3D-Printed Terahertz Bragg Fiber

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***Abstract*—In this paper we demonstrate the terahertz propagation in Bragg fiber manufactured through rapid prototyping technique using low cost 3D printer. The fiber was numerically and experimentally characterized using software based on beam propagation method (BPM) and a terahertz time domain spectrometer (THz-TDS). The transmission structures indicate a good agreement between numerical and experimental data.**

I. INTRODUCTION

TERAHERTZ Bragg fibers are important fiber designs due to propagate terahertz (THz) waves at the lossless air-core. The manufacture of such kind of fibers was demonstrated in the literature, based on concentric rings of air-holes in a microstructured fiber, also by stacking two polymers films with high refractive index contrast or using separating layers with air. [1,2]. Recently, 3D printers have been demonstrated as an option to fabricate THz waveguides and other devices quickly and inexpensively [3,4]. In this work, we present for the first time a Bragg fiber fabricated using 3D rapid prototyping technique in polymer using a low cost commercial printer to create low and high refractive index layers. The transmission spectrum of printed Bragg fiber was numerically evaluated by software based on the beam propagation method and experimentally measured in a THz time domain spectrometer (TDS).

II. RESULTS

The ease and low cost of printing impose limitations in the manufacture of THz guides. The printing accuracy is limited by the printer resolution (model OrionDelta from SeeMeCNC®) defined by the minimum displacement of extruder nozzle (~150 µm) and by its diameter (~400 µm).

The Bragg fiber design consists of concentric polymer rings separated by air layers. The six high refractive index layers were printed using ABS polymer (acrylonitrile butadiene styrene) with real part of refractive index around 1.6 and imaginary part presented in Fig. 1 [5].

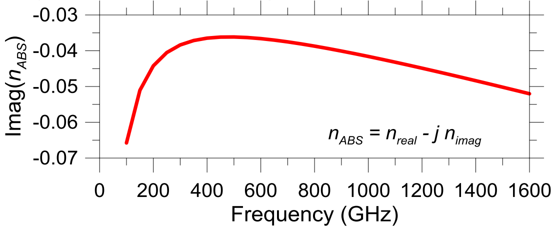

Fig. 1. Imaginary part of ABS refractive index [5].

The high and low index layers have width of e_h=0.55 mm and e_l=0.75 mm, respectively. The fiber was designed with core diameter D_{core}=7.2 mm, outside diameter of 22.8 mm and length L=93 mm.

The numerical analyses were performed using a commercial software based on 3D beam propagation method (BeamProp - RSOFT®). The Fig. 2 presents the Bragg fiber's spectral transmission considering an overall reduction on the geometric dimensions. It is possible to observe that the signal is transmitted with reduced losses for high THz frequencies, and that reduced fiber entails shift the high transmission peak for higher frequencies.

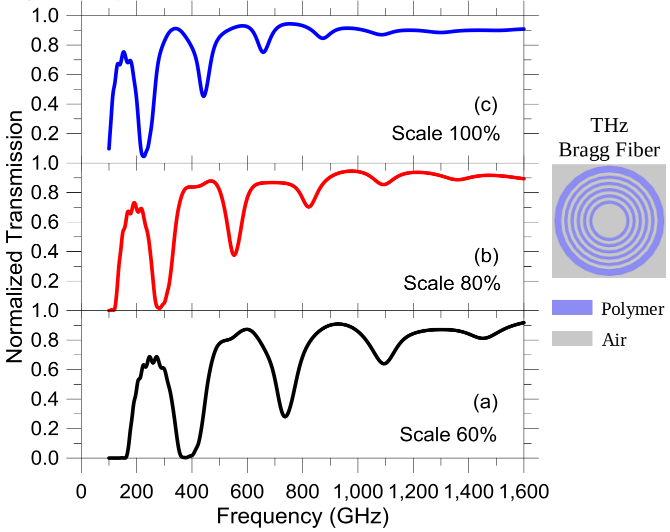

Fig. 2. Numerical evaluation of spectral transmission of reduced Bragg fiber dimensions. (a) Reduction to 60%. (b) Reduction to 80%. (c) Original fiber dimensions.

The main geometric parameter of printed fiber is the polymer thickness (e_h). The Figs. 3 and 4 show the spectral transmission as function of polymer thickness. From Fig. 3 we observe that decreasing e_h shifts the transmission peaks for high frequencies. Fig. 4 presents a surface plot of spectral normalized transmission as function of e_h, from 100 GHz to 1 THz. The results are similar to obtained to one single polymer tube with e_h thickness, what demonstrates that main phenomena supporting THz propagation is the anti-resonant effect at the polymeric ring. Other low index materials (e_l) could lead to obtain guides that support propagating the signal by Bragg reflections, as pointed in [1].

The experimental setup was configured to transmission measurements on a terahertz time-domain spectrometer (THz TDS), and used to obtain the frequency dependency complex refractive index of ABS polymer and the spectral transmission of printed Bragg fiber. The fiber was placed between two symmetric-pass lenses which delimit a test region [4].

The Fig. 5 shows the experimental setup to the THz transmission measurements. The electric field recorded by the THz spectrometer is shown in Fig. 6, where the black line represents the reference scan and the red line represents the temporal THz pulse when it passes through the fiber. The small displacement by just few ps from the reference pulse indicates that major part of the energy is propagating at the air-core.

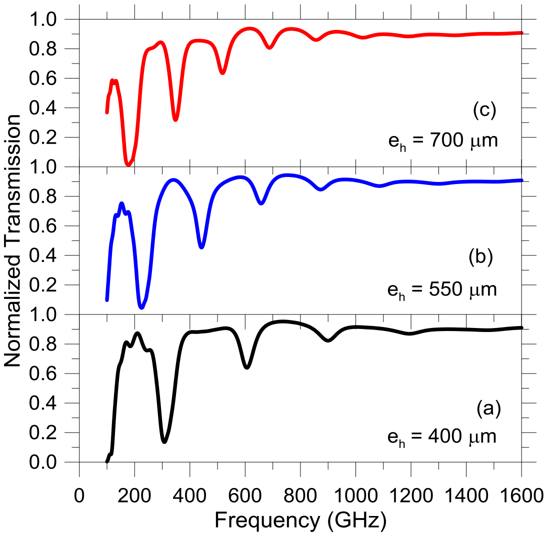

Fig. 3. Spectral transmission for three values of polymer thickness. (a) e_h of 400 μm. (b) e_h of 550 μm (fabricated dimension). (c) e_h of 700 μm.

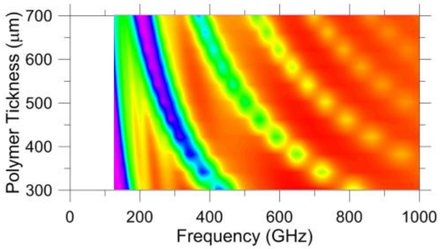

Fig. 4. Spectral normalized transmission as function of polymer thickness (e_h).

The Fig. 7 presents the spectral transmission of printed Bragg Fiber, obtained numerically (blue curve) and experimentally (red curve). Transmission bands were observed spanning 0.12–0.26 THz, 0.32–0.48 THz, and 0.50–1.00 THz. It can be notice a considerable agreement in the bandgap regions at low frequencies, but to high frequencies the dips in the transmission appear shifted. Such spectral variations can be attributed to the inaccuracy in the printing process. Nevertheless, the short length of the fabricated fiber (93 mm) is not enough to allow the establishment of all spectral transmission structures and its bandgaps, for some ranges of frequencies. Although there are limitations in using 3D printers to create THz waveguides, a 3D-printed Bragg fiber was demonstrated with guidance from 0.1 THz to at least 1.0 THz, with reduced losses starting from 0.35 THz.

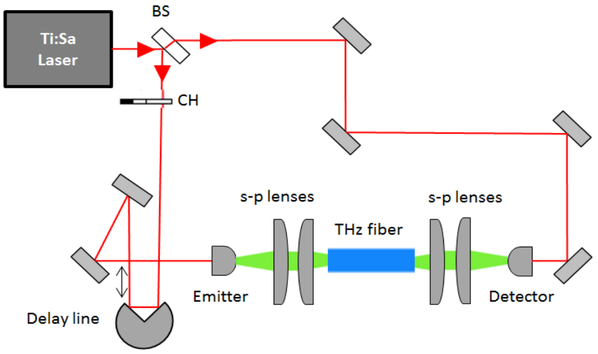

Fig. 5. Experimental setup using a terahertz time domain spectrometer.

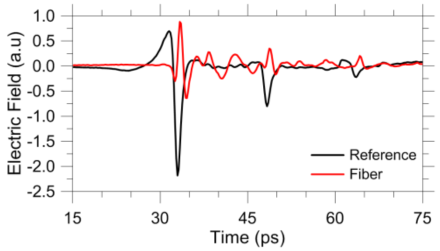

Fig. 6. Recorded THz electric field pulse for the reference scan and for the Bragg fiber.

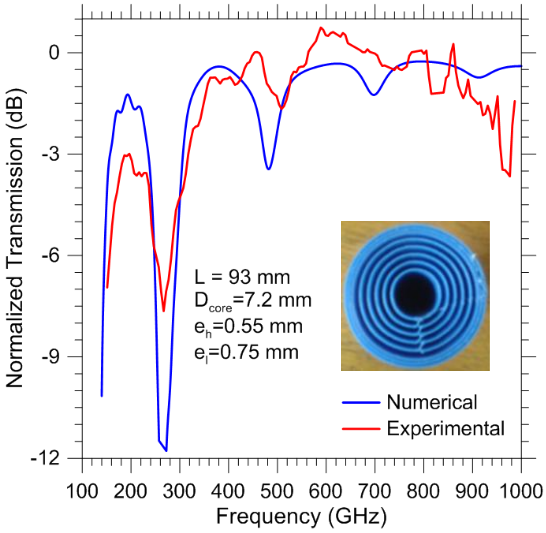

Fig. 7. Spectral transmission of polymeric 3D-printed terahertz Bragg fiber. Inset - Transversal view of printed THz Bragg fiber.

III. CONCLUSION

The production of terahertz Bragg fibers was demonstrated, using 3D rapid prototyping technique in polymer with a low cost printer. The printer accuracy allows manufacture fibers with mode guidance from 0.1 THz to at least 1.0 THz, and low loss propagation for frequencies higher than 0.35 THz. The numerical evaluation, considering the actual data to the refractive index of ABS polymer and its absorption, allows observing spectral transmission that match to the experimental results. It is easy to observe that changes in the fiber dimension leads to shifting the spectral transmission, but the main geometrical parameter is the thickness of high index polymer, because the THz propagation seems to be supported by the anti-resonant effect in the first polymer ring.

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