A New ns OPCPA Front End for Vulcan Petawatt

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Introduction

Optical parametric chirped pulse amplification (OPCPA) is now widely used in high intensity laser systems worldwide, and is a key technology used in the Vulcan laser system. The ultra-broadband amplification has enabled developments from the original Petawatt upgrade in 2002[1], to the recent demonstration of the 100+ nm, joule level front end for the Vulcan 20 PW upgrade[2].

The front end for the Petawatt beamline has been in operation for more than twelve years. It underwent a major upgrade in 2009, with the commissioning of the ps OPCPA[3]. This dual OPCPA scheme replaced the ~10^3 gain from the first stage of the ns OPCPA with equivalent or greater gain at the ps timescale. This gave a corresponding improvement in the ns scale laser contrast[4]. In order to retain the ability to operate without the ps pre-amplifier, the ns OPCPA was not reconfigured other than to block the pump to stage 1 under normal operations.

The heavy operational demands on the system precluded substantial modifications to the ns OPCPA. It was instead decided to build an upgraded replacement which would take advantage of the increased seed energy, while addressing performance and reliability issues.

Pump Source

The pump laser selected for the new ns OPCPA was, like the existing pump laser, a flashlamp pumped, Nd:YAG custom system from Continuum. However technological developments in recent years meant that a number of improvements were now commercially available. The new pump laser provides a temporally shapeble output pulse. This is set to a nominally square temporal profile, with the pulse length matched to the stretched seed pulse duration. Modifying the pump pulse profile then permits spectral shaping of the amplified seed. The pump laser runs at 2 Hz repetition rate, producing 1 J in the IR, which is frequency doubled to provide 500 mJ of pump light at 532 nm. The energy stability is 3% RMS.

Design Considerations

Gain narrowing of the optical bandwidth in the Nd:glass laser chain can make it more difficult to achieve a short pulse on target. Increasing the energy of the pulse seeding this chain reduces the gain required to reach high energy and hence maintains more bandwidth. The new OPCPA was designed to produce more than ten times the energy. It replicates the latter two stages of the previous design and adds an additional booster stage to increase the output. All stages are BBO in non-collinear geometry; the final stage is 10 mm thickness.

One of the main problems of the previous system was frequent optical damage from the pump, particularly associated with optics on vacuum relay tubes. This became more severe over time, gradually demanding increased effort to maintain the system at the required level. Despite being well within the stated damage threshold of the optics (<2.7 Jcm^{-2}), damage was regularly seen. The need to keep the system running constantly throughout the day during experimental periods effectively limited the energy that could reliably be produced. The new OPCPA was designed to operate at lower pump fluences and larger beam sizes to avoid similar issues.

The optical layout of the system was designed in 3D CAD, the final model is show below in figure 1. Image relaying of the pump beam from the laser output to the three stages maintains the 'top hat' spatial profile, imaging between stages helps ensure good seed beam quality. Imaging distances must be balanced with the requirement to match the optical path lengths such that the pump and seed arrive at each stage concurrently.

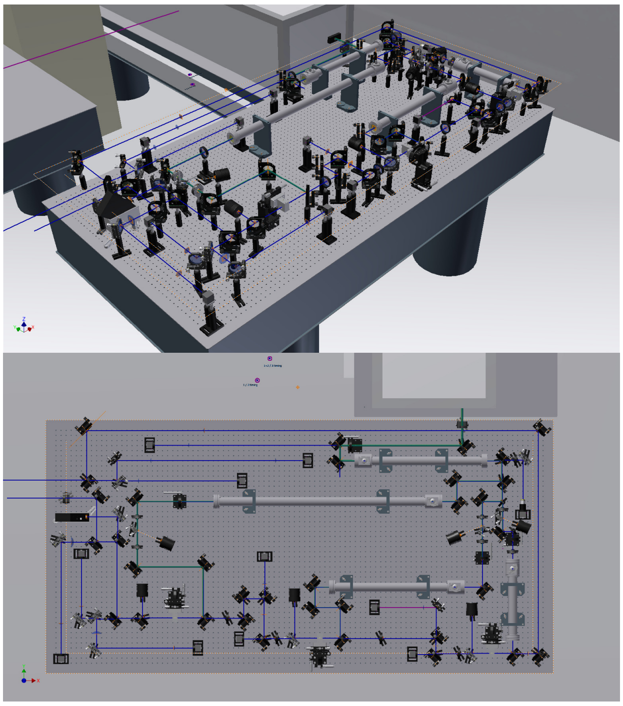

Figure 1: 3D and top down views of the CAD model design.

The system features improved diagnostics to monitor performance and assist in the prompt diagnosis of faults. The temporal profile of the pump laser is measured at various points using photodiodes and a fast oscilloscope. Each stage has a near-field (NF) camera imaging the output face of the BBO crystal and a far-field (FF) camera to look at the relative pump and seed pointing. There are also NF and FF cameras monitoring the output of the pump laser and the seed input from the stretcher. Integration of the NF images provide online energy measurements. In the case of the pump laser output, a flip-in mirror diverts the full beam to a pyro-electric energy meter for checking and calibration. Another energy meter and a spectrometer measure the characteristics of the IR output via a leakage beam.

Amplifier Performance

The seed for the ns OPCPA is the stretched output of the ps OPCPA previously described. This is typically 12-14 µJ in a 3 ps pulse. The Petawatt stretcher is a double decker Offner triplet design including eight reflections from a gold grating. We estimate the transmission to be between 1-10%, giving an input energy of hundreds of nJ, with a pulse length of 4.5 ns. An output energy of 60 mJ is achieved from the three stages of amplification, with the third stage slightly into saturation, giving 6% RMS stability. A NF image from the output is shown in figure 2. The bandwidth is 14 nm FWHM, centred on 1053 nm (figure 3).

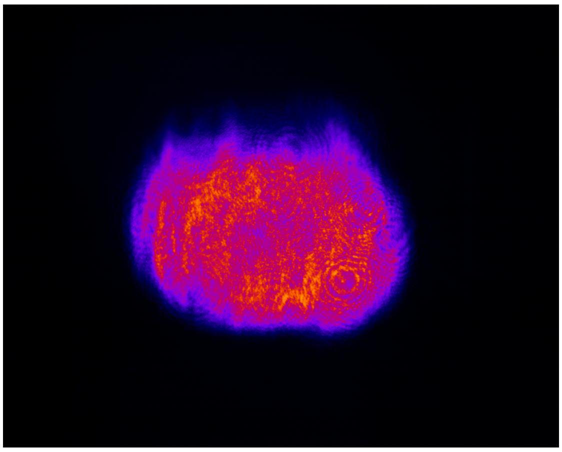

Figure 2: False colour near-field image of the amplified seed output.

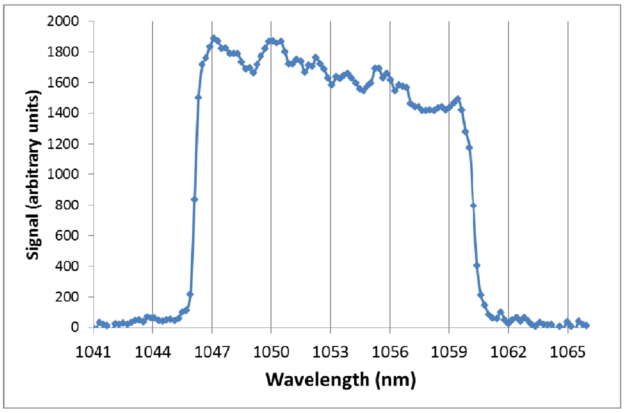

Figure 3: Spectrum of the amplified seed output.

Injection into Vulcan Amplifier Chain via New Beamlines

Pulse picking for input into the main Vulcan glass amplifier chain is done with a fast mechanical shutter (Thorlabs SH1/M). The beam transport from the front end to the laser area has been extensively modified to handle the high energy seed. A set of new beamlines was built, integrating the various seed sources in the front end and collecting them into a fully enclosed line running at low level around the edge of the rooms. The 2 Hz OPCPA is imaged over the ~16 m propagation distance with a 1:1 telescope. Injection into the laser area is via a trench, eliminating the beams crossing the walkway and increasing safety. A suite of diagnostics has been added at the trench output, coupled with motorised mirrors to allow remote control and automatic alignment.

The energy that can be injected into Vulcan is currently limited by the aperture and air spatial filter that define the input of the rod chain. At full energy, air breakdown is seen at the diffraction limited pinhole. The calculated intensity at focus is 10^{10} Wcm^{-2}, which should be lower than the breakdown threshold for air; however it is believed the metallic pinhole plate is reducing this level. Ceramic pinholes were found to reduce the effect, but there was insufficient time in the commissioning phase to implement this change. In order to preserve the stability offered by the third stage saturation, rather than reducing the output of the 2 Hz OPCPA, the final mirror was temporarily replaced with a 15% R beamsplitter. Further work is scheduled for later in the year to overcome this interim restriction.

Full System Performance

Before the system could be run for user experiments, it was essential to verify the performance in Target Area Petawatt (TAP). Temporal contrast measurements with a scanning 3rd order cross correlator (Sequoia, Amplitude Technologies) require ~ mJ scale input energies. Losses through the Vulcan chain mean that it would be necessary to fire the rod amplifiers to obtain this energy, greatly reducing the repetition rate. To avoid this, the beam is diverted at the rod chain input and relayed to the TAP compressor avoiding the bulk glass amplifiers in the system. The stretcher length is adjusted to compensate the reduced dispersion. The standard TAP diagnostics lines are designed for high energy shots, so are not usable with small pulse energy. Instead a transmission beam line is needed to collect all the energy at the output of the TAP compressor. Figure 4 shows the setup of the transmission beam line and diagnostics used for the characterisation.

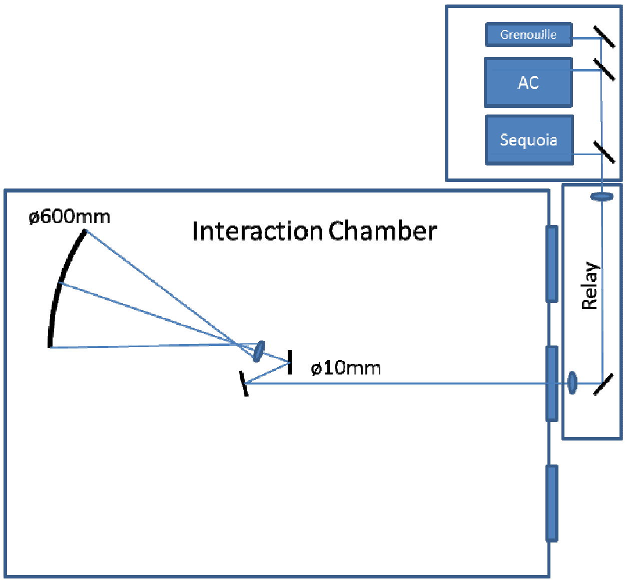

Figure 4: Diagram of the setup of the transmission beam line and diagnostics.

An F3 35mm focal length lens is used to collimate the beam after the parabola, the beam is then relayed outside the interaction chamber, which is under vacuum. An autocorrelator and FROG (Grenouille, Swamp Optics) were used to measure the pulse length and a Sequoia was used to measure the contrast. The resulting contrast scan is shown in figure 5, it indicates an ASE baseline of 10^{-8} and no significant pre-pulses out to 100 ps before the main pulse

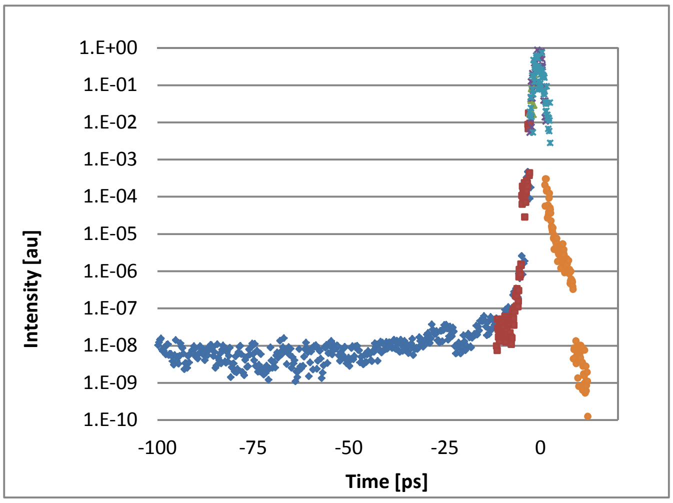

Figure 5: Temporal contrast scan of the 2 Hz OPCPA taken after compression in TAP.

As a final test, a sequence of commissioning shots on target up to full energy levels was performed. Shots were taken onto simple foil targets (copper, 20 µm thick) and proton yields compared with prior results. Protons with a peak energy of 40 MeV were produced, in line with previous experiments.

Conclusions

We have designed, built and commissioned a new ns OPCPA front-end for the Vulcan Petawatt facility. It addresses the reliability issues that were becoming increasingly problematic with the previous system, reducing facility downtime. The new system provides higher input energy to seed the glass amplifier chain, better stability and the ability to shape the spectral profile.

It represents an important upgrade to the Vulcan laser as reducing amplification in glass should improve the contrast, while permitting shorter pulse duration. The system is pictured in operation below in figure 6.

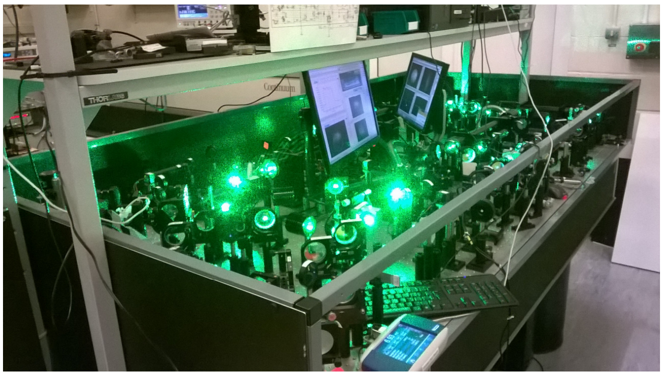

Figure 6: The 2 Hz ns OPCPA in operation during the commissioning period.

References

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2. A. Lyachev *et al.* – Development of the Joule level amplification stage for the Phase 1 of the Vulcan 10 PW OPCPA project – CLF Annual Report 2007-08

3. I. Musgrave *et al.* – Picosecond optical parametric chirped pulse amplifier as a preamplifier to generate high-energy seed pulses for contrast enhancement – Appl. Opt. 49, 6558 (2010)

4. Ian Musgrave *et al* – Close-in Contrast Measurements of the New ps OPCPA Front End – CLF Annual Report 2009-10