§3. Nanocluster Explosions and Ion Acceleration

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A plasma expansion into vacuum and the resultant ion acceleration are studied analytically and numerically. The expansion of an initially uniform spherical plasma (consisting of a nanocluster or micro-droplet) with radius R_{u0} and electron density n_{u0} is driven by the explosion of hot electrons having an initial temperature T_{e0}. A self-similar solution [1] describes the non-relativistic expansion of a finite plasma mass with a full account of charge separation effects. Such key features as the energy spectrum, maximum ion energy, and energy transfer efficiency from the electrons to the ions are given by simple analytic formulae as a function of the normalized droplet radius, $\Lambda_u=R_{u0}/\lambda_D$, where $\lambda_D = T_{e0}/4\pi n_{u0}e^2$ is the Debye length. The solution predicts that impurity ions doped homogeneously in a droplet plasma are accelerated quasi-monoenergetically by the electrostatic field generated by the charge separation. The prediction is confirmed by the N-body particle simulations. The origin of the monoenergetic spectrum is attributed to the spherical geometry.

Figure 1 compares the ion energy spectra comparing the self-similar solution and the N-body simulations [2]. The fixed parameters are Z=1, $n_{u0}=10^{23}$ cm^{-3} and R_{u0} = 2.15 nm, while the initial temperature is varied over the range T_{e0} = 4.5 - 4500 eV. The vertical positions of the simulation data and the model curves were adjusted to best fit each other. Meanwhile the ion kinetic energy on the horizontal axis is normalized by $2ZT_{e0}$ for both the self-similar model and the simulations.

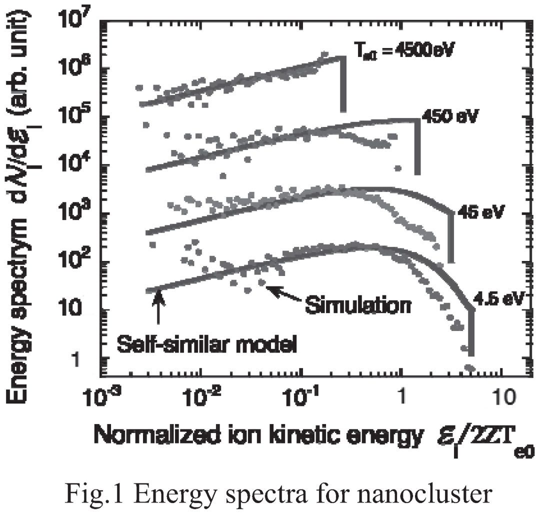

Fig.1 Energy spectra for nanocluster

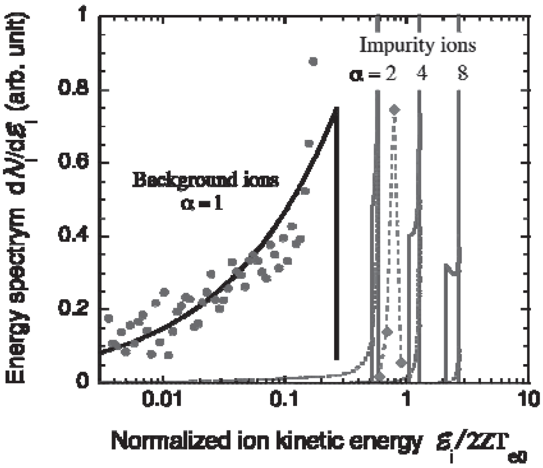

Fig.2 Generation of quasi-monoenergetic spectra

Figure 2 shows energy spectra for the background ions (α = 1) and for the impurity ions α = 2, 4, and 8 comparing the self-similar model (plotted as the curves) and the simulation (the circles), where α is the impurity-to-background charge-to-mass ratio. Parameters for the simulation are: $n_{u0}=10^{23}$ cm^{-3}, R_{u0} = 2.15 nm, T_{e0} = 4500 eV, and α = 4. The ion masses are fixed to be 100 times the electron mass. The number of impurity ions is only 150 (compared with 3600 for the background ions) in order not to degrade the self-consistent electric field. The vertical axis is in arbitrary units, so that the impurity ion spectra can be compared to the background ion spectra. The solid and dashed lines for the impurity ion spectra reveal the spatial origin of the ion emission.

In summary, we have generated quasimonoenergetic spectra using impurity ions that are homogeneously doped in a spherical pellet. The reason for this acceleration mechanism and the resultant quasimonoenergetic spectrum are as follows: In a spherical system, an impurity ion undergoes an increasing and decreasing electric field inside and outside the ion sphere, respectively.

1. M.Murakami and M.M.Basko, Phys. Plasmas **13**, 012105 (2006).
2. M.Tanaka and M.Sato, J. Chem. Phys. **126**, 034509 (2007).