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Efficient cw synchronously-pumped optical parametric oscillation beyond 5μm in periodically-poled lithium niobate

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Abstract

A cw synchronously-pumped optical parametric oscillator, based on periodically-poled lithium niobate has operated efficiently out to 5.3μm (signal 1.3μm). Available average idler power at 5.3μm is 10mW, corresponding to 25W of peak power, for ~1W of 1047nm pump. Additionally, oscillation has been observed at idler wavelengths as far as 6.3μm.

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Periodically-poled lithium niobate (PPLN) offers many attractive features for optical parametric oscillation (OPO). These include high nonlinearity and non-critical quasi-phase-matching in a wide spectral range, making it well-suited to synchronously-pumped operation. Using a cw mode-locked 1047nm pump, we recently demonstrated a low threshold singly-resonant oscillator tunable over the range 1.67μm - 2.8μm [1]. In this contribution we report a *major* extension of this tuning range, demonstrating singly resonant operation in the range 1.3μm - 5.3μm, while still retaining low threshold and high efficiency. Additionally we have observed oscillations with idler wavelengths out to 6.3μm. This now offers a widely tunable source covering wavelengths well into the mid-IR. This is made possible by the use of PPLN which allows operation at longer wavelengths than bulk lithium niobate, since the infrared absorption edge for extraordinary polarisation (as used in PPLN) is at a longer wavelength than that for ordinary polarisation[2] (see fig. 1). In addition, the high round trip gain in pulsed pumping of PPLN based OPO's allows generation of coherent, tunable radiation even in spectral regions where the crystal is highly absorbing. Thus, pumping with a mode-locked 1047nm Nd:YLF laser (4ps pulses at 120MHz repetition rate), we were able to generate 10mW of idler average power (20W peak) at 5.3μm (absorption coefficient, $\alpha \sim 1.2$ cm^{-1}) for 800mW of incident pump power, with an oscillation threshold of under 300mW. The observed pump depletion was ~63%.

In this contribution we also present results of the coupled-wave analysis of parametric oscillation in the presence of idler absorption. In the limit of high idler absorption, *i.e.* $\delta L>1$ where δ is the amplitude absorption coefficient of the idler wave and L is the length of the nonlinear crystal, the parametric gain is reduced by a factor $\frac{\delta}{\Gamma}$ and correspondingly, the oscillation threshold increases by a factor $2\delta L$, where Γ is parametric gain coefficient in the absence of idler absorption. Thus, using the fact that for a 19mm long PPLN crystal the observed threshold pump power for oscillation with signal at 1.8μm (idler 2.5μm) was 20mW (output coupler reflectivity = 0.95), a threshold of ~ 800 mW is predicted for oscillation at 6μm, where δ ($=2\alpha$) ~ 10 cm^{-1}. This is confirmed by our experimental observations.

Three, 19mm long, PPLN samples, each having 8 different grating periods were used to cover the tuning range shown in fig.2. The crystal was held at 160°C. Fine tuning of wavelength is achieved by changing the crystal temperature. The beam quality across the entire tuning range was very good with an M^2 value of ~1. Fig. 3 shows the typical smooth spectral profile for the idler wave.

We have shown that PPLN is a very promising material for the development of a tunable source of mid-IR radiation. Our results are confirmed by a simple model predicting oscillation behaviour in the presence of high idler absorption.

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References

1. S.D. Butterworth, V. Pruneri and D.C. Hanna, Optics Letts. 21, 1345-1347 (1996)

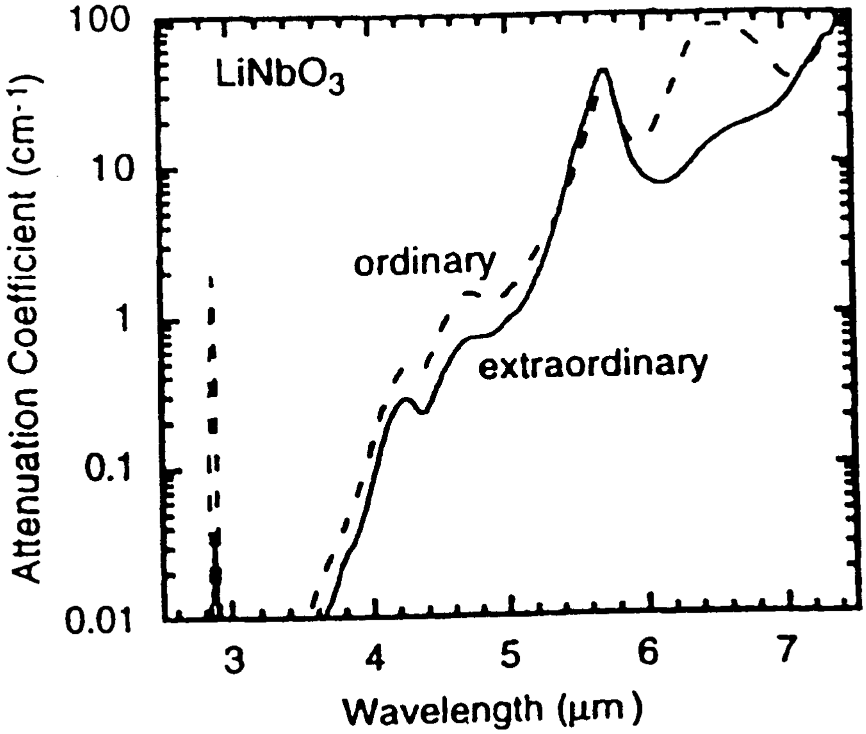
2. L.E. Myers, R.C. Eckhardt, M.M. Fejer, R. L. Byer, W.R. Bosenberg, Opt. Letts. 21, 591(1996)

Figure captions

Fig. 1. Absorption coefficient for the ordinary and extraordinary wave in PPLN, **cf ref.2.**

Fig. 2. Tuning curve for a PPLN based synchronously pumped OPO showing oscillation well into the region of idler absorption. The black circles are points at which oscillation was observed but no output power could be measured.

Fig. 3. Spectral profile of the idler wave.



100
10
1
0.1
0.01
LiNbO3
ordinary
extraordinary
Attenuation Coefficient (cm-1)
3
4
5
6
7
Wavelength (µm)

Figure 1

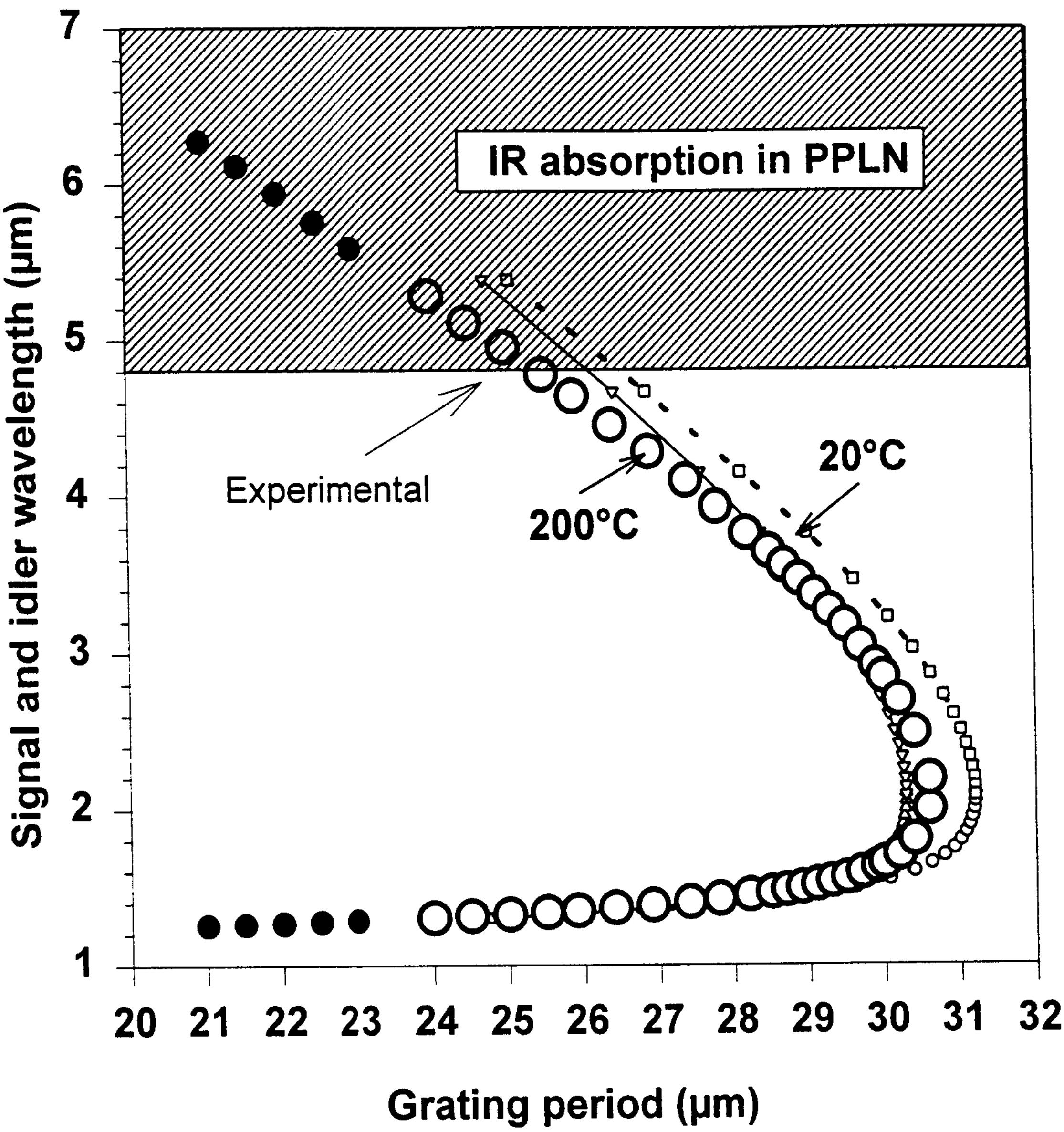
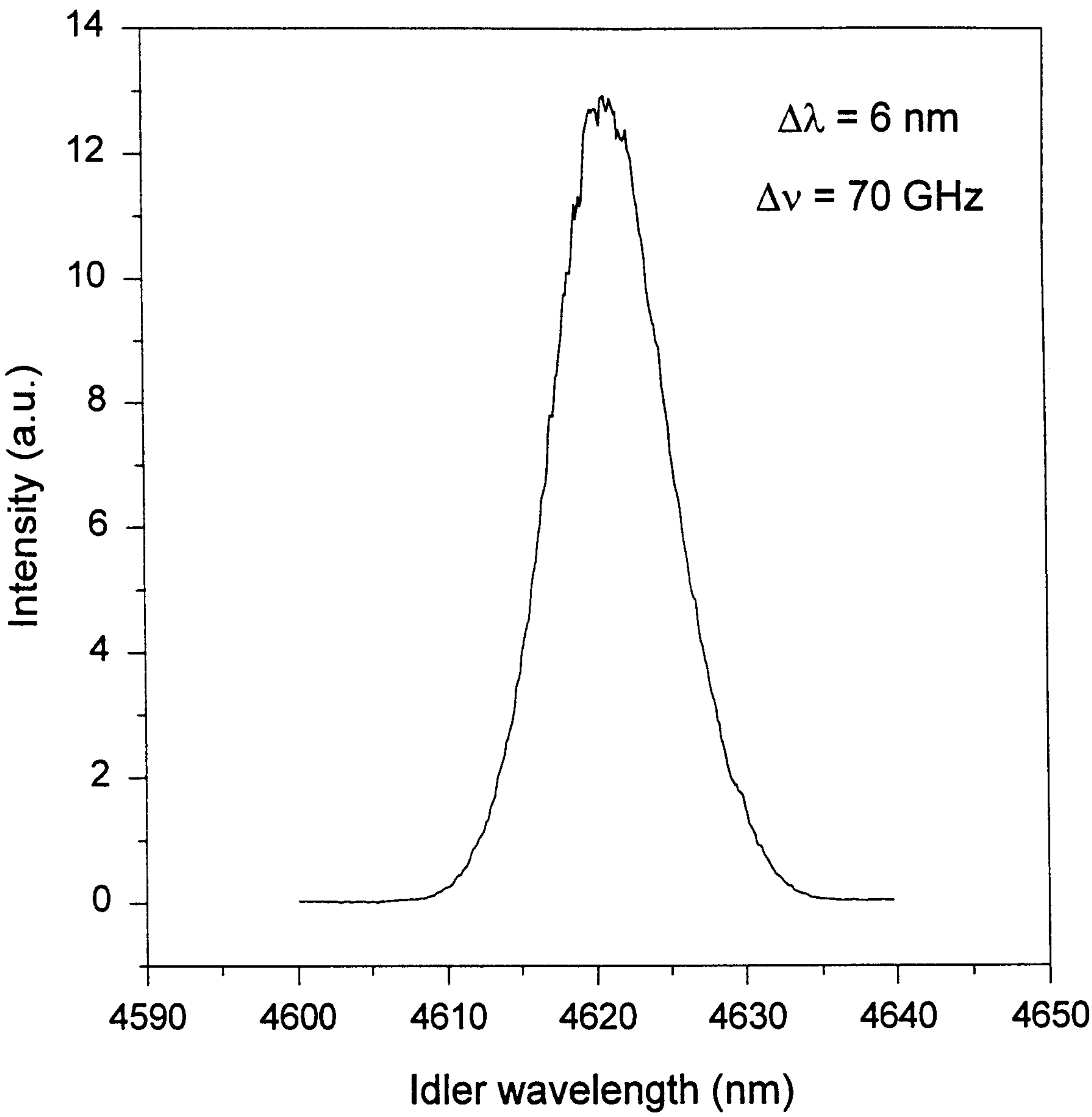

IR absorption in PPLN
Experimental
200°C
20°C
Signal and idler wavelength (µm)
Grating period (µm)
1
2
3
4
5
6
7
20
21
22
23
24
25
26
27
28
29
30
31
32

Figure 2



14
12
10
8
6
4
2
0
Intensity (a.u.)
Δλ = 6 nm
Δν = 70 GHz
4590
4600
4610
4620
4630
4640
4650
Idler wavelength (nm)

Figure 3