Intracavity-Pumped, Cascaded AgGaSe2 Optical Parametric Oscillator Tunable up to 18 μm

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Intracavity-Pumped, Cascaded $AgGaSe_2$ Optical Parametric Oscillator Tunable up to 18 µm

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Abstract: We report on a $AgGaSe_2$ optical parametric oscillator (OPO), intracavity pumped by the 1.85-µm signal pulses of a 1.064-µm pumped Rb:PPKTP OPO. It operates at 100 Hz with idler tunability from ~8 to 18 µm.
OCIS codes: (190.4970) Parametric oscillators and amplifiers; (160.4330) Nonlinear optical materials.

1. Introduction

Intracavity pumped optical parametric oscillators (OPOs) offer compact and robust design with higher pump power but cascaded or tandem schemes of this kind for down conversion of laser radiation into the mid-IR spectral range have rarely been realized [1]. The tunability of the second stage based on a non-oxide nonlinear crystal was in general limited and did not exceed 8 µm in earlier demonstrations with $ZnGeP_2$ (ZGP) [2,3]. Recently, we investigated a singly-resonant OPO (SRO) based on $AgGaSe_2$ (AGSe) intracavity pumped at 1.85 µm by the signal pulses of a Rb:PPKTP doubly-resonant OPO (DRO) which was tunable from 5.8 to 8.3 µm [4]. Here we extend this approach to an unprecedented for such schemes tuning range of ~8-18 µm by utilizing a type-II AGSe crystal.

2. Experimental set-up and Rb:PPKTP DRO performance

The set-up is shown in Fig. 1(a). Details on the pump source and the Rb:PPKTP crystal employed in the first stage can be found in [4]. The dichroic mirror DM1 is HR for the pump (P_1) radiation and HT both for signal (S_1) and idler (I_1). The ZnSe input-output coupler (IOC) is HT for P_1, HR for S_1 but not optimized (T=55%) for I_1. DM2 is HR both for the fundamental (1.064 µm) and the second-harmonic (SH) of the pump laser and HT for the s-polarized S_1 (96%) and I_1 (91%) waves. DM3 is at 50 mm from the IOC and HR for P_1 but transmits the SH. Thus a double pump pass in the Rb:PPKTP crystal is realized while the parasitic SH generated does not reach the AGSe crystal. The Rb:PPKTP DRO cavity length amounts to 101 mm (arm containing the AGSe crystal) and 88 mm (main idler I_1 beam arm). The cavity length of the AGSe SRO is 60 mm. The ZnSe output coupler (OC) is HR for the AGSe SRO signal (S_2) above 2.3 µm and transmits 76±5% in the 8-15 µm idler (I_2) tuning range.

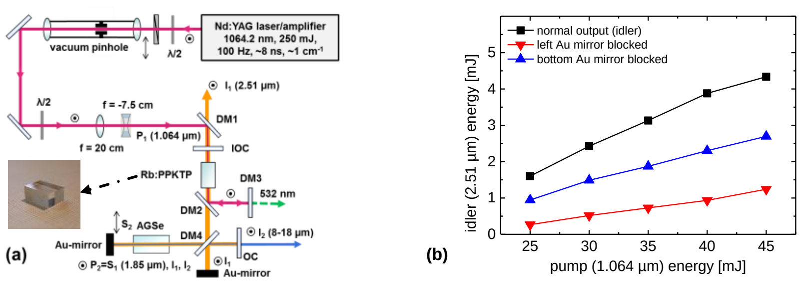

Fig. 1. Schematic of the intracavity pumped, cascaded AGSe OPO (a), and performance of the first stage (idler I_1) without the AGSe crystal (b).

The dichroic, 45° ZnSe mirror DM4 is HR for S_1=P_2 but is not optimized near 2.5 µm (I_1), where for s-polarization T~50%, and for the S_2 tuning range where for p-polarization T~75±5%. It transmits 60±10% in the 8-15 µm idler (I_2) tuning range. The performance of the Rb:PPKTP DRO with this cavity is shown in Fig. 1(b). At room temperature the signal S_1 was at 1.85 µm and the idler I_1 - at 2.51 µm. The output behind IOC consists mainly of the idler and is obviously not optimized for this configuration designed for intracavity pumping. Nevertheless, it is seen from the figure that both arms containing the Au-mirrors provide feedback for the idler I_1. The maximum I_1 output energy measured (4.34 mJ) leads to an estimate of 10.7 mJ for the intracavity S_1 energy that will be used for pumping the second AGSe stage, and P_1 (1.064 µm) depletion of 41%. With an extrapolated threshold of ~17 mJ, Fig. 1(b), the total (S_1 and I_1) internal slope efficiency reaches ~66%.

3. Performance of the AGSe SRO at 100 Hz

For long wavelength generation we employed a type-II AGSe sample (φ=0°, θ=51.3°) which exhibits higher effective nonlinearity, 15-mm long, with an aperture of 5×6 mm^2. It was AR-coated for S_1=P_2 (T=94%) but had also high transmission (T>87%) for S_2/I_1. In the I_2 tuning range we measured T>65% up to 12 µm, T~45% at 15 µm and T~5% at 18 µm due to intrinsic phonon absorption. The idler I_2 was extracted after a double pass through the crystal.

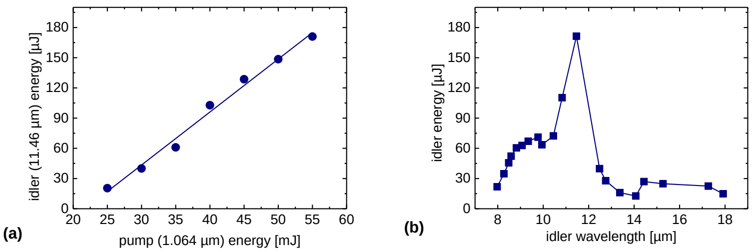

Fig. 2. Idler I_2 energy of the AGSe SRO at 11.46 µm (normal incidence, θ=51.3°) vs. pump P_1 energy at 1.064 µm (a), and angle tuning of the AGSe SRO in the mid-IR at a pump energy of 55 mJ at 1.064 µm (b).

Figure 2(a) shows the input-output characteristics of the cascaded OPO for an idler I_2 wavelength of 11.46 µm. The maximum output energy of 171 µJ obtained is roughly 15 times higher than the energy specified in [2] at the upper wavelength limit of ZGP (8 µm). In terms of average power (17.1 mW) the improvement we have achieved is ~300 times. The angle tuning results for the AGSe SRO are summarized in Fig. 2(b). Below 11.46 µm, where the feedback is enhanced at normal incidence, the behavior is determined by the increasing effective nonlinearity. Beyond 12 µm, the characteristics of the OC (both for S_2 and I_2) and the decreasing crystal transmission play a role.

Figure 3(a) shows the temporal pulse shapes measured. Since the mid-IR pulse measurement at 11.46 µm was not corrected for the 2-ns rise time of the (HgCdZn)Te detector used it can be concluded that all pulses are shorter than the 8-ns long P_1 (1.064 µm) pump. One can see the depletion of the P_2 pulse when the AGSe SRO is operating.

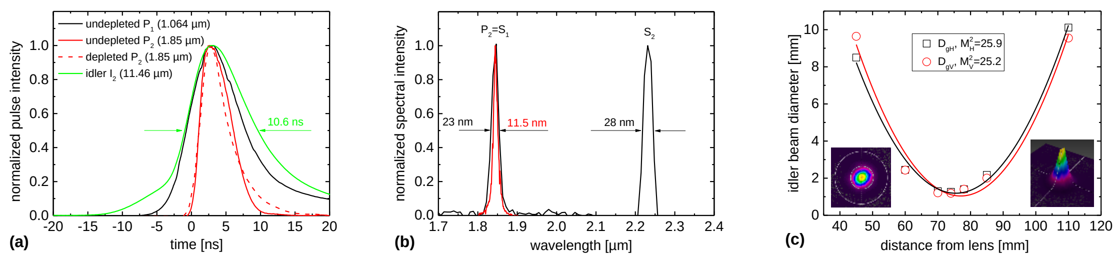

Fig. 3. Temporal shapes of the pump laser pulse at 1.064 µm (P_1), the P_2=S_1 pulse with and without the AGSe crystal, and the idler I_2 pulse at 11.46 µm (a). Low resolution spectra of the P_2=S_1 and S_2 pulses (black lines) at maximum power and high resolution spectrum of the P_2=S_1 pulse (red line) (b). M^2 measurements of the I_2 idler (11.46 µm) and its 2D and 3D beam profiles at 70 mm from the f=50 mm BaF_2 lens (insets) (c).

Figure 3(b) shows the spectra of the pump (P_2=S_1) and signal (S_2) pulses of the AGSe SRO. High-resolution spectrometer (InGaAs) was available only at shorter wavelengths yielding a FWHM bandwidth of the P_2=S_1 spectrum of 11.5 nm, roughly 2 times narrower than the 25 nm OPO bandwidth acceptance calculated for PPKTP assuming monochromatic pump. This can be explained by spectral narrowing in the Rb:PPKTP OPO. On the other hand, the measured P_2 spectral extent is ~3 times larger than the calculated pump spectral acceptance of the AGSe crystal (4 nm). By convolution of the two spectra (P_2 and S_2) one obtains a spectral bandwidth (FWHM) of 66 cm^{-1} for the idler I_2 or about 800 nm near 11 µm. Figure 3(c) shows the mid-IR idler beam profiles recorded at 45 mJ pump energy (1.064 µm) and the results of the M^2 fits by Gaussian diameters evaluated at the $1/e^2$ intensity level.

In conclusion, we studied an intracavity-pumped, cascaded AGSe OPO generating ns pulses in the 8-18 µm spectral range at 100 Hz with maximum energy of 171 µJ at 11.46 µm. Optimum idler (I_2) extraction will increase this level to ~350 µJ. Yet higher overall efficiency is expected by improved characteristics of DM4, OC, and IOC.

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