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Sensitivity Enhancement of a Cantilever-Enhanced Photo-Acoustic Spectroscopic Sensor by an Optical Build-Up Cavity

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Laser photo-acoustic spectroscopy (LPAS) is a highly sensitive and selective method for trace gas analysis. One of the most advanced LPAS techniques is cantilever-enhanced photo-acoustic spectroscopy (CEPAS), which can reach down to low-ppt and sub-ppt level trace gas detection sensitivities with high power lasers [1,2]. The selection of wavelengths and tunability of high power narrow linewidth lasers is, however, limited. They are also rarely suitable for field deployable analysers, which would require a small and robust form factor. An alternative approach, potentially overcoming these weaknesses, is to build up the optical power of a standard distributed feedback diode laser (DFB) or a quantum cascade laser in an external optical cavity [3,4].

Here, we show the first demonstration of enhancing the sensitivity of a CEPAS sensor with an external optical build-up cavity, a technique which we call the cavity-enhanced CEPAS (CE-CEPAS). We achieve an unprecedented normalised noise equivalent absorption (NNEA) value of $1.75 \times 10^{-12} \text{ W cm}^{-1} \text{ Hz}^{-1/2}$. In our work, the NNEA results in 75 ppt noise equivalent concentration for C_2H_2 with a 10 s integration time in the 1530 nm wavelength range. Compared to standard CEPAS, the detection limit is better by a factor of 100, which corresponds to the power build-up factor (BUF) of our cavity. With operation in the near-infrared region, we benefit from the highly reliable and inexpensive components of the telecommunications industry, while achieving a detection sensitivity that is comparable to the state-of-the-art results obtained in the mid-infrared region, where the molecular absorption lines are typically two orders of magnitude stronger.

The experimental setup (Fig. 1a inset) consists of a 7.5 mW DFB laser coupled into a linear optical cavity that accommodates the CEPAS sensor. The cavity has a finesse of ~ 200 , which is optimized for the linewidth of the DFB laser. The photo-acoustic signal is obtained by wavelength modulation with second harmonic detection. This modulation scheme allows us to avoid background signal, which is a typical problem with amplitude modulated LPAS [4]. The wavelength modulation at 30 Hz involves a continuous lock of the laser frequency to the cavity by the dither-and-lock method and dithering one of the cavity mirrors to change the resonance frequency of the cavity. The CE-CEPAS instrument is characterised by calibrating the sensor response (Fig. 1a) and performing an Allan deviation analysis (Fig. 1b) for both CE-CEPAS and CEPAS. The difference between the two techniques gives the BUF of 100, which also agrees with the cavity design.

Fig. 1 (a) CE-CEPAS and CEPAS second harmonic peak signal as a function of C_2H_2 volume mixing ratio. The inset shows the experimental setup. (b) Allan deviation analysis. The results are scaled by the BUF for comparison.

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