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Synchronously Pumped Mid-Infrared Ti:PPLN Waveguide Optical Parametric Oscillator

Sergey Orlov, Werner Grundkötter, Viktor Quiring, Raimund Ricken, Wolfgang Sohler

Angewandte Physik, Universität Paderborn, 33095, Paderborn, Germany
Phone : +49 5251 60 2296, Fax : +49 5251 60 3882
sol_so@physik.upb.de

Abstract: For the first time a synchronously pumped integrated optical parametric oscillator is demonstrated. It consists of a 6.8 cm long Ti:PPLN waveguide with dielectric end face mirrors. The device is pumped by a mode-locked fiber laser (10 GHz, 6.4 ps, $\lambda_p \sim 1550$ nm) and emits pulses in the mid infrared spectral range (2850 nm < λ_s, λ_i < 3350 nm).

1. Introduction

Integrated optical parametric oscillators (IOPOs) are attractive devices to generate tunable coherent radiation in a broad wavelength range with many applications mainly in environmental sensing.

In comparison to their bulk counterparts [1] IOPOs promise a lower oscillation threshold, a higher stability with respect to ambient fluctuations and spatial single mode emission. Lithium Niobate and in particular periodically poled Lithium Niobate (PPLN) to exploit quasi phase matching (QPM) proved to be the most attractive substrate material to develop IOPOs. Using Ti-indiffused waveguides very low propagation losses (down to 0.03 dB/cm in the mid infrared (MIR) spectral range) have been achieved, enabling the development of waveguide resonators of very high quality. For that reason Ti:PPLN waveguides are the preferred candidates to develop MIR-IOPOs. The state of the art of IOPOs utilizing a cw pump source has been reviewed in [2,3].

In this contribution we report the first synchronously pumped doubly resonant IOPO with 6.8 cm long Ti:PPLN waveguide resonator pumped by a Mode-Locked Laser (MLL) at a wavelength around1550 nm to generate MIR pulses in the wavelength range between 2850 and 3350 nm.

2. Sample Fabrication and Experimental Setup

Ti-doped waveguides were fabricated by diffusing 160 nm thick, 18 µm wide, vacuum-deposited Ti-stripes at a temperature of 1060 °C during 31 hrs into the surface of 0.5 mm thick and 12 mm wide Z-cut $LiNbO_3$ substrates; the stripes are aligned parallel to the X-axis. Subsequently, the ferroelectric domain pattern of a periodicity Λ of 31.44 µm was fabricated by electric field assisted poling. The waveguide propagation losses, measured by the low finesse method [4] with a He-Ne laser (λ = 3.394 µm), are in some waveguides as low as 0.03 dB/cm. External dielectric mirrors on a sapphire substrate with a reflectivity of 95-98 % for both signal and idler waves were clamped to the waveguide end faces to build the OPO resonator. Its finesse is up to 20 in good agreement with modeling results. Alternatively, dielectric mirrors were directly deposited on the polished waveguide end faces. The length of the sample is 68.05 mm to guarantee synchronous pumping with a 10 GHz mode-locked fiber laser (λ = 1.55 µm).

A schematic diagram of the experimental setup is presented in Fig. 1. A mode-locked fiber laser is used as pump source tuneable from λ = 1541 nm to 1564.5 nm. The laser emits pulses of 6.4 ps width at 10 GHz repe-

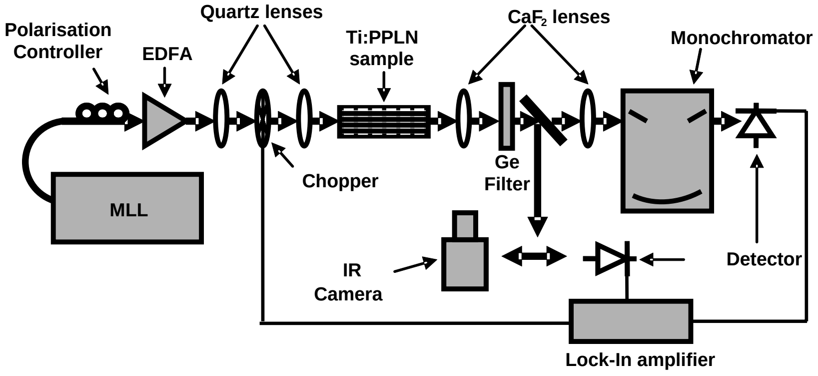

Fig. 1: Experimental setup. MLL – Mode-locked laser; EDFA – Erbium doped fiber amplifier; Detector: HgCdZnTe;

tition rate with up to 20 mW average power amplified up to 2 W by an Erbium Doped Fiber Amplifier (EDFA). A Germanium filter behind the OPO blocks the transmitted pump radiation. The polarization controller is used to adjust TM polarisation of the pump to exploit the largest nonlinear coefficient d_{33} of LN. The average power of the generated signal and idler radiation is measured with a (slow) IR detector (HgCdZnTe) using a lock-in technique. For spectral investigations a grating monochromator is used. The sample is temperature stabilized around 40 °C.

3. Results and Discussion

Optical parametric oscillation was observed above a threshold of 300 mW (average) coupled pump power (λ_p = 1554.75 nm); at 600 mW more than 4 mW of MIR (average) power was generated. Fig. 2 (left) shows the power characteristics as signal and idler (average) power plotted versus the pump power. The results of modelling calculations using the parameters as in the inset give a similar dependence, but with a lower threshold (62 mW) and higher output power (see Fig. 2 on the right).

The MIR-pulses have not yet been investigated with a fast detector nor with an autocorrelator. On the other hand, calculations predict that Gaussian pump pulses should result in nearly Gaussian signal and idler pulses of nearly the same width due to the small group velocity mismatch of the three pulses involved in the nonlinear interaction. Therefore, high MIR peak power levels can be expected (see the insets of Fig. 2, on the right, with transmitted pump, signal and idler pulses).

It was possible to tune the output wavelengths in the range of 2850 nm < λ_s, λ_i < 3350 nm by changing the pump wavelength appropriately in the range 1545 nm < λ_p < 1565 nm.

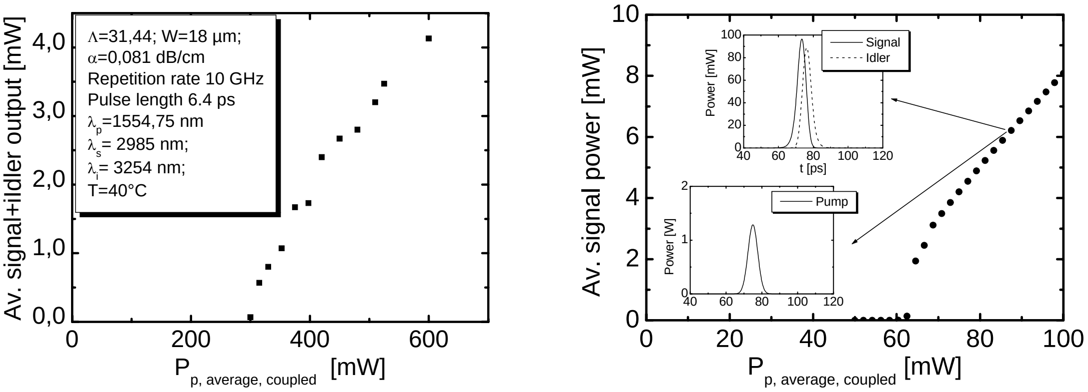

Fig.2: Power characteristics of the synchronously pumped OPO as average MIR output power versus the average pump power; parameters are given in the inset (left). Calculated power characteristics and output pulses of pump, signal and idler as inset (right).

4. Conclusions

The first synchronously pumped integrated OPO has been demonstrated generating MIR-pulses in the 3 µm spectral range; according to modelling results they should have a peak power of about 40 mW and a temporal width of about 5 ps. The comparison of experimental and theoretical OPO power characteristics demonstrates the great potential for further improvements of the device.

5. References

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