Quantum Electronics **49** (2) 115–118 (2019)

https://doi.org/10.1070/QEL16830

Intracavity sum-frequency generation of a 795 nm pulsed laser with a short pulse width based on two MgO : PPLN crystals

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Abstract. **We report a 795 nm tunable pulsed laser with intracavity sum-frequency generation (SFG) based on an optical parametric oscillator (OPO) pumped by a 1064 nm laser. The cavity consists of two periodically poled MgO : PPLN crystals, the periods of which are 22.0 and 31.0 μm. The crystal with the period of 31.0 μm is used to generate a mid-IR beam, while the other crystal is used for SFG of the pump beam and the mid-IR beam. The pulsed width of the 795 nm laser is 3.6 ns, and the repetition rate of the laser is 35.3 kHz. The peak power of the laser is 2.8 kW with a linewidth of 0.35 nm. The 795 nm laser threshold pump power is 1.4 W and the optical-to-optical efficiency of 1064 nm to 795 nm is 5.7% at a maximum output power. The laser is supposed to be a kind of a competitive near-IR laser source for studying a diode-pumped rubidium laser.**

Keywords: *sum-frequency generation, periodically poled structure, optical parametric oscillator, alkali laser, surrogate laser.*

1. Introduction

A pulsed near-IR laser (700–900 nm) can be used as a surrogate laser source for diode-pumped alkali lasers (DPALs). Nowadays, such sources are usually alexandrite lasers, Ti : sapphire lasers and dye lasers [1–3]. Nonlinear optics gives another way to approach the desired wavelength. Quasi-phase-matching (QPM) in periodically poled crystals is one of the effective methods to produce optical parametric oscillators (OPOs). Especially, MgO-doped periodically poled lithium niobate (MgO : PPLN), which has a large second-order nonlinear coefficient (d_{33}), is a typical example of a QPM crystal [4]. It has a wide transparency range (0.35 to 5 μm) and a large degree of homogeneity. MgO : PPLN-based OPOs pumped by a 1064 nm Nd^{3+}-doped laser can efficiently generate mid-IR output from 2.4 to 4.2 μm [5, 6]. By sum-frequency generation (SFG) of the idler beam with the IR pump laser, the wavelength can be tuned from 737 to 845 nm. In 2012, Kavita Devi et al. [7] reported a continuous-wave laser, the tunable range of which is from 775 to 807 nm. MgO : PPLN crystal and MgO-doped stoichiometric periodically poled lithium tantalite (MgO : SPPLT) are used for the OPO and the SFG, respectively. The optical-optical efficiency of the 1064 nm laser output to near-IR laser output is about 11.8% with a threshold pump power of 7.5 W.

Among the SFG crystals, MgO : PPLN has been proved to be of high efficiency and simple cavity configuration. In 2015, an output efficiency of 8.0% at 522 nm for SFG has been reported by Tae-Young Jeong et al. [8]. Taking into account the fact that the MgO:PPLN crystals can be simultaneously used for OPO and SFG, an OPO/SFG laser can be realised by using a single MgO : PPLN. In 1998, a kind of an OPO/SFG laser based on a single PPLN was reported by Walter et al [9]. They obtained 2.5 W, continuous-wave (cw), 629 nm laser pulses by SFG of a 1064 nm laser with the signal beam. The optical efficiency and threshold pump power were 21.2% and 6.3 W, respectively. In 2014, Simon Mieth et al. [10] reported a cw tunable red laser with an output power of > 1 W and optical efficiency of 11.5% based on a piece of a MgO : PPLN crystal. The corresponding threshold pump power was 8 W. Both crystals of the above OPO/SFG lasers contained two stages. One stage was used to generate the signal beam with a tunable wavelength from 1386 to 1445 nm through OPO and the other stage was used for SFG of the pump beam and the signal beam.

However, the lasers described above run in cw mode, while the surrogate laser for a DPAL should operate at a short pulse width and a high peak power. The lifetime of the upper level of the DPAL is usually dozens of nanoseconds, and therefore a short pulse width will take advantages in simulating the propagation of the DPAL.

In this paper, we describe a compact OPO/SFG laser, which through intracavity SFG of the pump beam with the idler beam generates 795 nm output with a low threshold and a short pulse width. The laser is a surrogate laser for a rubidium DPAL.

2. Experimental setup

The experimental setup is shown in Fig. 1. The pump source is a master oscillator–power amplifier laser with a wavelength of 1064 nm and an M^2 factor of 1.2. The repetition rate and pulse width of the laser is 35.3 kHz and 5.8 ns. After beam shaping with an inversed telescope, the 1064 nm laser output is injected into the cavity. The diameter of the focal spot is 0.76 mm. There are two pieces of 5%-MgO-doped MgO : PPLN. The 1064 nm laser output plays two roles in the cavity. One

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Received 30 September 2018; revision received 22 October 2018
Kvantovaya Elektronika **49** (2) 115–118 (2019)
Submitted in English

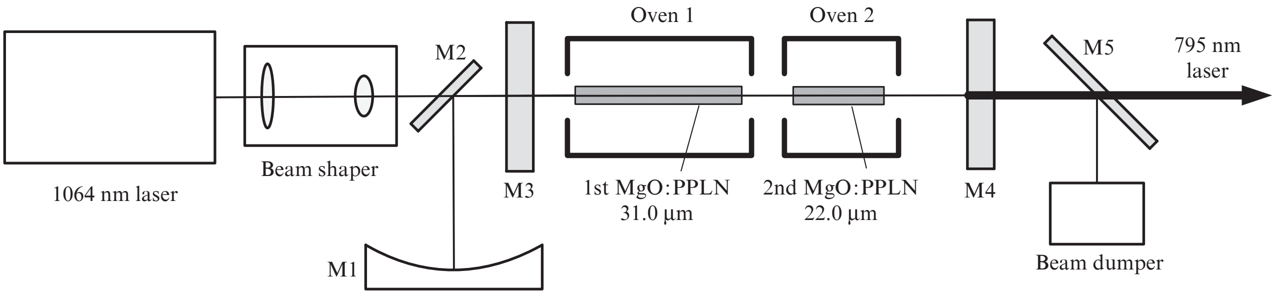

Figure 1. Experimental setup.

role is pumping the MgO:PPLN crystal in order to generate mid-IR laser output based on OPO. The other role is offering photons for SFG. The periods of the crystals are 31.0 µm (1st MgO:PPLN) and 22.0 µm (2nd MgO:PPLN) at room temperature. The phase-matching types of the two crystals are $\boldsymbol{e \rightarrow e + e}$ and $\boldsymbol{e + e \rightarrow e}$. The first MgO:PPLN crystal is used to generate the mid-IR laser output ($\omega_{1064} = \omega_{1610} + \omega_{3145}$). The size of the periodically poled structure is 2 × 2 mm. The length of the crystal is 50 mm. The facets are antireflection coated at 1064 nm and in the range from 1600 to 4000 nm. The second MgO:PPLN crystal is used for SFG of the 1064 nm beam with the idler beam ($\omega_{1064} = \omega_{1610} + \omega_{3145}$). The size of the periodically poled structure is 2 × 1 mm. The length of the crystal is 25 mm. The facets are antireflection coated at 795 nm, 1064 nm, and in the range from 1300 to 1700 nm and 3000 to 4000 nm. The temperatures of both crystals are controlled with accuracy of 0.1 °C.

The plane-concave resonate cavity consists of four mirrors: M1 is a highly reflecting mirror ($R > 99.8\%$) at a wavelength of 795 nm; M2 is a dichroic mirror with an incident angle of 45°, which is antireflection coated at 1064 nm and high-reflection coated at 795 nm ($R > 99.8\%$); M3 and M4 are plane mirrors high-reflection ($R > 99.5\%$) coated in the wavelength range of 3000–3600 nm and 1300–1600 µm, and antireflection coated a the wavelength of 1064 nm ($T > 99.0\%$). Mirrors M3 and M4 form the OPO cavity with a length of 12 cm. Since both mirrors have high reflectivity at signal and idler wavelengths of the OPO, the mid-IR photons can be generated with a low threshold. The SFG resonator consists of M1 and M4. The optical length between M1 and M4 without other optical components is 18 cm. The reflectivity of M4 at 795 nm is 30%. The radius of curvature of M1 is 200 mm. M5 is a filter which is used to separate the 795 nm laser radiation from the output light.

3. Results

Before SFG, the characteristics of the first MgO:PPLN crystal are tested. At a temperature of 51.8 °C, there arises coherent output at a wavelength of 3145 nm. By tuning the temperature of the second crystal, we can obtain 795 nm laser output through SFG. The output power at different temperatures of the second crystals with a pump power of 6.8 W is shown in Fig. 2.

We can see from Fig. 2 that the optimal temperature is 40.3 °C. When the temperature is lower than 35 °C, there are many peaks in the spectrum of the 795 nm laser output and the power decreases dramatically. The power is only 19.5% of the maximal power when the crystal temperature decreases by 5 °C below the optimal temperature. To explain this phenomenon, we measured the spectra at different crystal temperatures. Typical spectra at different temperatures are shown in Fig. 3. One can see that the wing of the spectrum contains many peaks. Although there is a single peak in the temperature range from 35.0 to 45.0 °C, the centre wavelength is shifted by adjusting the crystal temperature. The shift rate is approximately 50 pm °C^{-1}. Generally, these phenomena are mainly caused by the scattering and linewidth of the seed light.

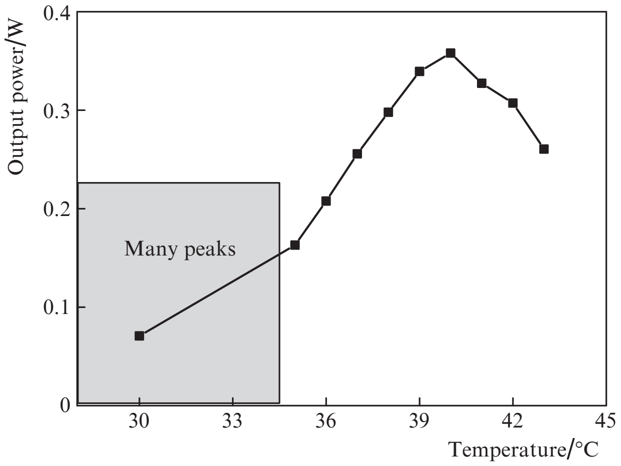

Figure 2. Output power vs. temperature of the second MgO:PPLN crystal.

When the temperatures of the first crystal and the second crystal are 51.8 and 40.3 °C, the curve of the 795 nm laser power versus 1064 nm power is shown in Fig. 4. As is shown in the figure, the slope efficiency is 7.2% and the threshold is 1.4 W. With a pump power of 6.8 W, the optical-to-optical efficiency is 5.7% and the averaged output power is 358 mW. Compared with the published results in work [8] and [10], the optical-to-optical efficiency is smaller. The main reason is that the facets of the first crystal are not antireflection coated at 795 nm. The reflectivity at 795 nm is approximately 35%. This will result in an additional cavity loss of the 795 nm laser output. In the future we will try to reduce the loss by depositing an antireflection coating at 795 nm on the facets of the first crystal.

It should be emphasised that the threshold pump averaged power is quite low due of the pulsed regime. The pulse shape is also shown in Fig. 4. One can see that the pulse width at a maximal output power is 3.6 ns. The corresponding peak power is 2.8 kW. At the maximal output power, the spectrum is also measured by fibre spectroscopy with a resolution of 0.02 nm. The linewidth of the 795 nm laser output is 0.35 nm.

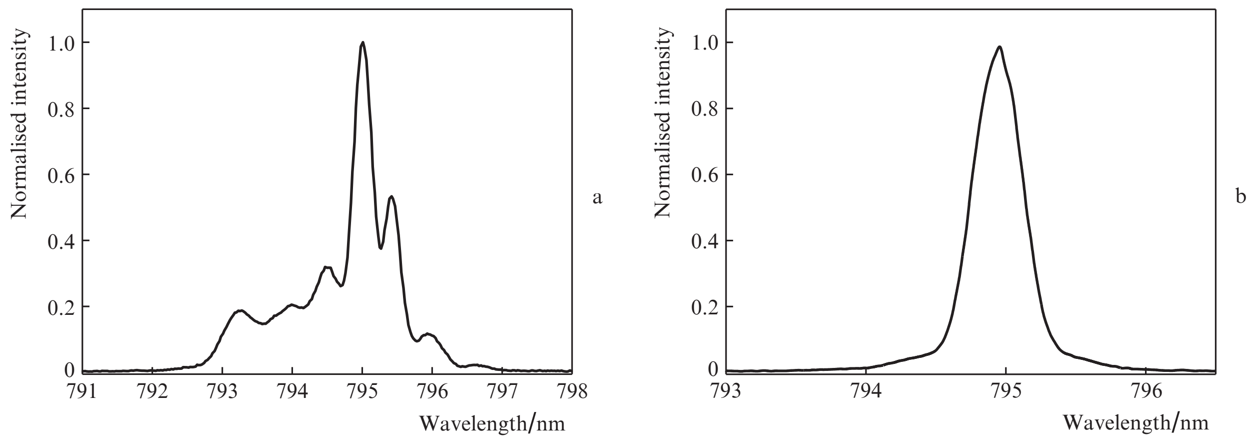

Figure 3. Emission spectra at second-crystal temperatures of (a) 20 and (b) 40 °C.

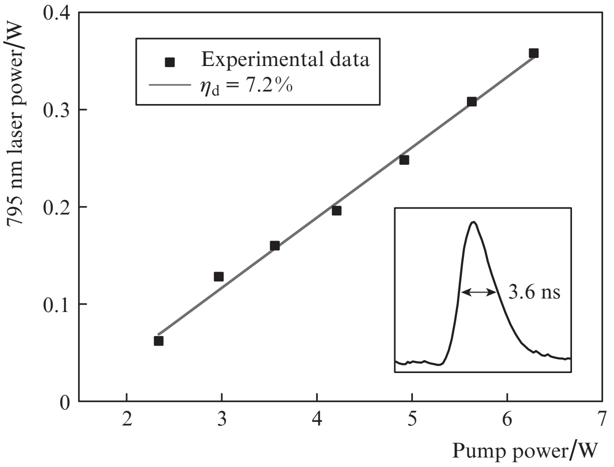

Figure 4. Output power vs. pump power. The inset shows the pulse shape at a maximal output power.

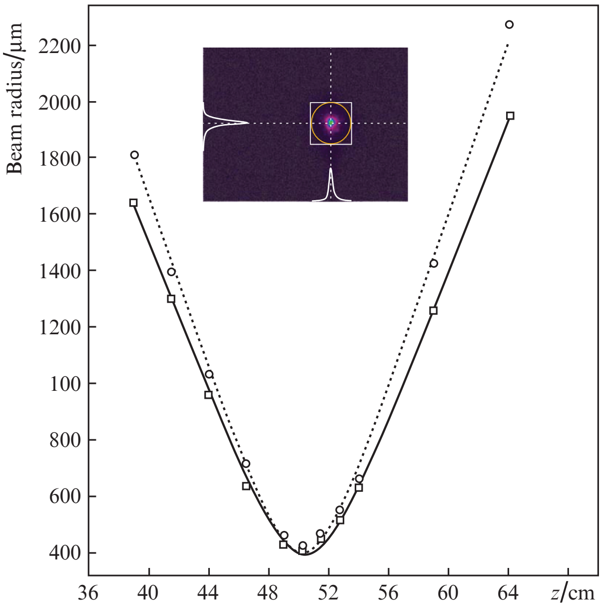

Figure 5. Beam quality and the focusing spot.

At a maximum output power, the beam quality and the focusing spot are shown in Fig. 5. The M^2 factor is 5.4 and 6.2 in the directions of x axis and y axis.

In fact, the mid-IR beam is generated through OPO. As a result, by adjusting the temperature of the first crystal, the wavelength of the mid-IR beam could be tuned. When the mid-IR beam comes to SFG with the pump beam, the centre wavelength of SFG could be changed. In the tuning of the wavelength, the temperature of the first MgO : PPLN crystal is varied based on the temperature of the second MgO : PPLN crystal. In the experiments, we obtained a centre wavelength of 797.32 nm when the temperatures of the second crystal is 75.0 °C Correspondingly, in order to obtain the best efficiency of SFG, the temperature of the first MgO : PPLN crystal should be adjusted from 51.8 to 28.0 °C. When the best efficiency of SFG is obtained, the total radiation power can remain unchanged during the tuning of the SFG wavelength.

4. Conclusions

We have designed a 35.3 kHz, 795 nm laser tunable through SFG by using two MgO:PPLN crystals. The M^2 factor is 5.4 and 6.2 in the diections of x axis and y axis. The corresponding peak power is 2.8 kW with the pulse width of 3.6 ns, while the laser threshold averaged power is 1.4 W. By adjusting the crystal temperatures, the centre wavelength can be tuned. Since this kind of laser has a high peak power and a short pulse width, the laser is supposed to be a competitive near-IR laser source for the study of a diode-pumped rubidium laser.

Acknowledgements. This work was supported by the National Natural Science Foundation of China (Grant Nos 61505212, 61775215 and 61875198) and Foundation of State Key Laboratory of Pulsed Power Laser Technology (Grant No. SKL2016KF02).

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