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The basic idea is to implement Thomson scattering with free electron laser (FEL) radiation at near-solid density plasmas as a diagnostic method which allows the determination of plasma temperatures and densities in the warm dense matter (WDM) regime (free electron density of n_e=10^{21}-10^{26} cm^{-3} with temperatures of several eV). The WDM regime [1] at near-solid density (n_e=10^{21}-10^{22} cm^{-3}) is of special interest because, it is where the transition from an ideal plasma to a degenerate, strongly coupled plasma occurs. A systematic understanding of this largely unknown WDM domain is crucial for the modelling and understanding of contemporary plasma experiments, like laser shock-wave or Z-pinch experiments as well as for inertial confinement fusion (ICF) experiments as the plasma evolution follows its path through this domain. In order to study basic plasma properties from scattered spectra, it is necessary that the respective radiation source is able to penetrate through dense plasmas, i.e. the frequency of the probing radiation ω_{rad} has to be larger than the density dependent electronic plasma frequency ω_{pe}. Available sources to probe such plasmas are backlighter systems in the x-ray regime as well as FEL radiation currently available in the VUV. Backlighter systems have been developed in ICF related research [2] and have been applied to solid density plasmas. Here, non-collective Thomson scattering [3] as well as collective Thomson scattering [4] experiments with x-rays in solid density plasmas have been successfully carried out. With the advent of new FEL sources, it has now become possible to do a collective Thomson scattering experiment with FEL radiation at FLASH [5]. In this experiment the aim is to resolve the plasmon resonances in the scattered spectrum to determine the electron density and temperature of a near-solid plasma. The scattered spectrum is mainly determined by the structure factor $S(k, \omega)$ which is schematically shown in Fig. 1. From the measured spectrum the electron temperature T_e (from the intensity asymmetry of the plasmons) and the electron density n_e (from the position ω_{res} of the plasmons) can be determined [5]. In order to get a strong signal from plasmon scattering but not from bound

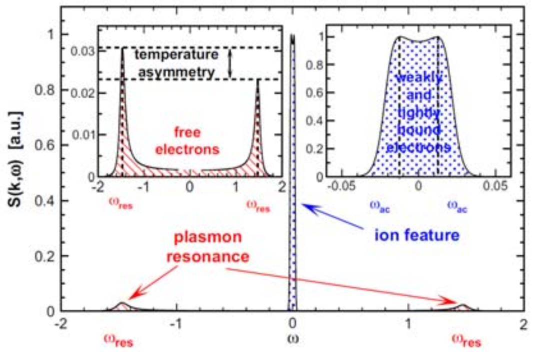

Figure 1: Schematic view of the dynamical strucure factor $S(k, \omega)$ as a function of the frequency shift ω in the collective scattering regime. Taken from [5].

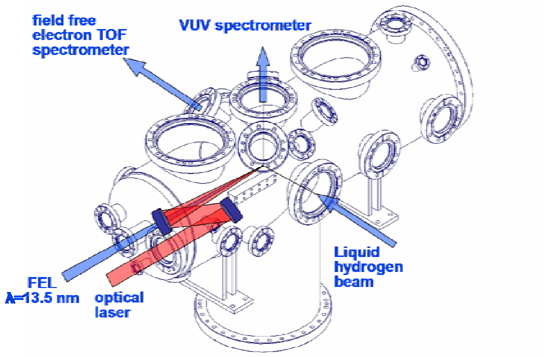

Figure 2: Experimental setup at FLASH.

electrons a low Z target material is used: a hydrogen pellet source [6]. The experimental setup of the first beamtime at FLASH is shown in Fig. 2. The FEL beam with a wavelength of 13.5 nm is focussed by the ellipsoidal mirror of beamline BL2 down to a focal spot size of ~20-30 µm FWHM. The vacuum chamber with its main flanges is centered at the focal distance of 2 m of this mirror. At this point the beam hits the hydrogen target which is injected horizontally from the right. A transmission grating spectrometer [7] which is optimized for efficiency detects the scattered light vertically under 90°. Unfortunately, the optical heating laser which should create the hydrogen plasma in a first step was not available during the first beamtime. So the idea was to test the basic components of the experiment and to investigate how the FEL beam itself interacts with the hydrogen target. With pulse energies of up to 100 µJ, energy densities of ~10^{13}-10^{14} W/cm^2 can be reached, enough to partially ionize the hydrogen target. The first expectation is that one would only see elastic (Rayleigh) scattering from bound electrons. In addition, a free-field electron time-of-flight spectrometer has been attached to record the photoelectron sidebands which one obtains when a VUV and an optical photon pulse are temporally and spatially superposed. This would allow to monitor the timing between optical and FEL pulse at the experiment. It is necessary as the probing FEL pulse must arrive ~0.5-1 ps after the optical heating pulse to guarantee that the produced hydrogen plasma is probed in thermal equilibrium [5], i.e. electron temperature and ion temperature are equal. One important result of the first beamtime is shown in Fig. 3. It shows normalized spectra of the elastically scattered FEL beam from the hydrogen target measured with the transmission grating spectrometer at different FEL intensities. The striking and unexpected features are the clearly visible sidepeaks in the spectrum. They originate from the two-dimensional support grid with 17x17 µm periods. The transmission grating itself consists of free standing gold bars with a 200 nm period. The problem is that the support grid of the grating bars acts as a 2-D transmission grating itself. First, this grid results in a dispersion of visible light which would add an additional unwanted background in the spectrum of the VUV radiation. Secondly, the grid can also diffract the VUV radiation which causes side peaks around the main peak with a wavelength shift of the side peak of about 0.4 nm. These side peaks would hinder the detection of the plasmons. As a consequence for the next beamtime the transmission grating spectrometer will be replaced with a reflecting grating spectrometer which is currently being built.

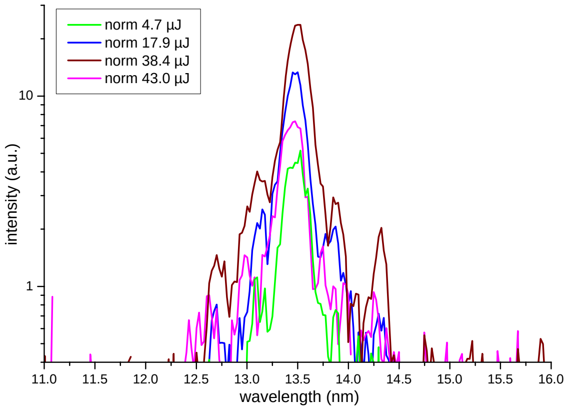

Figure 3: Normalized spectra of the scattered photons. The colors represent different FEL intensities. Clearly visible are sidepeaks which originate from the support grid of the transmission grating.

As expected the measured spectra show beside the mentioned spectrometer artefacts only elastic (Rayleigh) scattering from the hydrogen target. The elastic scattered intensity should rise linearly with higher incident FEL intensity. But at an average FEL intensity of ~38 µJ the scattered intensity does not increase any more but starts to decrase again. This non-linear behaviour is not understood so far and requires further investigation.

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