Faraday Modulation Spectroscopy of Nitric Oxide at 5.33 μm with an External Cavity Quantum Cascade Laser

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Abstract: The selection of the specific molecular transition is of great importance to achieve best sensitivity with Faraday rotation spectroscopy. Application of broadly-tunable external-cavity quantum cascade laser allowed targeting the optimum NO-Q(3/2) transition at 1875.8 cm^{-1}.

OCIS codes: (140.5965) Semiconductor lasers, quantum cascade; (300.6310) Spectroscopy, heterodyne

1. Introduction

Faraday rotation spectroscopy is an extremely sensitive technique for the detection of paramagnetic species such as nitric oxide. This method is intrinsically background free and can provide excellent selectivity, because its insensitivity to absorption from diamagnetic species. Under influence of external magnetic field the molecular transitions split into $\Delta M = +1$ and $\Delta M = -1$ components, with the former absorbing only right hand circularly polarized light and the latter only left hand circularly poloarized light [1,2,3,4]. The best sensitivity for nitric oxide detection can be obtained using the Q(3/2) fundamental transition at 1875.8 cm^{-1}, which consists of three $\Delta M = +1$ and three $\Delta M = -1$ overlapped transitions. This transition has the highest magnetic modulation sensitivity [2].

The apparatus used in this work is depicted in Fig. 1. As a spectroscopic source a Fabry Perot quantum cascade laser operating in an external cavity configuration at 5.2 μm was employed [5,6,7]. By changing the angle of the diffraction grating, this laser is capable of single mode tuning over a 155 cm^{-1} spectral range. For high resolution spectroscopy, mode hop free tuning over a range of 2 cm^{-1} can be performed anywhere between 1825 and 1980 cm^{-1} (see Fig. 2). The laser was operated at –30^{o}C with a maximum output power of 11 mW. The collimated output beam from the external cavity quantum cascade laser (EC-QCL) is split using ZnSe wedged window into two independent pathways. The main beam path is used for magnetic rotation detection while the second beam (~15% of the laser power) is used for reference purposes. The main laser beam passes through Rochon polarizer and is directed into 30cm absorption gas cell placed inside a 22 cm air core solenoid. The linearly polarized light can be analyzed as two equal amplitude right-handed and left-handed circularly polarized electromagnetic waves. In the presence of a magnetic field each circularly polarized wave will experience a different complex propagation constant originating from the interaction with either the Zeeman split $\Delta M = +1$ or the $\Delta M = -1$ NO transition components. This is observed as a rotation of the polarization axis of the initially linearly polarized light. By passing the beam through a second Rochon Polarizer (analyzer) with a nearly crossed polarization axis, this rotation is detected as changes in the intensity of the transmitted light measured with a thermoelectrically cooled mercury cadmium telluride photodetector. The experiment is performed using a modulated magnetic field and phase sensitive lock-in detection scheme. The magnetic coil is supplied from high power amplifier capable of supplying a 1.2 kHz, 2 A rms current waveform. The detected signal which is proportional to the first derivative of a dispersion line shape is demodulated by a lock in amplifier at the 1st harmonic of the modulation frequency and is recorded by a computer. Optimum sensitivity is obtained by the selection of the appropriate sample gas pressure, modulation depth of the magnetic field and the analyzer polarization angle.

A first measurement of a Faraday modulated spectrum of 10ppm NO in N_2 mixture recorded at 1875.8 cm^{-1} is presented in Fig.3. The spectrum was recorded at 20 Torr with a lock-in time constants of 500ms. The calculated minimum detection limit was 50 ppb. Studies and optimization of system sensitivity together with several examples of real world applications in environmental monitoring and medical diagnostics will be reported and sensitivity enhancement techniques using multipass and/or cavity enhanced configurations will be investigated.

2. Figures and tables

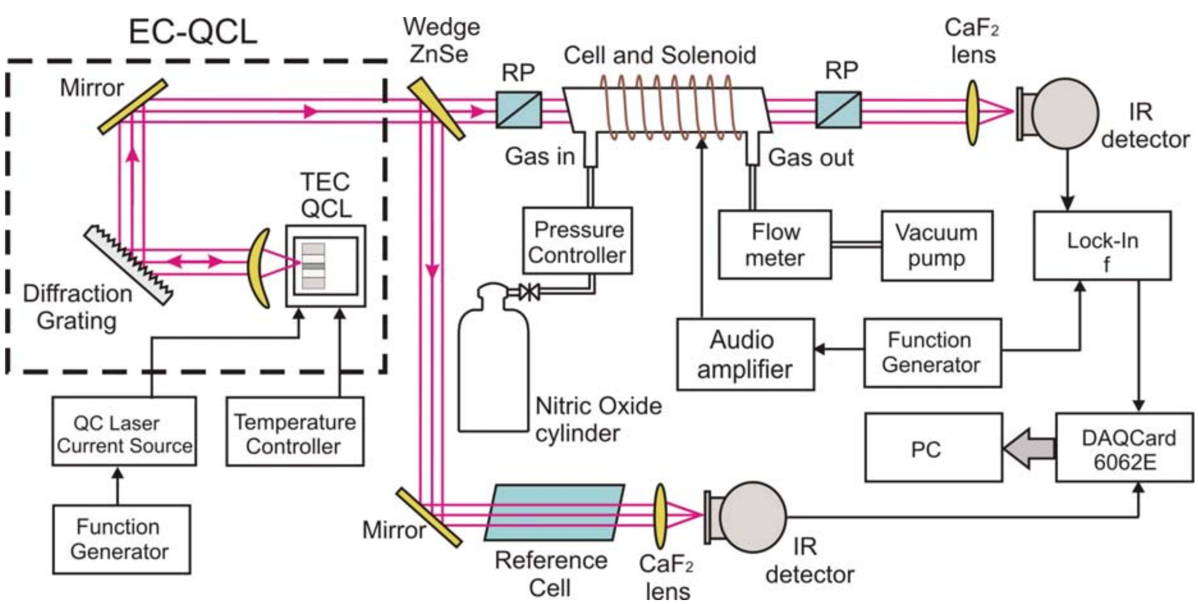

Fig. 1. Schematic configuration of the setup used for Laser Faraday Rotation Spectroscopy of NO.

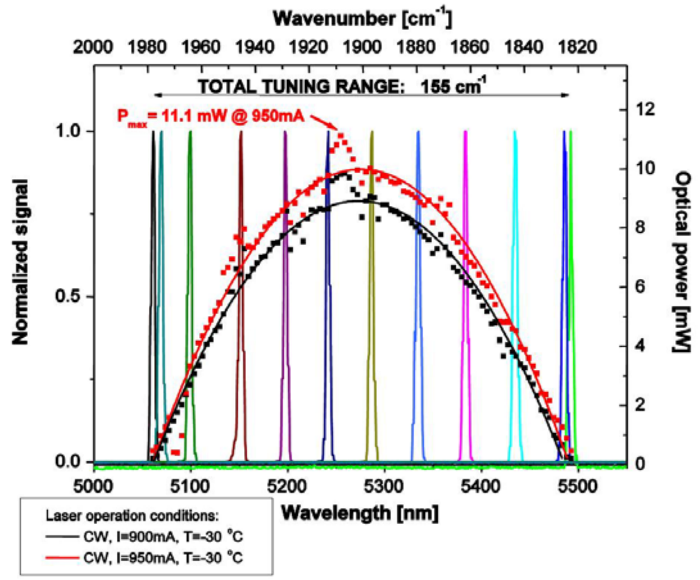

Fig. 2. Wavelength tuning range and corresponding laser power for a 5.2 μm EC-QCL.

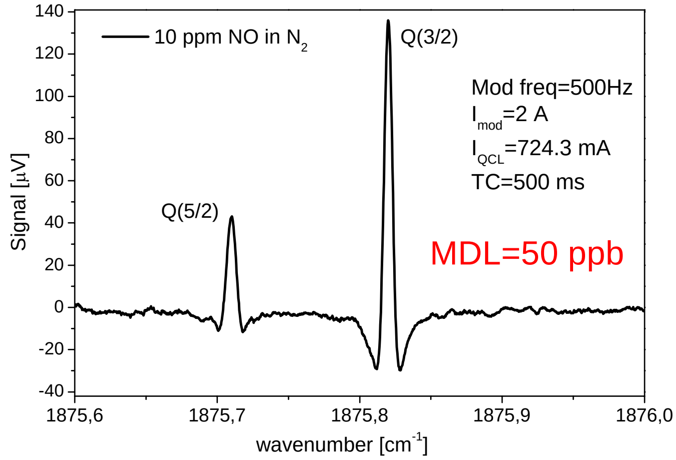

Fig. 3. Faraday rotation spectrum of NO Q(3/2) transition at 1873.8 cm^{-1}. Minimum detection limit for this measurement was 50 ppb in time constant of 500ms.

4. Acknowledgements

This work was performed with financial support from National Science Foundation Mid-Infrared Technologies for Health and the Environment (MIRTHE) Engineering Research Center, a subaward of a DoE STTR grant from Aerodyne Research, Inc., and the Robert Welch Foundation.

4. References

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