Chip-scale mid-infrared spectroscopy using electrically-pumped frequency comb sources

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Abstract: *Interband cascade- and diode laser optical frequency combs with gigahertz repetition rates are discussed as sources for mode-resolved, broadband mid-infrared spectroscopy. Their millimeter-scale size and sub-watt power consumption are appealing for use in portable instruments.*

The mid-wave infrared spectral region (MWIR, 3–5 µm) has come to play a critical role in sensing environmentally-relevant trace gases. In particular, chip-scale broadband coherent emitters with optical frequency comb (OFC) properties are highly-desirable for these applications. For spectroscopy, the discrete pattern of sharp, equidistant MWIR lines enables the multi-heterodyne (dual-comb) technique (Fig. 1a) to resolve individual comb lines on a nanosecond time scale with high signal-to-noise ratio (SNR). Especially attractive is the emerging interband cascade laser (ICL) OFC platform [1], which combines THz-wide spectral coverage and sub-MHz optical linewidth with the potential for realizing a complete room-temperature MWIR spectroscopic system that integrates a GHz-frequency interband cascade detector (see Fig. 1a) processed from the same wafer material as the ICL [2].

Figure 1b illustrates that the narrow optical linewidth of an ICL OFC also makes it well-suited for cavity-enhanced sensing techniques. The Vernier effect has been used in a centimeter-scale, high-finesse cavity to simultaneously enhance the optical path to 30 m and selectively filter the individual comb lines for broadband, millisecond-scale sensing of hydrocarbons at a wavelength near 3.6 µm [3]. This approach obviates the requirements for a fast photodetector and matched second comb source, which become even more difficult to fulfil in such challenging spectral regions as the long-wave infrared (LWIR) and terahertz (THz).

We will also discuss OFCs based on type-I GaSb Fabry-Pérot diode lasers, which have been shown to generate self-starting OFCs around 3.05 µm, with GHz repetition rate and frequency-modulated (FM) emission characteristics [4]. Although the timing stability is lower than for ICL OFCs, high spectral flatness and broad spectral tunability are combined with sub-MHz to MHz optical linewidth. This class of battery-operated OFC sources is well suited to the power-constrained detection of space-relevant molecules such as hydrogen cyanide (HCN) and acetylene (C_2H_2).

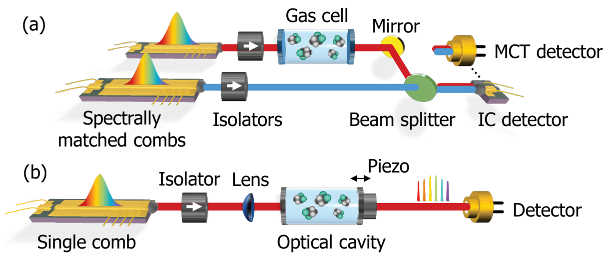

Fig. 1. Two topologies for chip-based, mode-resolved MWIR OFC spectroscopy: (a) Dual-comb spectrometer with a mercury-cadmium-telluride (MCT) or interband cascade (IC) detector. (b) Vernier spectrometer with cavity enhancement.

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