OS 4500 DC, cw-OPO: Widely tunable and narrow-linewidth radiation for near- to mid-IR spectroscopy

Frank Müller
LINOS Photonics GmbH & Co. KG, BU Laser Technology, Isartalstr. 43, D-80469 München, Germany
Email: ~~mike@rayscience.com~~

ABSTRACT: Pump-enhanced continuous-wave optical parametric oscillators (PE cw-OPOs) are commercially available since 2000. Pumped at 1064 nm, signal and idler emission ranges of 1380-2000 nm and 2280-4670 nm are achieved without changing any optics. Narrow linewidths < 10 kHz have been demonstrated so far. A special resonator design offers improved frequency tuning qualities. PE cw-OPOs have been applied in the fields of tracegas detection, molecular spectroscopy, metrology and material investigation.

Keywords: *nonlinear optics, laser spectroscopy*

1. Introduction

The development of new laser sources has been driven by many new applications and their increased requirements, namely: spectral coverage, small linewidth, tunability, power and transportability. Continuous-wave optical parametric oscillators (cw-OPOs) can meet all of these requirements. A brief description of the basic principles and an overview about the various types of OPOs can be found in [1,2]. Among these types, pump-enhanced cw-OPOs (PE cw-OPOs) are proven to be a good compromise refering to low pump threshold and the requirements mentioned above. The development of periodically poled nonlinear crystals, especially periodically poled LiNbO$_3$ (PPLN), encouraged the commercialization of cw-OPOs [3].
In 2000 LINOS Photonics presented the first commercially availlable cw-OPO, the OS 4000 [4]. It was based on a patented PE cw-OPO developed by the University of Konstanz [5]. In 2006 LINOS Photonics presented its successor, the OS 4500 [6]. Recently, a special version, OS 4500 DC, has been developed.

2. LINOS OS 4500 DC

The OS4500 is a PE cw-OPO with resonant pump and signal waves (Fig. 1). It uses MgO-doped PPLN as the nonlinear medium. A 1.2 W or 2 W cw Nd:YAG laser (linewidth ~ 1 kHZ / 100 ms, frequency-drift ~ 1 MHz / min) serves as the pump source. The OS 4500 is availlable in two different cavity designs: the standard OS 4500 and the OS 4500 DC. The OS 4500 DC can be easily converted into the standard design by its operator and so gives the opportunity to optimize the OPO performance depending on the requirements of the application. The measurements presented in this report were performed using a 2 W pumped OS 4500 DC. The wavelength was measured with a wavemeter (WA-1500, Burleigh)

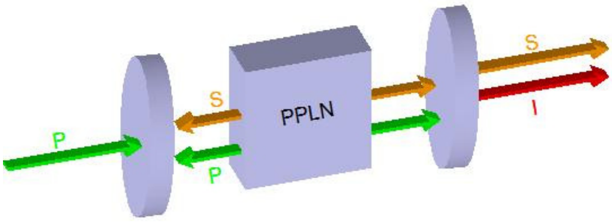

Fig. 1: PE cw-OPO

Emission spectrum:

There are two apertures for signal and two apertures for idler radiation. Figure 2 shows the emission spectrum. For this measurement, no intra-cavity etalon was installed. If an etalon is installed the emission range is limited to 1450-2000 nm (signal) and 2280-4100 nm due to additional losses for the resonant signal wave. Compared with the standard OS 4500 design the signal power is smaller.

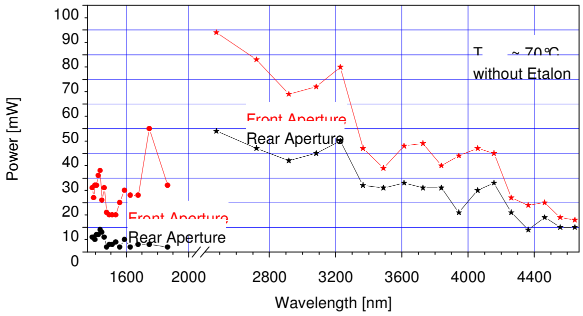

Fig. 2: Signal and Idler Emissions

Wavelength tuning:

Wavelength tuning is performed on several levels.
Coarse tuning is done manually by changing the lateral position of the nonlinear crystal to select a suitable poling period (Fig. 3).
PPLN temperature tuning is then used to coarse tune the wavelength within a selected poling period. When sweeping the temperature between 50 °C and 170 °C signal and idler wavelengths are tuned in step sizes of one etalon FSR (Fig. 4).

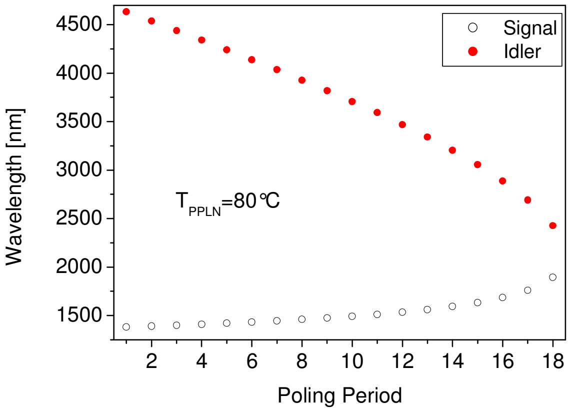

Fig.3: Coarse tuning by selecting between poling periods

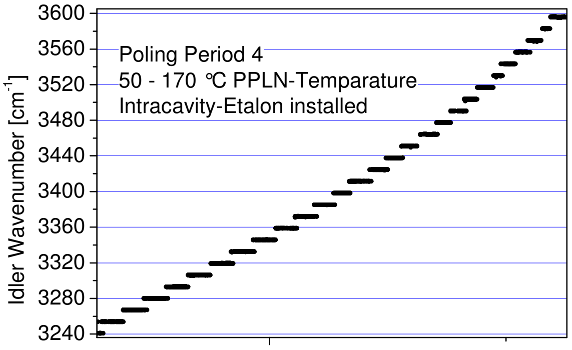

Fig. 4: PPLN temperature tuning

Etalon tuning selects the desired signal cavity mode within the gain bandwith of the OPO (Fig. 5). When scanning the etalon angle via a galvo, signal and idler are tuned in steps of one cavity FSR (~0.5 GHz) or multiples (1.0, 1.5, …GHz). The typical step-size depends on the etalon used. By turning the etalon, idler and signal frequencies can be typically modehop-tuned over more than 200 GHz.

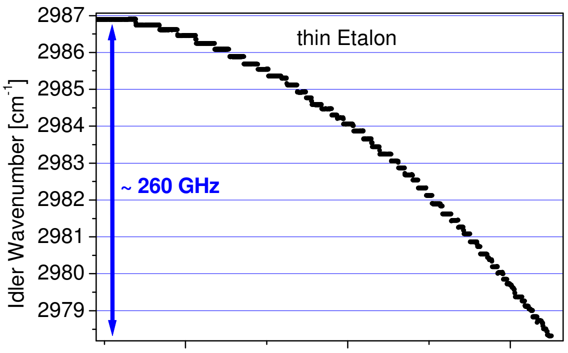

Fig. 5: Etalon tuning

Fine tuning can be performed using two different methods. One utilizes the possibility to scan the signal cavity length via a piezo. Then the signal and idler frequencies can be tuned over one cavity FSR (or multiples, if a thin etalon is installed) without suffering modehops (Fig. 6).

The second method makes use of the tunability of the pump laser. The laser can be tuned over more than 30 GHz in total, divided into sections of 6-9 GHz modehop-free. This tuning can be transferred to the idler frequency detuning (see inset of fig. 7). The signal frequency is not affected by this method.

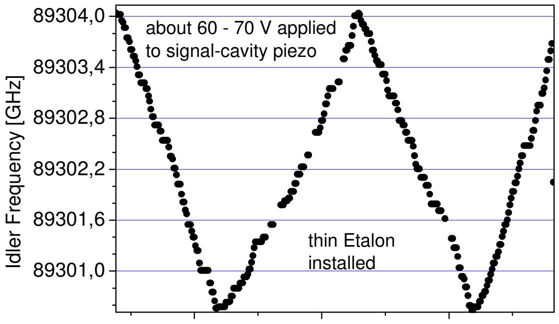

Fig. 6: Fine tuning via changing the signal cavity length. The resolution of the measurement is limited by the wavemeter properties.

Combined wavelength tuning:

If gap-free scanning over wider ranges is required, two or more methods for wavelength tuning have to be combined. The OPO applicant could either combine the pump laser tuning or the signal cavity tuning with the etalon tuning. One example is depicted in figure 7. The pump laser frequency is ramped up and down over 30 GHz. At every turning point the signal frequency is shifted by 30 GHz via changing etalon angle. This method is only applicable for the idler wavelength scanning.

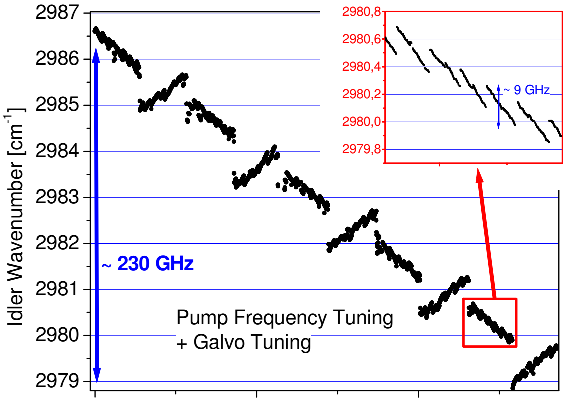

Fig. 7: Combined tuning of pump laser and etalon

Figure 8 depicts an example for method two. Here the signal cavity length is ramped up and down (compare fig. 6) while the etalon angle is scanned. This method acts on both waves, signal and idler, in the same way.
For wider scanning the PPLN temperature tuning has to be combined with the two methods described above.
PPLN temperature, etalon angle, signal cavity length and pump laser frequency can be set either manually via respective potentiometers or via respective analog inputs.

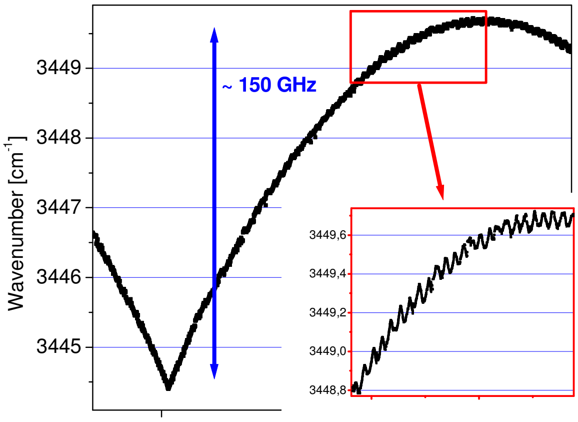

Fig. 8: Combined tuning of cavity length and etalon angle

Linewidth and stability

When the OS 4500 DC is operated free-running, the power stability is better than 5 %. The signal and idler frequencies drift by less than 500 MHz per hour (typically 200 MHz / h). The linewidths of comparable PE cw-OPOs have been measured using the cavity-ringing method to be smaller than 10 kHz in 20 µs [7].

OS 4500 Standard vs. DC

As mentioned before, the OS 4500 DC can be easily converted into the standard design. This is simply done by removing one optic and switching between two electronic plugs. In the standard configuration the OPO has slightly different specifications. The following table gives an overview.

	OS 4500 DC	**OS 4500 Standard**
Emission range: Idler Signal	 2280-4100 nm 1440-2000 nm	 2280-4670 nm 1380-2000 nm
Typ. modehop-free tuning: Idler Signal	 6-9 GHz 2-6 GHz	 1 GHz 2 GHz
Linewidth (20 µs)	< 10 kHz	< 10 kHz
Frequency drift	< 500 MHz / h	< 50 MHz / h
Max. output power: Idler, front/rear aperture Signal, front/rear aperture	 80 mW / 60 mW 30 mW / 8 mW	 80 mW / 80 mW 30 mW / 30 mW
Power stability	< 5% / h	< 5% / h

Table 1: OS 4500 properties (2 W pump laser)

Outlook and developments

PE cw-OPOs have also been demonstrated at wavelengths ranging from 0.7 to 2.2 µm [8].
Future developments of laser sources, nonlinear crystal materials and OPO designs will lead to:

- higher output powers
- new emission ranges
- wider modehop-free tuning
- custom solutions

This will open further applications for cw-OPOs in scientific research or industry.

3. Applications of PE cw-OPOs

In the past 10 years PE cw-OPOs have proven their usefulness in various kinds of applications. In the following a brief overview is given.

Tracegas detection

The selective detection of trace-amounts of gases plays an important role in biology (eg. Plant physiology), atmospheric chemistry and medicine (eg. breath analysis). Common techniques are photoacoustic and cw cavity ring-down spectroscopy (PAS, cw-CRDS). In combination with PE cw-OPOs sensitivities of 10^{-8} - 10^{-10} $cm^{-1}s^{-1}$ have been achieved [9,10].

Molecular spectroscopy

Molecular spectroscopy is a hot topic in chemistry. PE cw-OPOs have been successfully used for exciting molecules in various kind of experimental methods including IR-IR double resonance spectroscopy and laser induced reaction spectroscopy [11,12,13].

Metrology

Combined with a frequency comb PE cw-OPOs have been used as a phase-coherent bridge between different wavelength regions [14,15,16]. Stabilized to frequency standards they can offer ultra-stable emission frequencies [17] from the near- to the mid-infrared spectral region. This may also open new perspectives for molecular spectroscopy.

Material investigation

PE cw-OPOs have been applied for spectroscopy on solids. Using photon-trap spectroscopy, surface absorbances or trace impurities can be detected [18,19]. Lately, the near-field distribution of metamaterials has been investigated using an apertureless scanning near-field optical microscope [20]. The wide spectral coverage makes the OPO an interesting test tool for new optical materials for the near- to mid-infrared spectral region.

Acknowledgements:
Linos Photonics is grateful to the Quantum-Metrology group (University of Konstanz) for having given us the opportunity of making their PE cw-OPO a commercially available product. Linos also thanks Reiner Urschel and Dennis Weise for having realized and technically supported Linos OPO-systems and Yvonne Chao for having successfully introduced the PE cw-OPO to the US market. The technical support of development and electronic engineers is also acknowledged.

REFERENCES:

1. M.H. Dunn et al., SCIENCE **286**, 1513 (1999)
2. S. Schiller, Encyclopedia of Modern Optics **4**, 51 (2004)
3. L.E. Myers et al., JOSA B **12**, 2102 (1995)
4. Internal communication, Linos Photonics (2000)
5. EU-Patent 0857997, US-Patent 5999547
6. OPTOLINES **9**, 10 (2006), www.LINOS.de
7. F. Müller et al., Appl. Phys. B **3**, 307 (2005)
8. U. Strössner et al., Opt. Lett. **24**, 1602 (1999)
9. F. Müller et al., SPIE Proc. BIOS **5320**-19 Photonics West, San Jose (2004)
10. G.v. Basum et al., Opt. Lett. **29**, 797 (2004)
11. G.E. Douberly et al., Phys.Chem.Chem.Phys **7**, 463 (2005)
12. J.M. Merritt et al., J. Chem. Phys. **121**, 1309 (2004)
13. O. Asvany et al., J. Chem. Phys. **127**, 154317 (2007)
14. O.D. Mücke et al., Opt. Lett. **29,** 2806 (2004)
15. I. Ernsting et al., ICOLS Aviemore (2005)
16. E.V. Kovalchuk et al., Opt. Lett. **30**, 3141 (2005)
17. E.V. Kovalchuk et al., Proc 6th Symp. Frequency Standards and Metrology, World Scientific Singapore 513 (2002)
18. A. Terasaki et al., JOSA B **22**, 675 (2005)
19. K. Egashira et al., J. Chem. Phys. **126**, 221102 (2007)
20. T. Zentgraf et al., Opt. Lett. **33**, 848 (2008)