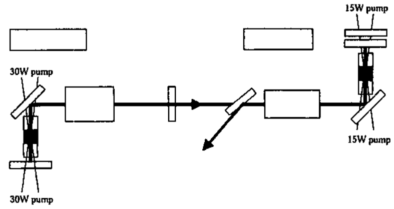
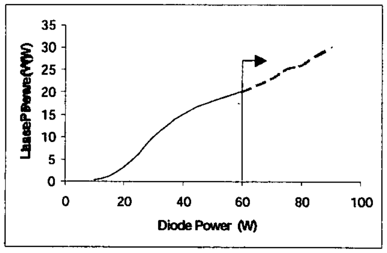
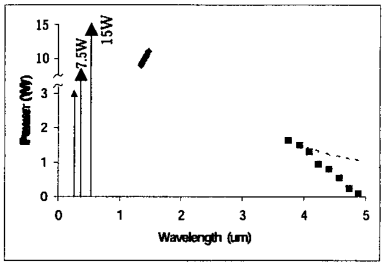


CMA2 Fig. 1. Short cavity, "bright" pumped, Q-switched Nd:YVO_4 laser oscillator.



CMA2 Fig. 2. Oscillator & Amplified output power vs. diode pump power.



CMA2 Fig. 3. Power vs. wavelength for various nonlinear processes pumped by the MOPA. Pump powers are limited by coating damage and are noted in text.

gain medium, giving high gain. The high gain results in reduced pulse length, giving a factor of 2.3 increase in the fundamental brightness of the oscillator over a conventional end-pumped architecture. The maximum conversion efficiency for any nonlinear process is determined by the brightness of the pump. Thus, this oscillator is optimized for nonlinear conversion efficiency.

The same pump scheme is used in the CW-pumped amplifier, using two 15 W high-brightness diodes. The amplifier increases the oscillator power to 30 W. As in the oscillator, the ability to form small collimated diode pump spots enables high gain. Figure 2 shows the oscillator and amplifier outputs as a function of diode pump power. The overall optical-to-optical efficiency of this system is 33%, with an electrical efficiency of approximately 10%.

This high brightness source is an ideal pump for nonlinear optical processes. For doubling in NCPM LBO we have obtained up to 15 W of 532 nm output at 30 kHz with 23 W of pump (60% efficient). For tripling with LBO we have generated 7.5 W from 15 W of 532 (50% efficient), and for quadrupling with BBO we have demonstrated 3 W at 266 nm with 15 W of 532 nm (20% efficient). For an NCPM KTP OPO operating at 1.57 μm, we have observed 6 W of eyesafe output with 13 W of pump (46% efficient). For a 0.5 mm thick PPLN OPO we have generated 4.2 W at 1.48 μm and 1.6 W at 3.75 μm with 11 W of pump (52% efficient). Figure 3 summarizes results of frequency doubling and OPO experiments.

The PPLN OPO results include a calculation of idler power, using the measured signal power and applying photon conservation, shown as a dashed curve. The difference between this dashed curve and the measured idler power represents the power absorbed in the PPLN. Clearly, there is strong absorption beyond 4 um which degrades OPO performance, but this has little impact on signal efficiency. However, the strong absorption of idler results in thermal gradients within the PPLN that create aspheric thermal lensing and can degrade beam quality. As with end-pumped lasers, it is necessary to employ appropriate cooling geometry's to minimize these thermal gradients otherwise a degradation in OPO beam quality occurs.

While oscillators can be power-scaled by enlarging the pump spot to reduce thermal aberrations, this results in increased pulse length. The amplifier not only preserves brightness but can actually shorten pulse length when driven into saturation. The result is a laser source that is scalable not only in power but also in nonlinear conversion capability.

CMA3 8:30 am

All-solid-state yellow laser source with 1W average power

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Stimulated Raman shifting (SRS) in optical crystals offers a practical and efficient approach to frequency down conversion of solid-state lasers.[1] When used in combination with second harmonic generation (SHG) in a second crystal, a variety of wavelengths in the visible can be targetted.[2,3] In this paper we report the use of such a scheme to generate 0.96W output at 580 nm, a wavelength which coincides with an absorption band of haemoglobin, and is of particular interest for a range of medical applications.

The approach we have adopted is to perform intracavity SRS of Nd:YAG laser radiation (1064 nm) in $LiIO_3$ to generate the first Stokes wavelength at 1160 nm, which is then converted to 580 nm by SHG in LBO, also performed intracavity. We have demonstrated this scheme previously[3] using an arclamp-pumped Nd:YAG laser, and now report its application in a diode-pumped Q-switched Nd:YAG laser to create an all-solid-state yellow laser source.

The cw-diode-pumped Nd:YAG laser used for the experiments is based on a commercial pump module (Light Solutions LightLab 1010). This module is a sealed unit containing a Nd:YAG rod double-end-pumped through dichroic turning mirrors. Fitted with a standard (flat-flat) optical cavity in Z-fold configuration, it produces up to 8W at 1064 nm. For our experiments it was acousto-optically Q-switched at 5–10 kHz, producing pulses of duration 20–30 ns. For the purpose of frequency conversion, the standard laser cavity was lengthened to ~30 cm to accommodate the two nonlinear crystals and obtain a large mode diameter in the $LiIO_3$ crystal; the latter is necessary to avoid optical damage to this material (damage threshold ~100 MW cm^{-2}). All mirrors were flat, with reflectivities chosen to provide a high-Q resonator for the pump and Stokes wavelengths. The yellow light was coupled out of the resonator through a 45-degree dichroic mirror.

To obtain efficient SRS without crystal damage it was necessary to operate below the diode current (25A) for maximum output at 1064 nm. 1.6W output at 1160 nm was obtained for 18A at 7kHz with 50% output coupler transmission. This represents a conversion efficiency of 54% with respect to the output (2.95W) of the standard Nd:YAG laser at 18A/7kHz. This conversion efficiency is somewhat lower than expected, due to transmission at 1160 nm through the turning mirrors inside the sealed Nd:YAG pump module. The conversion efficiency to 1160 nm if this "lost" 1160 nm output is accounted for is 73%.

A 4×4×10 mm piece of LBO, cut for type 1 non-critical phase-matching was positioned on a temperature-controlled mount near a beam waist. The maximum output we have obtained at the second harmonic is 0.96W, representing a conversion efficiency of 33% with respect to the 1064 nm output from the standard laser. This performance is also significantly affected by losses at 1160 nm through the turning mirrors inside the pump module.

The cavity design used for these experiments is a compromise between obtaining optimum beam waists in both nonlinear crystals, while maintaining cavity stability. Ongoing research is aimed at increasing the power at 580 nm, through cavity design and by investigating the complex temporal dynamics of a laser gain process and two nonlinear processes.

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CMA4 8:45 am

Scaling of high power diode-pumped self-frequency doubled Nd^{3+}:YCOB lasers

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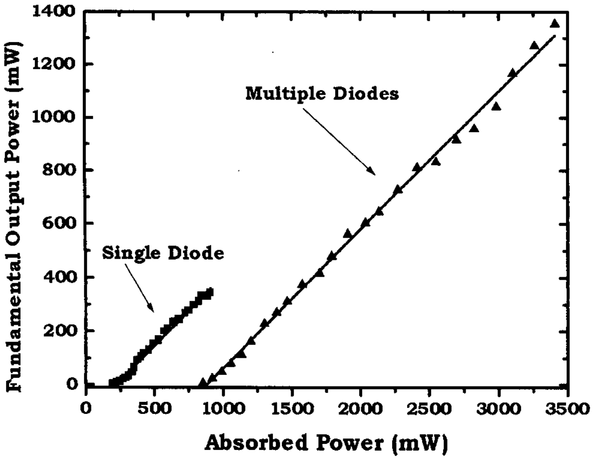
The development of high power, diode-pumped self-frequency doubling (SFD) lasers, such as Nd:YCOB[1] may be an attractive alternative to lasers incorporating intra-cavity dou-



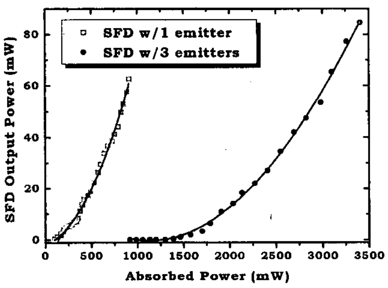
CMA4 Fig. 1. Fundamental laser output at 1060 nm with a 2% output coupler as a function of absorbed pump power for single and multiple diode emitters.

bling with a separate nonlinear crystal. Several SFD lasers have shown efficient frequency doubling into the green.[1-5] However, modeling of diode-pumped SFD lasers using end-pumping configurations have shown limitations resulting from a low power density of the pump volume.[4,6] We report fundamental laser action and SFD operation under high power diode-pumping of Nd:YCOB.

We have previously shown efficient laser action and SFD operation of Nd:YCOB using diode-pumping from a single 100 μm emitter.[1] Over 60 mW of green radiation was obtained using a linear hemispherical resonator and more than 350 mW of 1060 nm laser light was obtained using a 2% output coupler.

To scale SFD radiation to higher powers, we have used a Polaroid Polychrome Laser System[7] consisting of multiple single emitters, collimated and microlensed to reduce the beam divergence. The diode system was capable of producing more than 6.3 W of collimated radiation at 812 nm. When focused, the diode system could obtain spot sizes on the order of ~200 μm.

A hemispherical laser cavity was used consisting of a 5-meter radius of curvature high reflector and a 10-cm radius of curvature output coupler. The 3×3×5 mm long Nd:YCOB crystal was coated with a triple band anti-reflection coating and mounted on a cooled copper block next to the high reflector. Several different focusing geometries were investigated. The best results were obtained with 25-mm plano/convex lens that produced a 200 × 250 μm (FWHM) spot size at the crystal face. The output power at both the fundamental and self-frequency doubled laser wavelengths were measured for 0, 1%, and 2% output coupling. Figure 1 shows the fundamental output power for the one and two-percent output coupling versus the absorbed pump power. The highest slope efficiencies of 51.8% were observed with a 2% output coupler. The fundamental output powers exceeded 1.3 W for 3.4 W of absorbed pump power. Green self-frequency doubled output powers of over 85 mW were obtained as shown in Fig. 2. In comparison with our low power work,[1] there is a compromise between the focusing required for optimum laser performance and the waist size of the TEM$_{00}$ mode, which provides optimum frequency doubling. Further improvements in diode-pumped Nd:YCOB laser performance and modeling of the scaling of SFD lasers will be reported.



CMA4 Fig. 2. Self-frequency doubled emission at 530 nm as a function of absorbed pump power.

Q-switched flashlamp excitation could in principle lead to high pulsed SFD powers. We are investigating this possibility and have recently demonstrated both free-lasing and Q-switch operation of a flashlamp-pumped 4 mm diameter, 55 mm long, 5% Nd-doped YCOB rod. With a pump energy of 112 J, nearly 1 J of free-lasing energy is generated and ~25 mJ in the Q-switched mode. Experiments are now in progress to optimize flashlamp excitation of Nd:YCOB, and to demonstrate self-frequency generation in this regime.

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CMA5 **9:00 am**

All-solid-state continuous wave blue light laser source with 1.3 W output power at 473 nm

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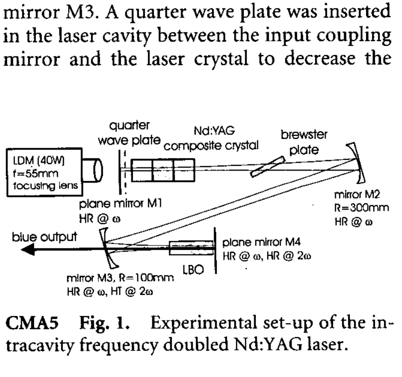
A cw all-solid-state laser system in the blue spectral region with an output power in the W-range is an alternative for air cooled argon-ion laser systems and the most suitable light source for laser based display technologies. The first demonstration of an all-solid-state blue laser source of nearly 1 W output power was a tapered InGaAs diode amplifier frequency doubled in an external cavity.[1]

In this work we report the generation of 1.3 W blue 473 nm radiation by intracavity frequency doubling of a Nd:YAG ground state laser. Figure 1 shows a schematic picture of the experimental set-up.

The mirrors M1–M4 were high reflection coated at the laser wavelength and coated for high transmission at 1.06 μm to avoid laser oscillation on this laser transition in Nd:YAG. The laser crystal was a diffusion bonded laser rod with a length of the active medium of 3 mm and two 3 mm undoped YAG ends. The LiB$_3$O$_5$ (LBO) crystal cut for critical phase matching at 946 nm at room temperature was placed near to the plane end mirror (M4, HR @473 nm) and the generated second harmonic wave was coupled out of the cavity through mirror M3. A quarter wave plate was inserted in the laser cavity between the input coupling mirror and the laser crystal to decrease the



CMA5 Fig. 1. Experimental set-up of the intracavity frequency doubled Nd:YAG laser.