SEO Diode-Pumped Laser Technology

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Schwartz Electro-Optics (SEO) has been involved in research and development of diode-pumped solid state lasers since the first “high-power” diode lasers (200 mW) became commercially available. In this presentation we will discuss a number of laser devices that take advantage of the latest technology in diode pump sources.

Nd-doped laser materials, providing laser operation in the 1-μm wavelength region, continue to be the basis for most solid state laser systems. As the power of diode lasers has increased so has that of diode-pumped Nd-doped lasers. At high powers, the same problems that have always been an issue for lamp-pumped lasers, optical distortion of the laser medium due to heat dissipation, become significant for diode-pumped devices. The optical distortion is due to thermal gradients in the bulk of the laser material and results from two main effects, the change in material refractive index with temperature and the change in index due to the stress in the material created by the gradients. Stress-induced refractive index changes can lead to optical distortion not only of the phasefront of the laser beam passing through the material but also of the polarization properties, since, in general, the stress creates birefringence in the material.

With regard to the problem of phasefront distortion in the bulk, it is well known that some classes of materials have greatly reduced thermal distortion compared to others. Fluoride materials, such as $LiYF_4$ (YLF) are one such class, and the low distortion is presumed to result from the negative change in refractive index with increasing temperature, which tends to cancel the positive change from increasing stress. YLF has the additional advantage of being naturally birefringent, which minimized the problem of stress birefringence.

We have developed a diode-pumped Nd:YLF laser design that combines high-power output, good beam quality and freedom from optical distortion of the laser material caused by the pumping process. A five-pass Nd:YLF gain element is at the heart of the laser design. A 3-cm-long Nd:YLF crystal is transversely pumped by a pair of 1-cm-long, 20-W diode-laser bars. The diode-laser bars are coupled to the gain element through a single fiber lens attached directly to each bar package. These lenses minimize the divergence of the pump light in the plane perpendicular to the linear emitter. The bars are offset on opposite sides of the Nd:YLF crystal to create a sheet of gain in the crystal.

In Figure 1 we plot the output power and mode diameter of the output beam as a function of diode pump power at 1047 nm. The particular resonator design we use leads to an elliptical output beam, hence the two diameters plotted in the figure. The essentially power-independent beam properties of the laser are an indication that phase-front distortion is not an important factor in the operation of the laser. We measured the output to be linearly polarized with power in the orthogonal polarization less than 1% of the total output at full pump power.

The average slope of the input-output curve in Fig. 1 is approximately 42%. If all the incident pump power was converted to laser output power the expected slope would be 77%, and thus the design extracts, in the TEM_{00} mode, 55% of the maximum possible power . The output powers observed both in near-diffraction-limited operation and multimode (>16 W) are, to our knowledge, the highest powers reported to date for cw, diode-pumped Nd:YLF lasers.

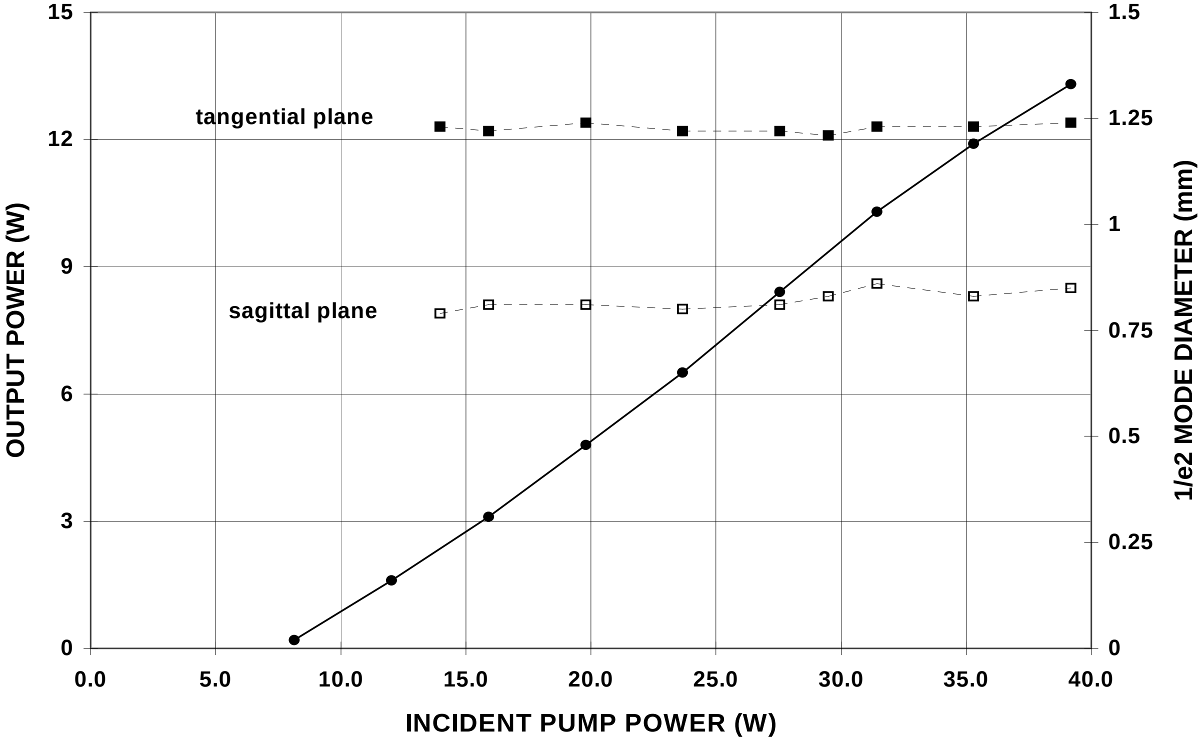

Figure 1. Near-diffraction-limited power output (solid curve) and beam dimensions (dotted curves) of SEO Nd:YLF laser as a function of diode-laser pump power.

Regarding one important mode of laser operation, cw pumped and repetitively Q-switched, an interesting feature of Nd:YLF compared to the more common Nd:YAG laser medium is the approximately 2x-longer storage time, which leads at low pulse rates to 2x more energetic Q-switched pulses. In Q-switched operation we have observed pulse energies as high as 3 mJ at 2 kHz and a peak power exceeding 100 kW. Above a pulse rate of 10 kHz, the average power of the laser is essentially constant, close to the cw level, and the pulse energy decreases inversely with pulse rate. In other work we have operated the laser with pulse rates over 100 kHz.

With the high peak powers available we can efficient convert the Nd:YLF laser to other wavelengths using nonlinear optics. In one experiment we generated nearly 7 W of average power in the second harmonic at a pulse rate of 10 kHz. The SHG source is an excellent pump for Ti:sapphire lasers to generate tunable near-IR power. We are investigating the generation of higher harmonics in the UV. Going in the other direction, we have developed an intracavity OPO based on the material KTA and generated over 1 W of average power at the OPO signal wavelength of 1507 nm. This device is an excellent source for eye-safe range-imaging lidar systems.

The same side-pumped, multipass laser design can utilize other Nd-doped materials. Recently, to develop a source for Na guidestar excitation, we have examined the more common Nd:YAG material and obtained power outputs comparable to that with Nd:YLF. As expected there was considerable thermal lensing, but because of the nearly unidirectional heat flow the effects of stress birefringence were minimal.

Solid state lasers with longer operating wavelengths than afforded by Nd-doped lasers have been based on crystals doped with the rare-earth ions Tm, Ho and Er. Given the laser properties of these ions, cw operation wth lamp pumping is possible only if the crystals are cryogenically cooled. One of the major impacts of diode-pumping has been the attainment of cw operation from Tm-, Ho- and Er-doped crystals at or near room temperature.

We have investigated cw-pumped, Ho-doped materials as 2-μm sources for coherent lidar and Er-doped lasers at near 3 μm as sources for laser medicine and calibration of infrared sensors. After studying several materials, we concluded that Tm,Ho:YLF was the most optimum crystal for 2-μm laser operation. Our latest efforts with this material have led to cw lasers with power outputs of 4.5 W, based on a fiber-coupled pump laser at 785 nm and a double-sided, longitudinal pump geometry. A variation on this design employed a ring cavity with a unidirectional element to generate single-longitudinal-mode output powers greater than 1 W. We developed a ruggedized versions of this laser for a mobile, wind-sensing lidar system. With the additional of a Q-switch we have operated the diode-pumped Tm,Ho:YLF laser in the cw-pumped, repetitively Q-switched mode to produce pulse energies of 6 mJ at 100 Hz, with a pulsewidth of 90 ns.

Laser transitions of the Er ion at wavelengths near 3 μm operate between the $^4I_{11/2}$ (upper) and the $^4I_{13/2}$ (lower) states. The long lifetime of the lower state impedes cw operation, but is mitigated by a rapid thermalization among the lower-state Stark-split levels. Thermalization favors laser action from transitions terminating in the highest-lying Stark levels. Upconversion from the lower state, identified as an important factor in early studies of long-pulse, flashlamp-pumped lasers, also aids in establishing net cw gain for crystals with high Er concentrations.

The cw laser configuration we used was a longitudinally pumped monolithic resonator. The laser crystals were 3 mm long and 3 mm in diameter. The flat, pump surfaces of the monoliths were coated to be highly transmitting at the 970-nm pump wavelength and highly reflecting at the laser wavelength. The output surfaces were coated for nominal 99.7% reflection at the laser wavelength and were polished with a convex 1-cm-radii-of-curvature. Materials used were 30%-doped Er:YSGG, 30%-doped Er:GGG and 33%-doped Er:YAG.

Using two polarization-coupled, 1-W InGaAs pump lasers, with 100-μm stripe widths we were able to generate 0.5 W of cw output from the Er:YSGG laser at 2797 nm. The slope effciency was 26%. The other materials produced lower powers and slope efficiencies. Current efforts are underway to scale up the power output and use an external-cavity design, to avoid problems with damage to coatings applied directly to the laser crystal.