Design and Performance of a 100 J Pump Laser Front-end for Use in a 10 Hz PW-class Amplifier

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Abstract

We present the front-end system for a diode-pumped solid state laser, optimised specifically for pumping a 10 Hz PW-class amplifier. The front-end provides 150 mJ, 1-15 ns pulses and has spatial and temporal pulse-shaping capabilities..

Introduction

Diode-pumped solid state lasers (DPSSL) are a better alternative to flashlamps for pumping amplifiers of PW-class lasers, as they are capable of providing much higher repetition rates and have longer lifetimes. This method is applied in the upcoming Extreme Photonics Applications Centre (EPAC), a new national facility at the STFC Rutherford Appleton Laboratory (RAL), where a Titanium-doped Sapphire (Ti:Sa) femtosecond amplifier will be pumped by a 120 J DPSSL. EPAC will house a PW-class 10 Hz laser, feeding radiation-shielded experimental areas, which will provide academia and industry with a range of applications from laser plasma acceleration to imaging with secondary sources of radiation.

Requirements

EPAC's main laser amplifier (see schematic in Fig. 1) uses Ti:Sa for its gain medium. Ti:Sa can be pumped by light of 515 nm wavelength, which can be generated by frequency-doubling 1030 nm light that is produced by Ytterbium-doped YAG (Yb:YAG) amplifiers. The pump laser is based on DiPOLE technology [1], a high energy, high repetition rate nanosecond laser amplifier architecture developed at the CLF. DiPOLE is based on diode-pumped, cryogenically-cooled multi-slab Yb:YAG. Recent DiPOLE performance highlights include the amplification of 10 ns pulses to 100 J at 10 Hz and of 15 ns pulses to 150 J at 1 Hz [2, 3]. The DiPOLE pump for EPAC (Fig. 2) is comprised of 3 main sections: the front-end, the 10 J cryogenic pre-amplifier and the 100 J cryogenic power amplifier. The EPAC pump laser must provide 90 J in 15 ns pulses at 515 nm wavelength. This means that the EPAC pump must amplify 1030 nm pulses to at least 120 J to allow for losses in the frequency-doubling process.

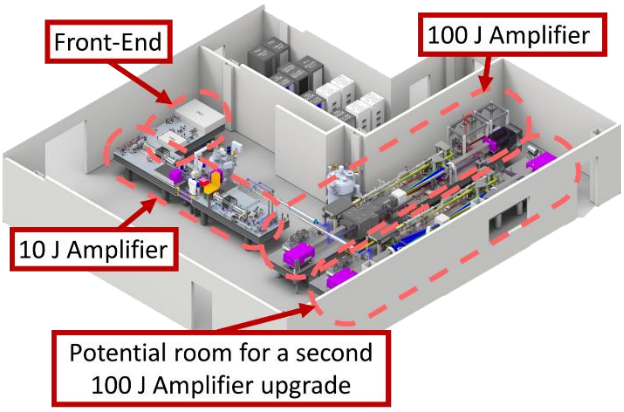


Fig. 2: An image of the EPAC Pump laser model, highlighting its main sections

For the EPAC pump to generate pulse energies of 120 J, the front-end must provide at least 60 mJ. However, there are plans to commission a second 100 J amplifier enabling the Ti:Sa amplifier to be pumped with two beams simultaneously. This will relax the requirements for the output energy for each 100 J section and increase the optics lifetime in the 100J sections due to a lower operating fluence. Operating two 100J amplifiers will require a higher output from the 10 J amplifier, which will be split into two beams. For this reason, the front-end output needs to have the capability to deliver up to 150 mJ. The optimum beam shape for amplification is a square super-gaussian of order 10 and the beam is expanded to 22 mm x 22 mm to keep the fluence below 2 J/cm^2. The front-end must also have temporal pulse-shaping capacity to increase the efficiency of power extraction and frequency-doubling. Imperfections in the front-end will be propagated and amplified throughout the rest of the pump laser, therefore it is critical that the front-end of the laser is up to specification.

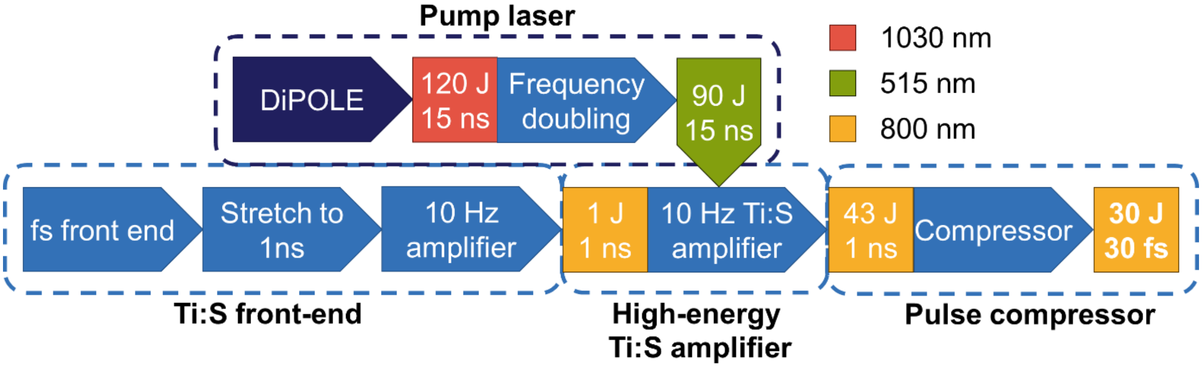


Fig. 1: A schematic of the EPAC laser system, detailing the required energy and pulse length for each stage

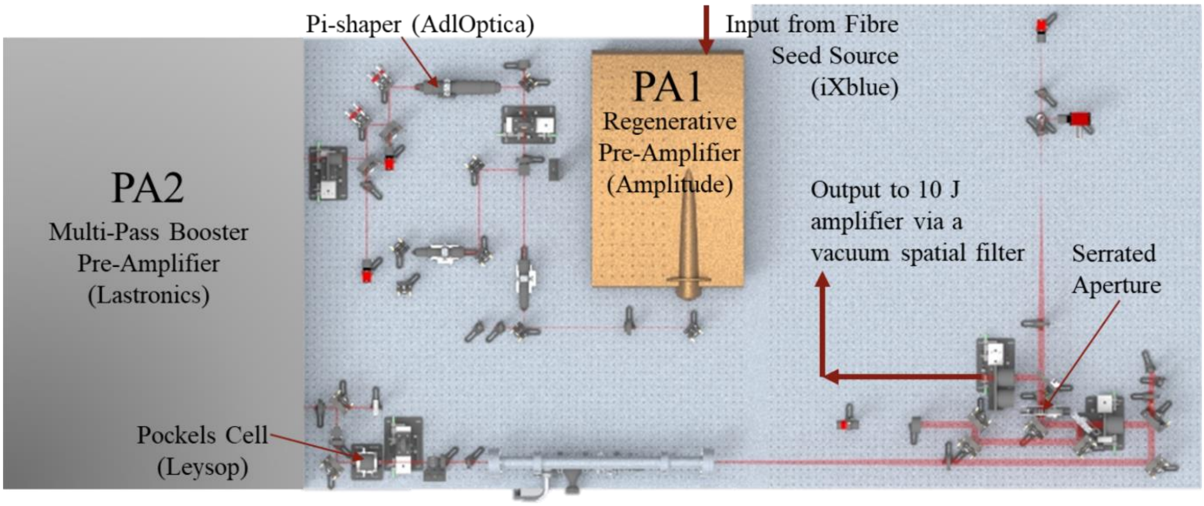


Fig. 3: Layout of the front end of the DPSSL pump laser for the Extreme Photonics Applications Centre

The pump laser front-end design

The front-end of the EPAC Pump Laser (Fig. 3) is currently in its build and commissioning phase and is due to be completed and characterised this summer. The final design is optimised for pumping the EPAC main amplifier and was based on lessons learnt from previous front-end builds, which include DiPOLE100 [4] for HiLASE and D100X for the European XFEL [5].

A fibre seed source (FSS) supplied by iXblue is the first component of the front-end. The FSS contains an acousto-optic modulator, which converts the continuous-wave output of its booster fibre amplifier into ~100 ns square pulses. It is followed by an electro-optic modulator controlled by an arbitrary waveform generator that allows precise control of the pulse shape in steps of 125 ps. This enables control of the pulse duration, ranging from 1 ns to 20 ns. The pulse shape is generated from either a data file or drawn by hand via the user-interface.

The FSS provides an output of 5 nJ, which is coupled through an optical fibre directly into a customised regenerative pre-amplifier (PA1) supplied by Amplitude. PA1 outputs a circular 1 mm 1/e^2 radius Gaussian beam of at least 1.5 mJ (and up to 3.5 mJ) at a 10 Hz repetition rate. The output of PA1 is expanded to 6 mm FWHM before passing through a pi-Shaper (supplied by AdlOptica), which converts it to a flat-top circular beam. This is input into the multi-pass booster pre-amplifier (PA2) - a custom-built system by Lastronics.

In previous designs, the beam would have been converted to a square super-gaussian before PA2 using a serrated aperture, however the sharp edges resulted in modulations on the beam profile after amplification by PA2. For this reason, PA2 now accepts the circular beam and uses a square pump beam profile to amplify a square area of the circular seed beam. This pre-shapes the beam spatially, reducing energy losses at the serrated aperture later on in the system. PA2 has capability to amplify the pulses up to a maximum of 150 mJ.

The output of PA2 propagates through a Pockels Cell (supplied by Leysop) for optical isolation and possibility of selecting a lower repetition rate, before being imaged onto a 22 mm x 22 mm FWHM serrated aperture. The beam is expanded to over-fill the aperture. This is followed by a 1:1 telescope with a pinhole to filter out the high spatial frequencies that contain information about the serrated features, such that a super-gaussian square beam profile is retained.

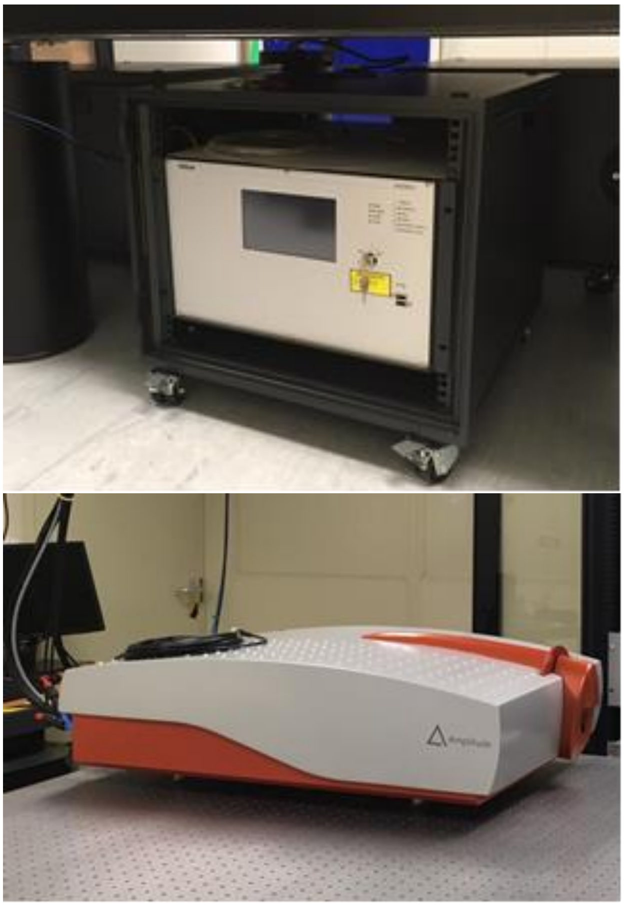


Fig. 4: iXblue ModBox fibre seed source in an under-table rack (top) and Amplitude's regenerative pre-amplifier installed on the optical table (bottom)

Results

To date, the FSS and PA1 (Fig. 4) have been fully commissioned and PA2 has been partially commissioned. The FSS has exceeded its energy requirement and is capable of providing a stable output averaging up to 11.5 nJ for 10 ns pulses (Fig.5). It is also capable of temporal pulse shaping, demonstrating a range of pulse lengths from 1 ns to 20 ns, as shown in the photodiode signal in Fig. 6.

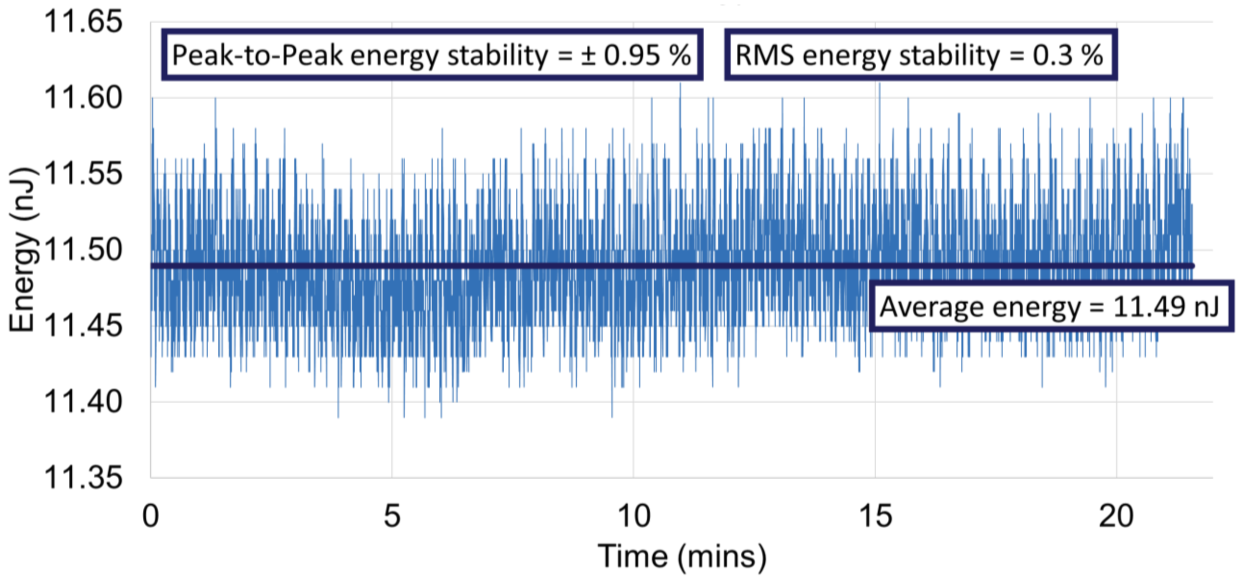


Fig. 5: The output energy and energy stability values of the iXblue ModBox fibre seed source operating at a repetition rate of 100 Hz, with pulse length of 10 ns

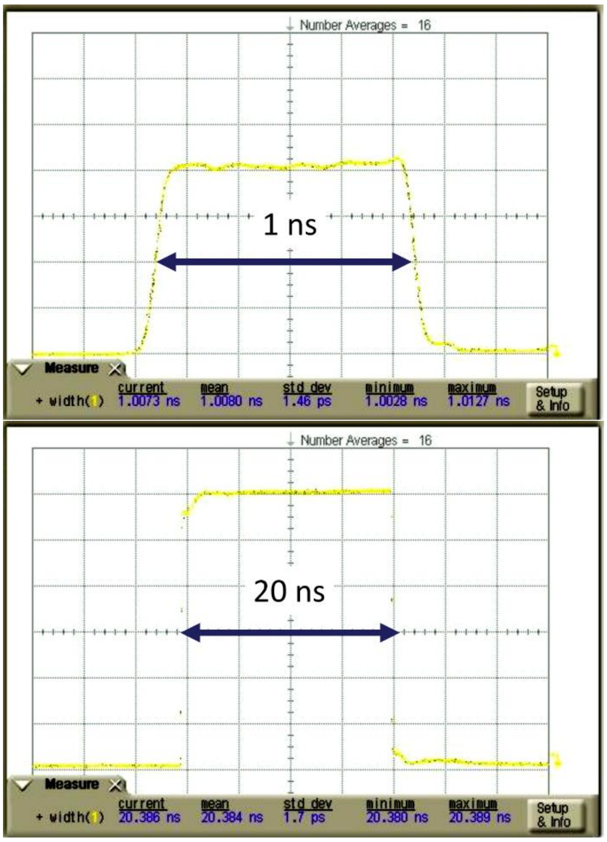


Fig. 6: A photodetector signal of the iXblue ModBox fibre seed source output, set to a square pulse of lengths of 1 ns (top) and 20 ns (bottom)

The FSS output is amplified by PA1 up to energies of 3.5 mJ at a 10 Hz repetition rate as shown in Fig. 7. The figure shows the energy output from PA2 over a period of ~20 hours. The energy averages 3.6 mJ, however there is a long-term energy drift that does not appear to reach equilibrium during operation. This drift, however, is slow and the RMS and peak-to-peak energy do not exceed 1.3% and ± 3% respectively over the 18 hour period. The cause of this drift is currently under investigation, but it is likely due to temperature instability in the laboratory. Fig. 8 shows the output beam profile with Gaussian 1/e2 radius of 1.3 mm, within the specified ± 0.5 mm tolerance of 1 mm.

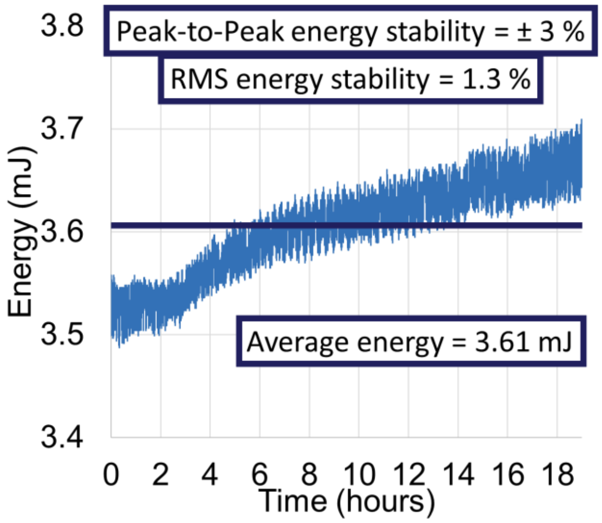
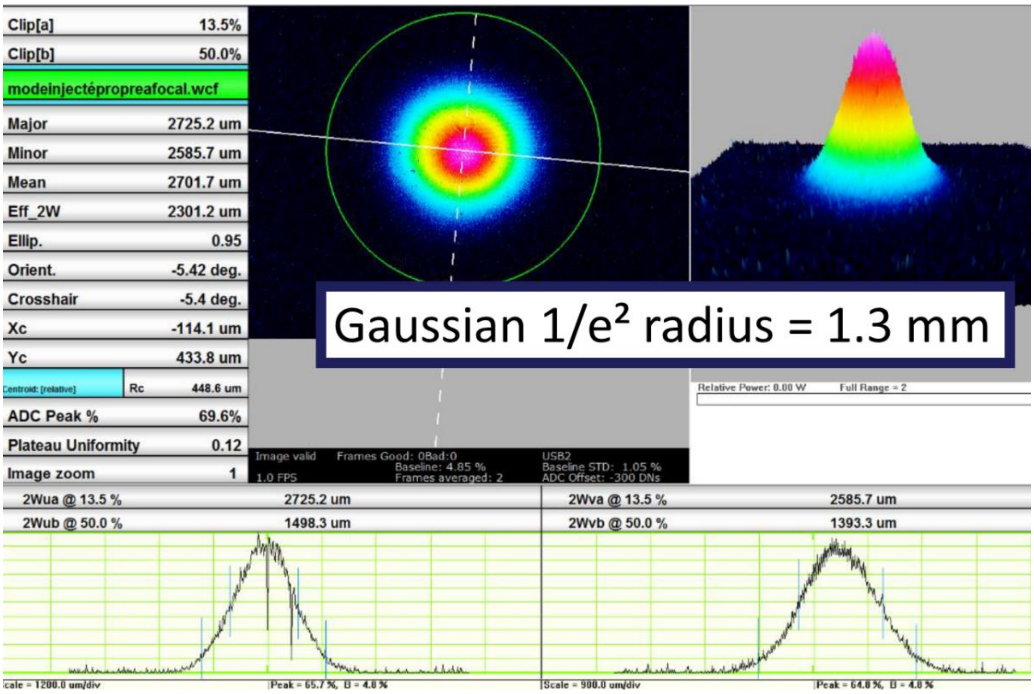


Fig. 7: The energy and energy stability of a 10 ns output from Amplitude's regenerative pre-amplifier, operating at a repetition rate of 10 Hz

PA2 has been delivered from Lastronics and installed at RAL (Fig. 9), however only partial commissioning was possible due to the current optics inside the amplifier having a coating with a lower than expected laser-induced damage threshold (LIDT). The optics will be replaced with a higher LIDT coating to allow the amplifier to reach its maximum energy. However, in the meantime it has been partially commissioned at a reduced energy of 15 mJ.

Conclusion

We have summarised the design of the front-end of a diode-pumped solid state laser, which will be used to pump a PW-class amplifier in the Extreme Photonics Applications Centre, STFC's new national research facility for academia and industry. The front-end will be capable of providing 1-15 ns pulses of up to 150 mJ and will have spatial and temporal pulse-shaping capabilities. The fibre seed source and regenerative pre-amplifier have both been commissioned and perform according to requirements. The multi-pass booster pre-amplifier has been delivered and installed and is awaiting final commissioning.



Clip[a]	13.5%
Clip[b]	50.0%
modeinjectépropreafocal.wcf	
Major	2725.2 um
Minor	2585.7 um
Mean	2701.7 um
Eff_2W	2301.2 um
Ellip.	0.95
Orient.	-5.42 deg.
Crosshair	-5.4 deg.
Xc	-114.1 um
Yc	433.8 um
Centroid: [relative] Rc	448.6 um
ADC Peak %	69.6%
Plateau Uniformity	0.12
Image zoom	1

Gaussian 1/e² radius = 1.3 mm

Relative Power: 0.00 W Full Range = 2

Image valid Frames Good: 0Bad:0 USB2
Baseline: 4.85 % Baseline STD: 1.05 %
1.0 FPS Frames averaged: 2 ADC Offset: -300 DNs

2Wua @ 13.5 %	2725.2 um	2Wva @ 13.5 %	2585.7 um
2Wub @ 50.0 %	1498.3 um	2Wvb @ 50.0 %	1393.3 um

Fig. 8: The output beam profile and dimensions of Amplitude's regenerative pre-amplifier

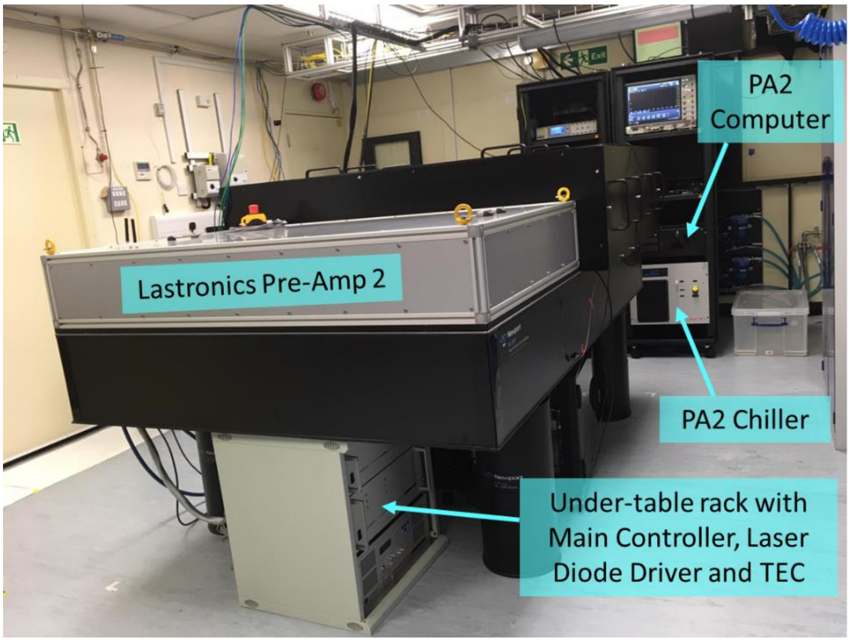


Fig. 9: Lastronics' booster pre-amplifier (PA2) and external devices installed at STFC's Rutherford Appleton Laboratory

References

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