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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 1.75×10^{-12} W cm^{-1} 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.

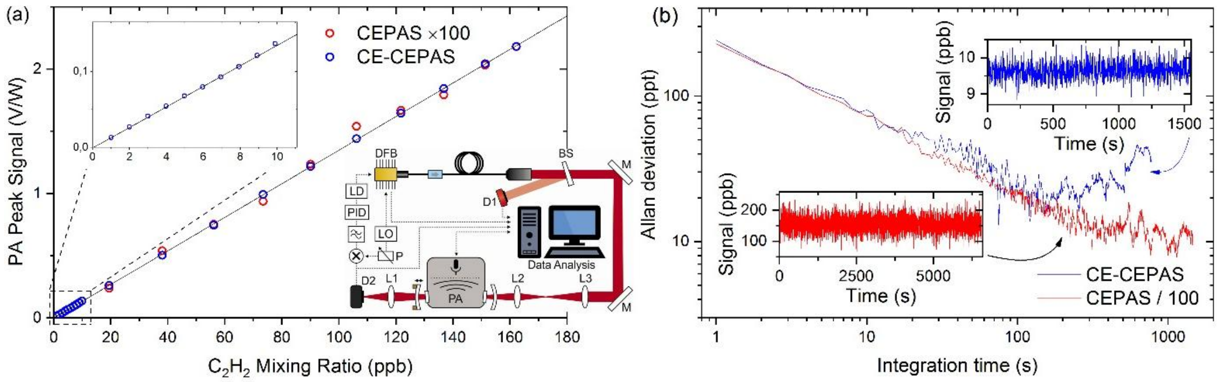

Fig. 1 (a) CE-CEPAS and CEPAS second harmonic peak signal as a function of C_2H_2 volume mixing ratio. The inset shows the experimental setup. (b) Allan deviation analysis. The results are scaled by the BUF for comparison.

References

[1] J. Peltola, T. Hieta and M. Vainio, "Parts-per-trillion-level detection of nitrogen dioxide by cantilever-enhanced photo-acoustic spectroscopy," Opt. Lett. **40**, 2933–6 (2015).

[2] T. Tomberg, M. Vainio, T. Hieta and L. Halonen, "Sub-parts-per-trillion level sensitivity in trace gas detection by cantilever-enhanced photo-acoustic spectroscopy," Sci Rep. **8**, 1848 (2018).

[3] A. Rossi, R. Buffa, M. Scotoni, D. Bassi, S. Iannotta and A. Boschetti, "Optical enhancement of diode laser-photoacoustic trace gas detection by means of external Fabry-Perot cavity," Appl. Phys. Lett. **87**, 041110 (2005).

[4] P. Patimisco, S. Borri, I. Galli, D. Mazzotti, G. Giusfredi, N. Akikusa, M. Yamanishi, G. Scamarcio, P. De Natale and V. Spagnolo, "High finesse optical cavity coupled with a quartz-enhanced photoacoustic spectroscopic sensor," Analyst **140**, 736 (2015).