Tunable telecom diode laser based mid-IR source at 2.64 microns

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Abstract: We report a new difference frequency mixing optical architecture for the generation of coherent mid-infrared radiation at ~2.64 μm. A fiber pigtailed optically pumped semiconductor laser operating at 981 nm is mixed with an Er/Yb fiber amplified DFB diode laser at 1562 nm in a 19 mm long periodically poled lithium niobate crystal (PPLN). With respective powers of ~450mW by each of these pump lasers, spectrally stable, narrow linewidth mid-IR radiation of 0.25 mW is generated with a near Gaussian beam profile. Wavelength tuning characteristics and the sensitive spectroscopic detection of HF and HDO are reported.

OCIS codes: (140.3480) Diode-Pumped Lasers; (190.2620) Frequency Conversion

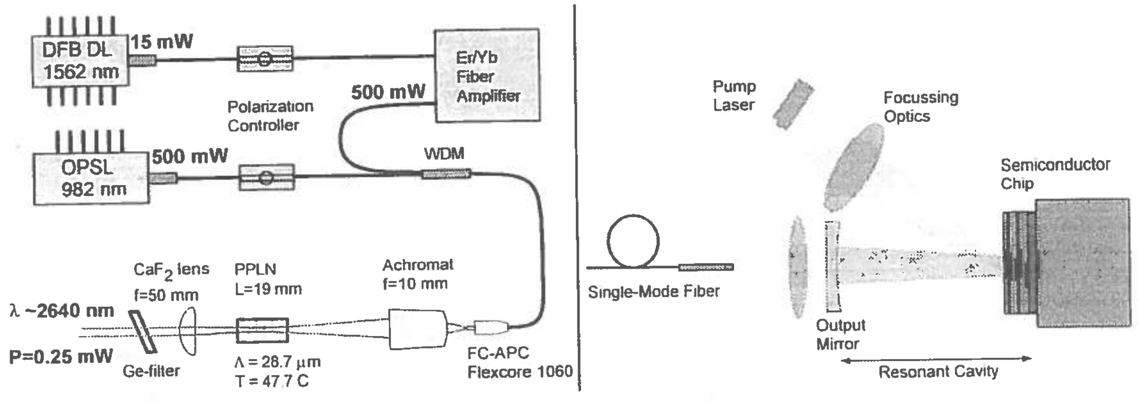
1. Introduction

Tunable and coherent mid-infrared laser sources in the 2-3 μm wavelength range are of interest in a variety of applications, including remote sensing, infrared countermeasures, environmental trace gas monitoring, chemical analysis and process control. For this purpose, advanced compact solid-state and diode laser sources, have been developed in recent years, based on rare-earth and metal doped solid state materials (e.g. Tm, Ho, Er, Pr, Cr), antimonite-, and lead-salt-diode lasers [1,2]. To be most useful, such tunable laser sources have to operate reliably and exhibit properties such as quasi-room-temperature operation, coherent spectral output, good beam quality and depending on the type of application, high output power (mW – W). With the advent of optical telecommunication and advances in optical frequency conversion materials employing quasi-phase matching, a new competitive class of tunable mid-infrared source has recently been developed [3]. These sources utilize watt-level optical fiber amplifier seeded by narrow-linewidth near-infrared diode lasers and can be efficiently mixed in periodically poled $LiNbO_3$, KTP or RTA crystal materials to generate any wavelength from 3 to 5 μm. In this paper we report on a novel optical configuration of difference-frequency generation, which employs a pump (at ~980 nm) and a signal telecom diode laser at S-C-L band wavelengths (i.e. 1480 – 1620 nm) and extends the DFG wavelength coverage below 3 μm down to 2.3 μm.

2. Experimental

The use of standard telecom diode lasers as DFG pump sources offers robust fiber optic coupling while providing the best possible pump beam quality (i.e. Gaussian), and a wide wavelength coverage by selecting and multiplexing off-the-shelf near-IR diode laser channels. In addition, telecom diode lasers based on InGaAsP/InGaAs/GaAs typically possess similar temperature tuning coefficients (~0.4 $cm^{-1} \cdot K^{-1}$) as one another. This offers predictable spectral performance and leads to a self-compensation of wavelength drifts in a DFG-based mid-IR architecture and minimizes the effect of electronic driver temperature instabilities as a result of environmental changes. This property can significantly increase the spectroscopic stability in a continuously changing operating environment encountered in industrial applications requiring long-term unattended operation.

Fig.1a shows the optical configuration used in this experiment. A 1562 nm single-mode fiber pigtailed DFB diode laser serves as the DFG pump source and provides an optical fiber output power of 15 mW, with <2 MHz linewidth and a 46 dB sidemode suppression ratio. The output fiber is fusion spliced to an Er/Yb optical fiber amplifier and produces a maximum output power of 575 mW. The long-term power stability of the seeded amplifier was measured to be less than 0.2 % h^{-1}.



a) b)

Fig.1: a) Schematic of difference frequency generation laser source at 2.64 μm. OPSL™, optically pumped semiconductor laser; DFB DL, distributed feedback diode laser; WDM, wavelength division multiplexer; FC-APC, fiber coupler – angled polished connector; b) Generic schematic of the optically pumped semiconductor laser (OPSL™).

The DFG signal source depicted in Fig.1b is an optically pumped semiconductor laser (OPSL™) and has recently become commercially available (Coherent OPSL 980-500) [4,5]. The OPSL™ consists of a high-power broad-band 808 nm diode laser which pumps a semiconductor gain portion incorporated in a multiplayer optical structure grown on a GaAs substrate and is embedded in a resonant cavity. The rear-end of the cavity is terminated by a Bragg mirror grown on the GaAs substrate. An AR coated concave output coupling mirror completes the cavity. The OPSL™ platform is temperature controlled by a Peltier element and packaged into a hermetically sealed single-sided 9-pin package (outer dimension: 60x20x11.25-mm^3).

The OPSL™ was designed for use as a telecom pump source in Er^{3+} doped fiber amplifiers and can also be configured for 488nm operation using intra-cavity second harmonic generation. Unlike other high-power 980 nm telecom diode laser sources, this laser provides excellent spectroscopic characteristics of >500mW single-frequency laser radiation from a single mode fiber (Corning 1060 PureMode™, Mode field diameter = 5.9 μm @ 980 nm). Both fibered laser sources were fusion spliced to a wavelength division multiplexer (WDM). The output fiber of the WDM was terminated by a Flexcore 1060 single-mode FC-APC fiber (8° fiber polished end). Respective insertion losses of 11% (OPSL™) and 5 % (Er/Yb fiber amplifier) were introduced by fiber fusion splices to the WDM, and inherent WDM coupling losses. The two DFG pump beams were imaged (M~12) into a 19 mm long / 0.5 mm thick PPLN crystal with a 28.7 μm quasi-phasematching period. The PPLN crystal was AR coated with a single SiO$_2$ layer and optical transmissions at 982 nm and 1562 nm were measured to be 0.84 and 0.98, respectively. A plano-convex CaF$_2$ lens (f=50mm) was used to collect and collimate the DFG radiation. Residual pump beams were blocked by a Ge-filter.

3. Optical characterization and spectroscopic measurements

Before splicing the OPSL™ device to the WDM, the output power as a function of pump current was measured. At a device temperature of 25 °C, a maximum optical fiber output power of 611 mW was observed with a pump current of 2.2 A. With various fiber and achromatic lens insertion losses a pump power of 492 mW (20% total insertion power loss) was available at the input facet of the PPLN crystal. Likewise, insertions losses in the 1562 mm channel resulted in a maximum effective pump power of 440mW (15% total insertion power loss) at the PPLN input facet. A maximum mid-IR DFG power of 250 μW was measured, which corresponds to a conversion efficiency of 650 ± 25 μW·W^{-2}·cm^{-1}. The conversion efficiency was determined by measuring the slope of DFG power (past the Ge-filter) at different input power levels as shown in Fig.2. Both pump and DFG power levels were measured with a NIST traceable calibrated thermopile detector.

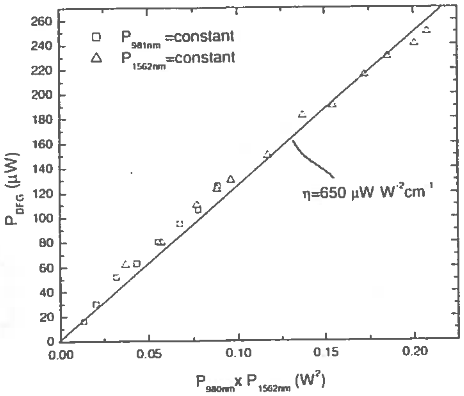


Fig.2: Slope efficiency measurement of difference frequency generation source.

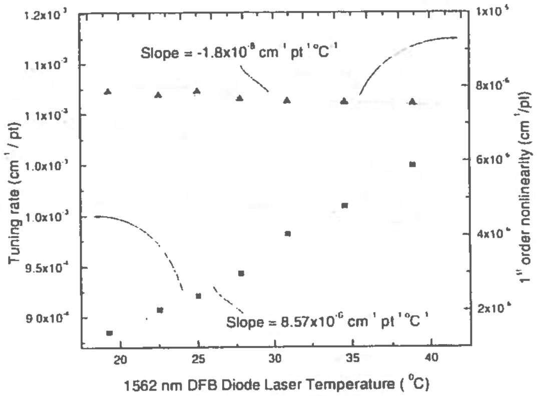


Fig.3: DFB-DL current-wavelength tuning characteristics as a function of temperature.

The mid-infrared radiation could be varied over 7.59 cm^{-1} (6404.98-6397.39 cm^{-1}) by means of temperatur tuning the 1562 nm DFB DL from 19.31 °C- 38.65 °C. Within this tuning range, the Hitran database [4 documents molecular absorptions of $H_2{}^{16}O$, $H_2{}^{17}O$, $H_2{}^{18}O$ and HDO, HF and NO. For the detection HF anc HDO at 2.64 µm, the DFB-DL was temperature tuned to 6398.599 cm^{-1} ($T_{DFB\text{-}DL}$=35.56 °C) and the diod laser current modulated by applying a 160 Hz triangular waveform. Using a Ge-etalon (FSR=0.01601cm^{-1} the mid-IR scan was frequency calibrated. Fig.3 illustrates the analysis of the Ge-etalon fringe spacing anc shows a small linear temperature dependence of the diode laser current-wavelength tuning. Th temperature specific tuning rate is superimposed by a 1st order nonlinearity of 8E-6 cm^{-1}/pt (500 pts/scan).

To evaluate the long term spectroscopic stability, HF absorption spectra at 2.64 µm wa periodically measured over a 200 minute time period using a sealed reference gas cell (L=10 cm). A peak to-peak noise equivalent absorbance of ~1E-4 was observed (0.6 s integration time), corresponding to a HI detection sensitivity of 12 ppb·m at a sampling pressure of 50 Torr. A drift of ±20 MHz over a 2 hou period and less than 5 MHz over a 10 minute time period was measured upon thermal stabilization Occasional mode-hopping of the OPSL™ was observed when the laser was operated from a cold start However, no mode-hopping was observed after the OPSL™ was continuously operated for 2-3 hours anc fully temperature stabilized.

In summary, a new tunable DFG based mid-infrared spectroscopic source at 2.64 µm and it application for the detection of HF and H_2O is demonstrated. Replacing the Er/Yb fiber amplifier with a Er^{3+} doped fiber inline with the OPSL™ and DFB-DL at 1.5 µm will result in an ultra compact low cos design [3]. This source can also be used as a seed laser for further amplification to very high power level exceeding >500mW by means of an Er/Pr co-doped ZBLAN fiber amplifier [7].

References:

1. C. Marshall, ed., Advanced Solid State Lasers, Trends in Optics and Photonics (TOPS) **50** (2001)
2. Daniel B. Oh, Alan C. Stanton, "Measurement of nitric oxide with an antimonide diode laser," Appl. Opt. **36**, 3294-3297 (1997)
3. D. Richter, "Portable mid-infrared gas sensors: Development and Applications," PhD-thesis, Rice University (2001)
4. Mark Kuznetsov, Farhad Hakimi, Robert Sprague, and A. Mooradian, "Design and Characteristics of High-Power (>0.5-W CW) Diode-Pumped Vertical-External-Cavity Surface-Emitting Semiconductor Laser with Circular TEM_{00} Beams," IEEE J. Select. Topics Quantum Electron. **5**, 561-573 (1999)
5. Coherent Telecom Group, Santa Clara, CA 95054 USA
6. L. S. Rothmann, et.al.,"The HITRAN molecular spectroscopic database and HAWKS (HITRAN atmospheric workstation): 1996 edition", J. Quant. Spectrosc. Radiat. Transfer **60**, 665-710 (1998)
7. B. Srinivasan, J. Tafoya, R.K. Jain, "High Power 'Watt-Level' CW operation of diode pumped 2.7 µm fiber laser using efficient cross relaxation and energy transfer mechanism," Optics Express **2**, 490-495 (1999)