Deformable wire array: fiber drawn tunable metamaterials

Simon Fleming[1], Alessio Stefani[1,2], Xiaoli Tang[1], Alexander Argyros[1], Daniel Kemsley[1], James Cordi[1], and Richard Lwin[1]

[1] Institute of Photonics and Optical Sciences (IPOS), School of Physics, The University of Sydney, NSW, 2006, Australia
[2] DTU Fotonik, Department of Photonics Engineering, Technical University of Denmark, DK-2800 Kgs. Lyngby, Denmark
simon.fleming@sydney.edu.au

Abstract—**By fiber drawing we fabricate a wire array metamaterial, the structure of which can be actively modified. The plasma frequency can be tuned by 50% by compressing the metamaterial; recovers when released and the process can be repeated.**

Keywords - Metamaterials; Artificially engineered materials; Microstructure fabrication.

I. Introduction

Engineered materials, and in particular metamaterials, find increasing interest because of their unique properties [1-6]. Such properties are due to subwavelength structures. Due to the fact that the properties depend on the structure, in most cases it is not possible to modify the behavior of a metamaterial after its fabrication. However, for practical applications it is desirable to be able to tune the physical response of the fabricated metamaterial. Several ways have been followed to reach such goal. Two solutions have been so far the most successful: the first being liquid crystals to change the background refractive index of the metamaterial and the second being metasurfaces/metastructures layers that can be mechanically moved with respect to each other [7]. However, there is a tradeoff between tunability and their ease of fabrication.

In this work we propose and demonstrate a scalable fabrication solution that also allows active post-fabrication modification of the properties of the metamaterial [8].

II. Fabrication and Results

The metamaterial under consideration is a metal wire array within a polymeric matrix. We use the fiber drawing technique combined with the Taylor wire process, as we previously demonstrated [9-10], to fabricate the metamaterial structure. This technique also allows the realization of long lengths of the metamaterial at once allowing the fabrication of large quantities.

In order to achieve tunability, we used polyurethane (TPU) as the bulk of the metamaterial structure. The low Young's modulus of TPU [11] allows for large elastic deformation and thus structural changes.

The change in the metamaterial properties was investigated by measuring the shift of the plasma frequency of the wire array. In a first approximation, the plasma frequency is dependent only on the geometry of the material [12]. This means that by changing the spacing of the wires, for example by compressing the structure, it is possible to change the plasma frequency. We designed and fabricated the structure so that the plasma frequency falls within our THz time domain spectroscopy measurement system. The fabricated fiber is shown is Fig. 1.

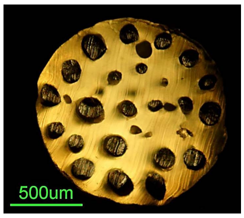

Figure 1. Fabricated fiber: TPU matrix (yellow) including Indium wires (dark circular areas).

We cut the fiber and stacked several sections next to each other to produce a 1x1 cm sample. We placed the sample between two Zeonex® plates, the separation of which could be changed by a set of screws. The measured plasma frequency (the boundary between low transmission metallic behavior and high transmission dielectric behavior) in the uncompressed state was 0.395 THz compared to 0.37 THz of the original design.

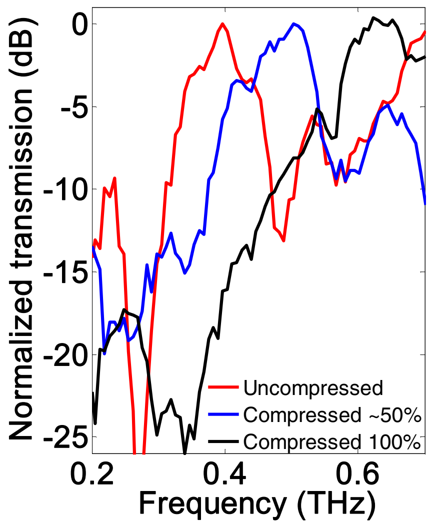

Figure 2. Transmission curves during the compression experiment.

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In order to demonstrate tunability, we compressed the sample by tightening the screws in consecutive steps. Figure 2 shows the THz beam transmission when no compression is applied, when it is compressed approximately 50% and when it is compressed 100% (as much as allowed by the set-up). The plasma frequency shifts up to about 0.6 THz, reaching a 50% increase compared to the original value. To confirm the metamaterial could be repeatedly and reversibly tuned, we released the pressure by loosening the screws, then compressed again and subsequently released once more. The transmission curves are showed in Fig. 3 (each cycle is vertically shifted for clarity). The plasma frequency can be tuned between the minimum and the maximum over various cycles, despite the poor manual control on the screws determining the level of compression.

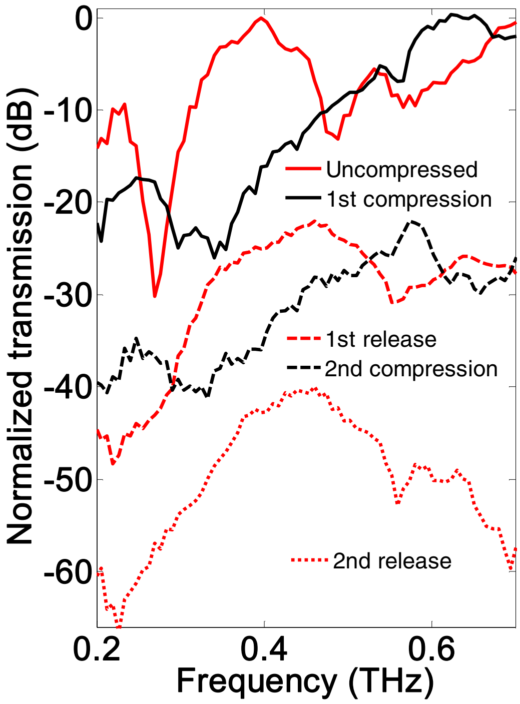

Figure 3. Demonstration of repeatability by cycles of compression and release of the metamaterial structure. Each cycle has been vertically shifted for clarity.

III. Conclusions

In conclusion, we have fabricated by fiber drawing a metamaterial that can be actively, repeatedly and reversibly tuned. We achieved a 50% tuning of the plasma frequency in the 0.3-0.6 THz region.

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