Gas Phase Thomson Scattering

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Self Thomson scattering from photo-ionized gases is expected to provide information about the anisotropic, non-equilibrium momentum or velocity distribution of the photo-ionized electrons [1]. An intense FEL pulse at a wavelength of 32 nm is used to first photo-ionize a dense gas sample and then, within the same pulse, to scatter from the ionized electrons. The Thomson scattered signal is very close to the fundamental wavelength and contains information about the velocity distribution of the electrons. A sonic gas jet nozzle 300×2000 μm^2 in size was employed and 5 different gases (H_2, He, N_2, Ne and Ar) were studied at interaction densities of up to 10^{19} atoms/cm^3. Both single bunch and multibunch pulses (29 bunches per train with 1µs pulse separation) were employed at a repetition rate of 5 Hz. It was found that the extra differential pumping stages (one on the entrance to the chamber and one on the end of the FEL beamline) were adequate to allow operation up to densities of 10^{19} cm^{-3} and repetition rates of 5 Hz. A VUV spectrometer with a resolution of 0.08 nm viewed the spectral range of 21 to 47 nm vertically at an angle of 90^o from the incident direction. The spectra were integrated over periods of 1 to 20 minutes revealing both weak self scattered Rayleigh and Thomson signals in H_2, He and Ar gases and line spectra up to ionization stages of 3+ for the various gases. The high ionization states with energies above the incident photon energy arise from the thermalization of the plasma after the initial photoionization interaction. Sample spectra are shown in Fig. 1.

All major experimental objectives were achieved. However, the low pulse energies (~10 µJ), which led to only partial ionization in the H_2 and He gas targets (~15% Hydrogen and 70% He), the large fluctuations in pulse energies in a given measurement sequence (1 to 20 µJ) and the broad spectrum of the FEL radiation (0.35-0.5 nm) prevented a clear distinction of Thomson scattering from the Rayleigh scattering in the scattering signatures seen. Since the gases were only partially ionized the Thomson scattering signal is significanty reduced compared to Rayleigh scattering. If energies up to 50 microjoules and linewidths of <0.1nm were available then it is expected that a clear distinction would have been visible between the Thomson scattering and the Rayleigh scattering signatures. A detailed analysis of the experimental data is in progress. From simultaneously performed transmission measurements it will be possible to compare to expected photoionization interaction and penetration of the pulse through the target as the photon flux is increased. Comparison of the single bunch versus multibunch data will reveal whether there is significant residual perturbation of the gas jet when subsequent pulses (at intervals of 1 µs) interact with previously ionized and shocked flowing gas target. A detailed assessment of the line spectra is under way and comparisons with plasma hydro and ionization modeling of the post interaction thermalization, expansion and cooling of the plasma column will give insight into the thermalization of the initially non equilibrium plasma.

From the scattered light measurements estimates can be made of the fractional Thomson scattering and Rayleigh scattering in the signals measured and the quantitative scattered signals compared to model calculations. At present the measured signals appear to be the right order of magnitude to

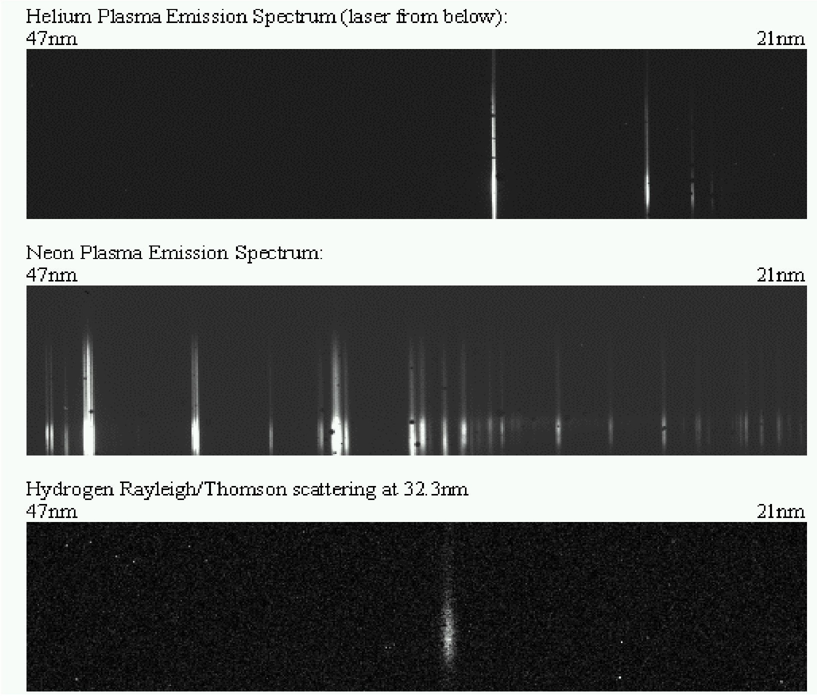

Figure 1: Emission and Scattered light spectra from Helium, Neon and Hydrogen.

those expected given the integration of 87000 to 348000 pulses in each 10 to 40 minute acquisition in multibunch mode of operation. The typical emission spectrum from helium and scattered spectrum from hydrogen are shown in Figs 2 and 3. The results show that the scattered light signals were strong enough and the stray light sufficiently suppressed in order to be able to view the expected Thomson scattering signals.

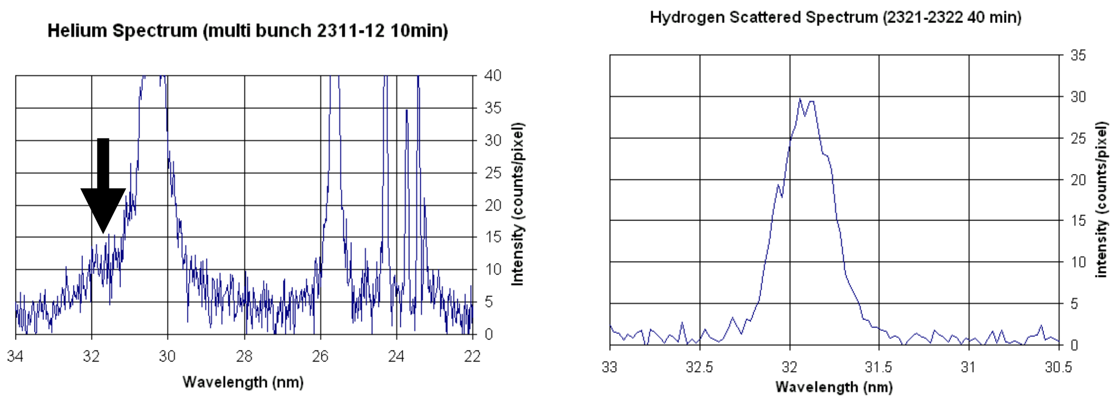

Figure 2: (Left) Helium line spectrum showing a weak Thomson and Rayleigh signal (arrow) in wing of the 30.4nm plasma emission line (10 minutes acquisition 29 bunches per pulse at 5Hz). (Right) Hydrogen spectrum showing clear Rayleigh/Thomson signal (40 minutes acquisition 29 bunches per pulse at 5Hz).

In summary the first VUV photoionized plasmas were created and studied in the experiments. A number of key issues were resolved and key results were obtained. It was determined that with adequate differential pumping one can operate high pressure gas jet targets of up to10^{19} cm^{-3} density. With adequate aperturing of the incoming beam the scattered stray light could be reduced to below the levels for the Thomson scattering signal from the gas targets. Multibunch operation signals could be obtained of the scattered light signal at levels expected from Thomson scattering and clear emission spectra of gaseous plasmas created by the FEL beam could be observed.

References

[1] V.Y. Bychenkov et al., Phys. Plasmas 13, 013101 (2006)