Nanosecond contrast measurements of the Vulcan Petawatt facility

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Introduction

The petawatt facility of the Vulcan laser is capable of producing on target intensities of 10^{21}Wm^{-2}. With such large intensities, the contrast of the laser pulses can influence the success or failure of experiments. Indeed, if the contrast is poorer than 10^{10} features arriving before the main pulse will form pre-plasmas disrupting the experimental conditions. Knowledge of the contrast of the laser is therefore crucial to meaningful interpretation of experimental results. In this paper, we report on contrast measurements of the Vulcan petawatt facility examining the contrast on the nanosecond time scale both before and after compression. On these time scales, the principle contribution to the reduction in contrast is amplified spontaneous emission, ASE, which is generated during amplification. On shorter timescales, coherent effects dominate the contrast of the laser pulses and have to be measured using cross correlation techniques[1)]. We report on the investigation of the influence of the different amplifier types used in the amplification process and what can be done to affect the contrast of the laser pulses.

Background

The pulse contrast represents a comparison of the energy or intensity in the main pulse to that of the ASE pedestal. However, an energy comparison gives no indication of the temporal nature of the pedestal. The contribution to the ASE of the different amplifiers used on the Vulcan Petawatt beamline depends on their small signal gain and their type. The stretched pulse is first amplified by an OPCPA pre-amplifier[2)] followed by a mixed glass rod[3)] chain and then a glass disk chain. The OPCPA when configured for normal operation conditions provides 10^8 gain amplifying the incident seed pulse from nJ to mJ. The mixed rod chain comprises rod amplifiers that can be silicate or phosphate glass and takes the mJ seed pulse to the Joule level. The seed is then amplified to the hundreds of joules level by the disk amplifier chain. Earlier measurements demonstrated that when there was no laser pulse present the ASE before compression had a similar duration to that of the pump of the OPCPA pre-amplifier. This suggests that the biggest contribution to the ASE is made by the OPCPA. ASE is generated in the OPCPA by optical parametric generation and is called parasitic parametric fluorescence or superfluorescence. The spectral bandwidth over which this process is efficient is limited by phase-matching conditions between the pump and the generated beams. This same phase-matching condition also has the consequence that the fluorescence with wavelengths close to that of the seed will propagate colinearly with the seed. Therefore, the far-field apertures that are used to remove the idler beam generated during amplification of the seed beam cannot be used to remove the parasitic fluorescence. Fluorescence is only generated in the OPCPA pre-amplifier when there is pump present, unlike the glass amplifiers where fluorescence begins almost instantaneously and lasts for several fluorescence lifetimes after the pump. The pump of the OPCPA therefore governs the temporal characteristics of the fluorescence generated in the OPCPA. Irrespective of the method of amplification used for CPA, the ASE that is lying beneath the seed pulse cannot be removed whilst the pulse is stretched. It can only be reduced after compression where it is present as a pedestal before the main pulse. Since the stretched seed pulse, which has a duration of several nanoseconds, governs the width of any isolating gates and the pump duration of the OPCPA, it would be expected that there would be a pedestal before the main pulse on the nanosecond timescales allowing fast diodes to be used rather than cross-correlation techniques.

Contrast Measurements

The contrast of the Vulcan petawatt was investigated before and after compression using photo-diode systems placed at two points along the beam line. The majority of the data reported in this paper was taken by a set of diodes positioned after compression in a beam relayed out of the TAP interaction chamber. An F3 achromat was used to collimate the beam after the off-axis parabola and then a system of mirrors and lenses were used to relay the beam onto the contrast measuring diodes. As a comparison diodes were placed in the diagnostics channel of the disk amplifier chain before compression. The diode setups are essentially the same comprising a set of two diodes to record the pulse envelope and examine the contrast. The incident beam is split into two, with the majority of the light going to the contrast diode. The diode examining the contrast could be protected by a water cell. Suitable filtration was applied to the other beam to prevent the diode from saturating so that the envelope of the pulse could be monitored. Monitoring of the envelope is required so that the impact of different parameters to the pulse energy can be assessed. Short lengths of SMA cable were used to connect the diodes to the oscilloscope to prevent the cables inhibiting the performance of the system. It was found that the oscilloscope was the limitation of the temporal resolution of the system. The traces from the oscilloscope were then relayed to a PC in the oscillator room which is where the OPCPA is sighted allowing real time monitoring of the effects of the parameters on the contrast.

A number of configurations were used to vary the dynamic range of the measurements. The 10Hz output of the OPCPA had a dynamic range of 10^6 but was insufficient to be able to resolve the pedestal. To increase the pulse intensity and thereby the dynamic range to 10^7 the 9mm silicate amplifier was used. With this increased pulse intensity, the diode was able to resolve the pedestal. This increased the time between pulses to approximately 30s. With this relatively fast repetition rate, it was possible to change operational parameters of the OPCPA and measure their impact on the contrast of the pulse. Using the whole rod chain with a dumping optic increased the dynamic range that the detection system could measure to 10^8. Firing the entire rod chain enables a comparison to be made between the silicate and phosphate mixed glass chain and the solely phosphate chain. To increase the dynamic range yet further the dumping optic used was replaced with a mirror that was a high reflector and a water cell employed to prevent damage to the contrast diode. This final configuration had a dynamic range of 10^9. The intensity of the pulses could be further increased by firing the large aperture faraday isolators that are in the system however it was found that the water cell was unable to prevent damage to the diode. Further increases beyond this were limited by the risk of damage to the collimating optic used to relay the beam out of the interaction chamber.

Stage Gains

Under normal operating conditions the OPCPA is run in saturation, this means that whilst there is some scope for increasing the gains of the different stages, but not by orders of magnitude. The nominal gains of the different stages are 10^3 for stages 1 and 2 and 10^2 for stage 3. The gain of the different stages is determined by the intensity of the pump slice and is controlled by the energy contained within that slice for the durations used. The energy of the pump slice is modified by using a series of half-waveplates and polarisors. In this way it was found that the gain of the different stages could be increased by a factor of 2. By altering the gains of the different stages it was found that the impact of the gain of stage 2 had the greatest effect on the pedestal as can be seen from Figure 1. The amplitude of the pedestal is increased by approximately an order of magnitude when the gain of stage 2 is increased. Since increasing the gain of stage 1 doesn't have the same effect it suggests that the increased gain of stage 2 acts to better amplify that fluorescence generated in stage 1. This demonstrates that on an operational basis it is critical to keep the gain of stage 2 to its nominal operating value to maintain good contrast.

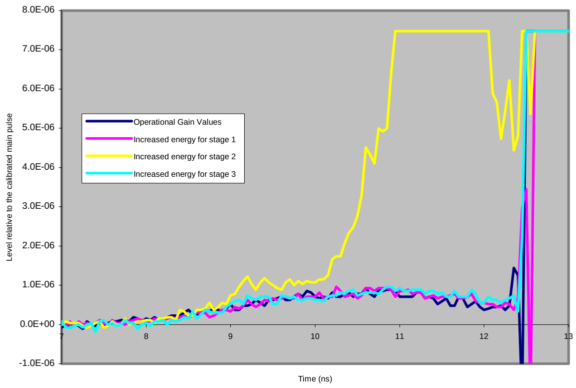

Figure 1. Effect of stage gain on ASE pedestal.

Pump Pulse Duration

Since fluorescence is only generated when the pump pulse is present in the non-linear medium varying the duration of the pump pulse will affect the temporal length of the pedestal. The pump pulse is formed by slicing the output from a Q-switched laser using a Pockels cell and a polarizer. The rise and fall-times of the pockells used in this process are several hundred picoseconds. This pump slice duration was varied between 4.5ns and 3.5ns by changing the pulse formation electronics controlling the Pockels cell. When the pump slice duration was varied from 4.5ns to 3.5ns it was found that amplitude of the pedestal was unaffected but as would be expected the time at which it started varied, by as much as 1ns depending on the wavelength being preferentially amplified. Figure 2 shows the ASE pedestal after compression without the amplifiers being seeded.

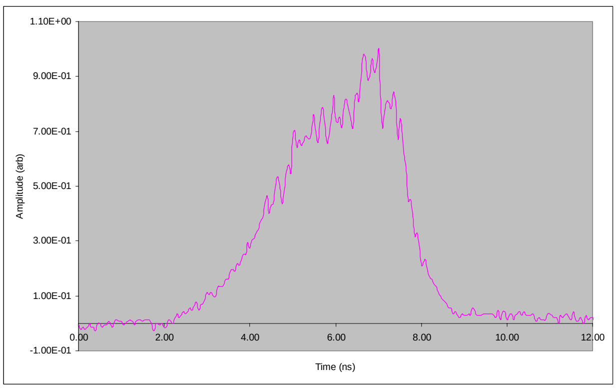

Figure 2. ASE pedestal after compression.

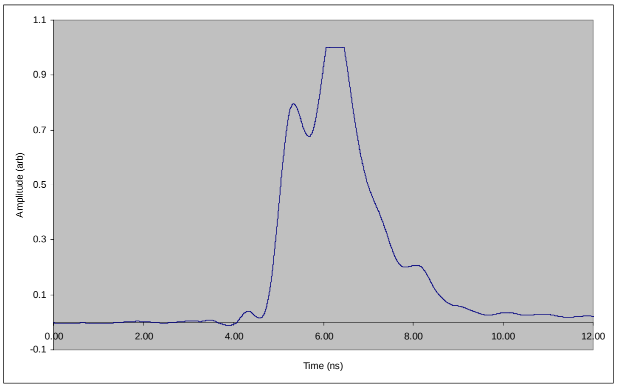

Figure 3. ASE pedestal before compression.

For comparison the ASE pedestal before compression is shown in Figure 3. As can be seen there are some distinct differences between Figures 2 and 3. If we compare the rise times, the rise time of the ASE before compression is faster than that after compression. If the durations of the respective ASE traces are compared it can be seen that the duration of the ASE after compression is longer. This suggests that the compressor is affecting the temporal nature of the ASE. This spreading occurs because although incoherent the ASE has a broad spectral bandwidth with each component experiencing a different delay through the compressor. This will to a certain extent improve the contrast because it is spreading it in time, however it will mean that the pedestal is pushed even further in time before the main pulse.

Relative Timing Between Pump and Seed

When the TAP beam line was first commissioned all the glass amplifiers were made from phosphate glass. These required the seed beam to have a central wavelength of 1053nm. The mixed glass chain on the other hand has a gain peak at 1055nm. This shift in central wavelength is made possible by the OPCPA and is achieved by varying the relative timing the pump and seed pulses. This works because the seed pulse has a positive chip when it passes through the OPCPA, changing the relative timing therefore selects the wavelengths that are preferentially amplified. The longer wavelengths are preferentially amplified by timing the pump pulse slice and the seed pulse so that they overlap at the leading edge of the seed pulse. The effect of changing the relative timing between the seed and pump pulses is shown in Figure 4. As can be seen when the pump pulse is timed to amplify the shorter 'blue' wavelengths the ASE pedestal is significantly reduced. Preferentially amplifying the longer wavelengths introduces several potential mechanisms that could reduce the contrast. The spectral distribution of the seed pulse is approximately Gaussian about the central wavelength. Therefore, by preferentially amplifying longer wavelengths the fluorescence is now competing with spectral components of the seed pulse that have a lower intensity than those around the central wavelength. If the duration of the slice is such that it extends beyond that of the seed then fluorescence will be generated before the pulse that will propagate through the system.

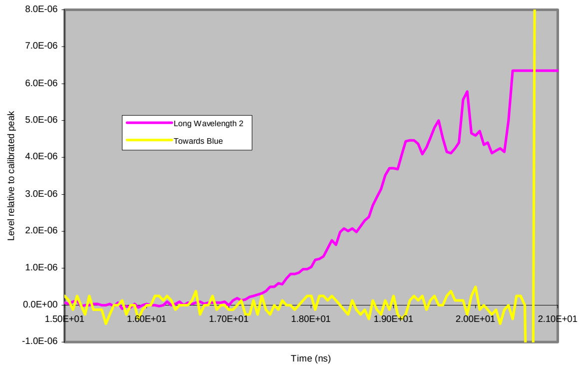

Figure 4. Variation of the relative timing between the seed and pump pulses in the OPCPA.

Influence of Near Field Apertures

To mitigate against the effects of walk-off in stages 1 and 2 the near field of the pump beam is larger than that of the seed beam. Consequently, there will be fluorescence generated in portions of the pump beam that do not overlap with the seed beam. As discussed above the apertures placed at the far-field of the relay imaging between stages cannot be used to remove this portion of the fluorescence. Indeed because the fluorescence is larger in the near field it will be smaller in the far field. However, near-field apertures can be employed to block the fluorescence that is generated in that part of the pump beam where there is no seed beam. When near field apertures are inserted into the OPCPA it is found that the biggest improvement is achieved when an aperture is placed after stage 1. Placing a suitable aperture here reduces the ASE pedestal amplitude by a factor of 2 as shown in Figure 5. However, the 1.0mm aperture cannot be reduced any further because it begins to attenuate the seed beam. This is to be expected since the fluorescence generated in stage 1 experiences the most gain. The pump and signal beams in stage 3 have similar radii, this means that there will be some gain aperturing of the fluorescence generated in the previous two stages.

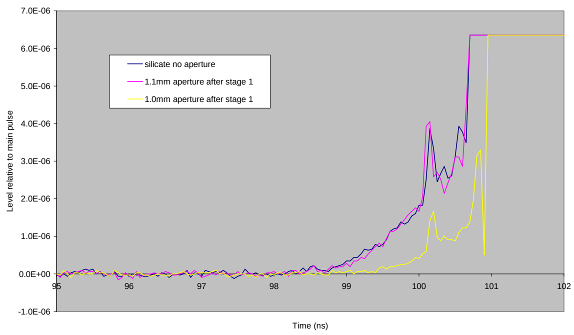

Figure 5. Influence of near field apertures.

Spectral Filtering

Comparing the contrast of the mixed glass and phosphate chains it can be seen that the phosphate chain has a pedestal that is a third of the mixed glass chain as shown in Figure 6. This is attributed to the mixed glass chain supporting a larger bandwidth, than the phosphate chain. The generated ASE has a large bandwidth, much larger than that of the seed being amplified. This is then filtered as it is amplified through the system by the mixed glass chain. It was found that the mixed silicate and phosphate rods support a bandwidth of 11nm FWHM compared to the 7nm FWHM of the phosphate rods.

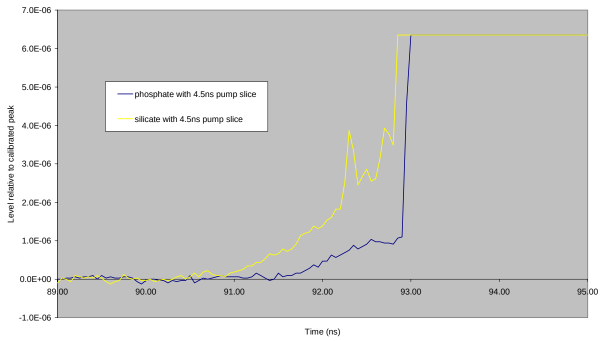

Figure 6. Influence of spectral filtering.

Analysis

Taking the direct ratio of the amplitude of the pedestal relative to that of the signal generated by the main pulse as displayed on the oscilloscope would give a mixture of the energy and intensity contrast because the system is able to resolve the nanosecond pedestal features but not the picosecond pulse. The signal measured by the oscilloscope is the convolution of the actual optical signal with the measuring system. The temporal limitations of the system were such that the 1ps main pulse was resolved as 80ps after compression. Convolution theory suggests that the response of the diode to the main pulse is 80 times smaller than if the system had a response time of 1ps. This enables us too estimate the intensity contrast rather than solely measure the energy contrast.

Conclusions

In conclusion we have reported on recent measurements of the contrast of the Vulcan petawatt facility on the nanosecond timescale. We have shown that there is an ASE pedestal that arrives ~2ns before the main pulse. By varying operational parameters of the OPCPA, we have shown that whilst the pedestal cannot be removed we can take certain actions to minimize it; by monitoring the output spectrum of the OPCPA and the gain of stage 2 and using apertures. Using convolution theory we believe that we have improved the intensity contrast for 2 minute shots to ~4×10^{-8} and that for full disk shots it will be comparable to this. We also suggest that there is the potential for compromise between pulse length and contrast if the phosphate amplifiers are used. To measure the contrast on full energy disk shots a similar diode system to those used to obtain these results will be placed in the TAP diagnostics beam. These results also suggest improvements to the design strategy of CPA lasers. Since the length of the pedestal is effectively governed by the length of the stretch it suggests that for the initial high-gain pre-amplification stages the stretch should be kept to a minimum. It could be envisaged that a dual stretch scheme would be of benefit allowing pre-amplification at short stretches with the final amplification being achieved with a longer stretch. This might negate the need for high loss pulse cleaning techniques.

References

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   CLF Annual Report 2001/2002, p 175

3. Hawkes *et al.*,
   CLF Annual Report 2003/2004, p 169