Characterisation of the backscattered radiation from Petawatt laser matter interactions

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Introduction

Following our previous investigations of the backscattered energy on the Vulcan petawatt beam line[1], this contribution reports on the results of the characterisation of the backscattered spectra from laser matter interactions in this facility. These measurements were taken before the compressor which acts as a 12 nm spectral filter, centered at 1055 nm. They are invaluable to ensure minimal damage to the optics will occur. With new facilities coming on line that will deliver shorter pulses with broader bandwidths the compressor will no long act as a spectral filter. Wavelengths between 800 nm to 1200 nm could potentially be passed back through the gratings, making the spectrum of the back scattered light an important area of investigation.

The results presented here were recorded during a number of experimental campaigns on the Vulcan petawatt laser. Consequently a number of parameters have been compared. These included the pulse energy and duration, target type and focusing geometry. The target types varied not only in material but also in density, from under to over dense. Here, we discuss the results of the spectral measurements made.

Backscatter spectrum

The schematic of the method used to measure the backscattered spectrum is shown in figure 1. The spectrum was observed before the compressor because it acts as a spectral filter. The laser pulse leaves the compressor chamber and is directed to an F3.1 off axis parabola (OAP) by mirror M1. The OAP then focuses the laser pulse onto the target. Backscattered light from the target that propagates towards the laser is then directed by the OAP towards M1. Mirror M2 diverts a portion of this beam to the spectrometer. Mirror M2 is positioned such that it lies in the shadow of a similar sized optic used to generate a probe beam and is displaced vertically from the optic axis. Mirror M2 is the limiting aperture of the collection system with 0.03 π steradians being collected. The position of M2 remained constant throughout the data collection process so there can be no inference as to the spatial dependence of the backscattered spectrum.

To observe the entire spectrum parts of the spectrum were allowed to saturate the CCD camera. Therefore, the exact intensities for these particular wavelengths could not be determined. The sensitivity range of the camera extended from 0.124 nm to 1240 nm. Lead shielding had to be placed around the camera to prevent x-rays generated by the interaction from obscuring the results[2]. The gratings inside the spectrometer were varied to examine different portions of the spectrum. For initial measurements the

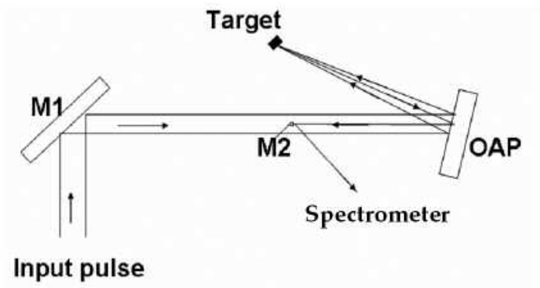

Figure 1. A schematic for the optical path for the back scat.

grating used had a line density of 150lines / mm allowing a broad spectral range to be observed from 500 nm to 1200 nm. The grating was then changed to 1200 lines / mm, which focused in on the 1053 nm region.

The spectrum observed was not only backscattered light but also the emission of light due to the interaction of the laser pulse with the plasma. This gives an indication as to the types of interactions occurring between the laser pulse and the plasma. Although the intensity of the spectrum varies between shots, the same general trend as in figure 2 is found for all solid targets.

As can be seen on figure 2, the spectrum has three main parts. The main 1053 nm peak has a shoulder on either side, due to Raman scattering. The lower intensity 532 peak is the 2nd harmonic of the fundamental, which is generated due to electron motion at the vacuum plasma interface.[3,4]

The cause of the 700-900 nm region is unknown at present, but it is clear that this region is more prominent in lower density materials like the gas jets in figure 3. With the numerous variables in such experiments, like plasmas and

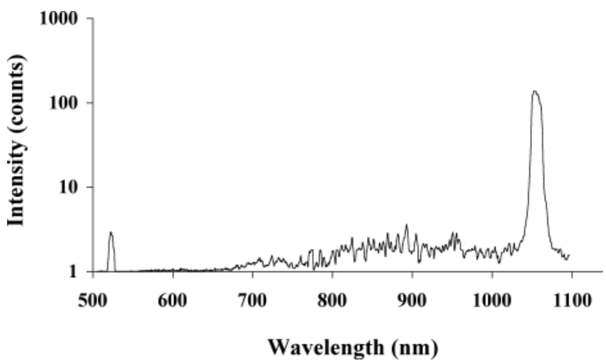

Figure 2. Spectrum of back scattered light for Cu targets.

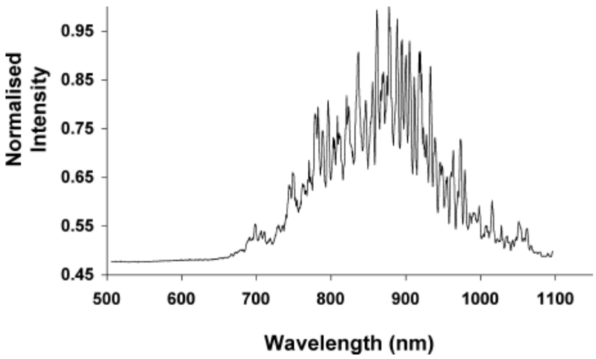

Figure 3. A typical gas jet spectrum.

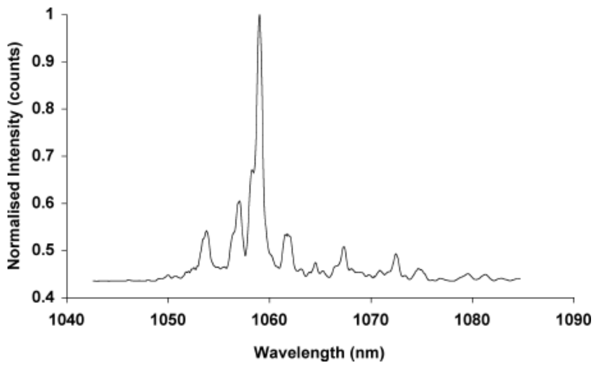

Figure 4. Cu spectrum between 1040 nm and 1090 nm.

target densities, it is hard to determine the exact reaction creating this region, and hence further investigation is required here. It is clear in figure 3 that there is little backscatter due to Raman and Brillouin scattering and there is no second harmonic generation in the backscattered direction. This is largely due to the under dense nature of the gas jet. Filters were used to ensure that the spectrum observed was backscattered light and not due to higher order scattering of the light in the spectrometer.

When the region between 1040 and 1090m is focused on as shown in figure 4 we can see in greater detail the reactions occurring here. As can be seen there are several distinct peaks that are at longer wavelengths than the laser fundamental. The plasma frequency for electron waves is given by

$$\varpi_p = \left[\frac{\eta_0 e^2}{\varepsilon_0 m_e}\right]^{1/2} \quad (1)$$

where T_p is the plasma frequency, 0_0 is the electron density, e is the electron charge, γ_0 is the permittivity of free space and me is the electron mass. Stimulated Raman scattering (SRS) occurs when the plasma density is less than a quarter of the critical density. For 1053 nm this equates to a density of $n_{cr}=1.04 \times 10^{21} cm^{-3}$. When a quarter of this value is used for the electron density in equation 1 we obtain a plasma frequency that would result in the generation of 1075 nm light. However, at these intensities the motion of the electrons can become relativistic and will modify their mass thereby changing the density. This may lead to the suppression of SRS.

Conclusion

The spectra of the backscattered light has shown peaks at the expected first and second harmonics and observed signals from 700 to 900 nm which are more prominent for gas targets then solid, and are still to be explained. This needs further investigation for systems where the gratings of the compressor will no longer filter out this region, allowing this energy to back-scatter to the laser. It is however likely that the increases in intensity will reduce the back-scattered energy, as seen with previous comparisons to lower intensity shots. Consequently it is expected that there will not be any problems experienced due to this.

References

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