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keV electron heating in laser-cluster interaction probed by X-ray and electron spectroscopy

H. Yin[†], G. Wachter^{†,1}, C. Deiss[†], C. Lemell[†], J. Burgdörfer[†],
E. Lamour^{*}, C. Prigent^{* 2}, C. Ramond^{*}, J.P. Rozet^{*}, S. Steydli^{*}, M. Trassinelli^{*}, D. Vernhet^{*}

[†]Institute for Theoretical Physics, Vienna University of Technology, A-1040 Vienna, Austria, EU

^{*}Institut des NanoSciences de Paris, CNRS, Sorbonne Université Pierre et Marie Curie,
UMR7588, 4 Place Jussieu, 75005 Paris, France, EU

Synopsis The interaction of intense laser pulses with nanoscopic rare-gas clusters provides a testing ground for laser-atom interaction at solid-state densities. We investigate the driven electronic dynamics on the femtosecond time scale both experimentally and theoretically using two complementary observables: the laser intensity dependence of characteristic X-ray emission and of high-energy (keV) electron spectra.

We study the interaction of moderately intense ($\sim 10^{16}$ W/cm²) near-infrared femtosecond laser pulses with nanoscopic ($\sim 10^5$ atoms) rare gas clusters both experimentally and theoretically.

The laser-driven electronic dynamics lead to the production of remarkably highly energetic (keV) electrons even for short pulses (~ 60 fs) and moderate intensities. These fast electrons can, in turn, create inner shell holes leading to characteristic X-ray emission, which can be used as in situ “thermometer” for the electrons inside the cluster. Complementarily, the energy spectrum of keV electrons allows to probe the temperature of the “hot” electrons emitted by the heated cluster.

We have measured [1,2] and have simulated characteristic X-ray photon yields on an absolute scale employing a mean-field classical transport simulation [3], taking into account focal-volume averaging for the experimental geometry. For short pulses ($\lesssim 100$ fs), good agreement between experiment and simulation is found for the absolute photon yield as well as for the intensity threshold (Fig. 1a), allowing us to identify the electron heating mechanisms inside the cluster. Remaining discrepancies are traced primarily to the Lotz cross section for electron impact ionization [4], the validity of which for multiply excited atoms in a plasma-like environment is questionable.

By adding an electron spectrometer to our improved experimental set-up we provide complementary information on the distribution of emitted energetic (\sim keV) electrons. First simulations suggest that the electron energy spectrum reflects the field enhancement at the cluster poles, thus probing the electromagnetic response of the highly excited and ionized cluster.

E-mail: georg.wachter@tuwien.ac.at

E-mail: christophe.prigent@insp.jussieu.fr

Qualitatively, in both experiment and theory, we observe that the fraction of energetic electrons increases for increasing laser intensity (Fig. 1b). However, large quantitative differences are observed. Experimentally, precise calibrations of the electron spectrometer are under progress. Theoretical efforts focus on the improved modeling of electron-impact ionization under such extreme conditions, and on the simulation of the Coulomb explosion and its influence on the electron spectrum.

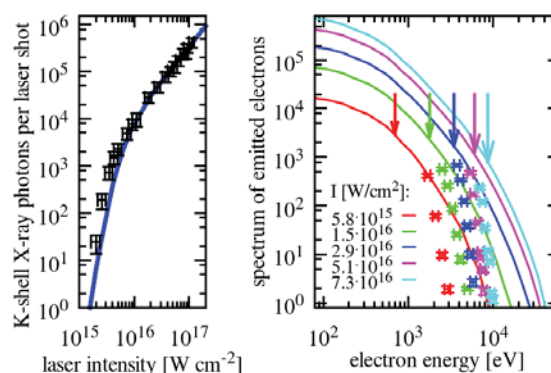


Figure 1. (a) Preliminary simulated (line) and measured (points with error bars, [3]) X-Ray yield as a function of laser intensity for Ar clusters ($2 \cdot 10^5$ atoms), laser pulse length 61 fs and wavelength 800 nm. (b) Theoretical (lines) and experimental (points) electron energy spectra at laser intensities increasing from left to right (other parameters as before). The arrows indicate the corresponding ponderomotive energies ($2U_p = I/2\omega^2$).

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