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Printed terahertz metasurfaces for multispectral imaging by thermo-conversion.

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ABSTRACT

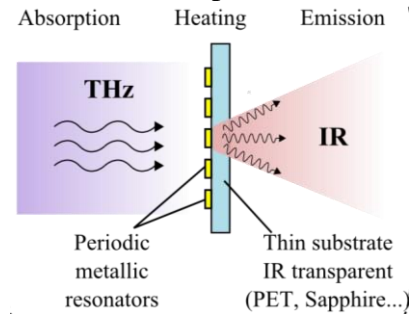
In this work, we investigate the fabrication and the application of ultra-thin terahertz metasurfaces as thermal converters for indirect terahertz imaging. The microstructures fabricated by an ultrasonically driven printing process (Microplotter) are used to improve the THz to IR conversion efficiency and tune the spectral or polarisation selectivity. The resulting conversion membranes show optical and thermal responses which are consistent with numerical simulations establishing reliable rules to design such membrane at various wavelengths. This work paves the way for a low-cost solution of multispectral terahertz imaging with a standard infrared camera.

I – INTRODUCTION

Terahertz (THz) imaging is an active field of research and finds numerous applications such as non-destructive industrial testing, security, chemical identification, medical imaging [1]. However the high cost, the low sensitivity and spectral selectivity of terahertz detectors constitute a serious obstacle for a wide range of applications. In this perspective, terahertz imaging by thermal conversion promises to be a low-cost alternative technique to conventional terahertz detectors but still suffers from low sensitivity ($P_{\min}(1\text{THz})=50\mu\text{W}/\text{cm}^2$) in comparison with micro bolometers and CMOS based detectors [2].

In this work, we investigate the use of ultra-thin terahertz metasurfaces as a thermal converter and a way to improve the THz to IR conversion efficiency and tune the spectral/polarisation selectivity (see Fig 1.). We demonstrate the fabrication of periodical arrays of metallic resonators such as split ring (SRR) on an ultra-thin substrate of PET ($3\mu\text{m}$) by an ultrasonically driven printing process (Microplotter). This modular method has been used for the rapid and low-cost fabrication of resonant structures in the 50GHz-1THz range [3]. The resulting conversion membranes show optical and thermal responses which are consistent with numerical simulations establishing reliable rules to design such membrane at various wavelengths, paving the way for a low-cost solution of multispectral terahertz imaging with a standard infrared camera.

Fig 1: Concept of terahertz imaging by thermoconversion. The thz wave is absorbed by the membrane which then heats up. This heating is then measurable by a thermal camera. The advantage of such a detection system is that it transfers all the technological complexity to the infrared camera.



II – FABRICATION METHOD

As a low-cost manufacturing process an inkjet printing technique based on ultrasonic excitation was used instead of optical lithography to fabricate the membrane (Microplotter II) [4]. Unlike conventional printers, the metallic patterns are drawn in a pencil like fashion through the use of a glass tip (see Fig 2a.). After being filled with ink containing silver nanoparticles (JS-A291 - Metalon) by capillary action, the stretched glass capillary is brought close to a substrate. Thanks to a piezoelectric element, we measure the variation of the resonance frequency of the capillary once it is in contact. The annealing of the ink by thermal conduction (100 to 250 degrees for 5min) sets the quality of the metal (see Fig 2b.) with a compromise to be found: the more the ink is heated the better the conductivity will be which increases the quality factor of the terahertz resonance at the cost of a lower infrared emissivity of the metal.

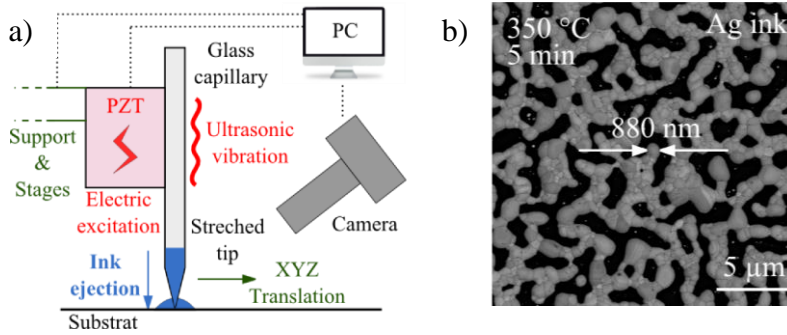


Fig 2: a. Diagram of the printing method.

b. Scanning electron microscopy image of the ink after annealing at 350° for 5min.

III – EXPERIMENTAL SETUP

First, we need to measure the plasmonic resonance of printed THz metasurfaces (see Fig 3a.) thanks to a sub-terahertz spectroscopy bench. A terahertz source based on Schottky diodes (Teraschottky - Lytid) is collimated on the sample designed for the 80 GHz band. The sample is placed in a vacuum cell which allows suppress the heat losses by convection if necessary. The transmitted or reflected signal is then picked up by a pyrometer (TeraPyro - Lytid) synchronized to the source by a lock-in amplifier (SR830 DSP).

The source being naturally polarized, we have two ways of illuminating our sample either in transverse electric or in transverse magnetic knowing that only one of these polarizations gives rise to the appearance of a resonance for SRR type structures [5] (see Fig 3b.). The electromagnetic response is simulated using COMSOL. To observe the thermal response of the membrane we must then replace the terahertz sensor with an infrared camera (FLIR SC700) showing that the heating is only present when there is resonance of the membrane (see Fig 3c.)

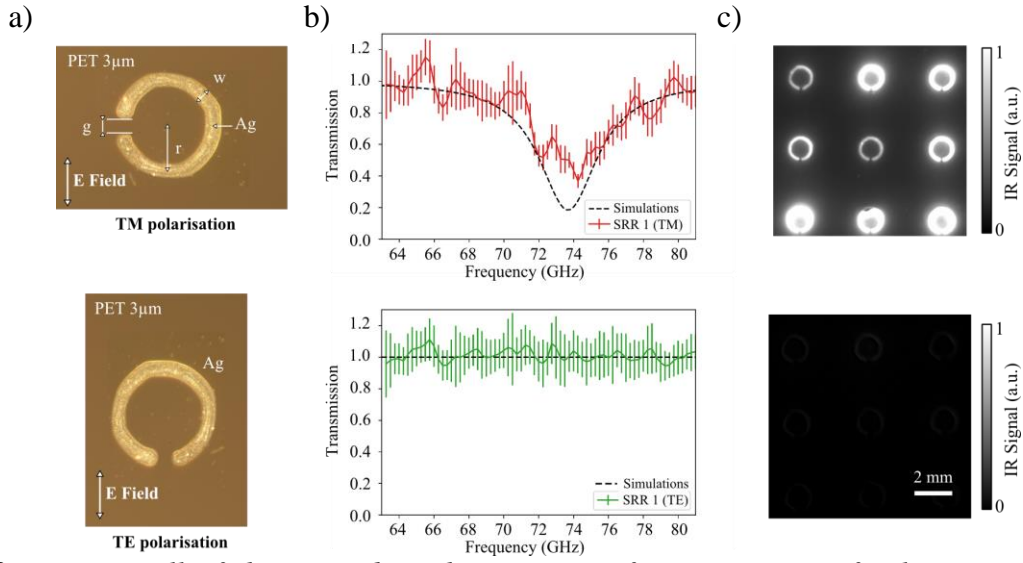


Fig 3: *a. Unit cell of the printed terahertz metasurface consisting of split ring resonators sized to resonate at 75 GHz in TM bias ($D=3000\mu\text{m}$, $L=2000\mu\text{m}$, $w=80\mu\text{m}$ and $g=50\mu\text{m}$). b. Experimental spectra measured by the sub-terahertz spectroscopy bench in TE and TM polarization. c. Corresponding infrared image in TE and TM polarization.*

IV – DISCUSSION

The resulting conversion membrane is then naturally spectrally and polarisation sensitive with selectivity depending on the quality factor of the plasmonic resonators. For SRR-type structures, this quality factor ($Q=\lambda/\Delta\lambda$) is close to 20, which gives a selectivity of only a few gigahertz at 75 GHz. Other types of resonators such as guided mode resonators [6] or coupled nano fabry perot [7] can improve this selectivity of the conversion membrane by increasing the quality factor of the resonance. Moreover, this concept is transposable to any terahertz frequency by adapting the geometrical parameters of the resonators.

Finally, the membrane can be used in a terahertz imaging scheme with a near state-of-the-art detectability threshold of $50\mu\text{W}/\text{cm}^2$ and a maximum acquisition frequency at high terahertz power ($>50\text{mW}/\text{cm}^2$) of 1Hz. For the proof of concept, a metallic triangle hidden behind a 5 mm thick cardboard is scanned and imaged with a surprisingly good resolution of two to three times the wavelength used (2mm), which is very promising for low-cost non-destructive testing applications (see Fig 4.).

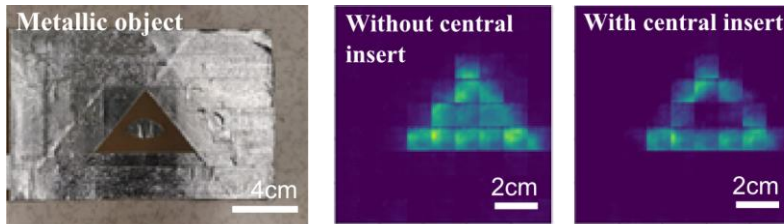


Fig 4: *Therahertz image of a metal object hidden behind a 5 mm thick cardboard. This object is resolved at 2λ thanks to the ability of the terahertz waves to pass through the cardboard.*

V – CONCLUSION

To conclude, we have demonstrated the use of inkjet printed terahertz metasurfaces as converters for terahertz imaging by thermoconversion. The fabricated microstructures have provided spectral and polarisation sensitivity in a terahertz imaging scheme. This work thus paves the way for a low-cost multispectral terahertz imaging solution based on a standard infrared camera.

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