Middle-infrared intracavity periodically poled $MgO:LiNbO_3$ optical parametric oscillator

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A periodically poled magnesium oxide-doped lithium niobate (5 mol% MgO:PPLN) intracavity optical parametric oscillator (OPO) pumped by a diode-pumped Q-switched Nd:YLF laser operating at 1.047 μm is reported. A broad continuous tunable middle-infrared (mid-IR) spectrum of 2.69—4.07 μm is obtained by changing the crystal grating periods from 28.5 to 31.5 μm. When the diode pump power is 8 W, the intracavity OPO operating at a repetition rate of 10 kHz produces average output power of 0.42 W, corresponding to conversion efficiency of 5.2% from the laser diode pump to OPO idler output.

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Compact tunable nanosecond pulsed laser sources in the middle-infrared (mid-IR) have widespread scientific, medical, and industrial applications. Such a laser source can be obtained by use of a diode-pumped intracavity optical parametric oscillator (OPO). Several investigations have been published[1−4]. In recent years there has been increasing interest in the use of a periodically poled lithium niobate (PPLN) with quasi-phase-matching (QPM) capability for a variety of frequency conversion applications. PPLN doped with magnesium oxide (MgO) is an important nonlinear optical material and potential candidate in OPO since it has low coercive field, greatly improved resistance to photorefractive damage threshold in contrast to the normal PPLN[5,6]. Conroy *et al.*[7] reported the performance of a compact diode pumped electro-optic Q-switched $Nd:YVO_4$/PPLN intracavity OPO. Tsai *et al.*[8] proposed a compact efficient passively Q-switched $Nd:GdVO_4$/PPLN/Cr^{4+}:YAG tunable intracavity OPO. Whereas to our knowledge, MgO-doped PPLN used in pulsed intracavity OPO has never been reported. Here we report an intracavity OPO based on a acousto-optical (AO) Q-switched Nd:YLF laser in a nearly hemispherical cavity incorporating with a multi-grating PPLN doped with MgO. The PPLN doped with MgO in the range of 4—7 mol% has more applications than the one without it. So the 5 mol% MgO-doped PPLN crystals are selected as the intracavity OPO nonlinear gain medium in this experiment. Translating the crystal across the cavity allowed pump beam interaction with the different grating regions, providing wavelength tuning in the range of 2.69—4.07 μm with no cavity re-alignment required. With incident pump power of 8 W, the intracavity OPO operating at 10 kHz produces an average output power up to 0.42 W with a pulse width of 20 ns.

A schematic of the experimental setup for an actively Q-switched intracavity MgO:PPLN OPO laser is shown in Fig. 1. A multi-grating 5 mol% MgO-doped PPLN (from HC Photonics) is used to avoid photorefractive damage to the crystal at room temperature[5]. Its dimension is $50 \times 8.2 \times 1$ (mm) with seven different grating periods from 28.5 to 31.5 μm in 0.5-μm increment to generate idler wavelengths covering the 3—4 μm spectral range. Both end facets of the MgO:PPLN were polished and antireflection (AR) coated at 1.064, 1.44—1.605, and 3.16—4.07 μm. The reflectivities at 1.064 μm and between 1.4 and 1.71 μm were less than 1%, increased to 4% at 2.1 μm, decreased to 1% at 2.6 μm, and increased to about 10% at 3.5 μm. The parametric interaction requires all polarizations have the electric field vector parallel to the z axis to access the largest component of the nonlinear coefficient tensor. The crystal was temperature-stabilized at 25 °C. In our experiment, the OPO resonator configurations were based on the coupled-cavity in which the resonators for the signal and pump light were separated. The singly resonant oscillator (SRO) OPO cavity consisted of a linear cavity and MgO:PPLN crystal, and OPO cavity length was about 60 mm. The input mirror (IC) was coated with high reflectivity (HR) at the signal light of 1.46—1.55 μm, high transmission (HT) at 1.047 μm and idler light of 3—4 μm. The output coupler (OC) with 100-mm radius-of-curvature had a HT coating at idler light and a HR coating at the pump light and signal light. A broadband filter (M1) with 3-μm cutoff wavelength is used to block residual pump light.

The laser cavity was formed by a Nd:YLF crystal, acousto-optical (AO) Q-switch, and two mirrors. The laser cavity length was about 110 mm. The active medium was an a-cut 0.6 at.-% Nd:YLF crystal with a length of 10 mm. One side of Nd:YLF crystal as the input mirror had HT coating at 792 nm and HR coating at 1047 nm. The other side was coated AR at 1047 and 792 nm. The laser crystal was wrapped with indium foil and mounted in water-cooled copper blocks. The water temperature was maintained at 25 °C. The AO Q-switch

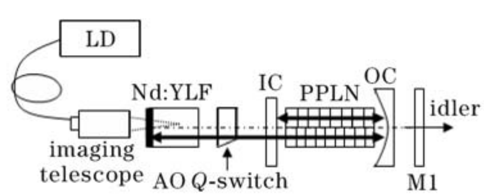

Fig. 1. Schematic diagram of the experimental setup for an intracavity MgO:PPLN OPO.

was a $18 \times 6 \times 13$ (mm) ZF6 glass, driven by an 8-V electric power supply. The pump source was a 25-W 792-nm fiber-coupled laser diode with a core diameter of 200 μm and a numerical aperture of 0.2. Two focusing lenses with 25- and 40-mm focal lengths were used to re-image the pump beam into the laser crystal. The pump spot radius was around 160 μm.

Figure 2 shows the average output power at 3.4 μm with respect to the diode pump power. The average output power reached 0.42 W, and the pulse repetition rate was 10 kHz with diode pump power of 8 W. The threshold power and the conversion efficiency from diode input power to OPO idler output power were 3 W and 5.2%. The low efficiency is attributed to the loss of reflection from the crystal and mirrors, and the absorption in PPLN. The pulse temporal behavior at 3.4 μm was recorded by a digital oscilloscope (300-MHz bandwidth) with a fast photovoltaic HgCdZnTe detector. Figure 3 shows the typical temporal shapes for the laser and idler pulse. The relatively short idler pulse indicates that the OPO effective cavity dumps the laser energy. In addition, we found that the temporal characteristics of the present cavity highly depend on the laser alignment. Since the OPO and laser resonator have different longitudinal mode spacings in the coupled cavity, generally one longitudinal laser mode is utilized to pump the OPO and only one idler longitudinal mode is built up.

The generated wavelengths were measured with a 300-mm focal length WDM1-3 monochromator (0.8-nm nominal resolution) and an InS detector. Figure 4 shows the change of signal and idler wavelength with grating period at room temperature. The continuous tunable idler range of 2.69—4.07 μm and signal of 1.41—1.71 μm are obtained. The theoretical results (solid curve) from the

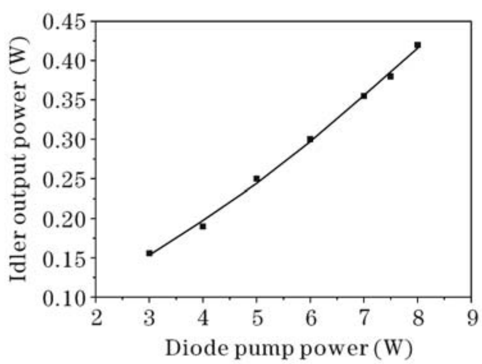

Fig. 2. Idler output power at 3.4 μm versus the diode pump power.

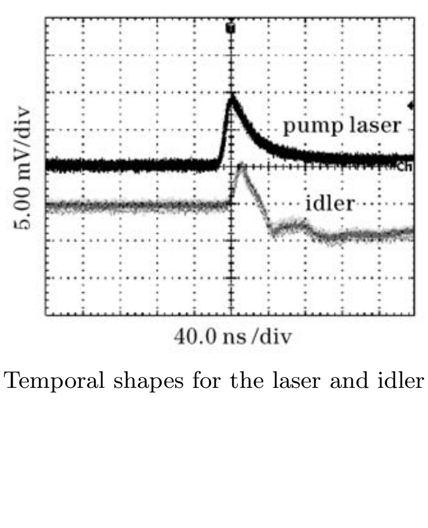

Fig. 3. Temporal shapes for the laser and idler pulses.

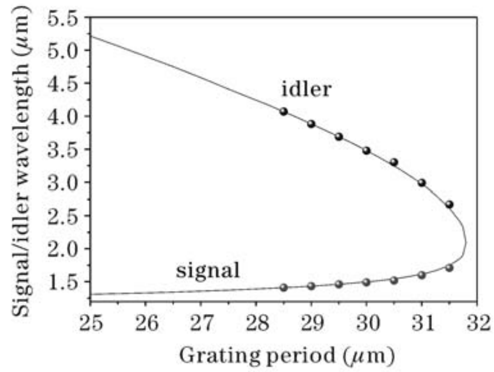

Fig. 4. Signal and idler wavelengths versus grating period at room temperature.

Sellmeier equation[9−11] are in good agreement with the experimental results (dots).

In summary, a singly resonant pulsed MgO:PPLN intracavity OPO pumped by a diode-pumped actively Q-switched Nd:YLF laser has been demonstrated. 5 mol% MgO-doped PPLN crystal used in the experiment is 50 mm long with multi-grating periods from 28.5 to 31.5 μm. The intracavity OPO device is tuned by translating the crystal through the resonator and the pump beam with no realignment needed. A broad continuous idler spectrum of 2.69—4.07 μm is obtained by changing the crystal periods. With an 8-W diode pump power, idler output power of 0.42 W at a repetition rate of 10 kHz is achieved. The conversion efficiency from diode laser power to OPO idler output power is up to 5.2%. Experimental results show that PPLN doped with MgO allows a relatively high energy intensity than the normal PPLN. These results are an initial discuss for the realization of mid-IR in MgO:PPLN intracavity OPO.

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