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The Vulcan 10 PW Project

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**Abstract**. The aim of this project is to establish a 10 PW facility on the Vulcan laser system capable of being focussed to intensities of at least  $10^{23}$  Wcm<sup>-2</sup> and integrate this into a flexible and unique user facility This paper will present progress made in Phase one developing the 10PW Front End as well as the concept for the new Vulcan 10 PW facility. The new facility will be configured in a unique way to maximise the scientific opportunities presented through a combination with the existing capabilities already established on Vulcan. This ground breaking development will open up a range of new scientific opportunities.

## 1. Introduction

The Vulcan 10 PW project will upgrade the Vulcan laser, located at the Central Laser Facility (CLF) to beyond the 10 PW power level and provide focussed intensities of greater than 10<sup>23</sup> Wcm<sup>-2</sup> to its international user community. This will be achieved by generating pulses with energies of 300J and with durations less than 30fs using the Optical Parametric Chirped Pulse Amplification (OPCPA)[1] technique. The generation of a high energy and ultra short laser pulses using the OPCPA concept offers high broadband gain with good contrast. This technique opens an affordable way of harnessing the high energy produced by laser systems such as Vulcan into multi-Petawatt ultra-short pulse systems.

Over the last decade the CLF through a number of research projects has demonstrated the scaling of the OPCPA technique from the table top to the Petawatt regime [2] to the large aperture demonstration [3] of pulse amplification up to 35J, with 70 nm bandwidth and 80 fs duration.

The Vulcan 10 PW design is based on a triple OPCPA amplification scheme with initial amplification occurring in the picosecond domain and subsequent amplification occurring in the nanosecond domain to guarantee a high contrast pulse. We divided the project into two Phases. The objective of phase one was to develop a novel Front End - sub 30 fs pulses at 910 nm with 1 J of energy that will seed the subsequent amplification stages to reach the required output energy. In addition another important aspect of phase one was to develop the concept design of the 10 PW facility and identify the technology that would need to be developed in advance to minimise any risks during phase 2, such as grating technology.

## 2. Methodology

The proposed scheme for the Vulcan 10 PW facility is shown in figure 1. The Front End comprises of the mJ broadband seed, a stretcher and an OPCPA J level amplifier based on LBO crystals. The sub-Joule output from the Front End system will enter an OPCPA amplification system, based on two large aperture deuterated Potassium Di-Hydrogen Phosphate (DKDP) crystals for amplification to the 500 J level. These two crystals will be pumped by long pulse beams from Vulcan. To achieve this level of energy two Vulcan high energy beam lines will be upgraded through the installation of additional 208 mm diameter amplifier chains. The amplified output beam will then be compressed in time and directed to different areas to be focussed between  $10^{22}$  Wcm<sup>-2</sup> and above  $10^{23}$  Wcm<sup>-2</sup>.



Figure 1. Schematic of the Vulcan 10 PW Facility

## 3. The 10 PW Front End

A novel Front End has been developed during phase one to seed the remainder of the system that will be built as part of phase 2. It currently delivers ultra short pulses at 910 nm, with energies of up to 0.4 Joule and with sufficient bandwidth to support a pulse with a duration of 30fs. The development of a broadband seed at 900nm [4] with a 150nm bandwidth specification has been key element of this system. The theoretical calculations show that the OPCPA scheme described above can support more than 150nm. Using this bandwidth is advantageous as the seed needs to be stretched to 3 ns pulse for amplification in the large aperture OPCPA stages.

The 910 nm seed currently generated with a chirped scheme has a bandwidth of 165 nm and energy of 40  $\mu$ J per pulse. This seed is then stretched to 1.87 ns FWHM on a test stretcher and amplified in two LBO crystals pumped by a commercial temporally shaped pump laser. The design of the Joule stage in terms of contrast, gains and energy were based on a millijoule of seed energy at the input. As the input seed energy is currently limited to 1~  $\mu$ J due to stretcher inefficiencies, additional gain over that originally anticipated has been provided in the first stage by placing two crystals consecutively. In this way the un-depleted pump energy from the first crystal is recycled to extract gain from the second one In using this scheme the output energy achieved so far is >15 mJ for stages 1 and 2 and 0.4 J for stage 3. We have demonstrated an amplified bandwidth of 100 nm at the output. There is a spectral loss of the input seed due to the limitation by the gratings size of the stretcher currently limiting the output bandwidth. Further loss in spectra of the amplified pulse is caused by limitation of currently used broadband mirrors .The evolution of the amplified pulse spectrum on the J level OPCPA stages is shown in figure 2.



Figure 2. Spectra of the Front End system at different points of amplification

The output beam from the Joule level OPA stages was directed to a test compressor and diagnostics suite for characterisation. We were able to measure the pulse length of the compressed pulse down to shorter than 30 fs using a commercial device.

To achieve the contrast specification of the Front End it is necessary to increase the output pulse energy of the mJ-stage OPA on ps time scale significantly from its current  $\sim 40\mu$ J to  $\sim 1$ mJ. This will allow the first stage to operate with a single crystal as originally designed, work is currently on going to increase the energy of the broadband seed to the mJ level and to characterise the contrast.

## 4. Large aperture OPCPA amplifiers

The high energy laser chain used for the pump generation and OPCPA stages have been designed and modelled to a level that ensures that the design meets the technical specifications required to deliver 300J in 30 fs. The laser chain required to pump the OPCPA stages will be a combination of the existing Vulcan Nd: glass amplifier chain and a new set of amplifiers.

The additional laser amplifier chain has been designed using a minimum number of amplifiers in a double pass configuration using angular multiplexing. A long pulse shaping system is required in order to ensure that the correct temporal shape of the pump pulse is achieved. The current Vulcan laser is composed of a series of small aperture rod amplifiers and large aperture circular disc amplifiers. To provide an optimised geometry for the OPCPA amplification and particularly pulse compression, square pump beams are required. The design requires the final 208 amplifiers with square slabs (as opposed to the current elliptical ones) which is a new type of technology to the one currently being used in Vulcan. As part the first phase of the project we have developed the technology to build this type of amplifiers.

There are two large aperture OPCPA stages to amplify the pulse from 1 J to 500J. We have performed 2D simulations on the amplification of the large aperture DKDP stages. An input signal of 1J centered at 910 nm with  $\Delta\lambda$ =150nm stretched pulse duration of 3ns is amplified in 2 DKPD crystals 220mm square pumped by pump pulses generated by frequency doubling the Vulcan beams to 600J at  $\lambda$ =527nm,  $\Delta$ t=3ns flat top. The theoretical model shows output energy prior to compressor of 592J over the entire bandwidth.

## 5. Compressor and grating technology

The compressor design is based on a single pass four grating scheme. The compressor gratings need a line density of between 900 l/mm and 1200 l/mm. Calculations performed indicate that the optimum line density for the gratings of the large aperture compressor for the bandwidth we intend to use is 900 l/mm. The grating should be efficient supporting 150 nm required pulse spectral bandwidth centred

around 910 nm .These low line density gratings are not readily available at the large aperture required from any manufacturer. We theoretically modelled the performance of the gratings under different configurations to establish the optimum geometrical configuration to use in the compressor. The calculations of expected diffraction efficiency from 900 l/mm gold gratings at S-polarisation for the required spectral region show very good efficiency of over 95 % within our pulse spectrum.

In addition working with the Plymouth Grating Laboratory (PGL) to investigate the theoretical performance over a large bandwidth of gold and dielectric gratings at 900-1100 l/mm, and to establish the feasibility to have these manufactured at large diameters apertures. Following these studies a second contract was placed with PGL to actually manufacture small grating samples in order for us to test their performance. We have received two sets of grating samples from the PGL over last year. First, gold gratings of binary type with different line densities with groove densities 900 l/mm, 1000 l/mm and 1100 l/mm. The second set were gold and silver gratings with 900 l/mm groove densities of Sinusoidal and Binary types. The tests showed that both silver and gold gratings of the binary type operating at Littrow out of plane configuration have quite uniform diffraction efficiency above 90%.

## 6. Facility

As part of phase one of this project an overall design for the new facility that will be built during phase two was developed. A significant extension to the Vulcan building infrastructure is required to accommodate the large amount of new equipment. The Vulcan laser facility comprises of laser hall, front end room, control rooms, capacitor bank and three target areas. The requirements of the new facility are to house a new Front end, new laser amplification chain and compressor and extend two of the existing target areas with the appropriate shielding.

The proposed new building requires the existing building to be extended on the South and West sides and a second floor built in above the two of the current Target Areas, Target Area West (TAW) and Target Area East (TAE). The upper floor would then house the additional laser chain, OPCPA amplifiers and compressor. TAE, traditionally used for low intensity experiments, would be transformed to become a dedicated *High Intensity* 10 PW area (HIA). The existing Target Area Petawatt (TAP) would be enhanced to become a combined 1+10 PW area (TAP10). Both areas HIA and TAP10 will be shielded appropriately to provide adequate radiation protection facility.

## References

- [1] I. N. Ross et al, Opt. Commun. 144, 125–133 (1997)
- [2] J.L.Collier et al, IFSA 2003, American Nuclear Society, Pub: Elsevier, 603-607, (2004)
- [3] J Collier et al, Applied Optics, 38, No. 36, (1999) 7486
- [4] Y Tang et al, Optics Letters, 33, No20, 2386-2388 (2008)