HIGH-SENSITIVITY VIBRATIONAL SPECTROSCOPY BY CANTILEVER ENHANCED PHOTOACOUSTIC SENSOR

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The race towards compact and robust sensors able to detect extremely low concentrations of molecules in the air plays an important role in our modern society, impacting sectors such as environmental and climate change monitoring, transportation, agriculture, safety, and security. During the last decade, optical detection with ultra-high sensitivity, down to the part-per-quadrillion level, was demonstrated with cavity-ring down techniques[1]. An alternative approach deals with photoacoustic spectroscopy, in which the target gas selectively absorbs a modulated laser light and generates acoustic waves by non-radiative energy relaxation processes, which are then converted into a measurable signal by a proper acoustic transducer. This approach is particularly appealing for its unique characteristics of robustness, record dynamic range, and compact size, which make them particularly attractive for in-field applications. Moreover, photoacoustic-based sensors have shown great potential in achieving a sensitivity at the level of the techniques mentioned above, when combined with narrow-linewidth mid-infrared lasers and high-finesse optical cavities[2,3,4,5].

[1] M.G. Delli Santi et al., *Biogenic Fraction Determination in Fuel Blends by Laser-Based 14CO2 Detection*, Advanced Photonics Research 2, 2000069 (2021)

[2] G. Zhao et al., *High-resolution trace gas detection by sub-Doppler noise-immune cavity-enhanced optical heterodyne molecular spectrometry*, Opt. Express 27, 17940 (2019)

[3] S. Borri et al., *Intracavity quartz-enhanced photoacoustic sensor*, Appl. Phys. Lett. 104, 091114

[4] Z. Wang et al., *Doubly resonant sub-ppt photoacoustic gas detection with eight decades dynamic range*, Photoacoustics 27, 100387 (2022)

[5] T. Tomberg et al., *Sub-parts-per-trillion level sensitivity in trace gas detection by cantilever-enhanced photo-acoustic spec- troscopy*, Sci. Rep. 8,1848 (2018)

In this framework, we designed a novel sensor combining all the advantages of the photoacoustic technique with the sensitivity enhancement provided by a doubly-resonant acoustic-optic system. In our setup a 4.5um-wavelength CW quantum cascade laser excites strong N_2O and CO rovibrational transitions. The acoustic-to-voltage transduction of the signal is performed by a Micro Electro Mecanichal cantilever, whose displacement is measured with a balanced Michelson interferometer. The cantilever is mounted in a homemade photoacoustic cell consisting of a high-Q-factor acoustic resonator placed inside a high-finesse optical resonator. This design, leveraging on a double standing wave e effect, achieves a combined acoustic and optical amplification factor of several orders of magnitude compared to the standard configuration, thus strongly enhancing the final detection sensitivity.