frontiers | Frontiers in Physics

TYPE Editorial
PUBLISHED 14 October 2024
DOI 10.3389/fphy.2024.1503351

OPEN ACCESS

EDITED AND REVIEWED BY
Lorenzo Pavesi,
University of Trento, Italy

*CORRESPONDENCE
Davide Gatti,
davide1.gatti@polimi.it

RECEIVED 28 September 2024
ACCEPTED 02 October 2024
PUBLISHED 14 October 2024

CITATION
Lamperti M, Gatti D, Moretti L, Womack CC, Saavedra C and Gotti R (2024) Editorial: Cavity-enhanced optical spectroscopy.
Front. Phys. 12:1503351.
doi: 10.3389/fphy.2024.1503351

Editorial: Cavity-enhanced optical spectroscopy

Marco Lamperti[1], Davide Gatti[2]*, Luca Moretti[2], Caroline C. Womack[3,4], Carlos Saavedra[5] and Riccardo Gotti[6]

[1]Dipartimento di Scienza e Alta tecnologia, Università degli studi dell'Insubria, Como, Italy, [2]Dipartimento di Fisica—Politecnico di Milano and IFN-CNR, Lecco, Italy, [3]Chemical Sciences Laboratory, National Oceanic and Atmospheric Administration, Boulder, CO, United States, [4]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, Boulder, CO, United States, [5]Department of Chemistry, University of Wisconsin–Madison, Madison, WI, United States, [6]Dipartimento di Ingegneria Industriale e dell'Informazione, Università di Pavia, Pavia, Italy

KEYWORDS

optical cavities, cavity-enhanced absorption spectroscopy, molecular spectroscopy, atmospheric monitoring, optical frequency comb (OFC), microbubble resonators

Editorial on the Research Topic
Cavity-enhanced optical spectroscopy

Recent advances in cavity-enhanced spectroscopy have led to significant improvements in the precision, sensitivity, and range of applications for optical detection and measurement. These developments have strong impacts across various fields, including environmental monitoring, quantum electrodynamics (QED), and biomedical research. The contributions featured in this Research Topic reflect the different approaches and novel methodologies emerging in this area, highlighting both theoretical insights and practical implementations.

Cavity ring-down spectroscopy (CRDS) is one of the most commonly used cavity-enhanced techniques, offering improved frequency noise resilience and exhibiting one of the highest sensitivities in this category. In their work, Liu et al. perform CRDS measurements employing two distributed feedback (DFB) lasers operating around 1,600 nm. One laser is used as probe beam which is injected in a multipass cell and is frequency stabilized against a CO_2 absorption line using frequency modulation spectroscopy, ensuring drift-free laser frequency. In the study, 90% of the radiation is injected into a 200-mm-long high-finesse (about 45,000) cavity, along with the second DFB laser, emitting at a similar wavelength, used to measure absorption-free ring-down time. This stabilization leads to a five-fold improvement in detection sensitivity, reaching $4.4{\cdot}10^{-11}$ cm^{-1} with a detection limit of 78 ppb, comparable to leading commercial systems. This approach has proven its efficacy in environmental and industrial gas sensing, validating its potential for broad practical applications.

CRDS, combined with an optical frequency comb, is used by Gotti et al., reaching unprecedented precision in measuring the P (5), P (6), and O (3) transitions of the HD molecule 2–0 band near 1.5 μm. Improving the accuracy of the P (5) transition, the only one investigated previously in the literature, by more than two orders of magnitude, they achieved uncertainties below 3 MHz, closely aligning with QED predictions. The analysis employed the Hartmann-Tran profile with β correction for precise line-shape description. This approach highlights the potential of combining advanced spectroscopic techniques to improve our understanding of molecular hydrogen, setting new benchmarks for future research in QED and molecular spectroscopy.

Cavities are not only a fundamental tool for spectroscopy but can be used for extremely precise comb characterization, as Giannotti et al. propose. In their paper, they describe a new approach to measure the carrier-envelope offset (CEO) frequency of an optical frequency comb exploiting an external optical resonator and avoiding non-linear frequency conversion, thus reducing the complexity of the experimental setup. They propose a variation of the well-known Pound-Drever-Hall (PDH) technique, performing a single-side spectral selection of the comb spectrum and retrieving an asymmetric PDH (a-PDH) signal. Through a rigorous theoretical and mathematical description, they underline the necessity to break the symmetrical compensation within the PDH signal. Exploiting the linear region of the a-PDH signal, they demonstrate the possibility to retrieve the CEO frequency. They test this novel approach on an experimental setup with an Er-fibre mode-locked laser and an optical cavity with known parameters. After a-PDH curve calibration, they achieve CEO values with 0.87% fractional precision relative to the repetition rate, outperforming conventional f-2f interferometers and offering greater versatility and reduced complexity.

Optical cavities find another important use in Klose et al. Here, the density distribution and the absorption coefficient of H_2O_2 present in the effluent of a cold atmospheric pressure plasma jet (CAPJs) was resolved using a highly sensitive detection method and a Fabry-Perot (FP) resonator. CAPJs have been employed in fields like medicine, materials processing for heat sensitive targets, and plasma agriculture due to the role that H_2O_2 has in cell reactions and development. H_2O_2 detection was demonstrated using a quantum cascade laser with an acousto-optic modulator (AOM). The zeroth diffraction order was monitored by a wavelength analyzer, while the first was coupled to the FP cavity. The FP transmission was detected by a fast detector, and the AOM was strobed to initiate the cavity ring-down process exposed to CAPJs. This method allowed the researchers to determine the density distribution of H_2O_2 in CAPJs produced by a KINPen-sci plasma jet, where the highest concentration lies in an elongated lobe close to the nozzle. This approach will help in understanding the chemical reactions present in the plasma zone including formation and consumption mechanisms of biomedically relevant species.

Still in the framework of absorption spectroscopy, the paper by Frigenti et al. demonstrates the use of microbubble resonators (MBRs) as highly compact, scattering-free absorption spectrometers, leveraging the thermal sensitivity of their whispering gallery mode resonances. By actively locking the probe laser wavelength to the selected MBR resonance, the sensitivity and stability of the system are significantly enhanced with respect to previous works, achieving a signal-to-background ratio above 10 even for a highly diluted water suspension of PEGylated gold nanorods. A direct comparison with the absorption profile measured by a standard spectrophotometer showed a close match with the MBR sensor, validating its accuracy. The authors also present a preliminary model to determine the absolute absorption coefficient of the sample within the MBR, showing that the correct order of magnitude is retrieved. However, more sophisticated computational models are needed to accurately determine the absorption coefficient. This study highlights the potential of MBR spectrometers for precise and efficient absorption measurements in various real-world scenarios, specifically for extremely small samples or low concentrations of absorbers.

In summary, through this Research Topic, we highlight the significant advances in spectroscopic techniques and cavity-enhanced methods that are pushing the limits of precision measurement in the spectroscopy field. These advancements pave the way for more accurate environmental monitoring, improved medical diagnostics, and deeper insights into molecular dynamics.

Author contributions

ML: Writing–original draft, Writing–review and editing. DG: Writing–original draft, Writing–review and editing. LM: Writing–original draft, Writing–review and editing. CW: Writing–original draft, Writing–review and editing. CS: Writing–original draft, Writing–review and editing. RG: Writing–original draft, Writing–review and editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note