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# Field confinement and its analysis in the THz range

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**Abstract – Confining the electromagnetic field in sub wavelength volume is a widespread challenge in any range of photonics. One of the specificities of the THz range is the relatively low losses of metal allowing the use of metallic structure to achieve this confinement. In this conference, we will show: - how such metallic structure allowed us to perform broadband spectroscopy on nanoliter-sized samples; - narrower band spectrometry on a fraction of nanolitres; and - characterize the near field of the photonic mode in our resonators**

*Keywords – Metasurface, Split ring resonator, Near Field Microscopy Time domain spectroscopy–*

## I. INTRODUCTION

Terahertz (THz) technology has demonstrated valuable purposes, e.g., for the uncovering of hidden items or detecting relevant chemical and biochemical compounds. Nonetheless, due to the use of relatively long wavelengths, traditional diffraction-limited optical systems that detect far-field radiation cannot address single objects smaller than a few hundredths of a millimeter. This limitation is critical for several applied purposes, e.g., characterizing a single micro-object in a resonator or building 2D materials-based THz modulators. It's also crucial for fundamental investigations into THz sub- $\lambda$  ultra-strong light-matter interactions [1].

In this conference, we will present different approaches to achieve sub wavelength (typically  $<100\mu$ ) THz field confinement, either by using near field microscopy or integrated photonic elements that confine light into sub wavelength volumes [2, 3]. These elements that can be either broadband or resonators.

## II. BROAD BAND THz CONCENTRATORS

Most of the broadband approaches use a metallic waveguides such as a parallel plate metallic waveguide [4] because the lowest frequency mode (transverse EM) has no cut-off, is low losses and dispersion characteristic. To achieve full 2D confinement, a thick slot waveguide coupled to a tapered antenna was proposed [5].

We further advanced this approach by employing an exponentially tapered antenna to minimize unwanted reflections [6]. This enabled the successful demonstration of spectroscopy on a 1 nl sample of dried glutamic acid solution [2, 3].

## III. THz RESONATORS

Metamaterials, originating from the field of radar, consist of periodic arrangements of sub-wavelength elements called meta-atoms. In the THz range, these meta-atoms are primarily metallic resonators fabricated using standard clean room techniques or additive manufacturing [7]. Typical examples include dipoles and split ring resonators (SRRs), which exhibit strong confinement ( $V < \lambda^3$ ) of the electric field of the resonant mode inside the gap, resulting in confinement factors exceeding 1000. SRRs have enabled the sensitive detection of extremely small amounts of chemicals [8, 9] and biological targets such as spores, bacteria and viruses [10, 11]. However, most of the demonstrations to date have utilized 2D arrays of resonators, which dilute the confinement and constrain the applicability to scenario repeatable enough to set the samples exactly the same way in every gap of the metasurfaces. Recent results focused on single resonators. The group of J. Faist [1] improved the signal collection by employing a silicon micro-lens to improve the directivity of the SRR and enable the probing of a sample volume of  $\sim 1$  pL at 2.7K under magnetic field showing the feasibility of such an approach even in tedious experimental conditions. On our side, we improved the time-domain spectroscopy (TDS) system collection by utilizing 2-inch mirrors and conducting a thorough analysis of noise sources [12, 13]. This enabled us to measure the resonance of a single resonator up to 2.2 THz

## II. THz s-SNOM

Still, to further use such near field resonators and push them to include nano gaps, the technology is challenging. Therefore, one needs reliable control point to evaluate the true confinement of the E-field. Scanning THz near-field microscopy a well-established technology for over two decades [14], is a suitable candidate for this characterization.

Using a s-SNOM setup excited by a CO<sub>2</sub>-pumped methanol gas laser at 2.52 THz, we characterized the electric field inside the gap of the SRR [15]. Our findings revealed that the experimental setup did not provide direct access to the near field. In fact, the SRR and the s-SNOM tip both act as scattering antennas, and the measured signal arises from the interferences between these two sources,

where the relative phase depends on the position of the tip on the resonator. This results in a combined signal containing both near electric field maps information and far-field interferences that must be interpreted carefully.

#### IV. CONCLUSION

Our exploration of both integrated photonics approaches and near-field microscopy has allowed us to investigate various structures and applications of field confinement in the THz range, including performing THz spectroscopy on microscopic samples and analyzing the mode of a photonic resonator. Our future steps include enabling the coupling of the resonator's mode with that of the sample to achieve, on a practical point of view, spectroscopy of smaller sample sizes and, on a more fundamental point of view, to study strong coupling behavior.

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