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Abstract: Applications using high energy 'petawatt-class' laser drivers operating at repetition rates beyond 0.01 Hz are only now being envisioned. The Mercury laser system is designed to operate at 100 J/pulse at 10 Hz. We investigate the potential of configuring the Mercury laser to produce a rep-rated, 'petawatt-class' source.

The Mercury laser is a prototype of a high energy, high repetition rate source (100 J, 10 Hz). The design of the Mercury laser is based on the ability to scale in energy through scaling in aperture. Mercury is one of several 100 J, high repetition rate (10 Hz) lasers sources currently under development (HALNA, LUCIA, POLARIS). We examine the possibility of using Mercury as a pump source for a high irradiance 'petawatt-class' source: either as a pump laser for an average power Ti:Sapphire laser, or as a pump laser for OPCPA based on $YCa_4O(BO_3)_3$ (YCOB), ideally producing a source approaching 30 J /30 fs /10 Hz – a high repetition rate petawatt. A comparison of the two systems with nominal configurations and efficiencies is shown in Table 1.

Ti:Sapphire system

The Mercury laser can be frequency doubled and used to pump a Ti:Sapphire laser (see Table 1). Recently, 227 W of 523.5 nm second harmonic generation was demonstrated on Mercury (10 Hz, 22.7 J 527 nm, 14 ns, η=50%). Modeling suggests that by increasing irradiance on the YCOB doubling crystal while maintaining the same pulse width will allow the conversion efficiency to approach 80%. With transport and efficiency losses the available pump energy should be approximately 39.6 J (72%) of the current 55 J pump. Approximately 1 J of chirped pulse input is required to extract 19.8 J with a center wavelength of 800 nm. High bandwidth multi-layer dielectric gratings will give a compression efficiency approaching 60%, yielding a 0.4 PW pulse (12 J, 30 fs, 10 Hz). The Ti:Sapphire would have an approximate 200 W thermal load, and would be gas cooled in a Brewster-angled 4-pass amplifier. The 12 cm dimension of the Ti:Sapphire is parallel to the low gain, z-crystalline axis. The risk issues with such an approach are (1) average power loading of the Ti:Sapphire and (2) ASE suppression of the amplifier. A schematic is shown in Fig. 1.

OPCPA using YCOB

OPCPA has a different set of risk issues and performance efficiencies. OPCPA is nominally an elastic process resulting in minimal heat deposition in the gain crystal. As such, side cooling of the YCOB crystal using water is sufficient. However, the pump pulse must have sufficient irradiance for energy extraction. Gain in OPCPA only occurs during the overlap of the pump pulse and input signal. The limit on pump pulse duration is potential optical damage to the laser source. Assuming a stretched seed limit of 3.3 ns and a pump pulse of 10 ns duration, three separate stages are required to efficiently extract energy from the pump pulse and transfer it to the signal. YCOB OPCPA nominally has large amplification bandwidth near degeneracy. The 1047 nm chirped signal must have approximately 1.7 times the bandwidth of the equivalent 800 nm chirped pulse to achieve the same compressed pulse width (30 fs). An idler with opposite odd order chirp will be generated during each stage of OPA amplification with ½ of the extracted energy. Again starting with 55 J of 1047 nm pump we consider an overall 72% conversion efficiency including transport losses or 39.6 J of 527 nm pump. We set the 3 stage OPA extraction efficiency to 40%. (80% pump depletion with 50% of the energy extracted as signal). The compressor uses a high bandwidth near infrared dielectric grating with a potential overall efficiency of 65% (slightly higher efficiency than the 800 nm compressor). This leads to a potential availability of 10 J with a center wavelength of 1047 nm compressed to 30 fs (0.33 PW). The primary risk issues for OPCPA are (1) a broadband custom amplifier and (2) high efficiency, high damage threshold dichroic mirrors. The custom short pulse seed source for 1047 nm OPCPA has already been demonstrated. The multi-layer high bandwidth dielectric grating at 1047 nm will potentially be of slightly higher efficiency than at 800 nm. A schematic of the OPCPA is shown in Figure 2.

A significant difference between Ti:Sapphire and OPCPA is that 50% of the OPA output is residual idler and 20% is undepleted pump. Potentially, a long idler pulse could be used as a secondary heating beam or partially compressed as a backlighter beam. The complexity between the 4-pass Ti:Sapphire and the 3-stage OPCPA is nearly equivalent. Both sources require a second pump source to produce approximately a 1-J seed pulse. The largest equipment difference concerns the heat removal mechanism for the Ti:Sapphire system.

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Table 1 – Estimated configuration and efficiencies of using the Mercury laser system to pump either Ti:Sapphire of OPCPA

Gain Media	Ti:Sapphire	YCOB
Stretched pulse length	1.8 ns	3.3 ns
Oscillator	Ti:Sapphire 30 fs 800 nm	Fiber laser 30 fs 1047 nm
Bandwidth (FWHM)	30 nm	50 nm
Compressor	Multi-layer dielectric	Multi-layer dielectric
Cooling	Gas cooling (non-cryogenic)	Water cooled (side)
ASE suppression	Bonded ASE absorber	1^{o} Wedged YCOB crystal
Aperture	12 x 6 cm (Brewster cut)	5.5 x 3.5 cm
Thickness	(2 Ti:Sapphire crystals) * 1 cm	(3 YCOB crystals) * 0.5cm
Configuration	4-pass	Single pass/3 gain stages
2ω Conversion Efficiency	80%	80%
Pump pulse length	15 ns	10 ns
Pump depletion	99% (2-pass absorbed)	80% (pump depletion)
Energy extraction	50% amplified signal	50% signal / 50% idler
Stretched pulse energy	19.8 J	15.8 J
Compressor Efficiency	60%	65%
30 fs pulse energy	12 J	10 J

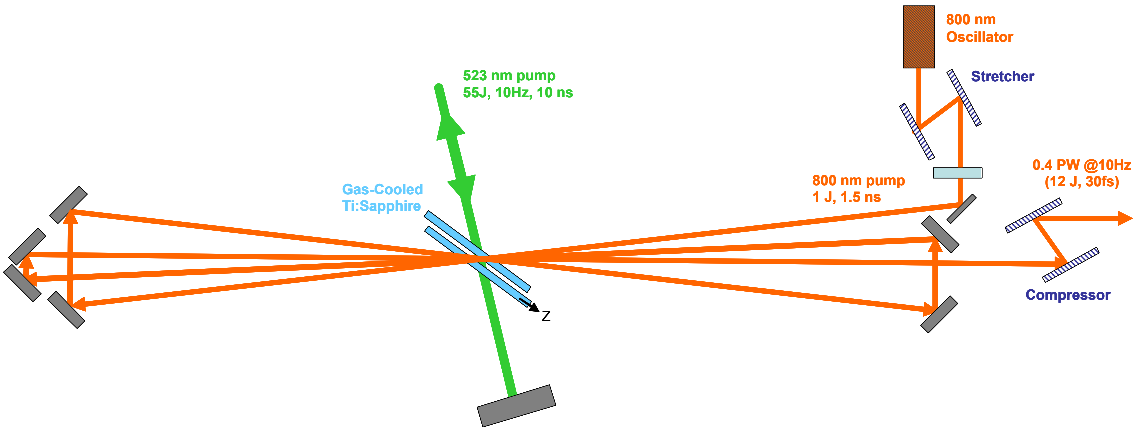

Fig. 1 When used to pump a Ti:Sapphire source – the Mercury laser is configured to deliver 55 J, 10 Hz, 12 ns. The compressed signal energy is expected to be approximately 12 J at 30 fs (30 nm bandwidth).

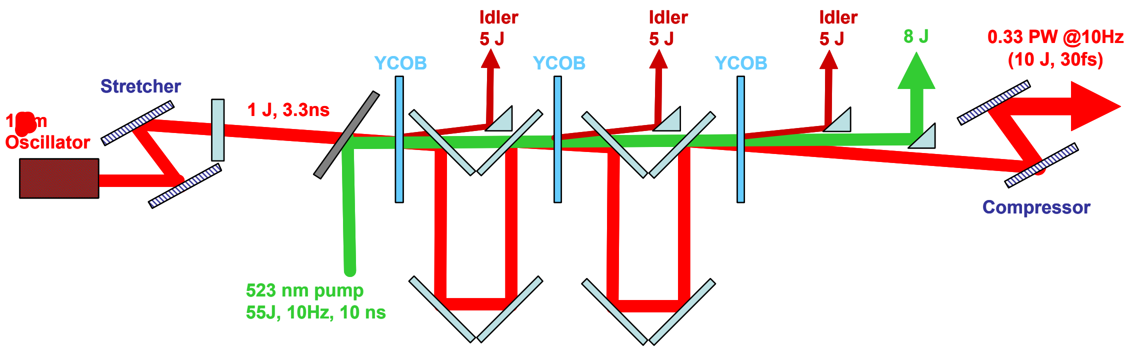

Fig. 2. When used as a pump source for OPCPA the signal is stretched to 3.3 ns and the Mercury laser pump source is configured as a 55 J, 10 Hz, 10 ns pump. Three YCOB OPCPA gain stages with the subsequent delay of the signal allows the generation of a 10 J, 30 fs compressed pulse. Approximately 10 J of pump and 15 J of idler (10 Hz, 10 ns) are available for alternative use if needed.