Orion: a high contrast user facility

D I Hillier, C N Danson, S J Duffield, D A Egan, S P Elsmere, M T Girling, E J Harvey, N W Hopps, M J Norman, S J F Parker, P T Treadwell, D N Winter, T H Bett

Plasma Physics Technology Centre, AWE, Aldermaston, Reading RG7 4PR, UK

Abstract. The Orion facility consists of two synchronized laser systems: two CPA (Chirped Pulse Amplification) beamlines each deliver 500J to target in a 0.5ps pulse (1PW) at 1054nm; and ten long pulse beamlines each deliver 500J in 0.1-5ns temporally shaped pulse at 351nm. One of the CPA beamlines has the option to be frequency doubled at sub-aperture to produce 100J laser pulses with a nanosecond contrast of $\sim 10^{14}$. Further work is under way to enhance the contrast of both CPA beamlines in the first harmonic.

1. Introduction

The Orion laser facility [1] was commissioned in 2012, received its “authority to operate” in early 2013, and has been running as an operational facility ever since. The facility consists of two distinct laser systems coupled together into the same target chamber. Orion has two CPA (chirped pulse amplification) beamlines which produce sub-picosecond, petawatt pulses and ten, temporally shaped nanosecond beamlines operating at 351nm. In addition one of the CPA beamlines can be frequency doubled at sub-aperture to produce 100J laser pulses with a nanosecond contrast of $\sim 10^{14}$. Further work is under way to enhance the contrast of both CPA beamlines in the first harmonic.

2. System operation

The nanosecond beamlines are seeded by a distributed feedback fiber laser from which 100ps to 5ns temporally shaped pulses are sculpted by a pair of integrated optical modulators. These are initially amplified using a pre-amplifier module (PAM) [3] consisting of a regenerative amplifier, spatial shaping, 2D smoothing by spectral dispersion (SSD) system and a 4-passed rod amplifier. The output from the PAM is split using a series of polarizers and half-wave plates to seed the 10 main beamlines. The main beamlines consist of four 200mm diameter Nd:Glass (phosphate) disc amplifiers. The disc amplifiers are 4-passed using a reverser configuration with a deformed mirror to compensate for on-shot thermal aberrations. Each amplification stage is isolated using Pockels cells to prevent parasitic lasing. The beamlines are each capable of generating 500J at 351nm in a 1ns square pulse. The beams are focused on to target in two 50 degree cones using 1.2m focal length lenses. Focal spot conditioning is achieved using continuous kinoform phase plates. Orion has two PAMs each seeded by an independent pulse shaping system; these can be used to either seed five beamlines each or one PAM can seed all ten beamlines.

The short pulse beamlines consist of a 200fs mode-locked oscillator, the output from which is split into two then stretched to 6ns using Offner triplet stretchers. These pulses are amplified using a three
stage optical parametric amplifier [4] to ~100mJ before being 4-passed through a pair of Nd:glass (phosphate and silicate) rod amplifiers then a series of Nd:glass (phosphate) disc amplifiers of increasing aperture to ~700J. The beam is compressed to ~500fs using a pair of gold diffraction gratings then focused onto target with a f/3 off-axis parabola to achieve an intensity of ~$10^{21}$ Wcm$^{-2}$.

**Figure 1 The Orion laser facility**

Orion can be operated in a range of configurations depending on the experiment: The base line configuration has one PAM seeding all 10 long pulse beamlines and the two short pulse beamlines operating independently. If two different pulse shapes are required or large delays between beamlines then each set of 5 beamlines can be seeded by a separate PAM. Alternatively either one or both of the short pulse beamlines can be seeded with shaped long pulses from PAM 2 with the output from the beamline being picked off prior to the compressor and sent down a separate path via frequency tripling crystals to target.

### 3. Contrast enhancement

CPA lasers incorporating optical parametric amplifiers (OPA) suffer from a reduction in their temporal contrast due to parametric fluorescence. On Orion this manifests itself as a pedestal with ~$10^8$ of the power of the compressed pulse and the same duration as the OPA pump pulse.

In order to enhance the contrast we frequency double the output of one of our short pulse beamlines (SP1) post compression. Conversion efficiency varies roughly linearly with intensity in the saturated/back-converting regime and quadratically in the low conversion efficiency regime. Hence the pedestal converts far less efficiently than the main pulse and the contrast increases dramatically.

The apparatus for frequency converting the beam line is installed in a vacuum chamber inserted between the compressor and target chambers (Figure 2). The 600mm diameter beam from the compressor is first reduced in size to 300mm using a segmented apodiser consisting of four pieces of absorbing glass with a solid metal back. The beam is then reflected off a 1054nm mirror and through a 3mm thick, 320mm diameter KDP crystal cut for type I second harmonic generation. Post conversion the beam is reflected off three dichroic mirrors all of which are high reflectors (HR) at 527nm and highly transmissive (HT) at 1054nm to provide extinction of the 1054nm light. The leakage thought the first of these contains the bulk of the unconverted 1054nm light and is dumped into a slab of
absorbing glass. The leakage through the second mirror is reduced using a Galilean telescope and used for diagnostics on the 527nm beam.

![Diagram](image1.png)

**Figure 2** The frequency doubling chamber is inserted into the main beamline between the compressor and target chambers.

After leaving the conversion chamber the beam is reflected off two further mirrors, both designed to be HR at 1054 and 527nm, before being focused onto target using a dichroic f/6 off-axis parabola which is HR at 527nm and HT at 1054nm. The intensity of any first harmonic light at target is reduced by a factor of $\sim 10^2$ by each dichroic mirror and the parabola giving a total extinction of $\sim 10^8$.

![Graph](image2.png)

**Figure 3** Output energies and conversion efficiencies from the frequency doubled beamline

The conversion crystal tuning angle was set by retro-reflecting light from the surface of the crystal then de-tuning by $\sim 1$ mrad in the slow axis to minimize back reflections in the beamline. This detuning angle is small enough to have only a negligible effect on the conversion efficiency.

A series of full system shots of increasing energies were fired giving a maximum of 100J in the second harmonic and conversion efficiencies of up to 65% (Figure 3). The system was then used to carry out a range of target experiments with shots mostly fired at full energy.
Contrast measurements were performed in the first and second harmonic using the two photodiode technique [5]. This showed that the contrast was improved by a factor of $10^6$ to give a contrast of $\sim 10^{14}$. Making a measurement with this dynamic range required careful calibration of the filtering, extensive shielding of the photodiodes and running the diagnostics station beyond its damage threshold.

![Figure 4 Frequency doubling the beamline enhances the contrast by 6 orders of magnitude](image)

### 4. Future work

A program of work is currently underway to improve the contrast of the Orion beamlines in the first harmonic in order to increase the energy available to the target. We are in the process of implementing a short pulse optical parametric amplifier (SPOPA) similar to those described by Dorrer [6] and Musgrave [5]. Our SPOPA is a modular unit that will be installed into our beamline between the short pulse oscillator and main stretcher. It takes the output from the oscillator and splits it into two: one pulse is amplified using a regenerative amplifier then frequency doubled to give a 6ps, 500μJ pump beam. The other beam is stretched to match the duration of the pump pulse using a Martinez stretcher. The two beams are mixed in an LBO crystal to give clean 10μJ output to seed the main OPA. This will be used to enhance the nanosecond contrast by the gain of the OPA giving a predicted contrast of $\sim 10^{11}$. If used in conjunction with our frequency doubling system this should allow us to deliver a $\sim 100$J, 527nm pulse with a $\sim 10^{20}$ contrast to target.

### 5. Conclusions

The main beamlines of the Orion laser facility are now fully commissioned and the facility is performing experiments [7]. One of the short pulse beamlines is capable of being frequency doubled allowing it to provide 100J, 527nm laser pulses with a nanosecond contrast of $\sim 10^{14}$.

### References

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