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Frequency Conversion Activation on the Mercury Laser

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Abstract: High efficiency frequency conversion while operating at average power is critical for the Mercury laser. We will demonstrate average power frequency conversion of face-cooled DKDP and YCOB crystals using a sapphire heat spreader approach.

OCIS codes: (140.3580) Solid State Lasers; (190.4400) Nonlinear Optics

1. Introduction

Diode-pumped solid-state lasers are one of four driver technologies being considered for inertial fusion energy power production. Each driver development program, including solid-state lasers, heavy ions, Z-Pinch, and KrF lasers is currently focused on demonstrating several proof-of-principal design concepts. For solid-state lasers, high efficiency frequency doubling and/or tripling of the laser at average power is a critical design requirement. As the Mercury laser undergoes activation, several key technologies including high power laser diodes, crystals, gas cooling, and high average power frequency conversion will be tested within an architecture that is modular and scalable to multi-kilojoule apertures with minimal beam line reengineering [1].

Mercury is currently in the process of system activation which, broadly speaking, takes place in two stages. The first stage will have an anticipated delivery of 50 J with a pulse width of 10 ns. The second stage will deliver 100 J with a pulse width of 3 ns. With a repetition rate of 10 Hz the system average power will be 500 W and 1000 W respectively. As previously discussed by Eimerl [2], even though the thermal loading on the nonlinear optical crystals is typically 100 times lower than the thermal loading on the gain medium, the need to maintain the phase velocities of the infrared and second harmonic light within in the crystal to a small fraction of a wave is complicated by the relatively large value of the thermal change in the refractive indices. Even modest temperature rises of a few degrees can result in significantly reduced conversion efficiencies. Currently we are implementing a two-tier strategy for technology development: a low-risk baseline and a moderate risk-high payoff. For the cooling technology, a more complex system of gas cooling with high-speed helium has already been demonstrated for the heat removal in the gain medium of Mercury. Our 'baseline' frequency conversion cooling technology employs a sapphire heat spreader concept to allow for more flexibility in crystal thickness and crystal geometries for the initial materials characterization. For the frequency conversion crystal we will test two materials: DKDP whose growth to 40 cm apertures has already been demonstrated by the National Ignition Facility and YCOB, a crystal with very favorable thermo-optic characteristics compared to DKDP.

2. Cooling Technology

Currently, all 7 Yb:SFAP slabs are separated by 1 mm helium flow channels in which the total heat removed from each crystal is on the order of 35 W with a thermal loading of approximately 2 W/cm^2. This technique has as a benefit over other cooling strategies in that scaling to multi-kilowatt apertures can be achieved. In contrast to the gain medium, nonlinear optical processes are elastic processes, with the thermal load arising strictly from residual linear and nonlinear absorption in the crystal. Typical absorption for transparent crystals is on the order of 0.0025/cm, leading to an average power loading of 0.01 W/cm^2 on the Mercury 4.5 cm x 7.5 cm aperture beamline. These extremely modest thermal loads lead to temperature gradients of 2-3 degrees C in the nonlinear optical crystal. Nevertheless, this gradient can lead to thermal dephasing (reduced conversion efficiency) or thermal fracture. The small amount of heat that needs to be removed by the cooling system is relatively modest compared to the gain medium cooling system, requiring a significantly lower velocity of the helium gas. An adaptation of the current gas cooling technology for frequency conversion would require modifications to introduce angular tuning capability.

Frequency conversion crystals require pointing adjustability. A typical pointing specification for critically phasematched crystals is 250 μrad. The difficulty is that the typical vendor orientation capability is on order of 17,000 μrad (+/- 0.5 degrees) thereby requiring the need to individually rotate the crystals with respect to the beam propagation direction.

Although the gas-cooling technology has the advantage in that it is well developed, we will require more flexibility in our initial experiments with the crystal thickness and conversion geometries. Therefore, another technology, recently utilized in an externally doubled high average power laser [3], will be commissioned. It relies on a highly thermally conductive and transparent substrate for cooling. We have chosen sapphire since it is widely used as an optical window substrate and has a relatively high thermal conductivity (3 W/cm/K) The frequency conversion cooler concept currently combines close coupling of the crystal to the sapphire plate and has been shown to scale to the required 20 cm aperture. The gas cooling and the heat spreader concepts are schematically shown in Figure 1.

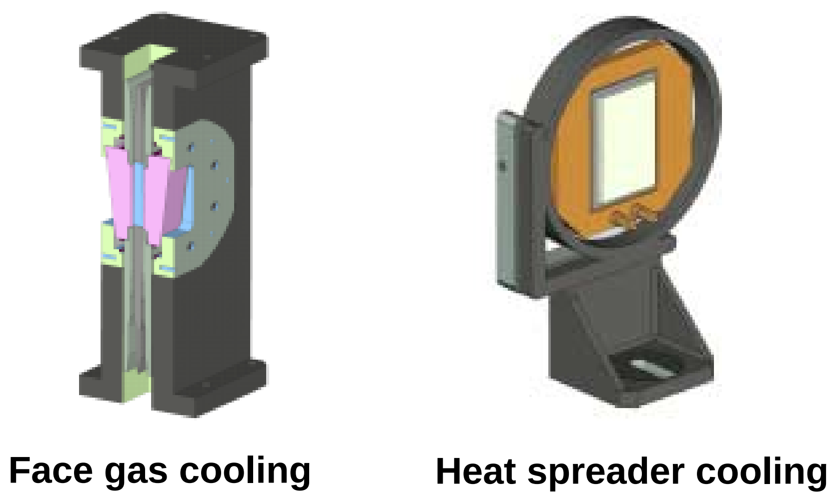

Figure 1. Helium gas cooling and heat spreader cooling are currently under development to manage the modest thermal loads present in the frequency conversion crystals.

3. Frequency Conversion Crystal

We choose our frequency conversion crystals based on the ability to perform second and third harmonic generation of 1047 nm with intrinsically low absorption. Of the commercially available crystals (DKDP, LBO, KTP, BBO, GdCOB, YCOB) DKDP and YCOB are chosen as the “baseline” and “advanced-concept” converter crystals, respectively. DKDP is a crystal with over 30 years of development effort with well-characterized material parameters such that the thermo-optical performance characteristics of DKDP can be reliably modeled. However, DKDP exhibits a relatively low fracture strength (less than 10 C), requiring the use of multiple plates to minimize thermal gradients. Recently, the nonlinear optical coefficients of two new oxoborates have been characterized [4,5]. We are beginning to supplement the knowledge regarding the long-term reliability of these crystals for use as harmonic generators. YCOB has a significantly larger thermal acceptance and fracture strength than DKDP. We are currently implementing lifetime tests on second harmonic generation in the oxoborates to ensure the suitability of these crystals for long-term operation. Figure 2 shows the recent YCOB crystal from which our reliability test plates will be obtained.

Figure 2. Slabs cut from this YCOB crystal will be utilized for lifetime measurements.

4. Thermal performance

Thermal management by gas face-cooling has already shown to be scaleable to the 20-30 cm aperture for thermally loaded Yb:SFAP. Potential limitations include the gas temperature rise between the time the gas first picks up heat from the lasing medium/nonlinear optical crystal and as it exits past the crystal. The modest heat loading from the frequency converter does not impose any such aperture constraints. Due to the small amount of heat that needs to be removed from the frequency conversion crystals, this transverse thermal gradient (transverse to the beam propagation direction) is less than 1/10th the longitudinal gradient (gradient across the thickness of the crystal) and has minor impact on the conversion efficiency. In a scaled configuration the side-cooled sapphire has limitations due to the need for heat transport across the optic before it is transferred to the cooling medium. Nevertheless, thermal modeling of the system indicates high conversion efficiency can be obtained, even with relatively large (20 cm) apertures.

5. Summary

We are implementing a two-tier strategy in activating frequency conversion system for the Mercury laser. We have chosen for our baseline technology DKDP for the doubler and tripler. As a moderate risk – high payoff strategy we are characterizing the thermal performance of a face cooled YCOB frequency conversion crystal. Both materials will be tested with the sapphire heat spreader for maximum flexibility for our experimental campaign.

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