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Investigation of the interaction of xenon cluster with intense EUV–FEL pulses using pulsed cluster beam source and momentum imaging spectrometer

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ABSTRACT

We investigated the interaction of rare-gas clusters with intense EUV–FEL pulses in the 51–62-nm region by using the SPring-8 Compact SASE Source (SCSS) test facility in Japan. For this purpose, we developed a pulsed cluster source consisting of a solenoid-type pulsed valve and a liquid helium cryostat. The interaction of giant xenon clusters with intense FEL pulses was investigated by detecting photoions using a momentum imaging spectrometer. We observed the emission of energetic highly charged ions when xenon cluster beam ($\langle N \rangle \sim 10{,}000$) was irradiated by intense FEL pulses of wavelength 62 nm.

1. Introduction

Recent developments of free electron lasers (FEL) based on self-amplified spontaneous-emission (SASE) in the extreme ultraviolet (EUV) region below $\lambda = 100$ nm have enabled us to investigate the interaction of intense short wavelength laser pulses with atoms [1–3], molecules [4,5], and clusters [6–9].

Experiments for investigating the interaction of a xenon cluster with VUV-FEL pulses were first carried out at the TESLA Test Facility (TTF) at Deutsches Elektronen-Synchrotron (DESY) by Wabnitz et al. [6]. They investigated the multiple ionization of the xenon cluster using 98-nm FEL pulses. They reported complete Coulomb explosion of the clusters and the emission of energetic ions with charge states of up to 8+, thus suggesting the deposition of a large amount of energy into a single cluster by one FEL shot. Their findings triggered several theoretical investigations [10–14] that indicated that various plasma-heating processes played an important role as energy deposition mechanisms. In addition to the TTF and its upgraded facility FLASH at DESY [6–9], a new FEL facility operating in the wavelength region of 51–62 nm has recently been established at SPring8 in Japan [15]. It provides opportunities to investigate the interaction of clusters with intense short wavelength FEL pulses [16,17].

In the present study, we developed a pulsed cluster beam source to investigate the interaction of a cluster with intense FEL light. The multiple ionization processes of xenon cluster were studied at a wavelength of 62 nm by using a dead-time-free multi-particle momentum spectroscopy technique.

2. Experimental

The experiments were performed at the SPring-8 Compact SASE Source (SCSS) test accelerator in Japan [15]. SCSS provides linearly polarized pulses in the wavelength region between 51 nm and 62 nm, the laser pulse repetition rate is up to 20 Hz. A Mg/Si multilayer mirror with focal length of 250 mm, which was fabricated at Lawrence Berkeley National Laboratory in the United States was used to focus the FEL pulses. The maximum laser power at the focusing point was estimated to be at most 2×10^{14} W/cm^2 using the estimated (diffraction limited) focal spot size of 3 μm; the experimental conditions considered for this estimation included the laser pulse energy (~30 μJ), pulse duration (~100 fs), total reflectivity of three mirrors, size of skimmers, and a partial light stopper for

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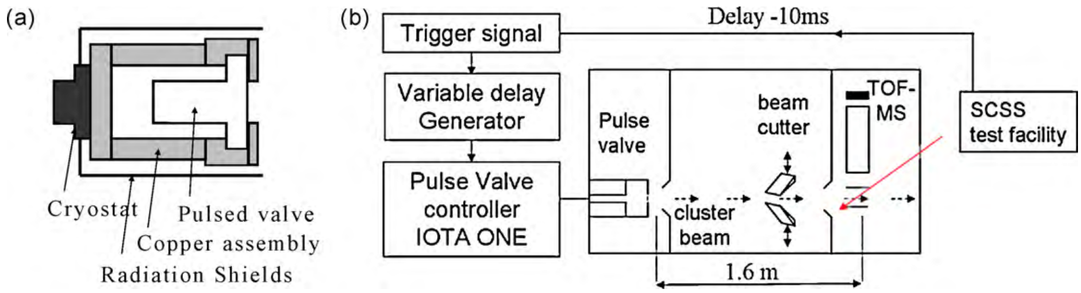

Fig. 1. (a) Schematic drawing of pulsed cluster source and (b) schematic drawing of test circuit for TOF-MS measurements at SCSS.

preventing the incidence of unfocused FEL on the cluster beam [16].

The ions emitted from the cluster by FEL irradiation were recorded by the momentum imaging spectrometer equipped with a position sensitive delay-line detector (HEX80 RoentDek). The three-dimensional momentum vectors for each ion were extracted from the time-of-flight (TOF) of those ions and their hit positions on the detector. A detailed design of the spectrometer is described in ref. [18]. We recorded the signal waveforms from the detector using two 4-channel digitizers (Acqiris DC282), which can substantially reduce the dead times of signals, as compared to a conventional time-to-digital converter system [19].

We have developed a new pulsed cluster beam apparatus for FEL experiments. We adopted the solenoid-type pulsed valve combined with liquid helium cryostat. This type pulsed source has been reported by Slipchenko et al. [20] who produced intense helium droplet beam. We use a Series 99 valve (Parker Instrumentation Corp.) that is encased in a copper assembly and attached to the cold head of a cryostat (Oxford Instruments), as shown in Fig. 1(a). The temperature is controlled by resistive heating of the cold head. The pulsed valve was operated by the commercial IOTA ONE driver (Parker Instrumentation Corp.). A cluster beam was produced by the supersonic expansion of a high-pressure (up to 1.8 MPa) sample gas through a nozzle having an inner diameter of 250 μm.

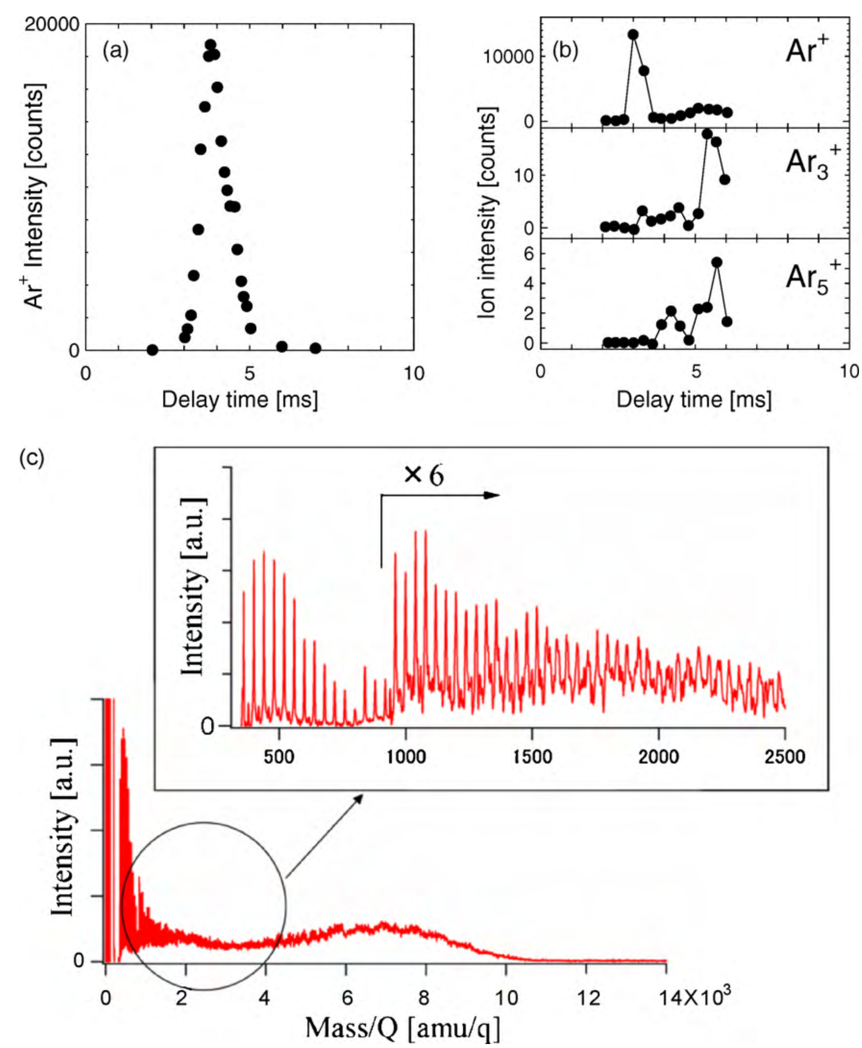

Fig. 2. (a) Temporal profile of pulse valve opening time measured by using TOF-MS for argon atomic beam. (b) Intensities of Ar^+, Ar_3^+ and Ar_5^+ of TOF spectrum plotted according to delay time. (c) Typical TOF-MS of argon clusters recorded by using unfocused FEL pulses at 62 nm.