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Spectral control of CW OPOs and their application to mid-infrared spectroscopy

Angus Henderson and Ryan Stafford
Aculight Corporation, 11805 N. Creek Parkway S. ,Suite 113, Bothel,l, WA 98011, USA
Angus.henderson@aculight.com
Anatoliy Kosterev, Frank Tittel and Tom Killian
Dept. of Electrical and Computer Engineering, Rice University
6100 Main Street, Houston, TX 77005-1892
fkt@ece.rice.edu, killian@rice.edu
J. Houston Miller
Dept. of Chemistry, George Washington University Corcoran Hall
Room 107, 725 21st St. NW, Washington, DC 20052
Houston@gwu.edu

Abstract: A fiber-laser-pumped CW OPO operating at 3170nm with a linewidth of 1MHz will be reported. We will describe spectral control of the output and its application to different spectroscopic measurement techniques.

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1. Introduction

Continuous wave optical parametric oscillators (CW OPOs) using periodically poled lithium niobate have been demonstrated to be useful laboratory tools for mid-infrared spectroscopy [1,2]. However, due to limitations in available pump sources it has remained challenging to obtain straightforward fine tuning characteristics as obtained in near-infrared tunable sources such as external-cavity diode lasers. With improved pump laser sources, it has become feasible to implement OPO configurations which enable simpler OPO tuning. In particular, the development of fiber lasers and amplifiers with high power output, excellent spectral and spatial characteristics has allowed extensive mode-hop-free OPO tuning ranges to be obtained [3,4]. Here we report a fiber-laser-pumped CW OPO whose idler output linewidth has been measured to be ~1MHz, and which may be rapidly tuned over 60GHz without mode-hops using a piezoelectric transducer which applies strain to the fiber laser pump source. We will also report details of the use of the OPO in photoacoustic spectroscopy, cavity ringdown measurement and laser cooling.

2. Experimental configuration

The experimental configuration of the OPO and its pump source has been described previously [4]. The pump source is an all-fiber device in a master-oscillator power-amplifier (MOPA) configuration. The seed source for the MOPA is a commercially available DFB fiber laser operating with 20mW single frequency, linearly polarized output at 1083nm. The measured linewidth of this source is 50kHz. Slow tuning of this seed can be performed by varying the fiber temperature between room temperature and 50^{o}C, or rapid tuning by applying a voltage to a piezoelectric transducer attached to the fiber. Continuous mode-hop-free tuning of the seed wavelength of ~60GHz is available by each of these mechanisms. The output fiber from this laser is connectorized into a commercial polarization-maintaining fiber amplifier. With 10mW seed power, up to 3.5 Watts of single frequency, single transverse mode output in a linear polarization is available to pump the OPO. The output from the amplifier is collimated by an aspheric lens, passed through a bulk optical isolator, and then focused into the OPO.

The OPO was configured as a four-mirror ring cavity, consisting of two flat mirrors and two plano-concave curved mirrors. The cavity was resonant at only the signal wavelength. The nonlinear material used was 5% Magnesium-Oxide doped PPLN. The crystal was poled with a range of poling periods with a linear variation in period across the aperture of the crystal, to allow coarse tuning at constant temperature. The OPO was typically operated with the MgO:PPLN crystal temperature-controlled just above room temperature at 30^{o}C.

3. Performance characteristics

Under optimum alignment conditions, oscillation thresholds as low as 780mW were measured at 2.8μm.

The maximum pump depletion was 85% at an input power of 2.8 Watts. At this input level 750mW idler power was measured. We were able to exceed oscillation threshold between idler wavelengths 2650nm and 3200nm. The beam quality of the idler output was measured using a scanning knife-edge and found to be near-diffraction-limited (measured M^2 parameter of 1.04) at a power output level of 500 mW.

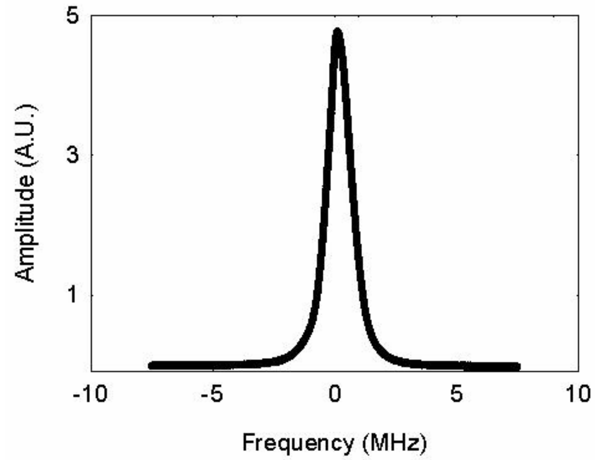

Fig. 1. OPO linewidth measured at a wavelength of 3.17μm

4. Spectrum and tuning

The spectra of all three of the interacting waves (pump, signal and idler) were confirmed to be a single longitudinal mode using scanning Fabry-Perot (FP) interferometer measurements. A direct estimate of the linewidth of the idler output at 3167nm was made by coupling the OPO beam into a static FP cavity. By linearly scanning the laser frequency using the pump PZT tuning, we were able to monitor the transmission peaks of the FP cavity over multiple 1GHz free spectral ranges. Based on the ratio of the time taken to scan between two transmission orders and the time to scan through an individual peak, we estimated a resolution-limited linewidth of 1.1MHz for the idler (Fig. 1).
Coarse tuning of the OPO could be performed by either translating the MgO:PPLN crystal relative to the pump beam such that the beam passed through a region of the crystal with a different poling period, or by varying the temperature of the crystal. Over 400nm tuning was demonstrated using the former mechanism (Fig 2). Intermediate level tuning of a few nanometers range could be performed by varying the tilt angle of the FP etalon inside the OPO cavity, to select a different longitudinal mode at the resonant wavelength. Fine tuning of the idler frequency was performed by tuning the pump laser, with the intracavity etalon fixing the resonant signal frequency.

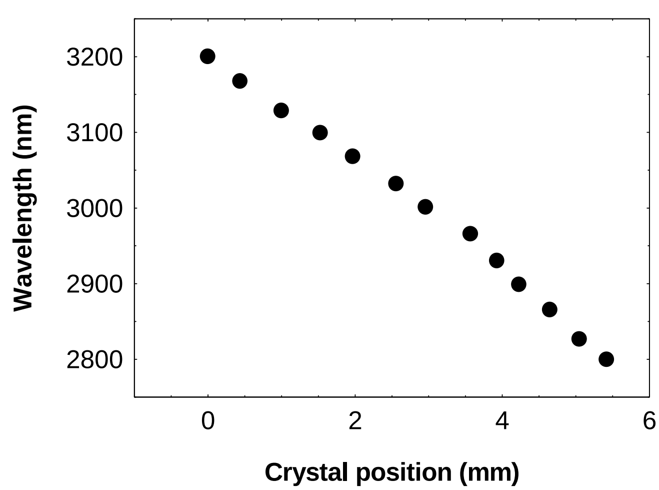

Fig. 2. Coarse idler tuning by translation of MgO:PPLN crystal

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In this way, when the pump frequency varies, the change in photon energy is directly transferred to the frequency of the idler wave. While monitoring the signal spectrum with the FP interferometer, the idler wavelength was recorded as a function of the pump tuning parameter using a wavemeter. Over a range of 60GHz tuning of the pump frequency (90V applied to the fiber PZT), the change in idler frequency exactly mirrored the tuning of the pump, and no signal mode-hops were observed. Extended OPO idler tuning (up to 130GHz) was obtained by using the temperature tuning of the fiber laser. We believe that the rapid tuning capability provided by pump PZT tuning could be significantly extended using a PZT with greater range of strain.

5. Spectroscopic measurements

Based on the available OPO idler coarse tuning from 2650nm to 3200nm, and the 60GHz range rapid PZT tuning, we were able to perform high resolution spectroscopic measurements of a variety of gases. We performed simple single-pass measurements of transmission of the idler wavelength while tuning the pump laser at a rate of 30Hz using a sawtooth waveform applied to the PZT. Continuous mode-hop free scans of up to 60GHz scans were recorded in water vapor at 2709 nm, carbon dioxide at 2810 nm, nitrous oxide at 2879 nm, ammonia at 2897 nm and methane at 3167 nm.

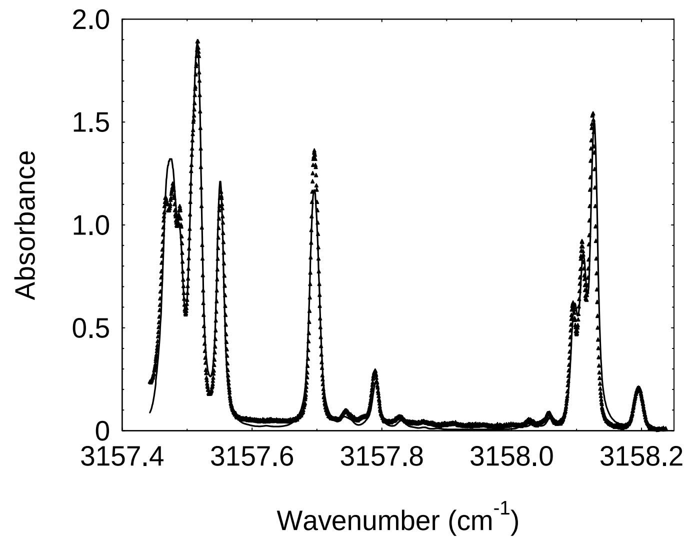

Fig. 3. Spectrum of methane measured at 3.17μm. 60cm cell containing 6% CH_4 in air at 30 Torr pressure. Solid line shows theoretical fit, generated using HITRAN data

Figure 3 shows a typical recorded spectrum for methane measured at 3167nm. A theoretical fit made using HITRAN 2004 data shows good agreement with the recorded data.
We plan to describe the application of the OPO to different spectroscopic techniques including cavity ring-down, photo-acoustic spectroscopy, and laser cooling of atoms. We will provide results of these experiments and discussion of OPO frequency control issues encountered during these measurements.

6. References

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