from the Nd:YAG laser and the first step in the harmonic generation process. With injection seeding of the OPO, output at the seeded wavelength in a single axial mode was achieved in both cases. The minimum injected energy to achieve single axial mode operation of the OPO was less than 2.5 μJ at 1.06 μm.

The observed high conversion efficiency, good stability, and narrow bandwidth operation indicate that the BaB_2O_4 OPO will become a very useful tunable source of coherent radiation as large high-quality crystal of this material becomes more widely available. Widely tunable Optical Parameteric Oscillators will offer several advantages when compared to tunable lasers.

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HIGH EFFICIENCY SECOND HARMONIC GENERATION OF A CW FREQUENCY STABLE LASER

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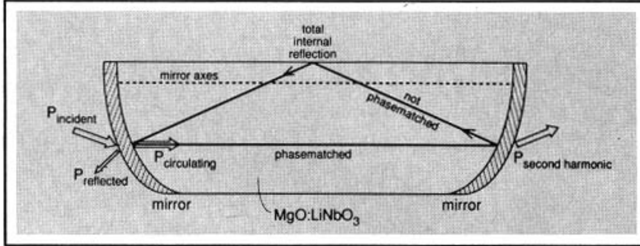
Nonlinear optics is often used to convert a laser output to other frequencies. In Second Harmonic Generation (SHG), for example, the laser is focused into a nonlinear crystal that produces an output beam at twice the laser frequency. The conversion efficiency of this process scales as the incident laser power. High-peak-power pulsed lasers are therefore easily converted with high efficiencies, but lower power continuous wave (cw) lasers have proven to be more difficult to convert efficiently.

One method of increasing the conversion efficiency for cw lasers is to use a cavity to enhance the fundamental intensity in the nonlinear crystal. This technique requires a laser of a single frequency, so that the external cavity can resonate the laser frequency. Earlier researchers have used this technique with single frequency argon or dye lasers and have achieved conversion efficiencies of less that 6%, limited by their intracavity losses of several percent. We have used a new monolithic external cavity design, with



The monolithic external cavity $MgO:LiNbO_3$ off-axis ring frequency doubler. The mirrors are deposited directed on the $MgO:LiNbO_3$ crystal to provide good cavity stability and low losses. The ring geometry produces single direction second harmonic output and eliminates feedback into the laser.

the mirrors deposited directly on the polished faces of the nonlinear crystal, to provide a very low loss and highly stable cavity. This design allows us to generate the second harmonic of a low power, cw, diode-laser-pumped Nd:YAG laser with a conversion efficiency of 56%.[1]

Diode-pumped solid state lasers are compact, stable, and efficient. The Nd:YAG laser used for these experiments was a nonplanar ring cavity[2] that generated cw single frequency output at 1.064 μm of 53 mW. Its monolithic design and diode-laser-pumping provided good frequency stability.

For these experiments, $MgO:LiNbO_3$ was chosen as the nonlinear crystal for its large nonlinearity, 90° noncritical phasematching, and low loss at 1.06 μm. Curvatures were polished on the crystal ends to form a stable resonator. As shown in the figure, a total internal reflection face was polished parallel to the mirror axes that completed an off-axis ring path that eliminated feedback into the laser and produced second harmonic in a single direction. Cavity Q measurements indicated that the total scatter and absorption losses for the cavity were 0.42%. Dielectric mirrors were deposited on the curved crystal ends that impedance matched the cavity, minimizing the laser light reflected and therefore maximizing both the resonated laser light and the output at the second harmonic.

The laser light was spatially mode-matched into the nonlinear cavity. Adjusting the cavity into resonance with the laser frequency was accomplished by applying a voltage across the crystal, using the electro-optic and piezoelectric effects to change the cavity's optical path length. The external cavity was locked onto the laser frequency by adjusting the voltage to maintain a minimum in the reflected light. When the crystal cavity was held on resonance and heated to the phasematching temperature of 107° C, the 53 mW in incident laser light built up 3 W of circulating power in the nonlinear cavity that generated 30 mW of output at the second harmonic. This represented a 56% conversion efficiency of the incident laser power to the second harmonic, a level previously attainable only with kW peak power lasers.

The output of the nonlinear cavity agreed well with the expected theoretical output. Theory also indicates that shorter cavities with their lower losses should offer improvements in efficiency, as should higher laser powers. These results indicate the advantage of using resonant external cavity frequency doubling and diode-pumped Nd:YAG lasers for producing highly efficient and frequency stable laser radiation.

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UPCONVERSION LASERS EXCITED BY PAIRS AND TRIOS

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Recent experiments in Er:YLF and other crystals have demonstrated efficient laser action from energy levels populated entirely by cooperative upconversion of pump energy from pairs and trios of excited Er ions.[1] This has revealed a general method for pumping solid state laser materials that is quite distinct from processes relying on the absorption of one or more photons by single ions. The new method permits excitation of high energy states by long wavelength radiation. For UV solid state lasers, it therefore offers an alternative to the use of deep ultraviolet pump sources that typically exhibit shallow penetration and can cause deleterious color center formation. Also, pair or multi-atom interactions can be exploited to achieve inversions on new transitions that may be normally self-quenching.

In 5% Er:YLF, pump energy at 1.54 μm promotes ground state Er ions to the first excited state where energy pooling takes place. A cooperative transition of excited, near-neighbor Er ions occurs subsequently that conserves energy overall and produces one high-energy ion and one or more ground state ions. Stimulated emission can in principle then occur between the upconverted energy state and lower levels at wavelengths as short as 0.8 μm for Er pairs or 0.5 μm for trios. To date, room temperature laser action from the upconverted states has been limited to a pair-pumped transition wavelength of 2.8 μm. But a noteworthy feature of this transition is that the lifetime of the lower laser level (23 ms) exceeds that of the upper level (4 ms), so that this transition is normally self-quenching. At cryogenic temperatures, trio-pumped laser action has been observed at wavelengths of 0.85, 1.23, and 1.73 μm.

The depletion rate of the pumped level, which is the lower laser level for the 2.8 and 0.85 μm emission lines, becomes a function of excitation in concentrated crystals, so that self-quenching can be avoided. True cw operation should be possible based on pair-pumping alone. Efficiencies achieved in the pulsed experiments have ranged so far