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532nm-Pumped Continuous-Wave Singly Resonant Optical Parametric Oscillator Based On Periodically-Poled Lithium Niobate

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Abstract

We report a continuous-wave 532-nm-pumped singly resonant optical parametric oscillator based on bulk periodically-poled lithium niobate (PPLN). Thermal focusing at 532nm in PPLN is reduced by chopping the pump. Less than one watt threshold and 64% quantum efficiency are achieved.

Key Words

Parametric oscillators, Singly-resonant, Periodically-poled, Lithium niobate.

Introduction

Continuous-wave (CW) singly resonant optical parametric oscillators (SROs) have recently been shown to be highly efficient sources for broadly tunable radiation with threshold and output powers of several watts [1]. The performance demonstrated in these devices results from the high gain, low loss and engineerability of periodically-poled lithium niobate (PPLN) [2]. In this work we extend the operation of PPLN-based CW SROs to sub-watt threshold utilizing a commercial 532-nm pump laser.

The experimental set-up is shown in Fig. 1. The pump is a single-transverse-mode, multi-longitudinal-mode intracavity-doubled diode-pumped Nd:YVO_4 laser [3]. The laser has an output of ~5W at 532nm. The pump laser is mode-matched to the 64µm waist (radius) of a 'bow-tie' ring OPO cavity. The cavity has two 20cm radius-of-curvature mirrors and two flat mirrors. The 5.3cm long, 0.5mm thick PPLN crystal has a 6.5µm grating period for first order quasi-phase-matching and is anti-reflection coated for the signal and idler waves from 0.8-1.1µm. The round-trip cavity loss of the signal wave is ~6% and feedback for the idler wave is less than 5%.

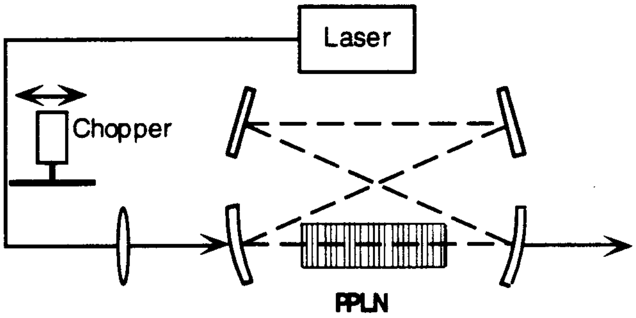

Figure 1. Schematic of the SRO four mirror 'bow-tie' ring cavity utilizing two 20cm radius-of-curvature and two flat mirrors. The PPLN crystal is 5.3cm long, 0.5mm thick and has a grating period of 6.5µm for first order quasi-phase-matching of the 532nm pump at temperatures >200°C.

Figure 2 shows temperature tuning of the SRO. We heated the PPLN crystal from 215-242°C obtaining continuous tuning from 953-1000nm and 1160-1234nm for the signal and idler wavelengths, respectively. The theoretical curve is derived from published Sellmeier coefficients for $LiNbO_3$.

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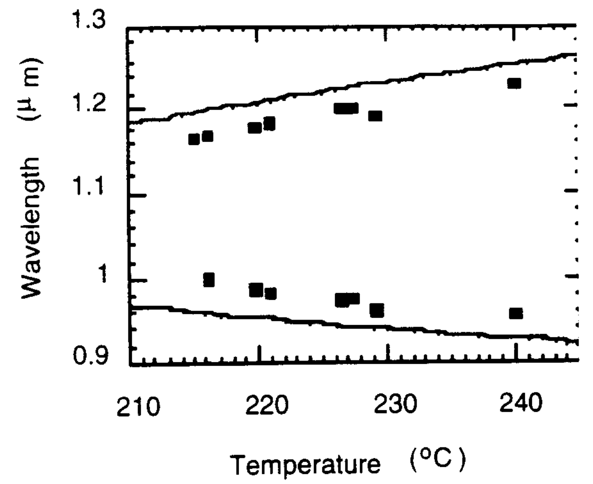

Figure 2. Temperature tuning data for the SRO. The PPLN crystal was heated from 215-242°C producing continuous tuning from 953-1000nm and 1160-1234nm for the signal and idler wavelengths, respectively. The theoretical curve is derived from published Sellmeier coefficients for $LiNbO_3$. The 15°C offset between experiment and theory has also been observed in SHG experiments using the same material.

Thermal lensing in the PPLN, due to 532nm absorption, increased cavity losses resulting in an oscillation threshold of ~2.2W. Chopping the pump with a 50% duty cycle at 0.1-2kHz, reduced thermal focusing in the PPLN, resulting in a threshold peak power of 1.2W at the input mirror and <1W at the input face of the PPLN crystal. Figure 3 shows pump depletion and idler peak output power as functions of peak pump power for chopped pump operation. The PPLN was heated to 220°C to operate at signal and idler wavelengths of 960.6nm and 1192nm. At 4.3W peak pump power at the input mirror, 0.9W of idler peak output power was generated. At pump powers up to the available 3.6 times threshold, the idler quantum slope efficiency taken inside the PPLN crystal was 89%. At 3.6 times threshold, pump depletion was 60% and idler peak output was 0.9W, achieving a quantum efficiency of 64%.

Exchanging one of the flat cavity mirrors with a 4% output coupler for the signal lead to an increased working threshold of ~2.3W peak pump power. Figure 4 shows peak signal and idler output powers as a function of peak pump power for this case.

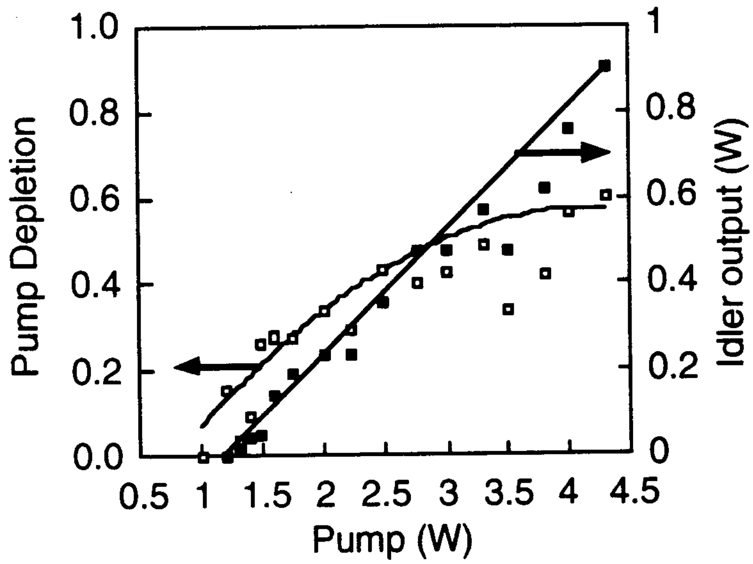

Figure 3. Pump depletion and idler peak output power vs. peak pump power incident on the curved input mirror. Idler quantum slope efficiency is 89%.

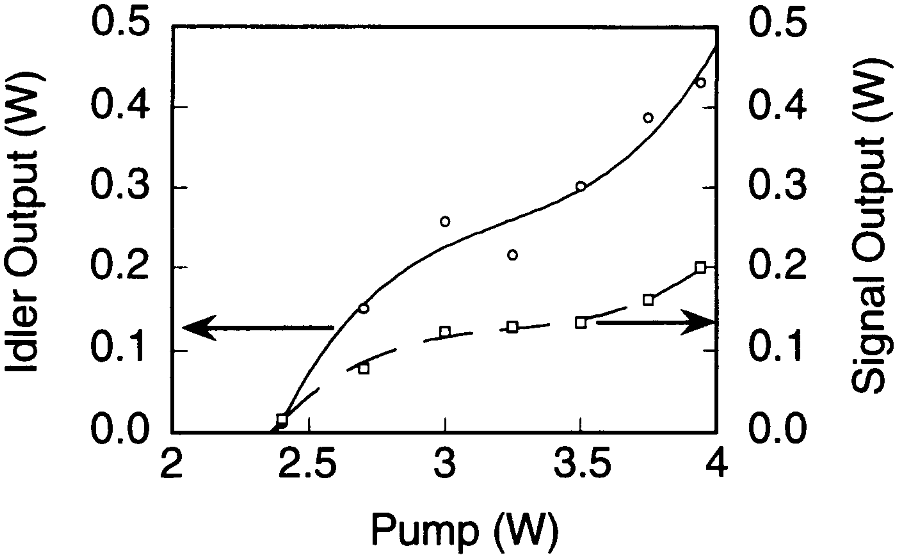

Figure 4. Signal and idler output power vs. pump power using a 4% output coupler for the signal instead of one of the flat cavity mirrors. Working threshold of the OPO increased to 2.3W.

Recently, 532nm anti-reflection coated SRO cavity mirrors were obtained. A Lightwave Series 220 diode-pumped CW Nd:YAG laser operating at 9W was then frequency-doubled using a single-pass 0.5mm-thick, 53mm-long second harmonic generator (SHG) PPLN crystal. With 7W of 1.06μm radiation incident on the SHG crystal, 1.8W of 532nm second harmonic radiation was generated and used to pump the SRO. In this configuration, an SRO oscillation threshold of 600mW was achieved.

In summary, we demonstrated a low threshold CW SRO pumped by a commercial 532nm multi-mode laser and obtained 0.9W of idler peak output power and a quantum efficiency of 64%. A second pump source was also demonstrated using a commercial CW Nd:YAG laser single-pass frequency doubled in PPLN. Thermal focusing effects in the PPLN were reduced but not completely eliminated by chopping the pump with a 50% duty cycle, so future work will focus on characterizing and reducing the thermal focusing in $LiNbO_3$.

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