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Tunable Intracavity Up-Converted Optical Parameteric Oscillator by Cascaded Adiadbatic Sum Frequency Generation

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We experimentally demonstrate efficient tunable up-conversion by cascading optical oscillation and wide-band adiabatic sum frequency generation in a single nonlinear crystal, yielding red light tunable over a 6.2nm wavelength band.

OCIS codes: 190.4223 Nonlinear wave mixing; 190.4970 Parametric oscillators and amplifiers

1. Introduction

Tunable and efficient up-conversion of laser radiation is an enabling technology for spectroscopy, interferometry, biosensing, etc. However, suggestions for the realization of such devices [1,2] have so far required a tunable pump laser, multiple crystals, mechanical tuning and compromise for efficiency and tuning range. By applying cascaded optical parametric oscillation (OPO) and adiabatic sum frequency generation (SFG) we achieve an efficient temperature-tuned up-converter realized in a single crystal and pumped by a fixed-wavelength laser.

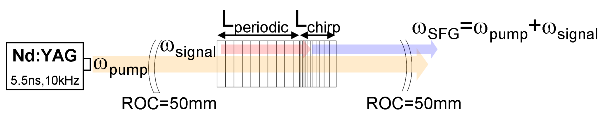
2. Design

Our nonlinear crystal is composed of two cascaded segments, as portrayed in fig. 1a: the first segment, of length $L_{periodic}$, is periodically poled to phase-match an OPO process. The second segment, of length L_{chirp}, is poled with a linear chirp in order to phase-match SFG of the pump and OPO signal over a large wavelength band of the signal. The chirped segment was constructed to allow adiabatic SFG as described by Suchowski et al. [3], which results in an efficient and robust conversion for a broad spectral range. To produce an adiabatic passage from the signal to the SFG product, the phase-mismatch parameter should vary slowly along the propagation axis, from a large negative phase-mismatch value to a large positive one. For this purpose we use a linear chirp poling that conforms to the adiabaticity condition

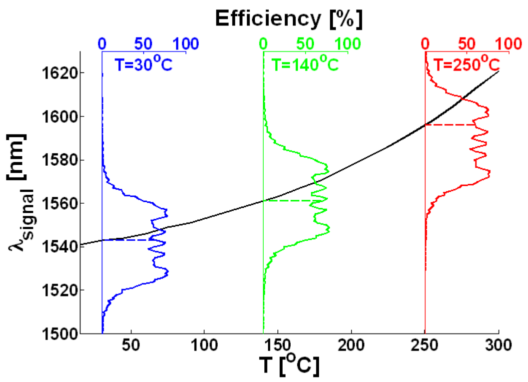
$$\frac{d(\Delta k_{SFG})}{dz} \ll \frac{(\Delta k_{SFG}^2 + \kappa^2)^{3/2}}{\kappa} \tag{1}$$

where $\kappa = \frac{8\pi\omega_s\omega_{SFG}}{(k_s k_{SFG})^{1/2}c^2} d_{eff} E_p$ is the coupling coefficient, Δk_{SFG} is the SFG process phase-mismatch, $\omega_s, \omega_{SFG}, k_s$ and k_{SFG} are the frequencies and propagation constants of the signal and SFG product, respectively, c is the velocity of light, d_{eff} is the effective second order nonlinear coefficient of the crystal, and E_p is the pump amplitude.

For the design, we used a 35mm long KTP crystal whose nonlinear coefficient was modulated by electric field poling – the first 27.5mm were periodically poled with a period of $35.6\mu m$ for the OPO process and the remaining

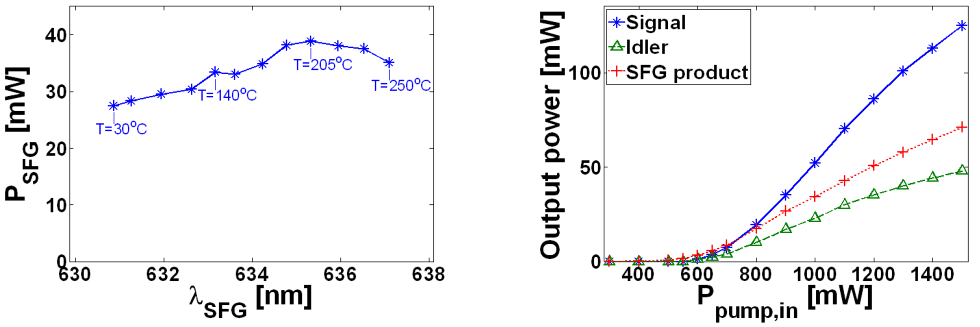


(a) Setup and crystal structure.



(b) OPO signal tuning (black) with temperature and adiabatic SFG signal-to-SFG product conversion efficiency (blue, green and red) for pump intensity of $50\frac{MW}{cm^2}$ in the chirped segment, for various crystal temperatures.

Fig. 1. Setup, crystal structure and simulation results.



(a) SFG product average output power when the crystal is pumped with 1W and the crystal temperature is tuned from 30^oC to 250^oC.

(b) Signal (solid blue line with stars), idler (green dashed line with triangles) and SFG product (red dotted line with crosses) average output power vs. average input pump power at $T = 250^oC, \lambda_{SFG} = 637.1nm$.

Fig. 2. Experimental results.

7.5mm were poled with a linearly chirped grating varying from 15.11 to $15.39\mu m$. The crystal was placed in a 55mm long linear cavity as described in fig. 1a, that resonated only the signal wave. The OPO signal and idler wavelengths were designed to tune in the range $\lambda_s = 1543nm - 1596nm$ and $\lambda_i = 3197nm - 3433nm$ by temperature tuning of $30^oC - 250^oC$. The corresponding wavelengths tuning range of the product of the SFG process between the $\lambda_p = 1064.5nm$ pump and the signal is $\lambda_{SFG} = 629.92 - 638.58nm$. We used Fradkin et al. [4] and Emanueli et al. [5] Sellemeir equations to account for the wavelength and temperature dependence of KTP refractive index. Even for a highly depleted and absorbed pump, with remaining peak intensity of $50\frac{MW}{cm^2}$ in the chirped segment, our simulation predicts 55-80% signal-to-SFG product conversion efficiency over the entire tuning range, as can be seen in fig. 1b. Using these experimental parameters, we assured that the adiabaticity criteria holds.

3. Experiment

Fig. 2a shows the average output power of the SFG product vs. its wavelength as the crystal temperature is tuned from 30^oC to 250^oC and average pump power is kept constant at 1W. It can be seen that pump-to-SFG product conversion efficiency is 2.7-3.9% over the entire tuning range of the OPO, yielding tunable red light over a 6.22nm wavelength band, thus demonstrating the robustness of our scheme. Fig. 2b depicts the average output power of the signal, idler and SFG product vs. average input pump power when the crystal temperature is 250^oC and $\lambda_{SFG} = 637.1nm$. SFG product power scales quickly with input pump power, reaching 4.7% pump-to-SFG product conversion efficincy at $P_{pump} = 1.5W$, suggesting higher efficiency for higher pump power. The tradeoff is the $\sim 600mW$ OPO threshold , a high value resulting from linear losses and nonlinear conversion losses along the chirped segment.

4. Summary

To conclude, we have shown experimentally for the first time an efficient temperature-tuned up-converter realized in a single crystal and pumped by a fixed-wavelength laser. Tunable pump up-conversion into a wavelength range of 6.22nm in the red wavelength band with efficiencies up to 4.7% has been obtained. Wide-band up-conversion efficiency was achieved by using optical paramteric osciallation in cascade with adiabatic SFG, realized by linear chirp poling. This scheme has the advantages of simplicity, compactness and robustness over previous configurations, while maintaining high conversion efficiency and wide tuning range.

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