FROM SENSING TO MAKING SENSE

Towards Miniature Dual-comb Spectroscopy Systems For Mid-ir Trace Gas Sensing

Kerry Vahala California Institute of Technology **Qiang Lin** University of Rochester

A high-resolution spectroscopic sensor for detection of chemical threats and with potential for chip-scale integration is described. A demonstration using discrete components is presented wherein mid-IR spectra of gas mixtures are measured. The sensor's operation is based upon dual-comb spectroscopy (DCS), a technique that precisely measures gas spectra at optical frequencies, but provides read-out in the form of a radio frequency spectrum. The method offers radio-frequency precision in spectral measurements, but does not require bulky mechanical spectrometers. Moreover, on account of recent progress in a key optical component, called a frequency microcomb, the method shows great promise for chip-integrated systems that could function in hand-held sensors.

The frequency microcomb is a semiconductor-chip-based optical source that provides a highly coherent and broad spectrum of equally-spaced-in-frequency `comb' lines. The frequencies extend over a range that can be as large as an octave. Also, the comb lines are separated by a readily controlled frequency that is typically in the microwave range. To implement DCS, two optical comb signals pass through a gas mixture so that the gas absorption spectrum is imprinted onto the comb spectra. As a result, the frequency combs sample the gas absorption spectra with a resolution set by their line spacing. The two combs are designed to have slightly mismatched comb line frequency spacings. DCS then proceeds by photo detection of the two comb signals to produce an electrical signal. Upon fast Fourier transform of this signal, an electrical comb of frequencies is revealed, which contains the original optical absorption spectrum except now compressed into a radio frequency bandwidth. This mapping from the optical to electrical spectrum can be understood to result from heterodyne inter-mixing in the photo detector of the two sets of optical comb lines. This intermixing generates the electrical comb lines spaced in frequency at the difference of the optical comb line frequency spacing. Significantly, analysis of the comb of radio frequencies measures the original gas absorption spectrum without the use of scanning gratings or interferometers.

For chemical finger printing using DCS, frequency comb operation in the mid-infrared (mid-IR) spectral bands is preferred. And conventional table-top frequency combs in these bands have made considerable progress in application to mid-IR DCS. This includes spectral resolution sufficient to distinguish isotopes of gas species. Here, we report microcomb-based DCS with GHz resolution in the mid-IR band. The two GHz-rate mid-IR combs are generated by interleaved difference-frequency-generation (iDFG) applied to four near-IR combs. DCS measurements of methane and ethane mixtures near 3.3 μm are presented as a test of feasibility of the system. In its present configuration, the system can be designed to operate over wavelengths from telecom to nearly 6 microns. However, by use of different materials for the difference frequency generation process operation at longer wavelengths is possible. After discussion of these results, we will review recent progress towards integration of specific DCS microcomb subsystems.

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