§23. Interaction of Intense Femtosecond Laser Pulses with Clusters

Sakabe, S., Hashida, M., Shimizu, S. (Kyoto Univ. ICR)
Iida, T., Sato, F. (Grad. Sch. Eng., Osaka Univ.)

Femtosecond laser-matter interaction is briefly reviewed comparing with nanosecond laser-plasma interactions. And first the intense laser-molecule interaction in the relatively low intensity range of 10^{12}-10^{16}W/cm^2, that is parent ion generation applicable to femtosecond laser mass spectrometry, are briefly reviewed, and second in the intensity region above 10^{16}W/cm^2 we have studied the energy distributions of ions generated by the Coulomb explosion in a cluster and a low-density plastic foam.

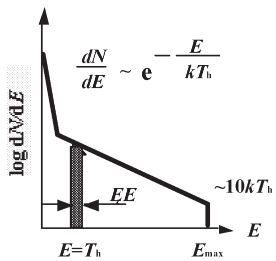
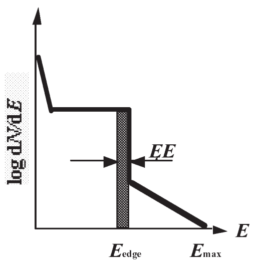
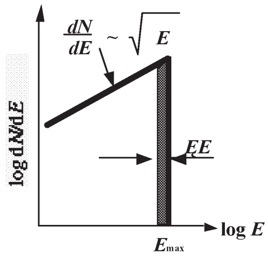
Recent progress in ultraintense femtosecond lasers has enabled the production of ionic radiation energetic enough to induce nuclear reactions, such as fusion, photofission, and electron-positron pair production. The generation of high-energy ion radiation by intense femtosecond laser plasma interactions can be effected by two mechanisms. One is by acceleration in an electrostatic field induced by high-energy electrons driven by a ponderomotive force in an overdense plasma in thin foils [1], and the other is by Coulomb explosion in a gas or underdense plasma [2]. The ion energy distributions resulting from the two mechanisms are quite different. Ions accelerated by the laser accelerated electron-induced electrostatic field generally exhibit a broad Boltzmann energy distribution. Ions generated by Coulomb explosion, however, exhibit an energy distribution of $dN/dE=E^{1/2}$ having a finite maximum E_{max}. The Coulomb explosion thus produces a much greater fraction of high-energy ions. However, due to the low density of the gases used, interaction rates are quite low, and so the overall efficiency of high-energy ion generation is much less than in the ejected electron method which takes place in over-dense plasmas. Although the Coulomb explosion is generally only induced in low-density gases by intense femtosecond lasers, it may be possible to induce the effect more efficiently in foam-structured material in which local density is high enough to support the Coulomb explosion, but average density is low enough to allow laser propagation. [3]

The energy distributions of protons emitted from the Coulomb explosion of hydrogen clusters by an intense femtosecond laser have been experimentally obtained. Ten thousand hydrogen clusters were exploded, emitting 8.1 keV protons under laser irradiation of intensity 6x10^{16} W/cm^2. The energy distributions are interpreted well by a spherical uniform cluster analytical model. The maximum energy of the emitted protons can be characterized by cluster size and laser intensity. The laser intensity scale for the maximum proton energy, given by a spherical cluster Coulomb-explosion model, is in fairly good agreement with the experimental results obtained at a laser intensity of 10^{16} –10^{17} W/cm^2 and also when extrapolated with the results of three-dimensional particle simulations at 10^{20} –10^{21} W/cm^2.

Energetic proton generation in low-density plastic (C_5H_{10}) foam by intense femtosecond laser pulse irradiation has been studied experimentally and numerically. Plastic foam was successfully produced by a sol-gel method, achieving an average density of 10 mg/cm^3. The foam target was irradiated by 100-fs pulses of a laser intensity 1x10^{18} W/cm^2. A plateau structure extending up to 200 keV was observed in the energy distribution of protons generated from the foam target, with the plateau shape well explained by Coulomb explosion of lamella in the foam. The laser-foam interaction and ion generation were studied qualitatively by two-dimensional particle-in-cell simulations, which indicated that energetic protons are mainly generated by the Coulomb explosion. From the results, the efficiency of energetic ion generation in a low-density foam target by Coulomb explosion is expected to be higher than in a gas-cluster target.

REFERENCES

[1] S. Okihara, *et al.*, J. Nucl. Sci. Tech. **39** (2002), 1.
[2] S. Sakabe, *et al.*, Phys. Rev. A **69**(2004), 023203, M. Hirokane *et al.*, Phys. Rev. A **69**, 063201(2004)..
[3] S. Okihara, *et al.*, Phys. Rev. E **69**(2004), 026401.

	Thin film	Foam	Cluster
Reference	(1)	(2)	(3)
Average target electron density (cm^{-3})	<1x10^{23}	8x10^{20}	10^{18}~10^{20}
Laser intensity(W/cm^2)	1.2x10^{18}	7x10^{17}	6x10^{16}
Energy distribution			
Yield of protons	1.9x10^5	8.7x10^6	1.6x10^6
Proton energy (keV)	180~200	180~200	3.8~4.2