Optics & Laser Technology 44 (2012) 1214–1218

Contents lists available at SciVerse ScienceDirect

Optics & Laser Technology

journal homepage: www.elsevier.com/locate/optlastec

Cascaded continuous-wave singly resonant optical parametric oscillator pumped by a single-frequency fiber laser

L. Liu*, X. Li, T. Liu, X.J. Xu, Z.F. Jiang

College of Optoelectric Science and Engineering, National University of Defense Technology, Changsha, Hunan 410073, China

ARTICLE INFO

Article history:
Received 11 December 2011
Received in revised form
11 January 2012
Accepted 11 January 2012
Available online 1 February 2012

Keywords:
Optical parametric oscillator
Continuous-wave
Terahertz

ABSTRACT

We present a cascaded continuous-wave singly resonant optical parametric oscillator (SRO) delivering idler output in mid-IR and terahertz frequency range. The SRO was pumped by an ytterbium-doped fiber laser with 27 W linear polarization pump powers, and based on periodically poled $MgO:LiNbO_3$ crystal (PPMgLN) in two-mirror linear cavity. The PPMgLN is 50 mm long with 29.5 μm period. The idler power output at 3811 nm was obtained 2.6 W. The additional spectral components that have been attributed to cascaded optical parametric processes are described at increasing pump levels. Besides the initial signal component at about 1476.8 nm, further generated wavelengths with frequency shifts about 47 cm^{-1}, 94 cm^{-1} and 104 cm^{-1} were observed. It was speculated that the idler waves lie in the terahertz (THz) domain from the observed results.

1. Introduction

In recent years, the development of tunable continuous-wave (CW) terahertz (THz) sources is of great interest for applications such as security [1], high-resolution spectroscopy [2], THz imaging [3], and so on. One approach to obtain this radiation is the nonlinear-optical methods. The monochromatic CW terahertz radiation from difference frequency generation (DFG) has been employed [4,5]. Though DFG is the most commonly used method to obtain THz radiation by means of nonlinear optics, parametric oscillation has better conversion efficiency and enables to simplify significantly the system configuration since only one single frequency laser source and a single nonlinear crystal are used. Recently Kiessling et al. reported a novel approach for CW THz-wave generation employing the cascaded phase-matched optical parametric processes in a PPMgLN OPO [6] and then demonstrate a continuous-wave optical parametric terahertz source based on a singly-resonant optical parametric oscillator with a four mirrors bow-tie cavity pumped by a CW Yb:YAG laser at 1030 nm [7].

In this paper, we present a cascaded two-mirror line cavity CW singly resonant optical parametric oscillator (SRO) pumped by an ytterbium-doped fiber laser at 1064 nm based on a single PPMgLN crystal delivering idler wave in the mid-infrared and terahertz range. The cascaded optical parametric oscillations are detected via the measurement of resonant signal spectrum. The results indicate that the CW terahertz waves can be generated from this scheme through cascaded optical parametric oscillations which may serve as a useful THz source.

2. Experimental configuration

A schematic of the SRO device is depicted in Fig. 1. A distributed feedback (DFB) polarization maintaining Yb-doped fiber laser with 1064 nm wavelength produced by NP Photonics Corporation was followed by homemade 3 stage all-fiber amplifiers. The DFB laser line width was below the 20 kHz resolution-limit. The master oscillator power amplifier (MOPA) structured single-frequency, single-mode, plane-polarized ytterbium-doped fiber laser is constructed on our own [8]. An optical isolation at 1064 nm was inserted between the pump laser and the OPO cavity for preventing the small fraction of a percent feedback from the OPO. In the experiment, the output beam of the fiber amplifier has a nearly diffraction-limited mode quality ($M^2 \sim 1.1$). The optical attenuator, consisting of half-wave plate and polarization beam splitter (PBS), is used to match the polarizing beam splitter and vary the input fundamental power. The maximum laser power through the attenuator of one linear polarization is up to 30 W. Due to a transmission loss, a maximum linear polarization power of 27 W was available at the input to the crystal.

The pump beam was mode matched to a two-mirror line cavity with a 50 cm focal-length lens, focused to a waist radius of 66 μm with a pump focusing parameter ∼0.9, positioned at the center of the PPMgLN crystal. This experiment was carried out on 5 mol% PPMgLN crystals (HC Photonics Corp.), 50 mm in length, and a dimension of 1 mm thickness, 1 mm width, with 29.5 μm

* Corresponding author.
E-mail address: llwm0319@163.com (L. Liu).

0030-3992/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.optlastec.2012.01.015

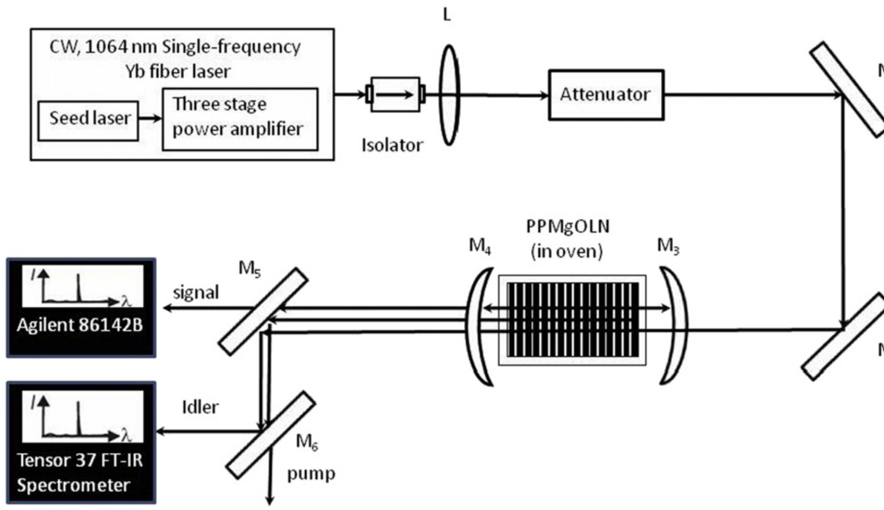

Fig. 1. Schematic of the CW line cavity OPO pumped by an Yb-fiber laser at 1064 nm: the pump source consists of a seed source and three stage fiber amplifiers. The two curved mirrors (M_3, M_4) have 100 mm radii of curvature. The lens (L) focuses the pump beam to the center of a PPMgLN crystal.

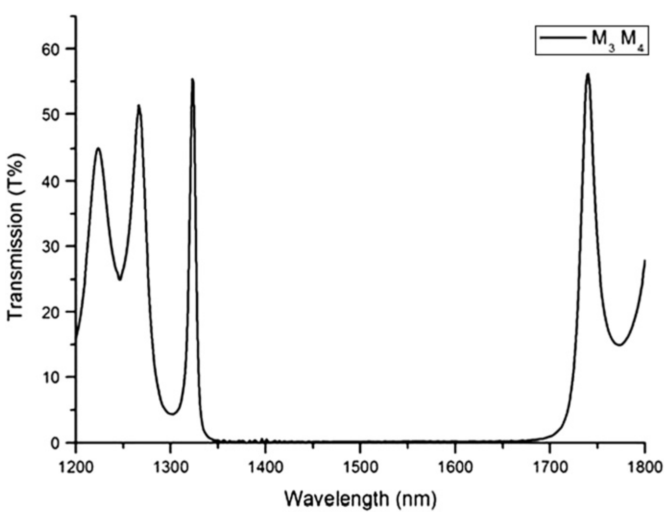

Fig. 2. Transmission curves of the two curved mirrors (M_3, M_4).

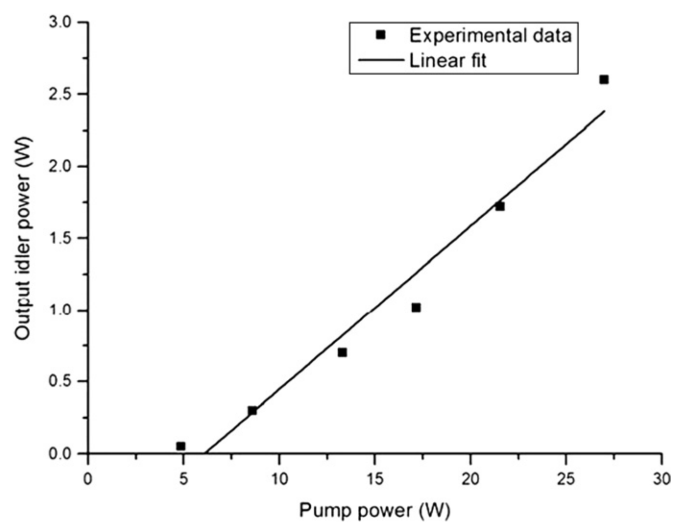

Fig. 3. Idler output power at 3811 nm versus pump power.

period of the crystal. The end surface of the PPMgLN crystal are polished and antireflection-coated at 1064 nm ($R<3\%$), 1450–1750 nm ($R<1\%$), 3000–4200 nm ($R<4.5\%$). The crystals are mounted in a temperature controlled oven for tuning capability. The linear cavity consists of two convex–concave mirrors (M_3, M_4). The substrates of convex–concave mirror are CaF_2. Singly resonant oscillation is achieved by use of mirrors with high reflectivity for the signal wave ($M_{3,4}$, $R>99.8\%$@ 1.4–1.6 μm) and transmission for the pump ($M_{3,4}$, $T>90\%$@1.064 μm) and idler waves ($M_{3,4}$, $T>98\%$@3.3–4 μm). The radius of convex–concave mirror is 100 mm. The spacing between the convex–concave mirrors is 100 mm. The transmission curves of the two curved mirrors (M_3, M_4) were shown in Fig. 2.

3. Experimental results and discussion

We obtained 2.6 W idler power output at 3811 nm under the pump power of 27 W after the filter M_6, in Fig. 1, corresponding to a $\sim$10% conversion efficiency from the pump to the mid-infrared idler radiation at the room temperature. The threshold is measured to be 5 W. By adjusting the pump laser power onto the OPO through the attenuator, we measured the idler output power after the filter M_6, versus the pump laser power of the OPO, which is shown in Fig. 3. The output power saturation of 3811 nm laser does not appear, so it is possible to obtain higher output power with higher pump power.

We also observed the spectrums of the signal wave (measured with Agilent 86142B) and the mid-IR idler wave (measured with Bruker tensor 37 FT-IR Spectrometer) of the OPO at the room temperature. The measured spectra of the resonant field under three pump power levels shows in Fig. 4(a) to (c).

We measured the idler spectrum with pump power of 26.9 W, as shown in Fig. 4(d). A typical signal spectrum can be seen in Fig. 4(a). The initial signal wave (λ_{s1}) of the initial parametric oscillation was centered at 1476.7 nm. With the increase of pump power, more additional components arose with frequency shifts ($\Delta\nu_1$, $\Delta\nu_2$, $\Delta\nu_3$) of 47 cm^{-1}, 94 cm^{-1} and 104 cm^{-1} with respect to the initial signal wavelength, respectively. The newly generated spectral components red-shifted from the initial signal frequency were attributed to Raman scattering processes [9], [10], however, no optical phonons with frequencies below the prominent value of 250 cm^{-1} have been identified in lithium niobate [11]. Kiessling et al. [6] have reassigned them to cascaded optical parametric processes and Sowade et al. [7] verified the