Time-resolved wide-angle x-ray scattering measurements of Xe clusters by X-FEL pulses

T. Nishiyama[*,†,1], Y. Kumagai[‡], A. Niozu[*,†], H. Fukuzawa[†,‡], K. Motomura[‡], M. Bucher[§], Y. Ito[‡], T. Takanashi[‡], K. Asa[*,†], Y. Sato[*,†], D. You[‡], Y. Li[‡], T. Ono[‡], E. Kukk[¶], C. Miron[,††], L. Neagu[††], C. Callegari[‡‡], M. D. Fraia[‡‡], G. Rossi[§§], D. E. Galli[§§], T. Pincelli[§§], A. Colombo[§§], S. Owada[†], T. Togashi[¶¶], K. Tono[¶¶], M. Yabashi[†], K. Matsuda[*], C. Bostedt[§], K. Nagaya[*,†], and K. Ueda[‡]**

[*] Department of Physics, Kyoto University, Kyoto 606-8502, Japan
[†] RIKEN SPring-8 Center, Sayo, Hyogo 679-5148, Japan
[‡]Institute of Multidisciplinary Research for Advanced Materials, Tohoku University, Sendai 980-8577, Japan
[§]Argonne National Laboratory, 9700 S. Cass Avenue, Argonne, IL 60439, United States of America
[¶] Department of Physics and Astronomy, University of Turku 20014 Turku, Finland
[**] Synchrotron SOLEIL, L'Orme des Merisiers, Saint-Aubin, BP 48, FR-91192 Gif-sur-Yvette Cedex, France
[††]Extreme Light Infrastructure - Nuclear Physics (ELI-NP), "Horia Hulubei" National Institute for Physics and Nuclear Engineering, 30 Reactorului Street, RO-077125 Măgurele, Jud. Ilfov, Romania
[‡‡] Elettra Sincrotrone Trieste, Strada Statale 14 - km 163,5 in AREA Science Park, 34149 Basovizza, Trieste, Italy
[§§] Department of Physics, Università degli Studi di Milano, Via Celoria 16 - 20133 Milano, Italy
[¶¶] Japan Synchrotron Radiation Research Institute (JASRI), Sayo, Hyogo 679-5198, Japan

Synopsis X-ray diffraction methods using x-ray free-electron lasers (XFELs) enable one to observe ultra-fast structural changes in the matter under extreme conditions, which are of importance for the understanding of non-equilibrium phenomena. Time-resolved wide-angle x-ray scattering measurements of Xe clusters were carried out at SACLA in Japan. Structural changes of the near-infrared (NIR) laser heated Xe clusters were observed as a significant decrease in the number of Bragg peaks obtained from the Xe clusters after irradiation of the NIR laser.

X-ray free-electron lasers (XFELs) deliver ultrashort, spatially coherent and extremely intense x-ray pulses. X-ray diffraction methods using XFELs enable one to observe ultrafast structural changes, such as lattice contraction [1] and surface softening [2], in matter under extreme conditions. These are of importance for the understanding of non-equilibrium phenomena. Here we report recent results of time-resolved wide-angle x-ray scattering experiments on highly excited Xe clusters. A near infrared pulse is used to transform the clusters into a nanoplasma. A second, hard x –ray, pulse probes the ultrafast evolution of the local cluster structure on the time scale of a few femtoseconds to picoseconds.

The experiments were carried out at the experimental hutch 2 of the beamline 3 at SACLA in Japan. Xe clusters were generated by expanding Xe gas through a conical nozzle with a 200 μm diameter and a 4˚ half-opening angle. The NIR pulses (800 nm, 30 fs FWHM) were used to heat the Xe clusters. The pulse energy of the NIR pulses were up to 12 mJ. The XFEL pulses (11.2 keV, 10 fs FWHM) were scattered by the heated Xe clusters. The pulse energy of the XFEL was ~60 μJ. The Bragg signals from the XFEL pulses were recorded with a multi-port charge-coupled device (MPCCD) octal sensor [3] installed 100 mm downstream of the interaction point. In coincidence with each single-shot scattering image, ion spectra were measured with an ion time-of-flight spectrometer. We observed the induced structural changes as a significant decrease in the number and intensity of the Bragg peaks from Xe clusters after irradiation with NIR compared to no or prior (negative delay) irradiation.

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References

[1] K. R. Ferguson *et al.*, 2016 *Sci. Adv.* **2**: e1500837
[2] T. Gorkhover *et al.*, 2016 *Nat. Photon.* **10** 93-97
[3] T. Kameshima *et al.*, 2014 *Rev. Sci. Instrum.* **85** 033110

[1] E-mail: t-nishiyama@scphys.kyoto-u.ac.jp