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CW Diode-Pumped Optical Parametric Oscillator in Bulk Periodically Poled LiNbO₃

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Abstract: We report a 1.96- μm optical parametric oscillator using bulk periodically poled LiNbO₃ directly pumped by a commercial 980-nm cw diode laser.

An optical parametric oscillator (OPO) directly pumped by a diode laser is potentially a compact and efficient source of radiation where current laser sources are unavailable or where tunability is needed. Recent advances in single frequency diode lasers make such a device feasible. Previous attempts using available nonlinear optical materials have been hampered because the gain and phasematching conditions placed difficult constraints on the wavelength and power requirements of the pump laser.¹ We have used the engineerable phasematching and high gain properties available through quasi-phasematching to demonstrate an OPO directly pumped by a commercial cw diode laser source.

The nonlinear optical material was periodically poled LiNbO₃ (PPLN) fabricated using the electric field poling technique reported elsewhere.² The pieces for this work were 0.5-mm thick with a 9.3-mm interaction length. The domain period for quasi-phasematching was 28.5 μm , designed for degenerate operation at 88°C as shown in Fig. 1.³ The polished end faces of the PPLN were AR coated for the signal/idler pair near degeneracy. The actual AR coating came out slightly short centered at 1.84 μm , and the total single pass power loss through the crystal was ~0.8% at 1.96 μm .

The experimental set-up is shown in Fig. 2. The pump source was a 977.6-nm master oscillator/power amplifier (MOPA) cw diode laser from SDL, Inc (model 5762). The laser was found to have reliable single frequency operation at limited points over its operating range of amplifier current and temperature. The laser was rated at 750 mW, but we operated at 500 mW for better stability. We used a scanning confocal interferometer with a resolution of 25 MHz to verify single frequency operation of the diode laser. The laser was susceptible to even small amounts of feedback, and two isolation stages were required for stable operation.

The doubly resonant OPO resonator was a linear cavity with 10-mm radius of curvature mirrors separated by 22 mm. We used an input mirror with a high reflectivity coating and output couplers of 0.3% and 0.7% transmission, all centered at 1.96 μm . The useful bandwidth of the mirrors was about 200 nm, and the pump reflectivity was ~20%.

Fig. 1. Temperature tuning curve for 977.6-nm-pumped, 28.5- μm period PPLN OPO. Phasematching temperature is 88°C at degeneracy ($\lambda = 1.955 \mu\text{m}$). The bandwidth of the mirrors is shown by the crosshatched region.

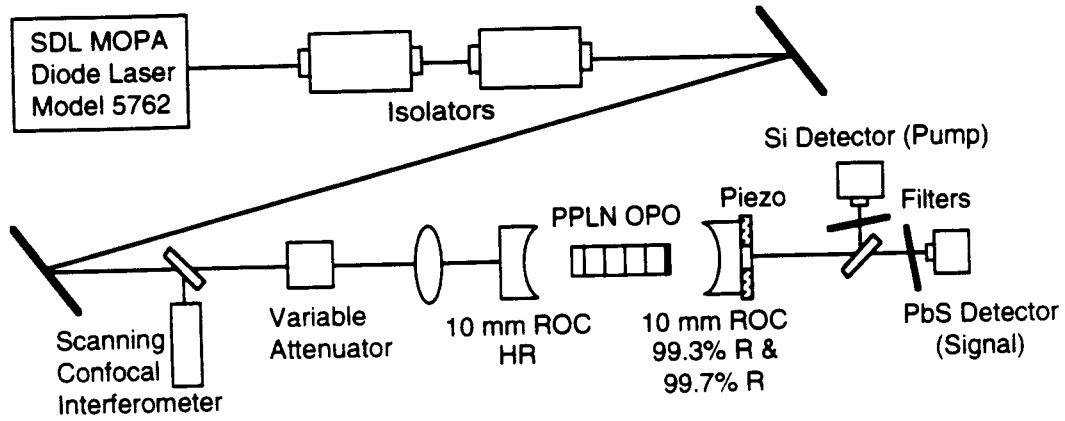
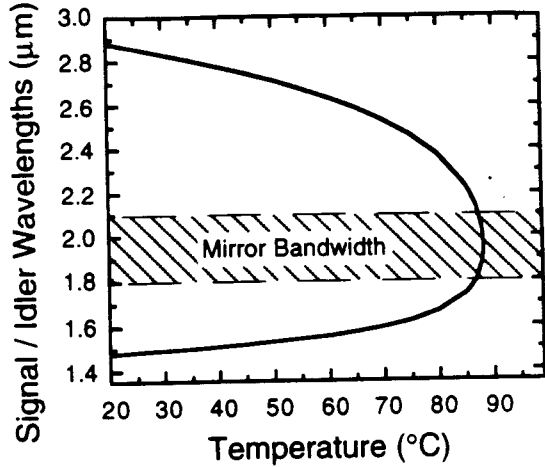


Fig. 2. Experimental set-up for diode-pumped OPO in bulk PPLN.

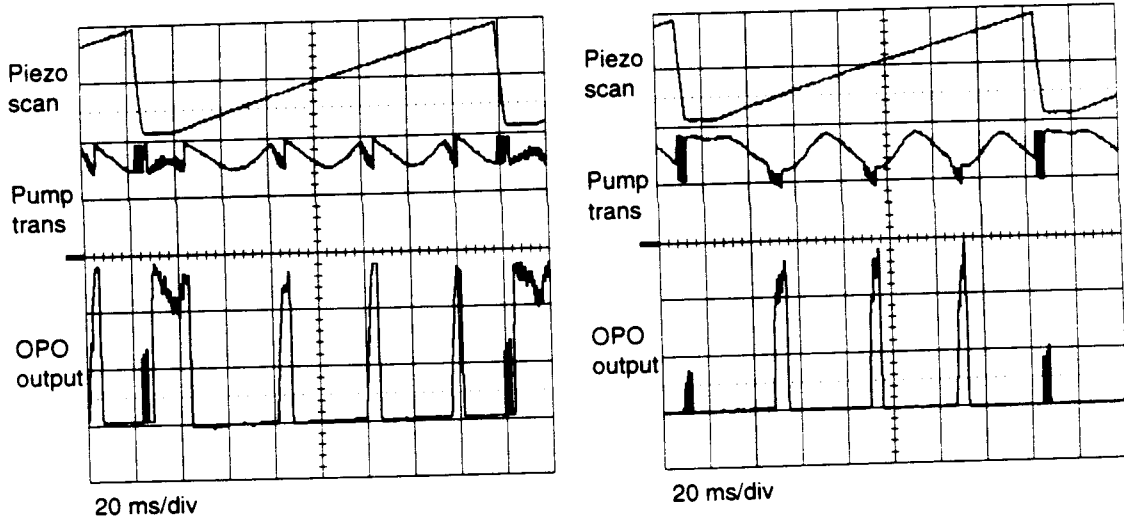


Fig 3. Cavity mirror piezo scan voltage, pump transmission with depletion, and $\sim 1.96\text{-}\mu\text{m}$ OPO output signals with 0.7% output coupler. The left plot shows an operating point near the peak of the pump transmission. The right plot shows a different operating point near the minimum of the pump transmission.

The pump beam was mode matched to the cavity by focusing through the high reflector with a 100-mm focal length lens. The pump beam in the cavity had a measured radial waist size of 37 μm with a beam quality of $M^2=1.3$, giving a ratio of crystal length to confocal parameter of 0.63. The beam had an ellipticity of 1.2 and astigmatism of 2.5 mm in the focus locations in air. The output coupler was mounted on an annular piezoelectric element for cavity length control. The OPO output near 1.96 μm was detected with a PbS detector through a filter to block the pump beam, and the residual pump beam transmitted through the cavity was detected with a Si detector.

Fig. 3 shows the cavity mirror piezo voltage, pump transmission through the cavity, and the OPO output through the 0.7% output coupler as the cavity length is scanned with the piezo. The threshold was 61 mW and 98 mW for the 0.3% and 0.7% output couplers respectively, which agree with calculated values for a doubly resonant oscillator (DRO).⁴ The peak phasematching temperature was measured at 91°C which agrees with the design calculation shown in Fig 1. For 370 mW of pump incident on the cavity mirror, we measured peak output powers of 34 mW and 64 mW for the 0.3% and 0.7% output couplers respectively. These values were determined by measuring the average power in the output beam and adjusting for the duty factor of the actual OPO operating time over the piezo scan. The conversion efficiencies of 9% and 17% agree with the values obtained from pump depletion and with a theoretical calculation for a DRO.⁴ The OPO operates in selected regions versus mirror position due to the cluster effect that is well known for DRO's.⁵ The OPO output could be shifted relative to the pump transmission by adjusting the temperature and the cavity length. The plot on the left in Fig. 3 shows a case when output occurs near a peak in the pump transmission, while the plot on the right shows a different operating point where the OPO output occurs near a pump transmission minimum. This verifies that threshold was reached even without the benefit of pump enhancement in the cavity. The plot on the left in Fig. 3 also shows a case where the piezo position was held at a resonant point for the OPO during the flat part before the voltage ramp. The continuous nature of the output at this point indicates the potential for adding stabilization control electronics to make a useful cw infrared tunable source.

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