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Generation of accelerated cluster-ion beams for nanotechnology

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Abstract: Formation of keV-energy Ar cluster ion beam is studied. Optimum condition for formation high intensity cluster beam with $2*10^{16}$ clusters/sm^2*sec investigated both experimentally and by numerical simulation. The mass distributions of the accelerated cluster ion beam were measured. It has been demonstrated that mass spectrum of cluster ion depend of collision processes between the ions during the formation.

Key words: cluster ion beam, supersonic jet, ionization.

1. Introduction

Currently considerable efforts of researchers focused on the development technologies of modification of physical properties of the materials at nanometer level. One of the promising methods is the use of the accelerated gas-phase cluster ion beams [1, 2]. The interaction of energetic cluster (complex, consisting of hundreds or thousands of particles) with a solid surface is radically different from the traditional cases of collisions of ions-monomers. Practically simultaneous interaction of a large number of particles of the cluster with approximately the same number of atoms of the solid leads to high energy release and, as a consequence, the strong nonlinear effects. Depending of the size and specific energy of clusters different materials modification processes occur: smoothing the surface of almost any material, including superhard (diamond, silicon carbide and others) down to the nanometer level without damaging the structure of the material [3], low-temperature formation of thin films [4], shallow implantation with high concentrations [5]. It was being found [3], that for the purpose of materials processing intensive cluster beams with a average cluster size up to one thousands units with energy up to 30-40 keV and radiation doses up to 10^{15}-10^{17} ions/cm^2 are requires. Apparently, the only source that can provide high-intensity clusters flow is molecular beam generated from the supersonic gas jet. In this paper the results of experimental investigations of the formation of accelerated cluster ion beams of Ar are discusses.

2. Experimental

The studies were performed on the experimental setup LEMPUS-1 of Novosibirsk State University [6, 7]. Schematic diagram of the measurements is shown in fig. 1. The working gas (argon) expansion through a supersonic conical nozzle (1) having a throat diameter of $d_* = 0.19$ mm and angle $\alpha = 12^\circ$. Stagnation pressure P_0 was varied from 1 to 10 bar, stagnation temperature T_0 was fixed 295˚C. The gas source (nozzle) located on 3-axis manipulator for changes the distance jet nozzle - skimmer to select the optimal parameters. The molecular beam was formed by a skimmer (3) with a diameter of the inlet $d_s = 1$ mm. Ionization cluster beam was in net ionizer (4) by electron impact. The source of ionizing electrons was a tablet of lanthanum hexaboride (5).

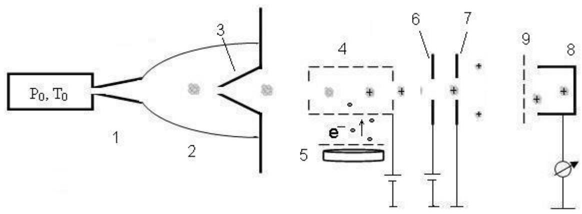

Fig.1. Schematic diagram of experiments.

Formed in the equipotential volume ionization ions drifted to the output aperture of the ionizer, where by using an extractor (6) with the potential U_{ext} formed to the cluster ion beam. Ionizer and extractor were situating at high potential, which provided the acceleration of the ion beam relative to the accelerating (grounded) electrode (7). Detection of the ion beam was carried out by the collector (8). For determine the size of cluster ions used retarding electrode (9).

3. Results and discussion

To determine the optimal parameters for the formation of the cluster beam the total intensity of the neutral molecular flow has been measured by varying the stagnation pressure P_0 and the nozzle - skimmer distance x_{ns}. Fig.2 shows the full intensity of molecular beam dependence of nozzle-skimmer distance. Despite the fact that the size of the jet (the distance to the Mach disk) changes markedly with increasing P_0, the optimum distance of the nozzle - skimmer of about the same - 150-200 calibers. The maximum intensity (~$2*10^{18}$

molecules/sm^2*sec) is attained at P_0 = 10 bar. It should be noted a significant non-linearity depending on the maximum intensity of the clustering molecular beam from the pressure P_0: at P_0 = 1 bar, the maximum intensity of more than 15 times smaller than at P_0 = 3 bar. One of the reasons is the influence of background gas in the expansion chamber. Another important reason is the various stages of condensation of gas flow in a supersonic flow [9].

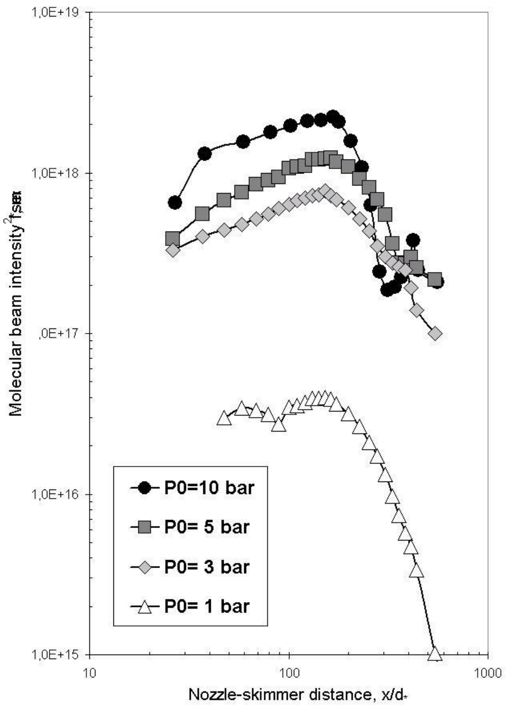

Fig.2. Molecular beam intensity dependence of nozzle-skimmer distance.

Taking into account that the main contribution into the detected full intensity of molecular beam are making clusters, on the basis of the measured data intensity of the cluster beam were calculated, expressed in terms of the number of clusters (fig.3). In the calculations used the average size of clusters, N, which were determined by the method of numerical simulation of the condensation in the framework of parabolic Navier-Stokes equations. It was determined that, since P_0>2 bar the expansion passes to the stage of development condensation. So fraction of condensed gas entering the skimmer reaches a maximum (~30%) but the average size of the cluster continues increases. As a result, increasing the stagnation pressure may lead to reduce the intensity of cluster beam. The maximum intensity of cluster beam (~2*10^{16} clusters/sm^2*sec) is attained at P_0 ~ 5 bar.

It's known that in a molecular beam extracted from a supersonic jet with condensation are present monomers and clusters. Moreover, clusters have a broad size distribution – from dimers up to several thousands units [8]. For the analysis of the mass spectrum of the accelerated ion beam a method of retarding potential was used. On the grid electrode with high transparency, situated on the axis of the beam, the positive retarding potential was applied. Since neutral particle in a supersonic molecular beam moving almost at the same velocity [8], the initial kinetic energy is determined by their weight (for cluster – the size).

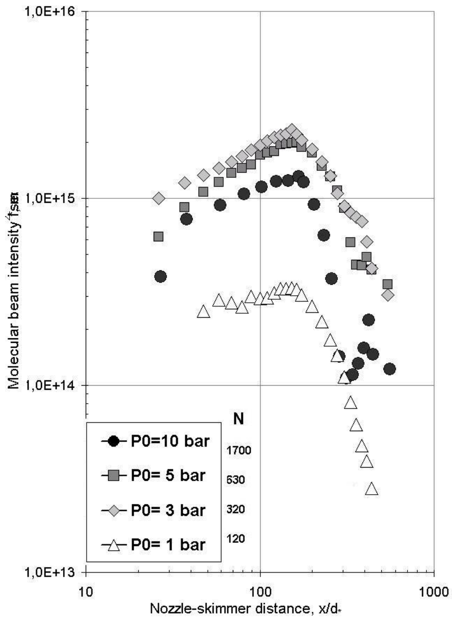

Fig.3. Cluster beam intensity dependence of nozzle-skimmer distance.

Fig. 4,a shows the ion current dependence of retarding potential U_{ret}, measured at fixed gas-dynamic parameters (P_0 = 6 bar, nozzle-skimmer distance x_{ns}=30 mm) and different extractor potential (U_{ext} = 10V and 100V). Recovered ion distribution size, N, expressed in atom/cluster, shown in fig. 4,b.

As can be seen at U_{ext} = 10 V in the beam mainly ions of small size was detected. In contrast, at high potential U_{ext} smallest ions are absent practically and an average size of ions is about 1000 atoms. Total ion current for a small extraction voltage is much lower than for large (1.8 and 8.7 mA, respectively), which can be explained by the large scattering of light ions. Formed ion-monomers and cluster ions at a fixed accelerating potential U_{HV} move at different speeds inversely proportional to their mass (size). Under certain conditions this may lead to collisions of the ions into the beam and as a result, the function of the size distribution of the ions may change.

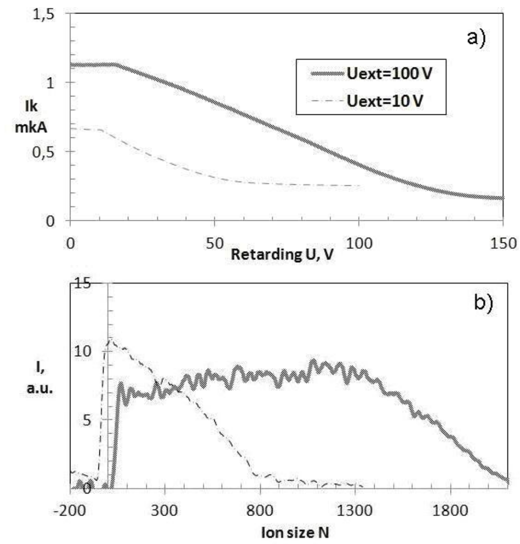

Fig.4,a. Ion current dependence of retarding voltage.
4,b. Cluster ion size distributions.

4. Conclusion

Thus, the experimentally recorded accelerated beam of argon ion clusters with energies up to 25 keV intensity up to $6x10^{13}$ ion/cm2/sec with average size of 10^3 atoms. The mass distributions of the accelerated cluster ion beam at different gas dynamic parameters were measured. Measurements showed that the mass composition of cluster ion flow is determined by collision processes between the ions during the formation stage of the beam can be adjusted and potentials of ion-optical system.

5. References

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