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Cavity-Enhanced Spectroscopy and Sensing

Springer

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In memory of my father, Angelo.

(May 2013) Gianluca Gagliardi

Preface

It is with deep satisfaction and pride that we present this book on cavity enhanced spectroscopy and sensing. The reader will find a wide variety of articles on techniques and applications related to the use optical cavities in this book. It would, of course, be impossible to provide a complete survey of the applications of optical cavities. Instead, in the selection of the chapters we aimed for a large breadth of topics that, we hope, is representative of the field in 2013.

Only a few years ago the term "cavity enhanced spectroscopy" would have implied the use of free-space optical cavities that are used primarily for gas detection and spectroscopy through a limited variety of methods—such as cavity ring-down spectroscopy and cavity-enhanced absorption spectroscopy. In parallel other research groups developed novel optical resonators made from fiber optic cables, pure dielectric materials or using silicon nanowires with intended applications as e.g. optical switches or refractive index sensors. In recent years, there appears to be a convergence of these two fields. The selection of chapters in this book shows that cavity-based optical measurements (such as time measurements) are increasingly used with e.g. fiber optic cavities, or microresonators, whereas interrogation methods that are derived from telecommunication technologies, and optical metrology find uses in gas phase spectroscopy. Newly developed techniques involving, for example, optical frequency comb synthesizers, tunable mid-infrared lasers, nonlinear light generators, fiber lasers, supercontinuum sources and active frequency locking of a laser to an optical cavity further accelerate the progress in the field. An excellent historic overview is provided by Romanini et al. as part of the first chapter of this book.

The following chapters introduce an astonishing variety of techniques and methods that all rest on the most prominent properties of optical cavities: first, that they are capable of storing light at high powers for a considerable amount of time and, second, that they act as narrow band-pass (or band rejection) filters. The second property may be considered a nuisance, but it is important for those interested in using cavities as optical switches, or for strain, vibration, and refractive index measurements.

Most contributions in this book use high finesse cavities made from two or more mirrors, but you will also find cavities made from fiber optic loops (Vallance, Wang) fiber optic strands and gratings (Avino & Gagliardi) as well as microtoroids (Wu & Vollmer) and microspheres (Barnes). The choice of light sources and spectral range is just as varied: pulsed lasers have been extended into the 7000–9000 cm^{-1} region using stimulated Raman shifting or difference frequency generation (Kine & Miller, and Cancio et al.), quantum cascade lasers permit ring-down studies in the 600–2250 cm^{-1} region (Welzel, Engeln & Röpcke, and Cancio et al.), and broadband light sources such as supercontinuum sources, lamps and LEDs are reviewed by Ruth, Dixneuf, and Raghunandan. Optical frequency combs are an emerging source of considerable importance to cavity enhanced spectroscopy, because of their unique coexistence of high temporal coherence and stability with an extraordinary spectral coverage. This opens the possibility to simultaneously couple into many different cavity modes with amazingly high spectral resolution over a wide wavelength range (Masłowski). In addition frequency combs can also be used to stabilize "conventional" lasers and thereby increase the sensitivity of a sensing experiment (Avino). On the other hand simple diode lasers can also be locked effectively to the optical resonators either by optical feedback (Morville et al., Welzel et al.) or using electronic feedback circuitry (Barnes, and Avino).

Of particular interest is noise-immune cavity-enhanced optical heterodyne molecular spectroscopy (NICE-OHMS) which is a cavity enhanced absorption method that is record-breaking with regards to sensitivity, detection limit and dynamic range. Chapters by Axner, and by Siller & McCall, present the technical details and the different applications of the method, whereas the introductory chapter by Romanini et al. gives a historic and scientific overview in the context to all cavity-based methods.

The choice of applications for cavity enhanced detection schemes has also grown to include practically all absorption, attenuation and scattering phenomena from optical absorption of trace gases, atmospheric sensing, transient absorption in reaction mixtures, breath analysis, liquid absorption and detection, etc. to even include mechanical deformation, vibration, strain, pressure and temperature. Given the diversity of the research field one may wonder whether those involved in cavity enhanced spectroscopy and sensing still find common ground. Yet, in our experience, the borders across disciplines are surprisingly permeable and each research group occupies typically not just one niche of the field but uses a variety of methods—each adapted to a particular application.

Again, we hope you will find this book instructive, and enjoy learning from some of the world experts about the state-of-the-art in cavity enhanced spectroscopy and sensing.

Napoli, Italy — Gianluca Gagliardi
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