e}$, particle energy transferred to the plasma–layer interface.

The electron current $\dot{I}_e^A$ was determined, as in the theory of these probes [3], by linear extrapolation of the ion branch of the probe characteristic. In determining α_i the points on the curve $T_w = T_w(V)$ were chosen in such a way that $e|V^A| \ll W_i$.

The results of measurement of the accommodation coefficient α_i as a function of the angle of attack of the aluminum alloy AMg6-M and D16T targets are shown in Fig. 1 ($\theta = 0$ corresponds to normal incidence). Figure 2 shows the data for the targets of steel 25 and of the silicon element of the solar cell panels. The vertical lines show the scatter in values of α_i due to uncertainty in choosing values of the work function $\varkappa$ and the secondary emission coefficient γ_i. The probe surface temperature in the measurement of α_i was T_w = 304-318°K.

For the metal targets the results obtained can be represented in the form [7]

$$\alpha_i(\theta) \simeq \begin{cases} \alpha_0(\theta = 0), & 0 \leqslant \theta \leqslant \beta, \\ \alpha_0 \cos(\theta - \beta), & \beta \leqslant \theta \leqslant \pi/2. \end{cases} \quad (1)$$

For Amg6-M and the silicon element it turned out that $\beta \simeq 12°$, and for D16T and steel 25 we found $25 - \beta \simeq 10°$.

Within the error band in measurement of α_i, shown by vertical lines in Figs. 1 and 2, the experimental data on investigations conducted for nitrogen ions with $u_\infty \simeq 10$ km/sec and targets of the materials examined gave a value of β which may be taken to be $\beta \simeq 12°$.

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