Ultra-compact mid-IR spectroscopic source based on frequency converted Yb - Er/Yb fiber amplified cw diode lasers

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Abstract: A novel narrow-linewidth mid-IR source based on frequency conversion of fiber coupled diode laser seed sources at 1.08 μm and 1.56 μm mixed in periodically poled $LiNbO_3$ will be reported. Both seed pump wavelengths are amplified by a cascaded Yb and Er/Yb amplifier combination to generate up to 0.1 mW at 3.5 μm.

OCIS Codes: (060.2320) Fiber optics amplifiers and oscillators; (190.2620) Frequency conversion

The availability of tunable, spectrally narrow mid-infrared light sources permits selective and sensitive detection of trace gas species based on direct, dual-beam, 2f and cavity-ring-down absorption spectroscopy. Important applications include industrial and environmental emission monitoring. For certain field applications, demanding operating conditions must be considered in the design of a reliable gas detection system to minimize vibration, humidity, and temperature cycling effects. In this work, we report the design, implementation and validation of a compact modular mid-infrared source that is based on the use of telecommunication fiber optic pump sources and recent advances in non-linear optical materials.

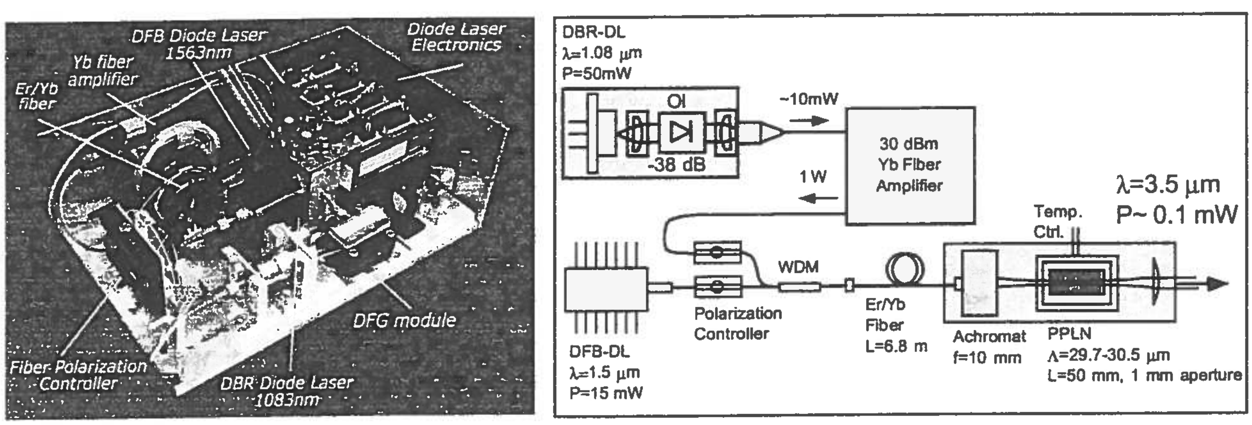
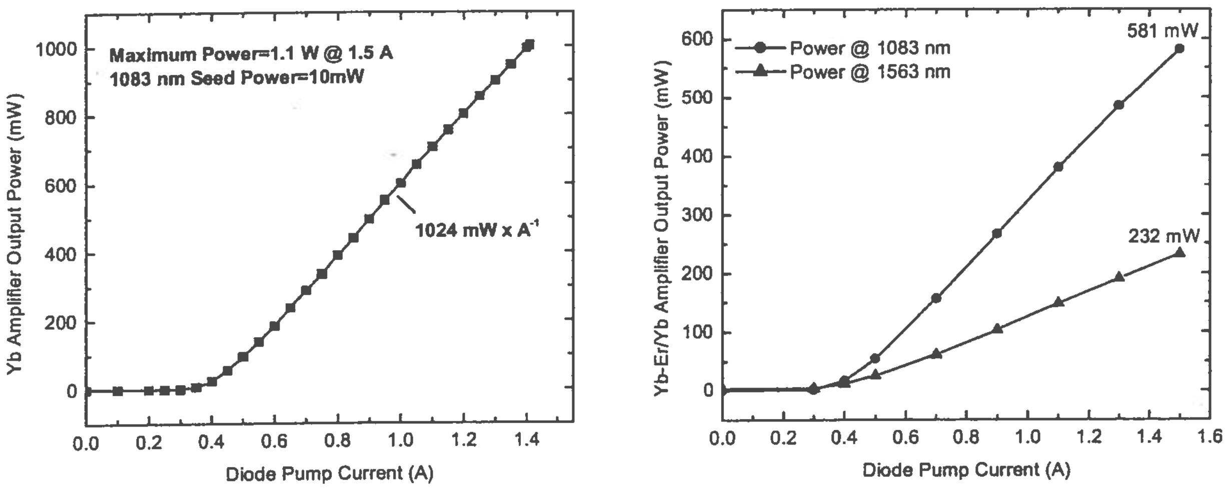


Fig.1: Schematic and photograph of a compact DFG based mid-infrared source with outer dimensions of 13" × 8.5" × 4.5".

Two fiber amplified near infrared diode lasers operating at 1083nm (DBR, 50 mW) and 1563 nm (DFB, 15mW) respectively are difference frequency converted to the mid-IR using a 50 mm long periodically poled lithium niobate (PPLN) crystal.

The use of fiber optics provides diffraction limited Gaussian pump beams and inherent spatial beam overlap, which is crucial for an effective and robust difference frequency mixing process. Its novel design is reflected in the use of only one active 30 dBm Yb fiber amplifier fusion spliced to a 6.8 m Er/Yb co-doped single mode fiber that provides amplification at both 1 and

1.5 μm (Fig.1) [1]. The Er/Yb silica glass fiber is co-doped with phosphorous for efficient energy transfer from the Yb^{3+}, $^2F_{5/2}$ level to Er^{3+}, $^4I_{11/2}$ level to provide gain at 1.5 μm [2]. The Er/Yb fiber with a N.A. of 0.16 and core diameter of 5.1 μm has an absorption coefficient of 0.6 dB/m at 1083 nm and is pigtailed to a Lucent truewave fiber and terminated with an 8° angle fiber connector. An f=10 mm achromat is used to image (M~11) the amplified pump beams with respective mode field diameters 8.8 μm (1563 nm) and 5.9 μm (1083 nm) into the PPLN crystal. The generated mid-IR radiation is collimated by a CaF_2 lens (f=5 cm) and can be directed to either an open path or extractive optical multi pass absorption cell module.



(a) (b)

Fig. 2: a) Yb amplifier output power as a function of pump diode laser current. b) Yb - Er/Yb fiber amplifier output power as a function of Yb fiber amplifier pump current. Seed powers were 10 mW (1083 nm) and 13 mW (1563), respectively.

The fiber amplifier pumping scheme was initially optimized to provide a balanced pumping power product $P_{1083nm} \times P_{1563nm}$ that is directly proportional to the generated difference frequency mid-IR power. The Yb fiber amplifier (IPG Photonics) is pumped by three parallel 970 nm broadband diode pump sources with an efficiency of 1024 mW/A and a operating bandwidth from 1060 nm to 1090 nm with the maximum gain at 1083 nm. The output of the Yb-amplifier is spliced to a 2x1 WDM and combined with a 15 mW DFB diode laser operating at 1563 nm. Fig. 2a shows the output power of the Yb fiber amplifier as a function of diode laser pump current with a fiber coupled seed power of ~10 mW at 1083nm. Fig.2b depicts the maximum power of the Er/Yb fiber amplifier with 581 mW at 1083 nm and 232 mW at 1563 nm just prior to the achromat. These powers correspond to an effective Er/Yb fiber amplifier slope efficiency of 46%.

Recent improvements in electric field poling of lithium niobate lead to the development of 1 mm thick PPLN crystals and consequently allow the use of longer crystals without experiencing aperture clipping of the pump and DFG beams. To determine the impact of poling quality differences, length and thickness, the conversion efficiencies of four PPLN crystals were compared.

Table 1: Conversion efficiency of various PPLN crystals

PPLN Sample	A	B	C	D
Thickness (mm)	0.5	1	1	0.5
Length (mm)	19	19	50	20.5
Conversion Efficiency ($\mu W \times W^{-1} \times cm^{-1}$)	199	174	181	176

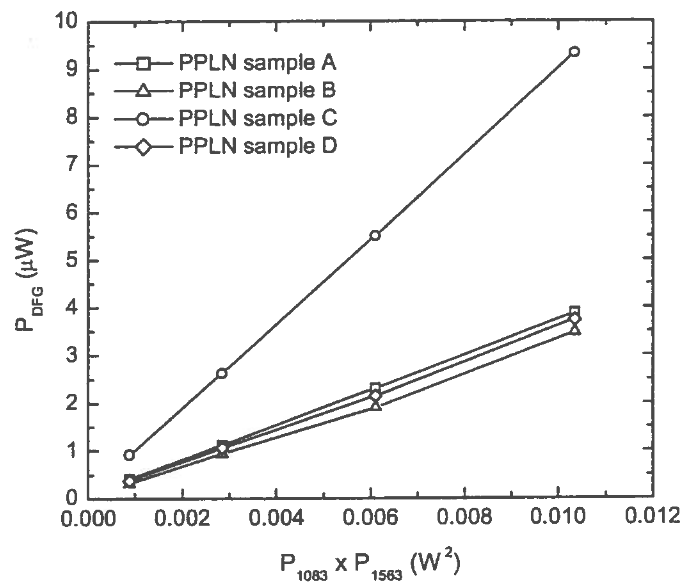


Fig. 3: DFG power at 3.5 μm measured with a calibrated InSb detector as a function of incident pump power product for PPLN samples listed in Table 1

PPLN samples A, B and C were fabricated from the same wafer run and polished. All PPLN crystals were anti-reflection coated for pump, signal and idler wavelength. The four samples were placed consecutively in the fixed fiber to crystal imaging stage (M=11). The conversion efficiency appears to be independent of crystal thickness as evident from Table 1. With the maximum generated pump power product of 0.135 W^2 (Fig.2b) a DFG power of ~0.1 mW (measured with a calibrated thermopile detector) of stable narrow linewidth light is generated using a 50 mm long, 1 mm thick PPLN crystal.

Reference:

1. L. Goldberg, J. Koplow, D.G. Lancaster, R.F. Curl, F.K. Tittel, "Mid-infrared difference-frequency generation source pumped by a 1.1-1.5 μm dual wavelength fiber amplifier for trace gas detection", Opt.Lett. **23**, 1517-1519 (1998)
2. J. Townsend, W.L. Barnes, K.P. Jedrzejewski, and S.G. Grubb, "Yb^{3+} sensitised Er^{3+} doped silica optical fibre with ultrahigh transfer efficiency and gain", Electron. Lett. **27**, 1958 (1991)

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