Optical Parametric Processes in the Presence of Strong Two-Photon Absorption

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OPO or OPG Processes in Periodically-Poled $LiNbO_3$ (PPLN)

- **Different pump wavelengths, configurations, or structures (relevant list):**

Myers, Eckardt, Fejer et al. (1995)
Pruneri, Webjörn, Russell, Hanna (1995)
Myers, Eckardt, Fejer et al. (1996)
Butterworth, Pruneri, Hanna (1996)
Schneider, Kramper, Schiller, Mlynek (1997)
Burr, Tang, Arbore, Fejer (1997)
Bäder, Meyn, Bartschke et al. (1999)
Russell, Powers, Missey, Schepler (2001)
Haidar, Usami, Ito (2002)
Bäder, Mattern , Bauer et al. (2003)
Zotova, Ding, Mu, Khurgin (2003)

Tuning Ranges for Different Pump Lasers Using PPLN as Nonlinear Crystal

- **OPO & OPG – used for achieving tunable radiation**
  - ✓ Large nonlinear coefficient: d_{eff} ~ 17 pm/V
  - ✓ Broad tuning ranges

Pump laser	Tuning range
1.064 μm	1.33 – 5.4 μm
Ti:Sapphire	0.81 – 5.4 μm
532 nm	0.59 – 5.4 μm

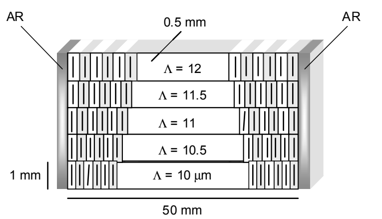
Competing Effects for OPO & OPG in PPLN Pumped by Short Wavelengths

- **Two-photon absorption (TPA)**
- **Accumulated thermal effect (ATE)**
- **Linear absorption**

This Work

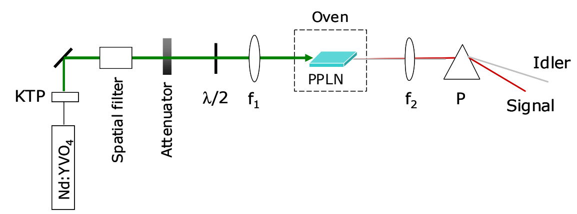
- **532-nm-pumped OPG & OPO in PPLN** – achieved
- **Influences of linear absorption, TPA, and ATE on OPG & OPO** – investigated
- **Performances of OPG & OPO** – analyzed & compared
- **Optimum repetition rate for pump** – determined

Structure of PPLN Crystal



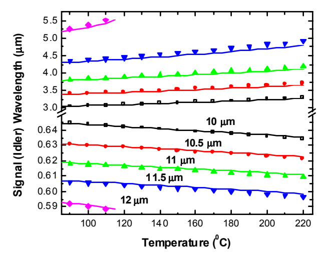
- **5 grating periods:** 10, 10.5, 11, 11.5, 12 μm
- **Dimensions:** 50 mm (length), 1 mm (width), 0.5 mm (thickness)
- **AR coatings** @ 532 nm and signal wavelengths (T ≥ 99%)

Experimental Setup for OPG



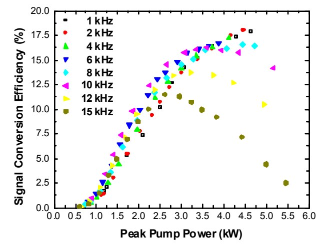
- **Pump laser:** LD-pumped Nd:YVO_4; pulse width ≈ 3.5 ns; adjustable repetition rate
- **Oven temperature** ≤ 220 °C
- $f_1 \approx f_2 \approx$ 200 mm
- $w_0 \approx$ 63 μm

Wavelength-Tuning Characteristics



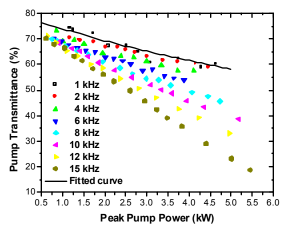
- **Sellmeier equations:** *Jundt (1997)*
- **Signal wave:** 589 – 644 nm (90-220 °C)
- **Idler wave:** 3.06 – 5.41 μm (90-220 °C)

Conversion Efficiency vs. Repetition Rate of Pump for OPG



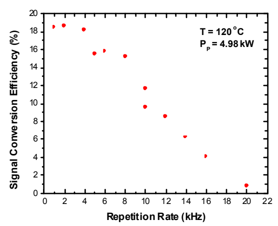
- **17.3%** for grating period of **10 μm** (signal power ≈ 6.54 mW; idler power ≈ 1.2 mW)
- 17%, 15%, 13%, 8% for 10.5, 11, 11.5, 12 μm
- **Conversion efficiency** – dramatically decreased at high pump repetition rate or pump power

TPA at Different Pump Repetition Rates



- **Determined from this experiment:** $\alpha \approx 0.042\ cm^{-1}$, $\beta \approx 2.01$ cm/GW
  Consistent with α ~ 0.019 – 0.045 cm^{-1}, β ~ 1.57 - 2.9 cm/GW
  (*Dmitriev, Gurzadyan, Nikogosyan, Handbook of Nonlinear Optical Crystals*)
- **Pump-beam waist** – reduced due to ATE primarily induced by TPA at high pump repetition rates > 4 kHz (self-focusing effect)
- **TPA loss** ≈ 60% at 15 kHz and 5.5 kW

Characteristic Time Constant for Heat Dissipation

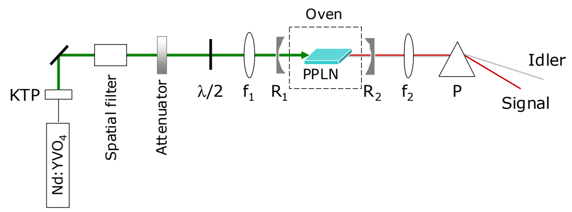


- **Determined from this experiment:** $t_c \approx$ 0.25 ms
  Consistent with our theoretical value based on *Kamada, Matsunaga, Yoshino, Ohta (2003)*:

$$t_c = w_0^2 c\rho / 8\sigma \approx 0.256\,ms$$

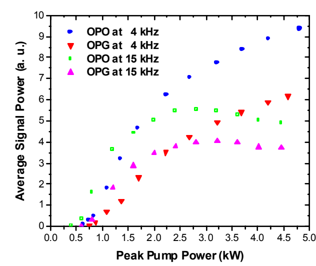
for $w_0 \approx$ 63 μm, $c \approx$ 648 $Jkg^{-1}K^{-1}$, $\rho \approx$ 4.628 gcm^{-3}, $\sigma \approx$ 5.6 $Wm^{-1}K^{-1}$

Experimental Setup for OPO



- R_1 & R_2 – concave mirrors
  Reflectivity ≥ 99% @ signal wavelengths
  Radii of curvature ≈ 50 mm
- **Cavity length** ≈ 100-150 mm

Comparison of Threshold Powers for OPG & OPO



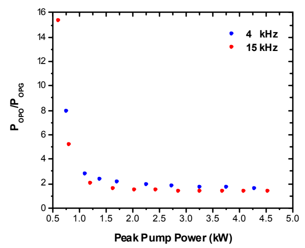
- 0.76 kW for OPG vs. 0.63 kW for OPO

Theoretical Threshold for OPO

$$I_{th} = \frac{\lambda_s \lambda_i n_s n_i n_p (1 - R_1 R_2)}{2\pi^2 \eta_0 d_{eff}^2 L^2}$$

- For $R_1 \approx R_2 \approx$ 80%, $\lambda_s \approx$ 640 nm, $\lambda_i \approx$ 3.10 μm, $d_{eff} \approx$ 17 pm/V, $L \approx$ 5 cm, $I_{th} \approx$ 138 kW/cm², $P_{th} \approx$ 0.172 kW – much lower than measured value (0.63 kW)
  - ➔ Number of round trips for signal beam – reduced due to short pulse duration of pump beam (~ 2.5 ns)
  - ➔ Large absorption losses, especially TPA, – not included

Comparison of Signal Powers for OPG & OPO



- **Signal powers inside PPLN** – a factor of 1.3–1.6 higher for OPO
- However, **output powers outside OPO cavity** – greatly reduced to microwatts due to high-reflectivity output coupler

Conclusion

- **OPG & OPO** – investigated when TPA for pump beam – very strong
- **532-nm-pumped OPO** inherently has high threshold due to large absorption losses, especially TPA
- **OPG** becomes more efficient than **OPO** for generation of signal wavelengths in visible range
- **OPG & OPO** – dramatically modified by TPA
- **Effective TPA** – significantly enhanced by ATE
- To reduce TPA & ATE, **pump repetition period** – longer than characteristic time constant for heat dissipation

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