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Space-resolved analysis of highly charged radiating target ions generated by kilojoule laser beams

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Abstract

Correlations of Doppler shifted line shapes with time-of-flight spectra of fast ions has been established for nanosecond-laser pulses. Fast ion energies of different velocity groups have been established in the large interval of $I\lambda^2 = 4 \times 10^{12}$–$5 \times 10^{16}$ W/cm^2 μm^2. The obtained scaling relations differ markedly from those reported by Gitomer *et al.* (1996).

Keywords: Laser produced plasmas; Fast ions; Spectroscopy

1. INTRODUCTION

Creation of fast ions by means of intense lasers has received continuous interest since the development of high energy CO_2-laser (Gitomer *et al.*, 1996). Currently, applications as a laser plasma source of highly charged ions have obtained a rather advanced status in many laboratories (Sharkov, 1996). Despite numerous investigations, theoretical understanding is still required to explain several observations made in various laboratories (e.g., Boiko *et al.*, 1979; Wägli & Donaldson, 1978; Gitomer *et al.*, 1996; Sharkov *et al.*, 1996; Rosmej *et al.*, 2002) of very fast ion emission in the intensity range between $I\lambda^2 = 1 \times 10^{13}$ and 1×10^{17} W/cm^2 μm^2. Kinetic theoretical analysis (e.g., by means of particle in cell simulations) is exceedingly difficult because the considered intensity range essentially involves nanosecond-laser pulse durations. Pursuing this we have conducted a kilojoule nanosecond-laser experiment at the PALS facility in Prague to cover the intensity range of interest.

Data of fast ion creation recorded by means of time-of-flight methods are very suitable for some practical applications; however, they have serious limitations (e.g., fast ions are recorded usually several meters away from the place of plasma creation) for studies of the fast ion production mechanism inside the laser-produced plasma. To provide data about fast ion velocity *inside* the plasma volume (with space resolution) we performed high resolution Doppler X-ray spectroscopy by means of spherically bent Bragg crystals.

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2. FAST ION VELOCITIES

Figure 1 shows a typical ion-collector signal. The distance to the collector target is 184 cm; a time of flight of 0.2 μs therefore corresponds to an ion velocity of $v = 9.2 \cdot 10^7$ cm/s, that is, an ion energy of 4.4 keV/amu. The irradiation conditions of Figure 1 are: massive Mg target, $\lambda = 0.438$ μm (i.e., 3ω), $E = 17$ J, laser spot size $\phi = 500$ μm.

Figure 2 shows the fast ion energy versus $I\lambda^2$ for different irradiation conditions (massive targets, foils, 1ω, 3ω). The straight lines are introduced to "guide" the eye in the double logarithmic scale. The thick grey bars indicate the results from Gitomer *et al.* (1996). Lines indicated with "I," "II," and "III" relate to flight times defined in Figure 1. The respective integrals for "high," "medium," and "low" ion velocities are indicated: $I_I = 4.1 \cdot 10^{-2}$, $I_{II} = 6.0 \cdot 10^{-1}$, and $I_{III} = 3.3 \cdot 10^{-1}$. It should be noted that the number of ions in group I is still a rather large quantity (about 10^{13}–10^{15} particles), which is of large interest for applications and basic studies of ion acceleration.

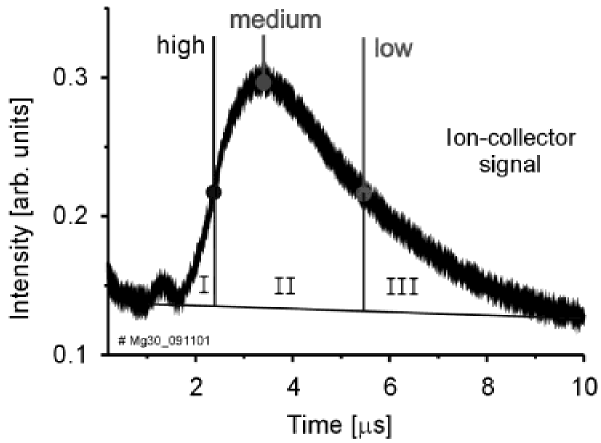

Fig. 1. Ion-collector signal.

3. DOPPLER X-RAY SPECTROSCOPY OF HIGHLY IONIZED FAST TARGET IONS

Figure 3 shows the experimental scheme for Doppler X-ray spectroscopy and the implementation of focusing spectrometers with space resolution. In the present experiments, we have employed spherically bent mica and quartz crystals provided from Multi-Charged Ion Spectra Data Center of VNIIFTRI (Skobelev *et al.*, 1995) to realize simultaneous high spectral and spatial resolution while maintaining high luminosity. Concerning the measurements with time of flight methods (Sect. 2), it has been noted previously (Rosmej *et al.*, 2002), that Doppler spectroscopy seems to provide access to the largest available ion energies under real experimental conditions.

Figure 4 show the spectral image and traces of the He-like series of Mg. To avoid opacity effects and line overlapping by dielectronic satellites, space-resolved high resolution X-ray spectroscopy of the Rydberg lines $1snp\ ^1P_1 - 1s^2\ ^1S_0 + h\nu$ of He-like Mg and Al ions have been carried out. The line profiles show distinct variations when going from

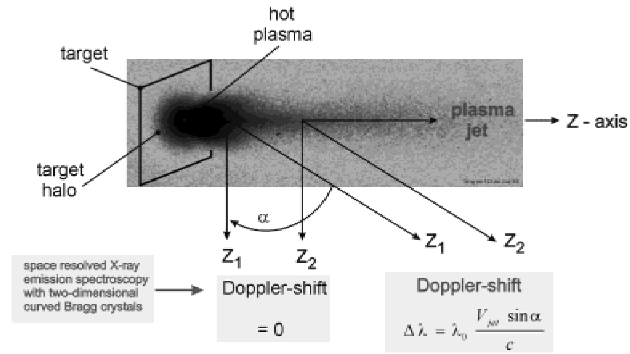

Fig. 3. Experimental scheme of space-resolved Doppler X-ray spectroscopy of accelerated target ions.

the target surface to the far expanding plasma. The indicated line center shift corresponds to an ion velocity of about $2 \cdot 10^7$ cm/s. Also clearly seen is an asymmetry in the line shape of He_δ near the target surface (corresponding to about 2–4 times the line center shift). This asymmetry correlates with the shape of the time-of-flight measurements (Fig. 1), that is, the line shapes of He_δ and He_ϵ near the target surface qualitatively agree with the ion-collector signal shown in Figure 1 (even with respect to the time scale and Doppler shift).

4. CONCLUSION

Fast ion emission has been analyzed by means of time-of-flight methods and space-resolved Doppler X-ray spectroscopy of highly charged target ions *inside* the plasma volume. Correlation's between fast ion collector signals and spectral line shapes of target ions has been established. The broad intensity range between $I\lambda^2 = 4 \times 10^{12}$ and 5×10^{16} W/cm^2 μm^2 was covered to stimulate theoretical analysis of fast ion kinetics for ns-laser pulses.

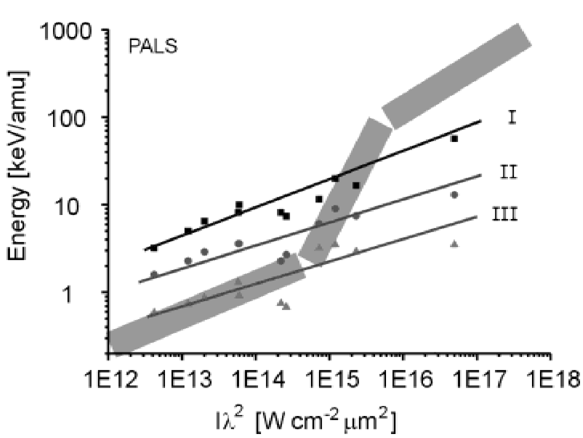

Fig. 2. Fast ion energy in dependence for different irradiation intensities and different ion groups I, II, and III.

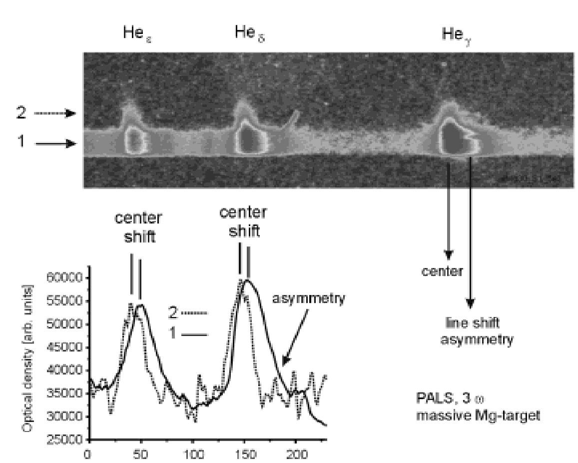

Fig. 4. Spectral image and line profiles of Mg, He_δ, and He_ε, (1) near the target surface, (2) expanding plasma.

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