Development of a Non-Invasive Blood and Tissue CO_2 Sensor Using Mid-Infrared Quantum Cascade Lasers

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Carbon dioxide is a natural by-product of cellular respiration in the human body. High levels of CO_2 in the body are a direct indication of abnormal metabolism, circulation and ventilation.[1] As a result, a non-invasive CO_2 in blood sensor is a highly desirable medical diagnostic tool. Sensors for CO_2 in both gas and in aqueous form have already been successfully developed using quantum cascade (QC) lasers since CO_2 strongly absorbs at 2345 cm^{-1} (4.3 μm) in the mid-infrared region.[2,3] Similarly, our research team aims to develop a non-invasive sensor using QC lasers that will reliably quantify CO_2 in the human body at room temperature with a quick response time.

QC lasers are currently being developed for optical sensors in environmental and medical applications due to their monolithic and highly tunable nature. Although the wavelength at which a QC laser emits is predetermined by the structure of its alternating layers, further tuning within its bandwith is possible by altering the length of the cavity. A relation between the length of the cavity and its wavelength exists due to the effects of the operating voltage on the gain to loss ratio. Further fine tuning can be achieved altering the temperature and current. As the first part of this project, we characterized 10 ± 2 μm wide multimode lasers. The cavity lengths ranged from 1-3 mm, and its lasing wavelengths were recorded from 80K-320K. Results in Figure 1 showed lasing from 4.18-4.37 μm, straddling the CO_2 absorption range. The optimum QC laser for our sensor will lase at 4.3μm at room temperature. A distributive feedback (DFB) grating will later be incorporated to achieve single-mode operation. These lasers will be used in a prototype CO_2 sensing system which is currently under development. The sensor will be similar in nature to pulse oximeters in that it will use a QC laser based diffuse scattering absorption spectroscopy system.

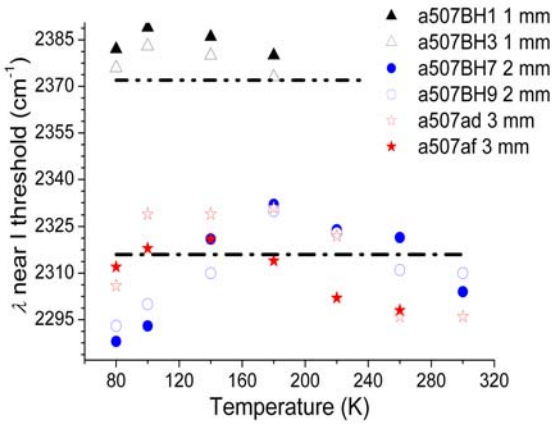

Figure 1 Lasing wavenumbers for 1-3 mm length lasers at different temperatures from 80K-320K. CO_2 strongly absorbs at 2345 cm^{-1} (4.3 μm) in the mid-infrared region.

[1] Bhende MS. "End-tidal carbon dioxide monitoring in pediatrics: concepts and technology." *Journal of Postgraduate Medicine* 47:153, 2001.

[2] A. A. Kosterev, F. K. Tittel, C. Gmachl, F. Capasso, D. L. Sivco, J. N. Baillargeon, A. L. Hutchinson, and A. Y. Cho. "Trace-gas detection in ambient air with a thermoelectrically cooled, pulsed quantum cascade distributed feedback laser." *Applied Optics,* 39 (36):6866-6872, 2000.

[3] S. Schaden, M. Haberkorn, J. Frank, J. R. Baena and B. Lendl. "Direct determination of carbon dioxide in aqueous solution using mid-infrared quantum cascade lasers." *Applied Spectroscopy,* 58:667-670(4), 2004.