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Simultaneous oscillation of dual optical parametric oscillators on monolithic chi(2) nonlinear photonic crystals

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Abstract. Simultaneous oscillation of two pairs of signals and idlers was demonstrated. We also showed the efficiency of the sum frequency generation of two idlers was comparable with second harmonic generation of each idler. Our design shows the potential of building multi-wavelength laser source from UV to NIR on monolithic crystal.

Introduction

The quasi-phase matching (QPM) technique of nonlinear photonic crystals (NPCs) has great potential to build frequency conversion lasers [1]. Wavelength-tunable lasers based upon parametric down conversion and optical parametric oscillation (OPO) have been reported by using nonlinear optical (NLO) crystals and QPM NPCs [2, 3]. Further, in the regime of multi-wavelengths OPO, Walter et al. had studied the spectral dynamic behaviours on apodized aperiodically poled lithium niobate [4]. However, the latter spectra exhibited unequal power distribution because of gain competition and the cascaded effect in increasing the threshold for the second OPO. To extend the spectral coverage of multi-OPOs, we proposed a simple design of QPM architectures to facilitate multi wavelengths in a linear cavity.

In this paper, we demonstrated the design, and the optical characterization of weaving-like QPM NPCs which can facilitate dual-OPOs in parallel and cascaded NLO processes of second-harmonic generation (SHG) and sum frequency generation (SFG). To deliver our idea, we assumed a confocal cavity and a NPC with two different QPM periodicities transverse to the beam propagation direction, as shown in Fig.1 We also assumed two pairs of (signal, idler) waves (λ_{s1},λ_{i1}) and (λ_{s2},λ_{i2}) which are quasi-matched to the OPOs with QPM periodicity of Λ_1 and Λ_2, respectively. According to the ray optics, the oscillation of (λ_s,λ_i) would follow the optical path marked in Fg.1. As the oscillatory waves propagated along the path of point 1 to 2, they would encounter the QPM period, Λ_1, from which the QPM condition would render the generation of (λ_{s1}, λ_{i1}). Then, from the optical path of point 2 to 3, the NLO waves would encounter both Λ_1 and Λ_2 with a tilt angle, so the phase-matching condition would be lost. Similarly, from the optical path from point 3 to 4, only λ_{s2} and λ_{i2} are phase matched. From the optical path of point 4 to 1, the QPM condition is not fulfilled. As a result, each of these two OPOs will maintain its NLO gain in the respective optical paths, thus to avoid gain competition of them.

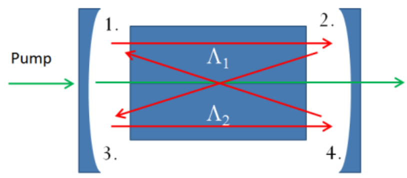

Fig. 1 the design pattern and setup of parallel OPOs

Experimental setup and results

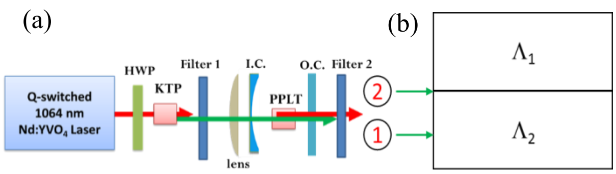

Fig. 2 (a) Experiment setup, filter 1 was to filter out the residual 1064 nm and filter 2 was to filter out the residual 532 nm (b) input beam and its entering position in the experiment

Figure 2(a) showed our experimental setup, a Nd:YVO4 laser with repetition rate of 500 Hz, pulse width of 7 ns and wavelength of 1064 nm. A half-wave plate (HWP) was used to control the polarization of the 1064 nm. A SHG- crystal of KTP was used to convert 1064 nm into 532 nm. The 532nm pump beam was focused to a planar-concave OPO cavity with beam waist radius of 200 μm. The input coupler (I.C.) had high transmittance for pump and signal but high reflectivity for idler. And the output coupler (O.C.) had high transmittance for pump and idler but high reflectivity for signal. Schematically drawn in Fig. 2(b) was the dual-OPO structure, where we chose Λ_1=7.67 μm as and Λ_2=7.66

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μm. At QPM temperature T=140 ºC, their corresponding (signal, idler) wavelengths were (972 nm, 1175 nm) and (980 nm, 1163 nm), respectively. Figure 2 (b) also illustrated a way to enable the operation of either a single- or a dual-OPO by aligning the 532nm pump beam to a proper QPM architecture in the transverse plane. Note that the beam diameter (400μm) was much smaller than the width (~3mm) of each OPO section. So, the setup was a single OPO at position ① but a dual OPO at position ②. In Fig.3 (a), we measured the optical power of the idler waves at these two positions. The corresponding thresholds were about 16 MW/cm^2 for the single OPO and about 28 MW/cm^2 for the parallel OPO, whereas their slope efficiencies were 12.9 % and 12.5 %, respectively. In Fig. 3 (b) and (c) we illustrate the idler wave spectra corresponding to the operation of single and parallel OPO. It can be found that in Fig 3 (c), the two idler waves can exhibit almost an equal optical power distribution while the respective spectral width (~5 nm) was narrower than the case of single OPO. The latter was due to a higher threshold in the operation of dual-OPO, which in turn reduces the NLO gain at the same pump power.

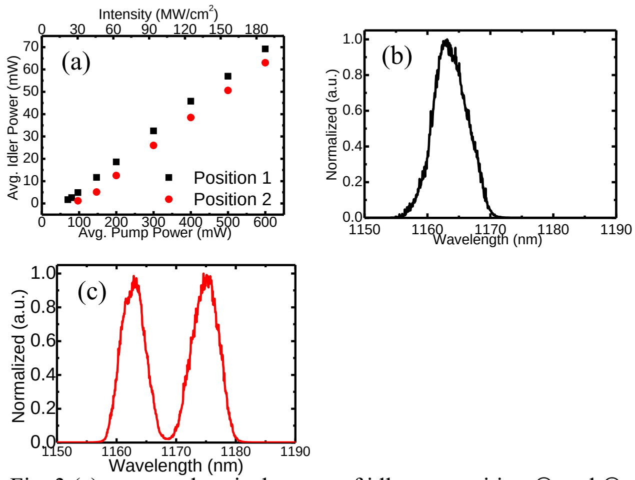

Fig. 3 (a) measured optical power of idlers at position ① and ②, spectra of idler at (b) position ① and (c) position ②

To confirm the spatial mode overlap in the (signal, idler) waves generated from the parallel OPOs, we consider an up-converted structure of QPM periodicity Λ= 10.05μm after the OPO sections in Fig. 4 (a). The formal was chosen to facilitate SFG of two idlers from Λ_1 and Λ_2 at 140 ºC and SHG of the idler from Λ_1 and Λ_2 at 137.5 and 142.5ºC. As shown in Fig. 4 (b), the respective temperature tuning curves of the idler waves for QPM periodicities Λ_1 and Λ_2 are shown to intersect with the up-conversion curve of Λ. We denote the intersection points marked with solid orange circle as the SHG processes, whereas the open orange circle as the SFG of idler 1 and idler 2. To confirm such NLO design, we changed the output coupling mirror such that idlers were locked inside the OPO cavity. Fig. 4 (c) showed the measured power of intra-cavity up-converter at 137.6 ºC and 140 ºC. The thresholds at two temperatures were near 100 MW/cm^2. The slope efficiencies were 2% at 137.6 ºC and 3% at 140 ºC. The experimental results showed that even with parallel OPO design, the two idlers could produce sum frequency generation efficiently.

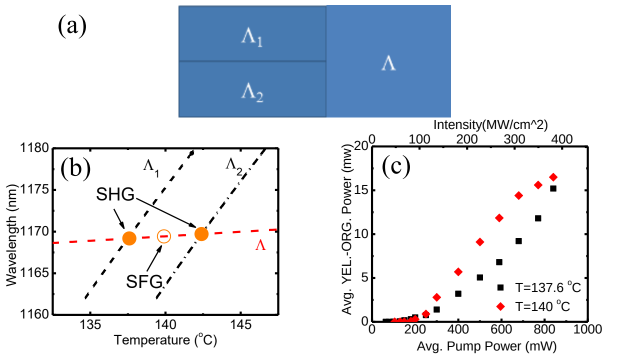

Fig. 4 (a) design pattern with additional cascaded periodicity, Λ (b) phase matching diagram of Λ_1, Λ_2 and Λ versus T (c) experimental results of intra-cavity up converter at two different temperature

Conclusion

Dual-wavelength OPO was demonstrated with periodicities arranged in parallel. Compared with a single OPO, the parallel OPOs had almost same slope efficiency but twice as large as in threshold intensity. The measured spectra and power showed that it had exactly two OPOs which were oscillated in the cavity. Furthermore, with additional cascaded periodicity behind the design, we showed that the sum frequency generation of two idlers was comparable to the second harmonic generation of each idler. This confirmed that the spatial distribution of two OPOs could be overlapped effectively in the cavity. Since our design was simply a combination of two periodicities in parallel, it would preserve the advantage of a single OPO such as wavelength tuning with temperature. Further, our design showed the potential to facilitate multi-wavelength laser from NIR to UV band on monolithic crystal.

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