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Abstract: Initial measurements are reported for the Mercury laser system, a scalable driver for rep-rated high energy density physics research. The performance goals include 10% electrical efficiency at 10 Hz and 100 J with a 2-10 ns pulse length. This laser is an angularly multiplexed 4-pass gas-cooled amplifier system based on image relaying to minimize wavefront distortion and optical damage risk at the 10 Hz operating point. The efficiency requirements are fulfilled using diode laser pumping of ytterbium doped strontium fluorapatite crystals.

OCIS codes: (140.3580) Solid State Lasers; (140.3280) Laser Amplifiers

I. Introduction

The Mercury laser system design is based on achieving a scalable architecture for inertial fusion as described in a theoretical paper by Orth and Payne[1] that examines the necessary technological and economic requirements for an inertial fusion power plant to be viable. To achieve the goals of 10 % electrical efficiencies and 10 Hertz operation, three major technologies had to be developed to enhance the current technology in high power laser fusion drivers: large-scale high performance diode lasers, high speed gas cooling of the gain media, and $Yb^{3+}:Sr_5(PO_4)_3F$ (Yb:S-FAP) crystal amplifiers.

II. Architecture

The Mercury laser system has been designed to minimize damage and create a scalable architecture. The diode array packaging drove the design in the pump delivery to accommodate the 55º angle of pump light emission. The “backplane’ was split into two elements to allow for the passage of the 1047 nm extraction beam through the middle as shown in Fig. 1. This design minimizes the number of optics in the beam line thereby lowering the overall B-integral of the laser extraction, while maximizing the pump transport efficiency at the current diode power and divergence. The arrangement of the diode array “tiles” on the backplane delivers the light to the amplifier by means of a hollow lens duct and optical homogenizer whose lengths were optimized for transport efficiency and homogeneity at the amplifiers. Ray tracing was used to find the optimal configuration of the tiles with the result being an arrangement of 7 tiles wide by 5 tiles high in each half of the split backplane providing the optimal transport efficiency and homogeneity of 78% at the first amplifier slab. Efficient extraction of this stored energy is accomplished using a 4-pass double amplifier system which can amplify a 10 mJ narrowband input pulse to the full 100 J output. In a 3 x 5 cm aperture, the output fluence is greater than 6.6 J/cm2, which is more than twice the saturation fluence of S-FAP (3.0 J/cm^2[2]) allowing efficient extraction of the energy.

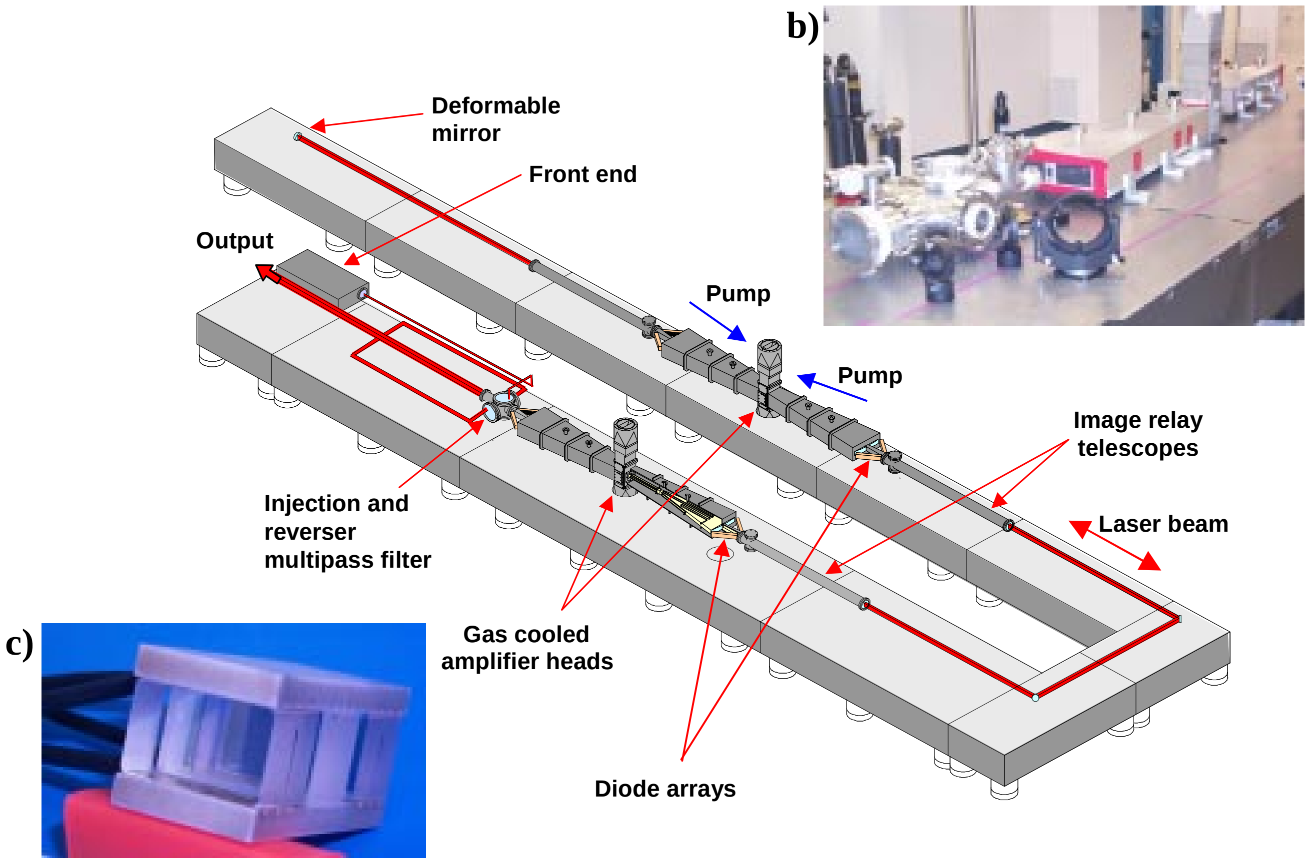
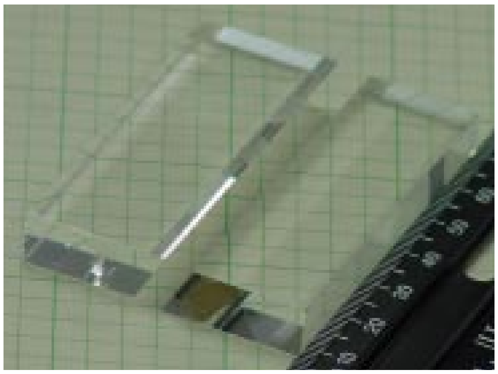


Fig. 1. The new architecture design for the Mercury laser shows a split backplane design employing V-BASIS diode arrays, and an imaging lens position near to amplifiers to avoid high frequency beam modulation that could cause laser damage. The photo shows the actual hardware in the lab.

The four pass configuration is accomplished through angular multiplexing image relay system, which eliminates the need for a Pockel's cell for switching the pulse out (not possible at 10 Hz with current technology). Laser damage and nonlinear beam distortion are minimized by placing the telescope lenses close to the amplifiers, where the image plane is located, in order to minimize incident beam modulation caused by diffraction of the quasi-flat-top extraction beam. This is especially important given the thermal and static phase distortions of the S-FAP amplifiers at this relatively high repetition rate. Likewise, the output telescope undergoes 2X magnification to lower the fluence of the beam at the output lens where the diffracted beam modulation is large. Extensive ghost and amplified spontaneous emission analysis was performed, validating the current architecture and setting constraints on optical quality, surface reflectivity, wedges, and the extinction required of a Pockel's cell in the reverser (an image relay beam path which turns the beam and re-injects for the 3 and 4^{th} passes through the system). Even though this Pockel's cell sees relatively low energy pulses (< 0.5 J/cm2), extensive development was required since thermal birefringence severely limits the extinction of the cell. This problem is overcome by employing a dual crystal design where the two crystals are oriented such that their thermal birefringence cancels. The average power Pockel's cell shown in Fig. 2 has an aperture of 1.5 x 2.5 cm, and is capable of extintion of 200:1 at an incident power of 100 W. The ytterbium doped S-FAP slabs will be slightly wedged and will have 1-2 degree canted edges to help suppress parasitics, etalon effects in the transmitted wavefront, and nonlinear losses such as stimulated Brillouin and stimulated Raman scattering.

III. Crystal Growth

Recent breakthroughs have been made in the growth of the ytterbium doped strontium fluorapatite (S-FAP) crystals. Current growths have produced crystals free of major defects (Fig. 2a and 2b) at a size that would allow 1/2 scale slabs to be optically bonded together to achieve full-scale amplifier slabs[2]. These Czochralski grown crystals have been plagued by a wide variety of defects including: cracking, cloudiness, bubble core defects, and grain boundaries or slip dislocations[3].

a) 

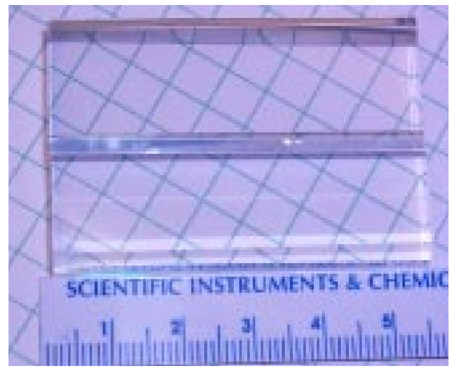
b) 

Fig. 2 a. Sub-slab components from a Litton-Airtron boule to be fabricated into a full size Mercury amplifier slab, b. Sub-slab components from a Livermore boule to be fabricated into a nearly full size slab.

Recently, two new defects were discovered: anomalous absorption and crystal inclusions or asteration, which are both related to the ytterbium dopant. Anomalous absorption is caused by ytterbium doping into an alternate site in the lattice, which produces a spectrum similar to ytterbium doped phosphate glass. The alternate site is thought to be the A_I site, which is nine coordinate oxygen polyhedron, associated with the PO_4 groups. This defect appears to be dependant upon the orientation of the seed from which the boule grows as well as the thermal gradient the growing boule experiences. Changes in these growth parameters affect the growth facet interface as well as the conduction of ions along channels in the crystal lattice. The crystal inclusions are caused by the incorporation or growth of micro crystals almost entirely composed of ytterbium oxide into the outer edge of the boule. These defects seem to be mitigated by careful choice of thermal gradients during growth and an atmosphere surrounding the crucible that minimizes solid particulates of evaporated components, such as SrF_2, falling back into the melt.

IV. Diode Lasers

A 23-bar monolithic diode laser package was developed for the Mercury Laser, referred to as Bars And Springs In Slots (V-BASIS)[3], where microlensed diodes are mounted to a V-groove etched silicon wafer which is then bonded to a Molybdenum block for structural support, and then mounted to a water cooled copper backplane (see Fig. 3). The electrical feed-throughs and coolant channels are located through the backplane itself to maximize the diode tile packing density and the overall brightness of the array.

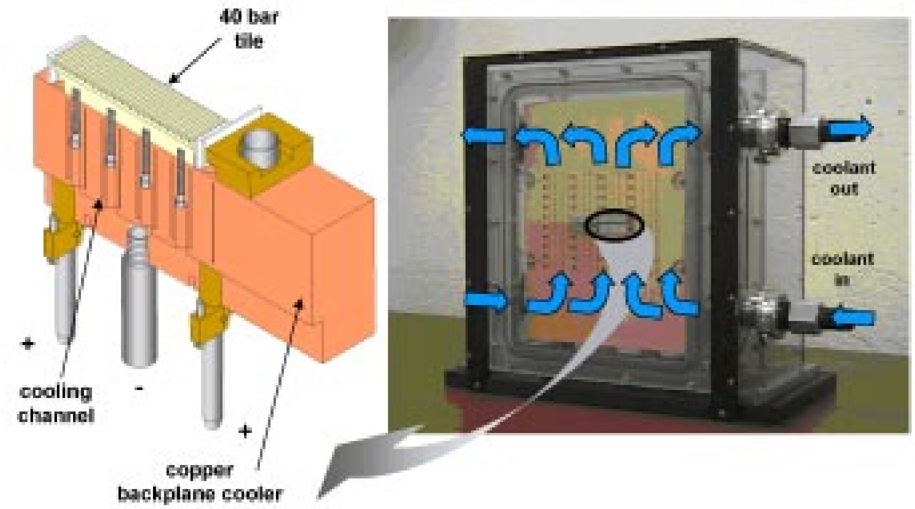


Fig. 3 The V-BASIS diode backplane assembly showing the tiles, which hold 23 diode bars, are modular, and can be replaced individually.

The V-groove architecture balances the trade off between two competing problems for high power diode arrays for inertial fusion energy (IFE). High peak irradiance is desirable which leads to compact diode spacing. However, the diode spacing must be kept to some minimum spacing to accommodate the 1 mm cavity length of the bars. The package must be consistent with our low duty factor (1%) and the need for low cost packaging (6624 diode bars in the system). The V-Basis design, which balances both of these requirements and allows for compact mounting onto the copper backplane cooler. One full back plane delivers up to 640 kW of peak power in a 750 μs pulse with a divergence of 1° in the fast axis, 10° in the slow, and a 6 nm bandwidth. Recent experiments based on Coherent bars show these diodes can operate at a peak power up to 150 W per bar at an electrical efficiency of at least 45% per bar. Experimental life tests of a 23 bar V-BASIS tiles at 10 Hz / 115 W yields a lifetime of greater than 10^8 shots.

V. Activation

Initial activation included investigation of several key components in the system. Support equipment was activated and the resulting vibrations measured. After isolation of the gas recirculator via bellows, the vibration at the table dropped to acceptable levels for laser system stability and beam pointing. The amplifier slabs are mounted into aerodynamic vanes[4] that accelerate the gas to produce turbulent flow across the amplifier slabs for maximum cooling, and then decelerate the gas with a minimum of vibration (fig. 4a). The pressure balance across the 8 gas channels in an amplifier head was found to be an average of 0.775 psi pressure drop with maximum variations of +0.056 and –0.052 psi, which is adequate to preclude formation of wake disturbances as the flows merge at the trailing edge of the vane. Thermal modeling of the pump delivery shows that with gas cooling, the only major wavefront distortion is tilt due to heating of the gas as it traverses the amplifier. These results were confirmed experimentally by measuring the differential wavefront distortion of a gas-cooled amplifier head loaded with surrogate Nd:glass slabs and found to be less than λ/16 (fig. 4b).

Gain experiments were conducted on the system by operating a partial diode array at 890 nm to allow efficient wing pumping of Nd:glass surrogate slabs. The small signal gain of an amplifier head as well as the pump uniformity can be seen in Fig. 4c. Only ¼ of the backplane was active for these experiments, which accounts for the asymmetry in the gain. The small signal gain was sampled at various points across the 3 x 5 cm aperture using an attenuated Nd:YLF laser at 1053 nm to match the gain peak in Nd:glass. An energetics model of the system agrees with the measured small signal gain.

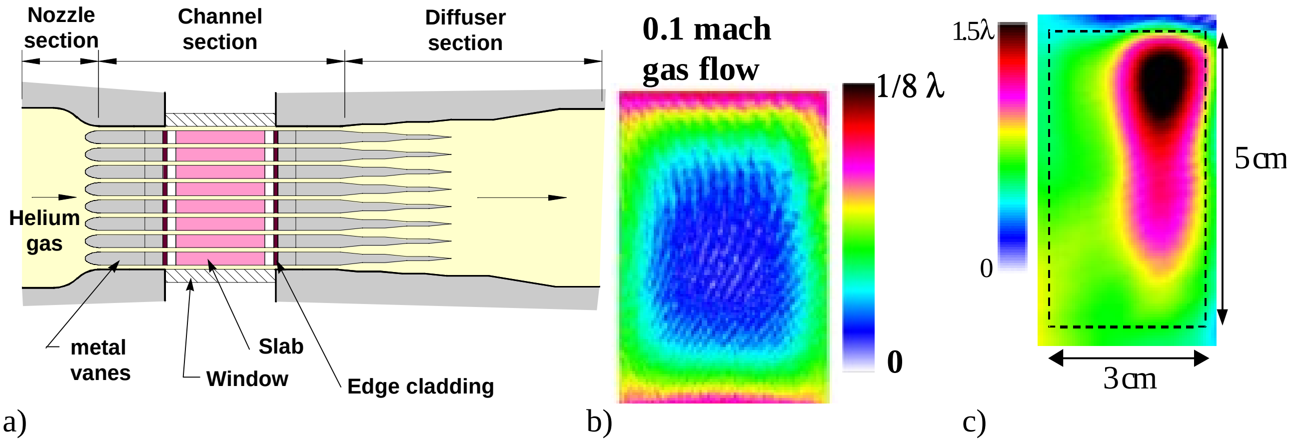


Fig. 4 a. A side view of the gas-cooled head design, b. Single pass differential wavefront error of < l/16 for gas cooling at 0.1 Mach flow of a seven slab amplifier, c. Only one quadrant was pumped with 400 diode bars operating at 3 Hz, 750 ms, 100 amperes. The extraction beam footprint is depicted by the dashed line.

Currently 80 23-bar tiles have been fabricated and assembled into a full backplane. Diode laser bars for the full Mercury system have been ordered from Coherent, Inc., with additional tile fabrication to begin in March. Using surrogate Nd:glass slabs, near term experiments will entail full aperture extraction including gain uniformity and wavefront distortion measurements. These experiments will be used to validate beam propagation codes as well as the integrity of the architecture, allowing one final round of fine tuning before the full system is assembled. These experiments are crucial to estabilishing tolerance limits on hardware and beam alignment of this brand new architecture. Fabrication of the first Yb:S-FAP slab is anticipated by June, 2001.

We would like to thank Mark Emanuel and Jay Skidmore for their work developing the laser diodes, and C.D. Orth for performing propagation analysis for a previous laser architecture. This article is dedicated to the memory of Howard Powell for his unwavering support of the Mercury Laser. This work was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

VI. References

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