Experimental investigation of dispersion properties of THz porous fibers

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***Abstract*— Here we demonstrate the experimental results on in-house fabricated polymer THz porous fiber with sub-wavelength features. The experimental results confirm the theoretical prediction of low dispersion characteristics in a THz porous fiber as compared to a microwire.**

I. Introduction

A number of waveguide solutions based on technologies from both electronics and photonics, have been studied for guiding THz radiation, among which solid-core sub-wavelength fibers [1] (called THz microwires [2, 3]), air-core microstructured fibers [4, 5], and Ag/PS-coated hollow glass fibers [6] have the lowest loss reported in the literature for dielectric based waveguides. These fibers are only suitable for relatively narrow band applications.

Recently, a novel class of THz fibers, porous fibers, was proposed [7, 8]. These fibers are air-clad fibers with diameters less or comparable to the operating wavelengths with sub-wavelength features in the core, which allow low loss propagation and improved confinement of the field compared to microwires (solid core air-clad fibers) [8]. It is also theoretically demonstrated that porous fibers have a significant improvement in the group velocity, i.e. lower dispersion, relative to microwires [9].

The porous fiber and microwire used here are made of polymethyl methacrylate (PMMA). The porous fiber is fabricated in a two-step process. First the preform is fabricated by using the extrusion technique, and then the preform is drawn down to a fiber with outer diameter of 350 μm using a fiber drawing tower [10]. The cross section of fabricated preform and SEM (scanning electron microscope) image of the porous fiber is shown in Fig. 1(a) and Fig. 1(b), respectively. For comparison purposes we also consider a microwire with 250 μm outer diameter fabricated in-house. The diameters are chosen in a way that the effective material loss of the fibers are the same order of magnitude.

In this paper, we measure and compare the effective refractive index of a porous fiber and a microwire.

II. Experiment

The THz properties of the fabricated porous fibers are investigated by using terahertz time domain spectroscopy (THz-TDS). A mode-locked Ti:sapphire laser with a pulse width of less than 170 fs, central wavelength of 800 nm and a repetition rate of 76 MHz is used to drive the photoconductive switches [11]. The fiber tips are directly launched on the emitter and detector as shown in Fig. 2.

The measured and theoretically calculated effective refractive index of the porous fiber and microwire are shown in Fig. 3. The SEM images of the cross-sections of the fabricated porous fiber, Fig. 1(b), is used for the numerical modeling. The electric fields of the output terahertz pulse are measured for three different lengths of each fiber. The fiber lengths used

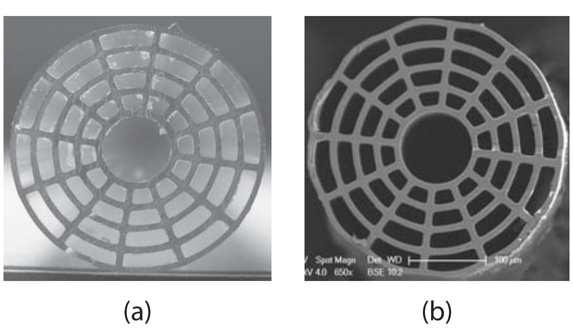

Fig. 1. (a) Cross section of the porous fiber preform. (b) SEM image of the porous fiber.

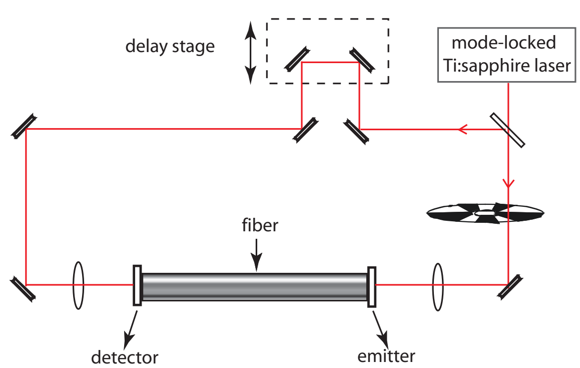

Fig. 2. Schematic of the THz-TDS setup.

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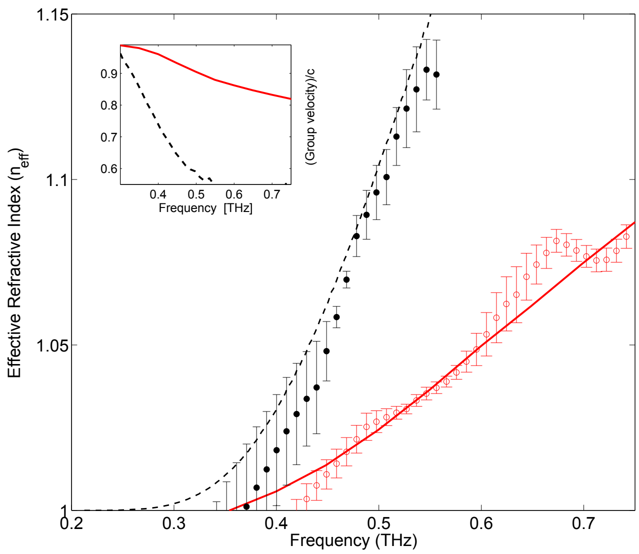

Fig. 3. The experimental and theoretical calculated effective refractive index of a 350 μm diameter porous fiber (open circles and solid line respectively) and a 250 μm diameter of microwire (full circles and dashed line respectively). Normalized group velocity of the porous fiber and microwire is shown in the inset.

for the porous fiber are 24.4, 21.0 and 15.4 mm, and for the microwire are 25.0, 20.2 and 17.7 mm.

The effective refractive index (n_{eff}) for the fibers is determined by comparing the output electric fields of each pair of the three scans. Then, the three individual effective refractive indices obtained from comparison are averaged. As shown in Fig. 3, the measurements agree well with the expected theoretical results calculated based on the SEM image of the fabricated fibers. Experimental results also indicate that the refractive index of porous fiber is a flatter function of frequency compared to that of the microwire, which corresponds to a lower dispersion. As the frequency increases, most of the guided power of the microwire is transfered to the solid core, while most of the guided power of the porous fiber is transfered to the sub-wavelength air-hole regions. This results into a lower dispersion characteristic for porous fiber compared to microwire. For easier comparison, the normalized theoretical group velocities of the fibers are calculated and shown in the inset of Fig. 3.

Here, we consider two major sources of errors: fiber length and data processing uncertainties as explained as follows. A ± 0.1 mm variation is considered for the length uncertainty. In order to remove the low-frequency $1/f$ noise two techniques have been used, which are base line removal and high pass filtering. The difference between these methods and the effect of variation of the cut-off frequency of the high pass filter are considered as the source of data processing uncertainty. The error bars shown in Fig. 3 represent the quadrature sum of standard deviations obtained from two sources of uncertainty described above. It is worth mentioning that the difference between the experimental and theoretical values at lower effective refractive index values is most likely due to the slight bending of the fibers. Due to the week confinement of the mode, the power is lost as radiation.

III. Conclusion

The measured effective refractive index of the porous fiber is a flatter function of frequency compared to that of the microwire. This verifies experimentally the low dispersion characteristics of the THz porous fiber.

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