**CThO31** **1:00 pm**

## Trace $NO_2$ Detection with Yb Fiber Laser Pumped Mid-IR Difference Frequency Generation

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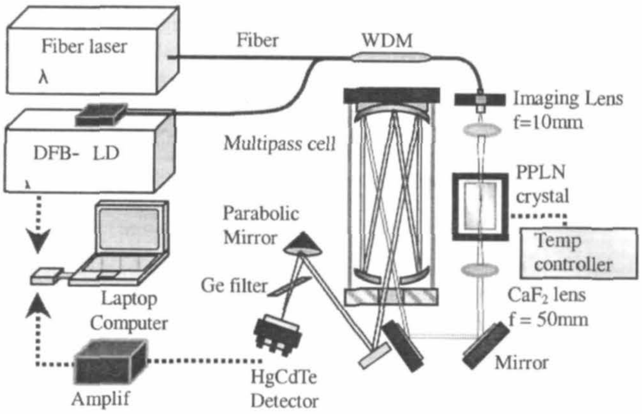
### 1. Introduction

A cw narrow-linewidth tunable mid-IR coherent source has become a useful tool for trace gas detection since almost all gases exhibit fundamental ro-vibrational absorption lines with high absorption strength in the mid-IR. This particular source is obtained by a difference frequency generation (DFG) technique which is that two near-IR laser pump sources ($\lambda_1$, $\lambda_2$) are mixed to generate mid-IR ($\lambda_3 = (1/\lambda_1 - 1/\lambda_2)^{-1}$) in a quasi-phase-matched (QPM) nonlinear optical crystal such as a periodically poled $LiNbO_3$ (PPLN) in single-pass geometry. Such spectroscopic source can operate at room temperature with single spatial mode, single frequency and tunable in wide frequency region without mode hop. This paper reports an experimental study of a fiber laser [1,2](1064 nm) based mid-IR generation to detect $NO_2$. This DFG source is applied to $NO_2$ detection which is of interest in various applications such as combustion, environmental trace gas monitoring. This work reports the demonstration of a fiber laser pumped DFG based mid-IR source for trace gas sensing, and the detection of $NO_2$ line at ~3.5 μm with a high-resolution DFG spectroscopic source with a PPLN crystal.

### 2. Experimental conditions

The schematic of the mid-IR ~3.5 μm DFG spectroscopic source and trace $NO_2$ gas detection system is shown in Fig. 1. As mentioned above, key components for generation of the tunable mid-IR source in this work are two compact single-mode-fiber-pigtailed DFG pump sources consisted of a wavelength-fixed Yb fiber laser and a tunable telecommunication DFB laser diode (LD). To access the 3.5 μm mid-IR spectral region, the Yb fiber laser is operated at 1064 nm. The second pump source is a 1532 nm DFB LD with an output power of 15 mW. Both laser are linearly and vertically polarized to optimize the interaction of the "e + e → e" DFG mixing process in the PPLN crystal. WDM Fiber optics is used for the pump beam delivery to the PPLN crystal. There is a power loss at the fiber connection between laser sources and the WDM and mis-match




**CThO31 Fig. 1.** Schematic of a mid-IR 3.5 μm spectroscopic DFG source and configured $NO_2$ gas detection.

in a mode field diameter of each fiber. However, the use of WDM allows persistent optical beam alignment, which leads to a more robust optical system than the use of a traditional dichroic beam coupler. The PPLN crystal used in this experiment is 20 mm long. The PPLN is antireflection-coated for the two pump wavelengths and output wavelength. the 30.1 μm grating channel is selected as the optimum period and the PPLN is maintained at 25 °C by placing it on a Peltier thermo-electric element. The mid-IR DFG radiation from the PPLN is collimated by a $CaF_2$ lens (f = 50 mm) and the residual pump-beam are blocked by a Ge filter. Trace $NO_2$ gas detection is performed by using a gas cell with $CaF_2$ windows in order to evaluate the DFG spectroscopic source. The 3.5 μm DFG probe beam transmitted from the gas cell (optical path length 10 mm) is collected by using an off-axis parabolic mirror (f = 50 mm) into a thermoelectrically cooled detector with 1 $mm^2$ active area. The detected signal is amplified and acquired to laptop computer.

### 3. Experimental result and Discussion

Figure 3 shows the spectrum around at 3.48 μm obtained by scanning the DFG spectroscopic source with use of a 1000 ppm concentration of $NO_2$ at presser of 100 Torr in the multipass cell (Optical path length; 10 m). This measurement is made with 256 averages at a 70 Hz modulation frequency. Though the wavelength tuning of the DFG spectroscopic source can be over 300 GHz (10 $cm^{-1}$) range without mode hop. The FWHM of the absorption profile has been with good coincidence that from the theoretical calculation by HITRAN '96.

### 4. Conclusion

A DFG based narrow-linewidth spectroscopic source pumped by high power fiber laser—DFB laser diode combination is demonstrated successfully at 3.5 μm for $NO_2$ detection. This demonstration is helpful in the design of DFG based gas sensors utilizing present and future demonstrations of optical fiber and photonic technologies.

A high resolution specroscopic results (a spectral linewidth of <30 MHz) will be also discussed.

### References

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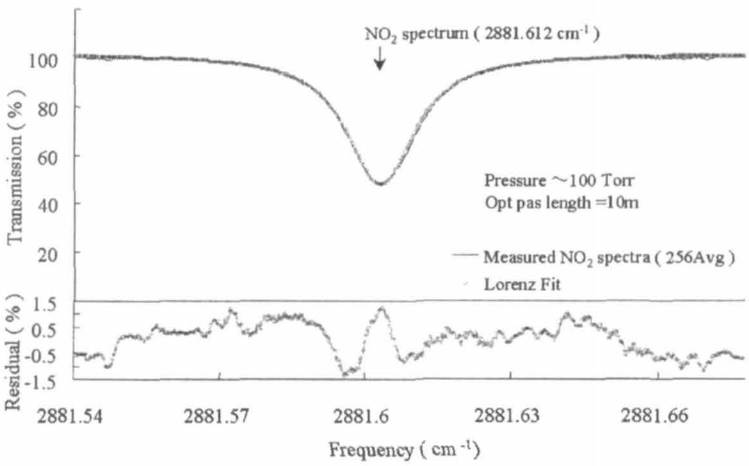


**CThO31 Fig. 2.** High-resolution $NO_2$ absorption spectrum at 2881.6 $cm^{-1}$ at a cell pressure of 13.3 kPa and a path length of 10 m.