THz technologies for sensing and non-destructive testing

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Abstract: Progress in the far infrared part of the spectrum now allows to make metrological measurements of molecular transition frequencies and may help to develop novel coherent set-ups for imaging.
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1. Introduction

The 300-50 micron wavelength spectral window, often referred as TeraHertz (THz), promises to have countless applications in strategic fields, as bio-medical diagnostics, communication technology, security and defense. Nevertheless, the THz spectrum is still under-explored even for fundamental applications of science and technology. The realization and control of radiation sources is a crucial issue for THz advance. Quantum Cascade Lasers (QCLs) certainly represented a major breakthrough, thanks to their compactness and flexibility.

In this scenario, we developed several state-of-the-art experimental setups, ranging from THz QCL-based metrological-grade spectrometer to THz holographic imaging systems.

Indeed, our pioneering measurement of intrinsic frequency fluctuations of a THz QCL evidenced linewidth values approaching the quantum limit, despite the broadening induced by thermal photons [1]. In order to realize a metrological THz source, the QCL phase/frequency has to be stabilized, making functional its intrinsic spectral purity. In this framework, a key advance is represented by the extension to the THz region of optical standards, by means of frequency-comb synthesizers (FCSs), that can significantly enhance the metrological performance of THz QCLs [2]. This stabilization system of the QCL provides a narrow continuous-wave THz radiation with an absolute frequency reference.

We have now demonstrated that this source can achieve a record low 10 parts per trillion absolute frequency stability (in tens of seconds), enabling high precision molecular spectroscopy [3]. A simple, though sensitive, direct absorption spectroscopy set-up could be used thanks to the mW-level power available from the QCL. The 10 kHz uncertainty level ranks this technique among the most precise ever developed in the THz range, challenging present theoretical molecular models. Hence, we expect that this new class of THz spectrometers opens new scenarios for metrological-grade molecular physics. These scenarios include also high sensitivity trace-gas sensing for environmental real-time monitoring of pollution, dioxins or other hazardous chemicals (H_2S, CH_3OH, etc.). Moreover this kind of experimental set-up can be used to monitor the development of gases in combustion chambers in order to optimize the generation of cleaner energy.

At the same time a lot of efforts have been spent in developing imaging experiments and setups. We have demonstrated that new generation room temperature detectors, based on semiconductor nanowire-FET can be successfully used in THz imaging setups [4]. Moreover, an even simpler QCL-based setup, making use of virtually no optical elements, can be used for THz digital holography. Infrared (IR) digital holography based on CO_2 lasers has proven to be a powerful coherent imaging technique due to the reduced sensitivity to mechanical vibrations, to the increased field of view, to the high optical power and to possible vision through scattering media, such as smoke [5]. In this contribution we report THz digital holography based on the combination of quantum cascade laser (QCL) sources and a high-resolution microbolometric camera. Our holographic system is suitable for the acquisition of both transmission holograms of transparent objects and speckle holograms of scattering objects, which can be processed in real time to retrieve both amplitude and phase. This allows to take advantage of the different optical response of the imaged object at different frequencies, which is crucial for applications such as non-destructive testing and biological imaging. Among them it is worth to mention the monitoring of water content in living plants, as well as their breathing, or the non-destructive structural testing of mechanical components of energy production devices, such as gas turbine or wind turbine blades.

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