Pulse length optimization for the Petawatt performance of the Vulcan laser facility

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Introduction

The Vulcan laser facility demostrated its first Petawatt shot to target on 5th October 2004. The first Petawatt shot delivered 1.03 Petawatts; 423 J onto target in a 410 femtosecond pulse.

The Petawatt facility came online to users in 2002 delivering 300 TW. The Petawatt beam line was originally commissioned delivering 250 J of energy on target and with a pulse length ~700 fs. Since then, there has been a gradual ramp-up in energy and optimisation of the pulsewidth to meet the original design parameters[1,2)].

The energy requirement was met first but the pulse width was limited by the bandwidth of the system. This has been the last parameter to be optimized and increasing the bandwidth made it possible to achieve a 400fs short pulse. The output bandwidth had been calculated as 4 nm and it was achieved by the commissioning of a new mixed glass chain and a broader bandwidth OPCPA front end. The commissioning of the mixed glass chain[3)] occurred in November 2003. We report in this article the modifications to the Front End and Compressor to achieve a Petawatt.

OPCPA changes

The OPCPA preamplifier[4)] was originally designed for the Target Area West (TAW) configuration[5)], using a 2.4 ns long stretched pulse and a 3ns long pump pulse. The first option considered to make this OPCPA preamplifier compatible with the Target Area Petawatt (TAP) beam line was to use a scheme of ‘stretch-amplify- stretch’. This option was considered because of the design of the TAP stretcher. It is a double-decker Offner stretcher[6)], that on the lower deck stretches the pulse to 2.4ns, then the beam is re-injected onto the top deck for further stretching to achieve the 4.8 ns required. Therefore it would be possible to stretch the pulse to 2.4 ns then direct the beam to the OPCPA amplifier, which would amplify the pulse to mJ energies. Finally the amplified pulse would be redirected to the top deck of the stretcher to achieve the required 4.8 ns pulse.

This scheme, however, was not implemented because initial tests proved that the configuration whilst feasible , presented a high risk for the long term operations due to the high fluence on the optics of the second deck of the stretcher. Therefore for the first two operational years of the Vulcan Petawatt facility the OPCPA was configured to amplify only a 3ns stretched pulse centered at 1053nm, which limited the bandwidth of the preamplifier to 8nm.

The ideal solution to increase the bandwidth was to minimize the number of changes to the design of the OPCPA amplifier itself, as the original configuration had proven to perform as expected. Therefore by increasing the pump duration time to that of the stretched pulse and maintaining the same intensities in all the stages of the amplifier would provide a way forward. The main risk with this option was that the increase of the energy and pump pulse length would translate into higher fluences. In the OPCPA stages 1&2 the fluences would increase to 2.2 J/cm^2 and to 1.5J/cm^2 in OPCPA stage 3. This means that the amplifier would operate close to the damage fluences of stages one and two- nominally 2J/cm^2. For stage three the damage would still be below the damage threshold. Some tests had to be performed to see if this would be a viable solution.

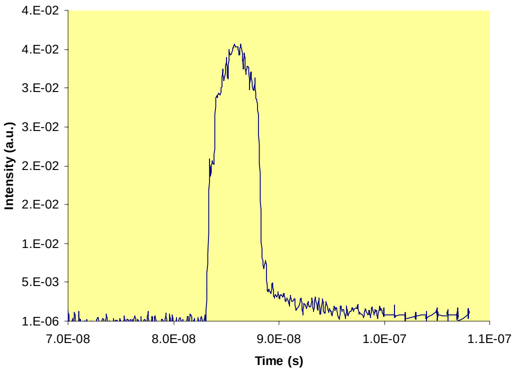

Figure 1. OPCPA pump laser trace.

The pump pulse is generated by slicing a 15ns long pulse with the use of a fast Pockels cell and driver. In order to amplify the entire stretched pulse the pump pulse should be longer than the stretched pulse (4.8 ns long). However because of the Gaussian nature of the original pump pulse, increasing the sliced pulse means that now the shape of it will significantly depart from a top hat temporal profile. Figure 1 shows a 4 ns FWHM pump pulse at 532 nm which highlights this effect.

The shape of pump pulse will be imprinted on the chirped pulse as it is amplified, this will translate into the amplified spectrum of the seed. After measuring the shapes and fluences it was found that the optimum setting was to use a 4ns pump pulse, which will produce a 13nm amplified spectrum.

Bandwidth increase

Injecting the 13 nm output of the OPCPA amplifier into the Vulcan Nd:glass amplifier chain produces an amplified spectrum with bandwidths larger than 5 nm. Figure 2 shows the amplified spectrum for ~140J shot obtained when injecting the original 8nm OPCPA pulse into an entirely phosphate rod chain . Figure 3 shows a spectrum of a 150 J shot obtained when the enhanced 13nm OPCPA pulse is injected into a silicate-phosphate glass rod chain. This spectrum is over 5nm more than the required 4nm to obtain 500fs.

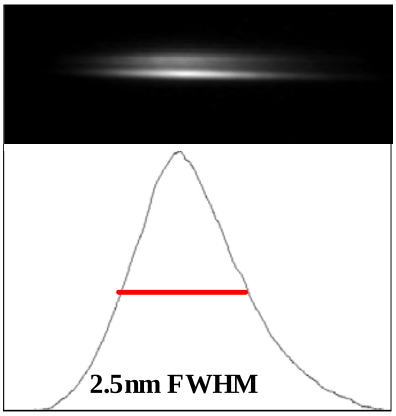

Figure 2. Spectrum with a line centre at 1053nm of a 140J disc shot using entirely phosphate rod chain, with the original 8nm OPCPA front end.

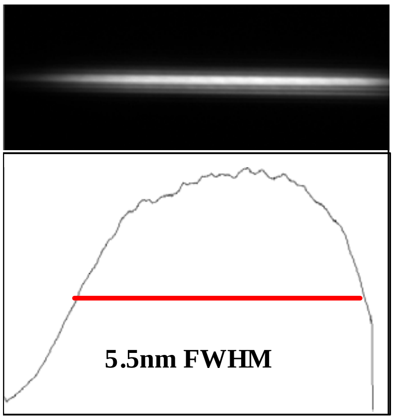

Figure 3. Spectrum centred at 1054.5 of a 150J disc shot using mixed silicate and phosphate rod chain, with the enhanced 13nm OPCPA front end.

Compressor changes

Broadening the bandwidth of the pulse by operating the silicate chain with the full bandwidth of the OPCPA preamplifier has shifted the central wavelength of the pulse towards the expected 1055 nm.

This means that there will be an energy loss through the compressor for the central wavelength as the compressor was originally set for 1053 nm. On Figure 4 we can see the spectral acceptance of the compressor. There are two possible ways to amend this loss: one is to change the input and output angles of both the stretcher and compressor, or the second one is to simply displace the near field position of the North grating (second grating of the single pass compressor) such that the centre wavelength fills the second grating. It is possible to achieve this simply by displacing the North grating in the same plane of the surface of the grating. The grating mount has linear slides that allow movement on x, y and z in the horizontal plane. The slides were not at the end of their range, and therefore it was possible to carry out the movement without having to remove the grating mount from the compressor chamber. The consequence was that now the beam will be displaced 5 cm closer to the tank wall adjacent to the interaction chamber. Figure 5 shows the compressor with all optics positioned for 1053 nm, and it is highlighted the optics that needed to be repositioned. In the case of the mirror that directs the light into the interaction chamber M2, the base of the mirror mount had to be altered and the whole mirror mount repositioned. Additionally the mirror that directs the light into the diagnostics channel (DM1) had to be translated accordingly.

It was noticed that the motors that control the vertical movement or tip of the optics had deteriorated since they were installed[7)]. The serious backlash that was observed when releasing the brake to move the mirror was such that it was no longer possible to correctly align the compressor. Therefore all the motors of the compressor mounts were fitted with a gearbox that removed the problem. Experience of adjusting all the mounts in the compressor has been good after fitting with the new gearbox.

These changes were carried out in August 2004. After these new gear boxes were installed it was possible to accurately align the compressor, following the alignment and tuning procedure of the stretcher and compressor, pulses on the order of 400 fs were achieved with the new OPCPA amplifier and silicate chain.

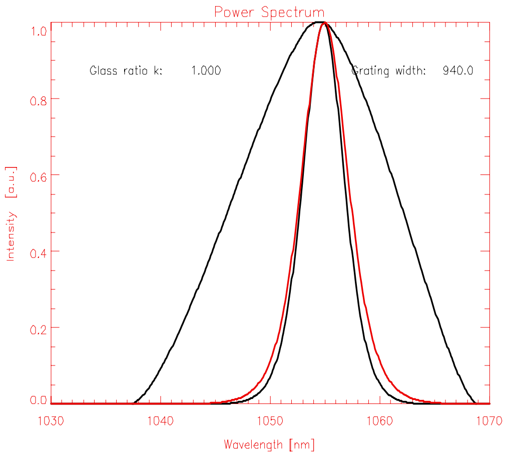

Figure 4. Spectral acceptance of the compressor for 1054.5 nm.

References

1. J Collier *et al*., CLF Annual Report 1999 –2000, p 174
2. J Collier *et al*., CLF 2002-2003 Annual Report, p 168
3. S Hawkes *et al*., CLF 2003-2004 Annual Report, p169
4. C Hernandez-Gomez *et al.*, CLF Annual Report 2001-2002, p 172
5. C Hernandez-Gomez et al, CLF Annual Report 2001-2002, pg. 172, p 175
6. J Collier et al, CLF Annual Report 2001-2002, p 173
7. S Hancock, CLF Annual Report 2000-2001 p 151

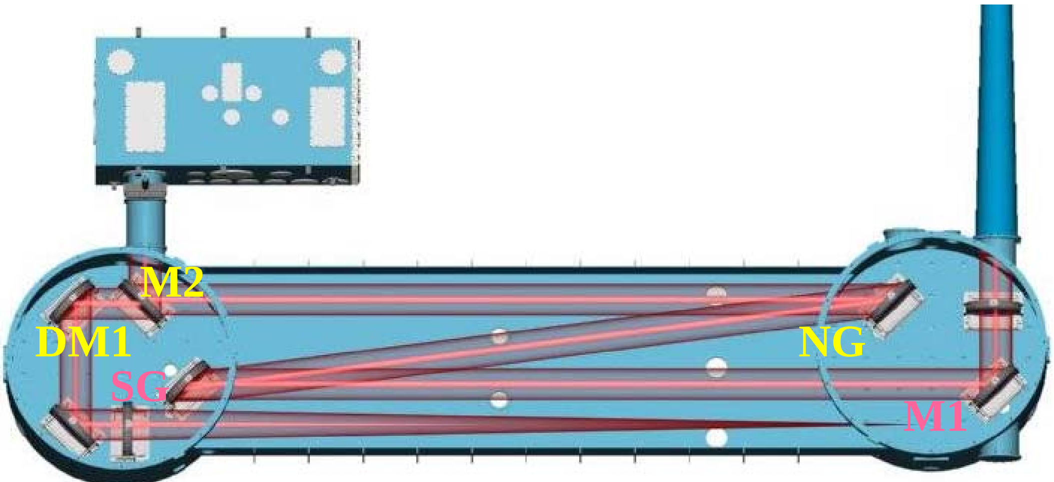

Figure 5. DM1, M2 and NG of the TAP compressor were repositioned in August 2004.