Scalable Diode-Pumped Solid State Laser Architecture for Inertial Fusion Energy

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A study of diode-pumped solid state lasers for fusion energy is presented, including performance of a subscale laser oscillator and amplifier, radiation-hardness of the final optic, and a system-level modeling exercise.
Flashlamp-pumped Nd:glass solid state lasers have served as the main driver by which the physics of inertial confinement fusion has been studied. As a consequence of much progress in this area, there now exists the belief that a megajoule-scale Nd:glass laser will drive the fusion target to ignition. In this paper, we discuss how flashlamp-pumped Nd:glass solid state technology can be parlayed into advanced architectures based on diode-pumped solid state lasers (DPSSLs), and thereby provide a means for devising an efficient (~10%), high repetition-rate (~10 Hz) system for inertial fusion energy (IFE).

The proposed laser architecture is illustrated in Fig. 1, where it is seen that diode arrays are arranged to longitudinally-pump 11 slabs of the gain medium. The gain medium is known as Yb:S-FAP, a 1.047 μm laser material judged to be near optimal for IFE. The Yb:S-FAP crystals are to be cooled by flowing helium gas across the optical aperture. The laser is envisioned to operate as a multipass amplifier, utilizing a polarizer/Pockels cell pair. The beam is converted to the third harmonic at 0.349 μm.
and focused onto the fusion target. The last optic which the laser beam traverses must be able to survive the flux of ionizing radiation emanating from the target.

We have pursued an experimental program aimed at examining the main technical issues confronting the DPSSL. Toward this end we have constructed a small subscale Yb:S-FAP DPSSL amplifier and oscillator, and have verified that the gain (Fig. 2a) and output power (Fig. 2b) are consistent with our expectations. The experiments of Figs. 1 and 2 entail the use of a 3 kW laser diode array operating at 900 nm with 1 msec pulses, which is concentrated down with a lens duct to >10 kW/cm² at the Yb:S-FAP gain medium.

IFE schemes employing lasers depend on the existence of a final optic that is survivable in the neutron/γ-ray environment near the fusion chamber. We have developed a final optic concept to satisfy the IFE objectives, where fused silica is held at an elevated temperature (~400°C) in order to rapidly anneal out the defects and color centers. The result of room temperature n⁰/γ-ray irradiation of Corning 7980 fused silica appears in Fig. 3, where it is seen that there is little absorption at the laser wavelength of 349 nm.

We have developed an extensive computer code to model the cost-of-electricity (COE) for IFE power plants, by incorporating all of the essential laser physics and costing, and have calculated a COE of 8.6¢/kW · hr. One of the crucial issues confronting DPSSLs for IFE involves the ultimate cost of the laser diodes 20–30 years hence in a fusion economy. By our estimates, a sustained market demanding only several MW of diode power per year would lead to costs on the order of $1/watt. It is our belief, based on detailed cost center analysis, that a GW-level market would yield a diode price of $0.07/watt (7¢/watt).

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Figure captions

Fig. 1. Schematic representation of diode-pumped solid state laser driver for inertial fusion energy.

Fig. 2. Amplifier gain (a) and long-pulse oscillator efficiency (b) for a diode-pumped Yb:S-FAP laser.

Fig. 3. Absorption spectra of fused silica appearing after n⁰/γ-ray irradiation.
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