Emission Spectra from the Interaction of VUV FEL Radiation with Solid Aluminium at FLASH

L.F. Cao, U. Zastrau, I. Uschmann, E. Förster, C. Fortmann[1], A. Höll[1], T. Döppner[1], A. Przystawik[1], J. Tiggesbäumker[1], K.-H. Meiwes-Broer[1], H. Reinholz[1], G. Röpke[1], R. Thiele[1], Th. Bornath[1], N.X. Truong[1], R. Redmer[1], R. Fäustlin[2], S. Toleikis[2], S. Düsterer[2], P. Radcliffe[2], T. Tschentscher[2], S.H. Glenzer[3], H.J. Lee[4], T. Laarmann[5]

Institute for Optics and Quantum Electronics, Friedrich-Schiller-University, Max-Wien-Platz 1, 07743 Jena, Germany

[1]Institute for Physics, University Rostock, Universitätsplatz 3, 18051 Rostock, Germany

[2]HASYLAB, DESY Hamburg, Notkestraße 85, 22603 Hamburg, Germany

[3]Lawrence Livermore National Laboratory, 7000 East Av., Livermore, CA 94550, USA

[4]University of California, Berkeley, CA 94720, USA

[5]Max-Born-Institut, Max-Born-Str. 2A, 12489 Berlin, Germany

The fourth generation of brilliant X-ray light sources provided by free electron lasers (FELs) based on self-amplification stimulated emission (SASE) bring intriguing possibilities to extend the investigation of laser-matter interaction into the vacuum ultraviolet (VUV) and x-ray wavelength range [1]. Due to the short wavelength and the high brilliance of these sources, it is possible to heat matter much more uniformly than compared to optical high power lasers, because the light frequency is larger than the plasma frequency and allows deep penetration of matter and even plasma. Therefore, the VUV FEL beam provided by FLASH is an ideal tool to create and study warm dense matter (WDM), which is an intermediate state between cold condensed matter and an ideal hot plasma. The WDM regime is presently not well understood [2], but of high importance for fields such as inertial confinement fusion. Here we report on a measurement in which VUV FEL pulses have interacted with a solid Aluminium target. In particular, we have investigated emission radiation in the VUV wavelength regime produced by Aluminium ions in various ionization stages found in the created plasma.

The experiment has been performed at beamline BL2 of the FLASH facility, using basically the same setup as the Thomson scattering experiment [4]. VUV FEL pulses with 92 eV photon energy (13.5 nm), 50 μJ average pulse energy and ~30 fs pulse duration have been focussed down to a spot with ~25 μm diameter hitting a solid aluminium bulk target under ~45º incidence angle to the surface normal. For these conditions, a power density of about 1×10^{14}Wcm^{-2} can be expected on the target. The plasma emission has been recorded in the range from 5 to 18 nm using a transmission grating spectrometer [3]. The sum of all taken emission spectra is shown in Figure 1a. The emission spectrum is dominated by elastic scattering of the incoming FEL beam at 13.5 nm (92 eV). Besides this elastically scattered peak, plasma emission lines from Al^{2+} (17.24 nm) and Al^{3+} (11.63 nm and 16.15 nm) have been observed. The position of these emission lines corresponds well to databases like NIST [5]. In addition, simulations of the abundance of emission lines were performed as a function of electron temperature. However, the relative intensities of these two ion species are not characteristic for the electron plasma temperature. Higher ionization states are more sensitive, but their emission lines fall outside the spectrometer's wavelength range.

Furthermore, the intensity jump in the spectrum at 17 nm was found to be due to reabsorption at the Aluminium L-edge (Fig. 1a). From the height of this jump, the thickness of the absorbing layer and thus the plasma size were determined to be ~40 nm. The height of the L-edge was also utilized to fit the Aluminum absorption curve. With that, a spectrum free of reabsorption effects has been generated (Fig. 1b). Clearly visible in the spectrum of Figure 1b is the background due to Bremsstrahlung, which also can be calculated from theory. Fitting it to the recorded spectrum gives an idea of the experimental conditions. As a fit parameter, the mean electron temperature was used, since it has the biggest impact on the spectra. Figure 1b compares Bremsstrahlung backgrounds for three different temperatures. It shows that a mean electron temperature of 35 eV is in best agreement with the recorded spectrum (Fig. 1b). However, the spectral response of spectrometer and detector will have to be analysed to support the procedure above. Moreover, with this mean electron temperature of 35 eV, one expects a significant existence of Al^{4+} and Al^{5+} in the plasma, but, as stated before, these ion species do not produce emission lines in the recorded spectral range.

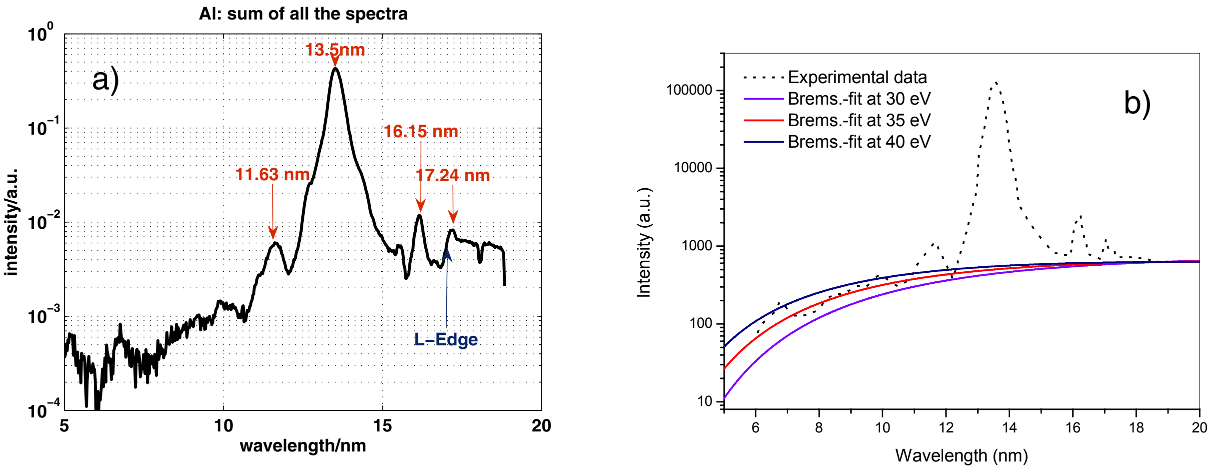

Figure 1: a) Sum of recorded spectra from the VUV irradiation of solid Aluminium; b) Spectrum without plasma reabsorption effects and Bremsstrahlung fits for electron temperature estimation

So far we can report, that we successfully conducted experiments investigating the interaction of high brilliance VUV radiation with solid Aluminium and recorded spectra of the resulting WDM plasma emission. What is more, a partial analysis of the acquired data has already been conducted. A more profound analysis is on the way. Further effects, such as target hole boring, oxidation, impurities as well as wavelength dependent detector response will have to be considered. Hydrodynamic simulation will also be conducted. A completed analysis of our experimental results will then be contributed to the community of WDM research.

References

[1] M. Fajardo, P. Zeitoun and J.–C. Gauthier, Eur. Phy. J. D. 29, 69 (2004)
[2] R.W. Lee, et al., J. Opt. Am. B **20**, 770 (2003)
[3] J. Jasny et al., Rev. Sci. Instrum. 65, 1631 (1994)
[4] S. Toleikis, et al., HASYLAB Annual Report 2007
[5] http://physics.nist.gov/PhysRefData/ASD/index.html