

# A NARROW LINEWIDTH SINGLY RESONANT ZGP OPO FOR MULTIPLE LIDAR APPLICATIONS

Jirong Yu<sup>(1)</sup>, Hyung R Lee<sup>(2)</sup>, Yingxin Bai<sup>(3)</sup>, Norman P. Barnes<sup>(1)</sup>

<sup>(1)</sup> NASA Langley Research Center, MS 468, Hampton, VA 23681 USA, jirong.yu-1@nasa.gov

<sup>(2)</sup> Department of Physics, Hampton University, Hampton, VA, 23668

<sup>(3)</sup> SAIC, One Enterprise Parkway, Suite 370, Hampton, VA 23666

## ABSTRACT

A singly resonant, injection seeded Zinc Germanium Phosphide (ZGP) optical parametric oscillator (OPO), capable to tune over 4.3-10.1 $\mu\text{m}$ , is demonstrated. This ZGP OPO uses a bow-tie cavity with a partially reflective mirror for injection seeding at the signal wavelength. The injection seed source can be either a continuous wave 3.39  $\mu\text{m}$  laser or a tunable near-infrared OPO laser, which provides wide wavelength tuning capability. The injection seeded ZGP OPO narrows the idler wavelength linewidth to less than 1nm, limited by the measurement resolution of the monochromator. This device has potential to be used as a transmitter for multiple purpose lidar applications.

## 1. INTRODUCTION

A widely tunable mid-infrared coherent laser source in the wavelength range of 3 – 12  $\mu\text{m}$  has great interest in many lidar and spectroscopic applications. This region, so-called the fingerprint region, is where most molecules in the atmosphere present special absorption. Water vapor, carbon dioxide, carbon monoxide, and methane have their strong absorption lines in this range. Among many typical mid-IR tunable lasers, ZGP OPO is the best candidate for a compact tunable laser system [1]. It can be tuned over the wavelength range from 2.2  $\mu\text{m}$  to above 10 $\mu\text{m}$ . A singly resonant ZGP OPO system pumped by TEM<sub>00</sub> mode, linearly polarized, Q-switched 2.05  $\mu\text{m}$  laser, produces high-energy output pulses with a relatively broad wavelength range for many applications.

For sufficient discrimination in detecting molecular species in the atmosphere, a spectral linewidth on the order of 0.1 $\text{cm}^{-1}$  or better is required. However, most early experiments of ZGP were focused on high average power and broad tunability in the mid-infrared region. Previous efforts to achieve narrow spectral linewidth utilized additional wavelength control elements such as gratings, prisms, and etalons [2]. Using line-narrowing elements may be inefficient due to insertion losses. In addition, damages may occur for a high energy laser system. Thus, injection seeding is a suitable method to achieve narrow linewidth pulses with high energy. Previous works have demonstrated the injection seed technique for a doubly resonant oscillator (DRO) using a

3.39  $\mu\text{m}$  He-Ne laser. In this paper, we describe an injection seeded singly resonant oscillator (SRO) by using a 3.39  $\mu\text{m}$  He-Ne laser or a tunable near infrared periodically poled lithium niobate (PPLN) optical parametric oscillator.

## 2. LASER SYSTEM DESCRIPTION

The schematic diagram of the experimental setup is shown in Figure 1. The OPO system is composed of three stages. The first stage is a TEM<sub>00</sub> 2.05 $\mu\text{m}$  pump laser, with a Q-switched pulse width of ~150 ns (FWHM). The second stage is a bow tie shaped ring cavity singly resonant type I ZGP oscillator. The last stage is a continuous wave narrow linewidth seed laser, either a He-Ne laser or a tunable PPLN optical parametric oscillator.

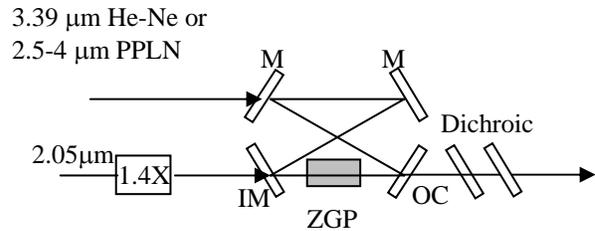


Fig. 1. Schematic of the injection seeded ZGP OPO

The 2.05 $\mu\text{m}$  laser produces maximum output energy per pulse of 40mJ [3]. The 2.05  $\mu\text{m}$  pump beam expands to a diameter of around 3 mm by a 1.4 times telescope and the collimated beam pumps the ZGP crystal. For continuous tunable operation in the entire mid-IR region, the ZGP crystal was oriented for type I phase matching ( $o \rightarrow e+e$ ). The spectrally well-controlled ~2mW 3.39  $\mu\text{m}$  He-Ne laser or a ~30mW PPLN OPO are used as seed lasers. The SRO consists of four flat mirrors and an 8 x 8 x 25 mm ZGP crystal with broadband AR coatings on both surfaces and optimized at the pump and signal wavelength. An input mirror, HT at the pump wavelength and HR at the signal wavelength, is used to couple the 2.05  $\mu\text{m}$  pump beam into the SRO. An output coupler has HR and HT at the signal and idler wavelength, 4.1 to 9.5  $\mu\text{m}$ , respectively. A partial reflectivity mirror, average  $R = 80\%$  at signal wavelength, serves as the injection seeding coupler. The seed laser also passes through a beam expander for mode

matching with the 2.05  $\mu\text{m}$  pump laser. Residual pump and signal energy is rejected by the two dichroic mirrors in series. Spectral linewidth of the angle tuned SRO idler output is measured by a 0.35m monochromator with a  $\text{LN}_2$  cooled HgCdTe detector.

There are several steps to achieve injection seeding. The first step is to calculate the idler wavelength of the SRO corresponding to the injection seed signal wavelength. The next step is to coarsely preset the SRO at the predicted idler wavelength by measuring the output wavelength using a monochromator. The third step is to maximize the peak gain of the parametric amplifier by adjusting the angle of the crystal and mode matching the seed beam with the pump beam. In this experiment, parametric amplification is measured by observing the signal with an  $\text{LN}_2$  cooled HgCdTe detector and fast oscilloscope. After maximizing the gain, reinstall the output coupler into cavity to form a SRO. Larger than 3 of the monitored gain of the parametric amplifier is required for this injection seeding procedure. A Pyrocam IR camera is also used for real time analysis of seeding effectiveness.

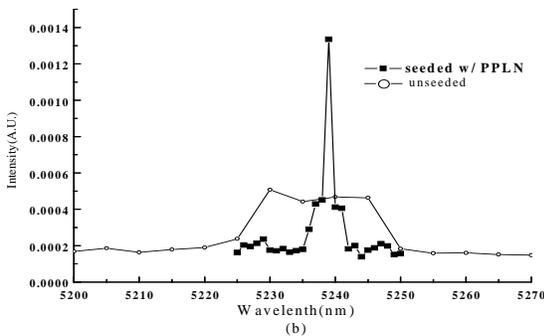
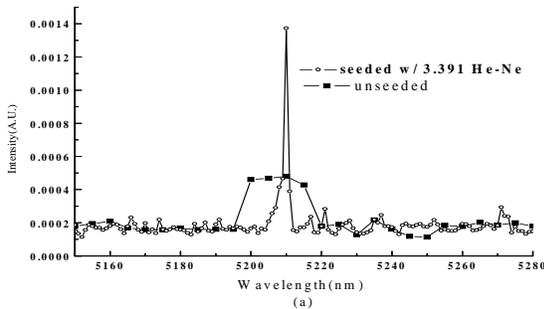


Fig. 2. Output spectra of the SRO ZGP (a) He-Ne Laser (b) PPLN injection seeding

Experimental results of spectral line narrowing are shown in Figure 2. The spectral linewidth of unseeded SRO near  $\lambda = 5.2 \mu\text{m}$  is  $\sim 20 \text{ nm}$  FWHM. When injection seeded, linewidth dramatically narrows to  $\sim 1 \text{ nm}$  FWHM, limited by the spectral resolution of the monochromator. The Fig.2 (a) and Fig.2 (b) show line narrowed results by using a CW 3.39  $\mu\text{m}$  He-Ne laser

and tunable PPLN OPO, respectively. Using a CW 3.39  $\mu\text{m}$  He-Ne laser as a seed source is relatively easy and simple, but it only produces one fixed wavelength. By selecting the seeding wavelength from the tunable near infrared PPLN OPO, any desired mid-IR wavelength with extremely narrow linewidth can be produced. The idler output could be tuned over the 4 to 10  $\mu\text{m}$  wavelength range. Fig. 3 shows the type I ZGP OPO experimental angular tuning curve. The solid curve is the theoretical result based on Sellmeier equation.

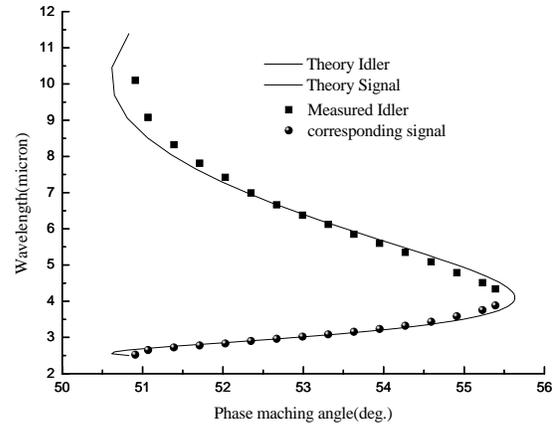


Fig. 3. Type I ZGP OPO angular tuning curve with 2.05  $\mu\text{m}$  pump

The maximum energy is obtained at wavelength of 4.8  $\mu\text{m}$ . The output energy correlates with the ZGP transmission and non-uniformity of the optical coatings for the OPO cavity mirrors. Optimizing the OPO for a selected wavelength range shall increase the energy.

### 3. CONCLUSION

We have demonstrated, for the first time as of our knowledge, an injection seeded line narrowing singly resonant ZGP oscillator. The measured  $\sim 1 \text{ nm}$  FWHM linewidth is limited by the resolution of the monochromator. The seeded SRO produces a  $\sim 2.5 \text{ mJ}$  idler output using 30mJ pump energy. This linewidth and pulse energy is sufficient for many spectroscopic applications. Further increase in output energy of the idler beam would be possible with higher pump energy or additional amplification stages.

### 4. REFERENCES

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