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Device for Broadband THz Spectroscopy of 1-nL-Volume Samples

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Abstract—We report on our recent progress in the development of a device for light-matter interaction enhancement in the full terahertz range for precise spectroscopy of minor-volume samples. The efficient confinement of a broadband terahertz pulse to a few-nL-volume was achieved, opening new perspectives for chemical and biological applications. We discuss modifications in the fabrication process leading to the improvement of our technique, following the detailed characterization of the device performances.

I. INTRODUCTION

INCREASING light-matter interactions by confining light to a subwavelength volume is crucial for nonlinear-optical effects and is especially important for the detection of small objects in the Terahertz (THz) range, such as molecules or biosamples – its volume is usually smaller than the cube of the THz wavelength, thus the light-matter interactions are extremely reduced. Moreover, confining light to an object with low refractive index (such as biosamples and their environment) is still a challenge for several spectral ranges. In the THz range this has been achieved using near-field microscopy [1] and wave guiding structures that confines the light in one direction using a parallel plate metallic waveguide (PPMW) [2] ideal for time-domain spectroscopy (TDS) experiments [3]. However, a specific coupling scheme is needed to properly excite the mode of interest. Our method combines the curved tapered antenna approach (similarly to Ref. [4]) to properly inject the beam into the waveguide together with the approach of Ref. [5], using a fully planar

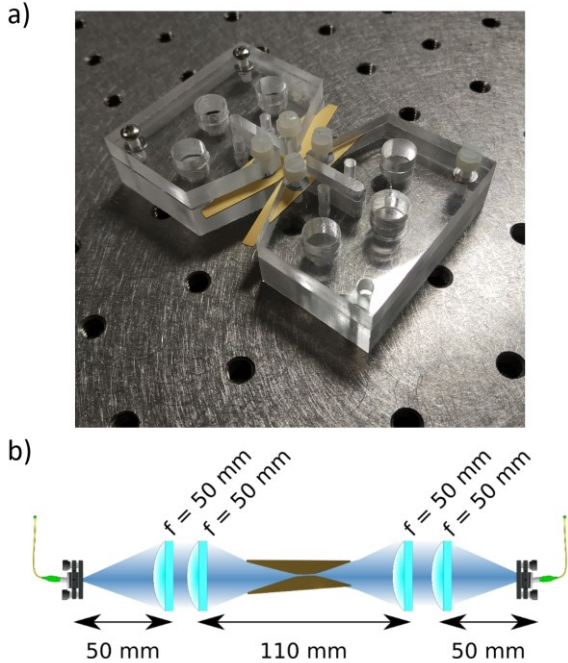


Fig. 1. a) Photo of the butterfly device. b) Schematics of the experimental setup showing the in and out coupling of the THz pulse within the device.

geometry and subsequent 2D confinement. Due to its shape and geometry, we named our exponential tapered antenna coupled metallic waveguide as “Butterfly” (see Fig. 1a.).

The conception was discussed for the first time last year [6, 7, 8], reporting the spectroscopy of few- μL samples in the range of 0.2-2 THz. Here we present the steps leading to further improvement of the technique, in particular showing its capacity to reach sample volumes below 10 nL. During the conference, we will present the detailed characterization of our device, as well as its applications in THz spectroscopy of biological samples.

II. RESULTS

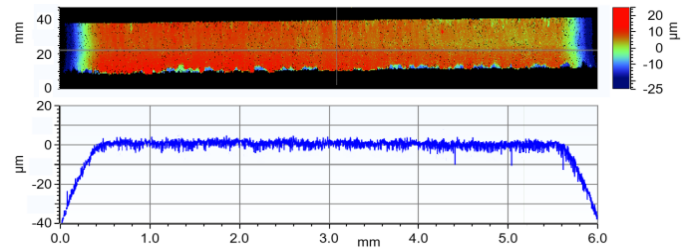


Fig. 2. Typical profile of the waveguide surface measured with Bruker Contour GT-X optical profilometer.

The butterfly devices were fabricated from 300- μm -thick silicon wafers using laser cutting allowing an improvement of the sidewall roughness (average arithmetical mean deviation $R_a \sim 1.5 \mu\text{m}$) and reduce in the production cost. A typical profile trace is presented in Fig.2. Then, the butterfly was covered with Ti/Au layer by means of sputtering. The gold layer thickness inside the waveguide is $\sim 500 \text{ nm}$. The TDS experiments was done using Menlo TeraSmart system with a set of four Polymethylpentene (“TPX”) lenses serving for the pre-focusing

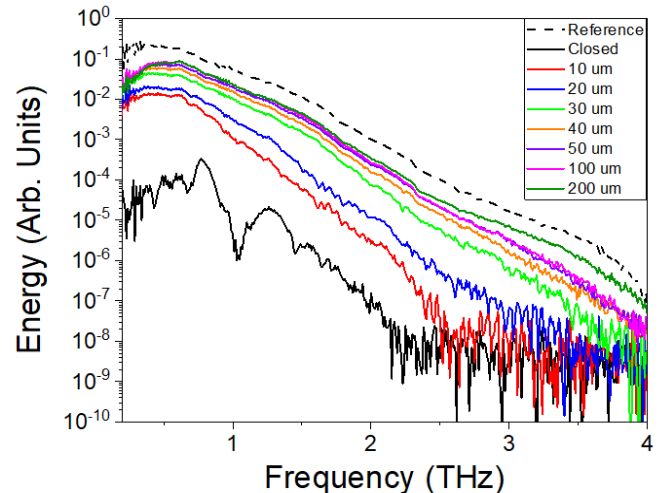


Fig. 3. Spectra of THz pulses transmitted through the butterfly with different widths of the waveguide.

of THz pulses to the injection antenna of the butterfly (see Fig.1b.). With the waveguide width of $30\ \mu\text{m}$ the device allows THz spectroscopy in the range of 0.2-4 THz (Fig.3.). In principle, the higher frequency is limited only by the alignment and by the characteristics of the TDS system. The device is compatible with different THz systems giving an access to the whole THz range.

Using this technique, we are able to measure THz spectra of organic compounds of $\sim 5\text{-}10\text{-nL}$ volume. As an example, the method was tested on samples of α -lactose monohydrate powder (obtained from Sigma-Aldrich) and on the ones of a dried liquid solution (the lactose powder was diluted in deionized water with a concentration of $10\ \text{g/L}$ and the waveguide was filled with a $0.5\text{-}\mu\text{L}$ drop of the solution). The absorption spectra are presented in Fig.4. showing the characteristic lactose THz fingerprints [9]. We believe that our technique could be efficient for the spectroscopy of samples with volumes even below $1\ \text{nL}$. However, a number of parameters of the waveguide and antennas has to be optimized, and an accurate characterization of the device is to be performed (losses, dispersion, far-field radiation patterns for the injection/extraction, etc.). Those results of calculations and of currently undergoing experiments will be presented during the conference.

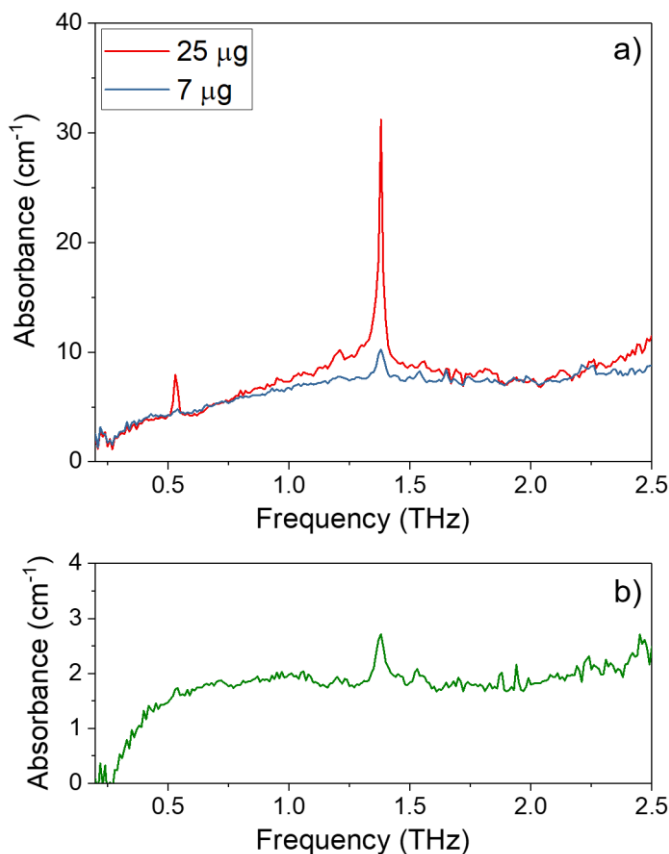


Fig. 4. Spectra of the absorbance of lactose samples: a) powder of $25\ \mu\text{g}$ and $7\ \mu\text{g}$, with corresponding volume of $\sim 15\ \text{nL}$ and $5\ \text{nL}$; b) dried solution corresponding to $\sim 3\ \text{nL}$ sample volume.

III. SUMMARY

We present our findings toward the broadband THz spectroscopy of $<1\text{-nL}$ -volume samples. An efficient improvement of our technique is achieved, allowing the spectroscopy of $\sim 10\text{-nL}$ -volume samples in the range of 0.2-4 THz. The device fabrication and its performance characterization will be discussed in detail during the conference.

IV. ACKNOWLEDGMENTS

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REFERENCES

- [1] S. Mastel, M.B. Lundeberg, P. Alonso-González, Y. Gao, K. Watanabe, T. Taniguchi, J. Hone, F.H.L. Koppens, A.Y. Nikitin, and R. Hillenbrand, “Terahertz nanofocusing with cantilevered terahertz-resonant antenna tips,” *Nano Letters*, vol. 17, no. 11, pp. 6526–6533, 2017.
- [2] R. Mendis and D. Grischkowsky, “Undistorted guided-wave propagation of subpicosecond terahertz pulses,” *Optics Letters*, vol. 26, no. 11, pp. 846–848, 2001.
- [3] M. Van Exter, C. Fattinger, and D. Grischkowsky, “Terahertz time-domain spectroscopy of water vapor,” *Optics letters*, vol. 14, no. 20, pp. 1128–1130, 1989.
- [4] A.J. Shutler and D. Grischkowsky, “Gap independent coupling into parallel plate terahertz waveguides using cylindrical horn antennas,” *Journal of Applied Physics*, vol. 112, no. 7, p. 073102, 2012.
- [5] C.L.C. Smith, A.H. Thilsted, C.E. Garcia-Ortiz, I.P. Radko, R. Marie, C. Jeppesen, C. Vannahme, S.I. Bozhevolnyi, and A. Kristensen, “Efficient excitation of channel plasmons in tailored, uv-lithography-defined v-grooves,” *Nano letters*, vol. 14, no. 3, p. 1659, 2014.
- [6] R. Peretti, F. Braud, E. Peytavit, E. Dubois, and J.-F. Lampin, “Broadband terahertz light–matter interaction enhancement for precise spectroscopy of thin films and micro-samples,” *MDPI Photonics*, vol. 5, no. 2, p. 11, 2018.
- [7] R. Peretti, S. Mityukovskiy, F. Braud, E. Peytavit, E. Dubois, and J.-F. Lampin, “Device for light-matter interaction enhancement in the full THz range for precise spectroscopy of small volume samples”, *43rd International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz)*, Nagoya, Japan, Sept. 9-14, 2018.
- [8] S. Mityukovskiy, M. Lavancier, F. Braud, G. Roos, T. Hannotte, E. Dubois, J.-F. Lampin, and R. Peretti, “Shining the Light to Terahertz Spectroscopy of nL-Volume Biological Samples”, *CLEO: Applications and Technology 2019*, San Jose, USA, May 5-10, 2019.
- [9] R. Peretti, S. Mityukovskiy, K. Froberger, M.A. Mebarki, S. Eliet, M. Vanwolleghem, and J.-F. Lampin, “THz-TDS time-trace analysis for the extraction of material and metamaterial parameters”, *IEEE transactions on Terahertz Science and Technology*, vol. 9, p. 136, 2019.