Interaction of intense VUV-radiation from the FEL with Ar-clusters

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The interaction of intense radiation with matter is of great scientific interest. Experiments with optical lasers with atoms and clusters produced a number of surprising results such as Coulomb explosion [1], X-Ray emission [2], fusion in deuterium [3] or generation of higher hamonics [4] just to name a few. All these phenomena can be explained with a quasi-static model in which the strong electric field of the laser bends the atomic potentials so that the electrons can tunnel out and are accelareted in the lasser field.

For shorter wavelength in the vacuum ultraviolet spectral regime no significant energy absorption was expected based on these models. Due to the higher frequencies the electrons cannot tunnel out of the atomic potentials any longer. First experiments, however, have shown surprisingly large energy absorption [6]. Xenon clusters irradiated with 100 nm light and power densities up to 10^{13} W/cm^2 disintigrated completely in a Coulomb explosion and ions with high charge states up to 7^+ and kinetic energies in the keV regime were produced. Electron spectroscopy revealed thermionic electron emission from the clusters showing efficient plasma absorption processes [7]. Based on these experimental results the theoretical models were refined and more realistic atomic potentials [8] and barrier suppression inside the clusters [9] were introduced.

The new FLASH facility at DESY now provides super intense laser radiation down to 13 nm with peak power densities up to 10^{14} W/cm^2. First experiments about the light – matter interaction were performed at BL2 with 32 nm radiation. The light was focussed down to an estimated 50 micron spot and interacted with the cluster beam under the aperture of a time-of-flight spectrometer. We used the 5 hz singlebunch-modus and acquired the data shot by shot along with the relative intensity of every shot. The clusters were produced with a pulsed cluster source.

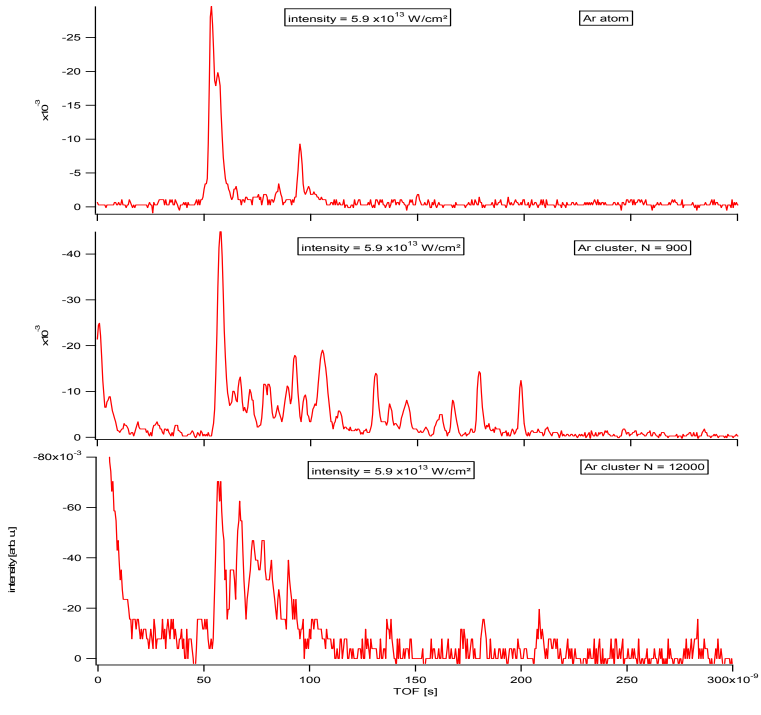
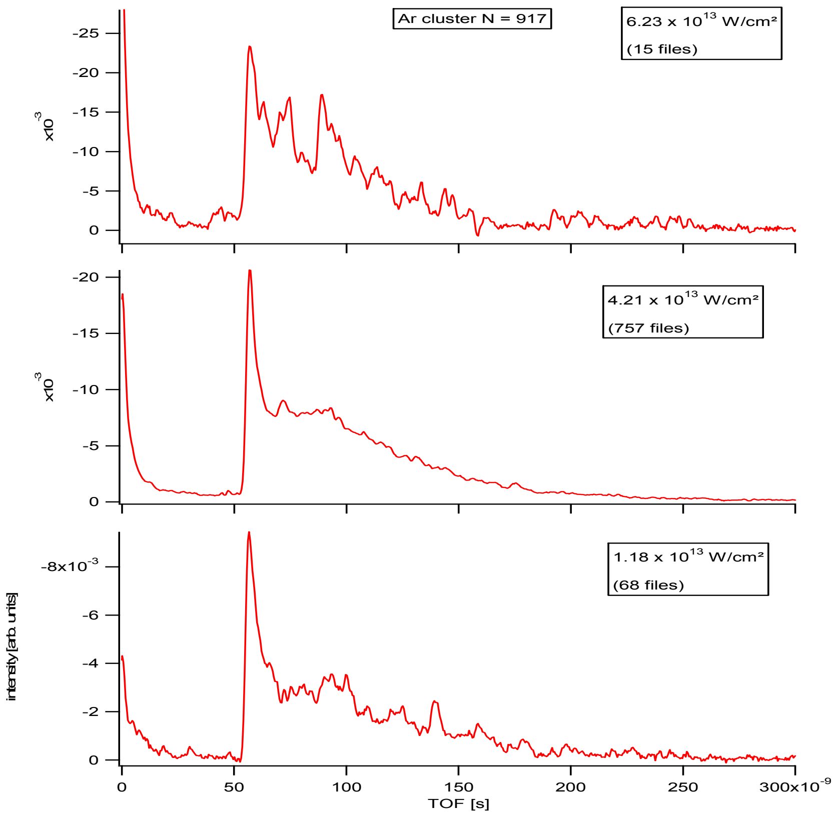


Figure 1: single shots of different cluster sizes, electron signal.

In figure 1 single-shot electron spectra from atoms and clusters with average sizes of <N>=900 and <N>=12000 atoms at power densities of 5.9x10^{13} W/cm² are shown. All spectra show a strong line at 53.5 ns flight time which can be attributed to the Ar 3p valence level. At zero flight times the cluster spectra show additional intensity from the incoming FEL light being scattered of the cluster Towards longer flight times a there is only one peak in the atomic spectra which can be related to either the Ar 3s level or the residual gas. In the cluster spectra many statistically distributed peaks appear. These peaks can be attributed to electrons leaving the remaining charged cluster serially with energies below the kinetic energy of the Ar 2p main line.



In figure 2 the electron emission spectra of clusters with an average size of <N>=900 atoms as a function of FEL power density are shown. The data has been sorted by FEL pulse energy and spectra in the same energy window have been averaged. Differences in their smoothenes are due to the varying number of available spectra in the respective energy window. All spectra show the sharp main line again and an increasingly intense tail of lower kinetic energy electrons. For the highest power density scans the intensity of the lower kinetic energy electrons is almost similar to the main line. Electrons with flight times below or in other words kinetic energies above the main line cannot be observed at any power densities. Such electrons would be indicative for thermionic electron emission.

Figure 2: averaged sorted shots of different cluster sizes, electron

These first experiments reveal already some very interesting changes in the light – matter interaction going further down in wavelength. Thermionic electron emission as seen in the experiments at 100 nm can not be observed at 32 nm any longer. Therefore the electrons do not gain any additional energy out of the laser field but leave the charging cluster serially in what can be best described as photoemission of a ionic cluster. Funding was provided by the Helmholtz Society Virtual Institute VI-103 „Atomic and Cluster Physics with Short Wavelength Radiation from Free-Electron Lasers“.

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