Low loss, low dispersion T-ray transmission in Microwires

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Abstract: We present low loss, < 0.01 1/cm, and dispersion, < 10 ps/(km.nm), properties of microwires for terahertz transmission. These wires have diameters smaller than the operating wavelength, resulting in the propagation of enhanced evanescent fields.

OCIS codes: (260.3090) physical optics, infrared far; (060.2430) Fibers, single mode

1. Introduction

Terahertz (THz) spectroscopic techniques have attracted a lot of interest due to their applications in detection of biological and chemical materials over the last decade[1]. Low loss and dispersion THz transmission is one of the key main issues of these techniques. Chen et al. have recently reported [2] loss values less than 0.01cm^{-1} near 0.3 THz in plastic fibers. The concept of THz guided propagation in these fibers is similar to nanowire optical fibers[3], i.e., the diameter of the fibers are smaller than the operating wavelength (THz) and hence we coin the term microwires for these fibers. Due to large wavelength-to-fiber-core ratio, the fractional power delivered inside the lossy core of microwires is reduced, thus reducing the overall loss.

Based on measurements of the refractive indices of four glasses (F2, SF6, SF57 and Bismuth) and a polymer (PMMA) in terahertz spectrum region, and an analytical model of vectorial form of Maxwell's equations for a simple rod geometry, we have investigated the loss and dispersion properties of microwires with different core diameters and glasses.

2. Experiment and results

To measure the refractive indices and losses of the glasses and the polymer, we use a commercially available THz time-domain spectrometer (Picometrix T-Ray 2000). The samples are well polished on both sides with cross section of 2 cm x 2 cm and 0.5 mm thickness. The results of the measurements of the refractive indices are show in Fig1., which indicates higher refractive indices of the glasses in comparison with PMMA. Based on experimental results and solution of vectorial form of Maxwell's equations, we have calculated the power fraction, PF; the fraction of total power of a guided mode existing outside the waveguide, as shown in Fig 2.

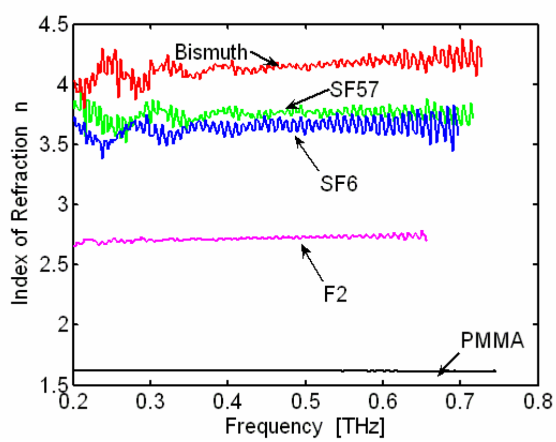

Figure 1. Refractive indices of the bulk materials measured with a THz time domain spectrometer.

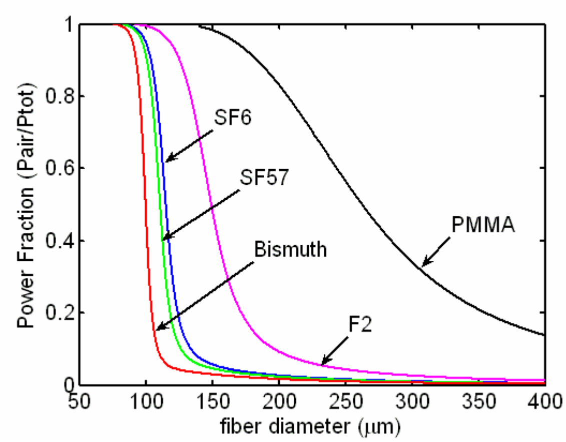

Figure 2. Power fraction outside the microwires versus the diameter at $f = 0.5$ THz ($\lambda = 600\ \mu$m).

Figure 2 clearly indicates that for microwires with diameter below the wavelength (λ=600 μm), PF approaches unity. However the slop and the value of the PF depend on rod-air refractive index contrast.

Defining the effective loss of a microwire as the material loss (rod and air) averaged with respect to the field distribution in the transverse directions, we have calculated the effective loss of microwires with different diameters and glass/polymer compositions at the wavelength λ = 600 μm, as shown in Fig. 3. For microwires with diameters above the wavelength, the effective loss approaches the loss values of the initial bulk materials. However, in the

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Microwire regime, where the diameter of the fiber is less than the wavelength, the effective loss of all microwires converges to a similar limit. As a matter of fact, enlarging the loss convergence limit of microwires with different materials in Fig.3, reveals that all the effective losses approach to order of 0.01 cm^{-1}, see Fig.4. This is due to the fact that in this regime most of the electromagnetic field is propagating outside the waveguide.

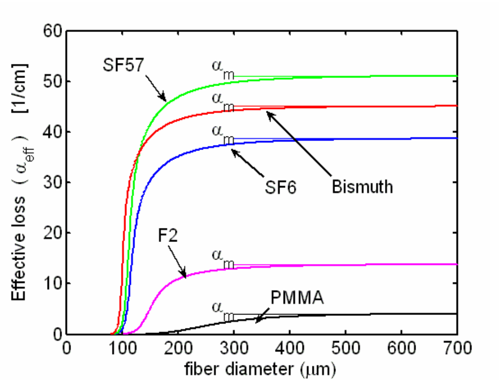

Figure 3. Effective loss of fibers versus fiber diameter at f = 0.5 THz (λ = 600 μm).

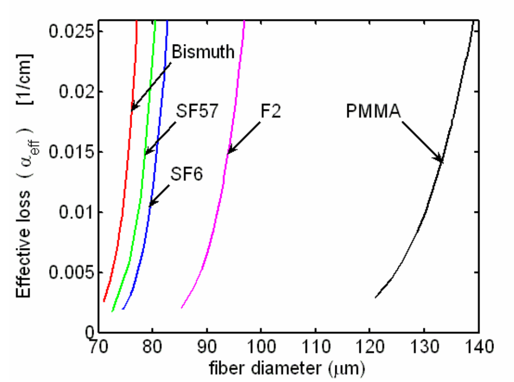

Figure 4. Magnification of the lower limit of the effective loss shown in Figure 3.

To study the dispersion properties of microwires, we have calculated the effective refractive indices of different microwires with different diameter and rod material, as shown in Fig. 5.

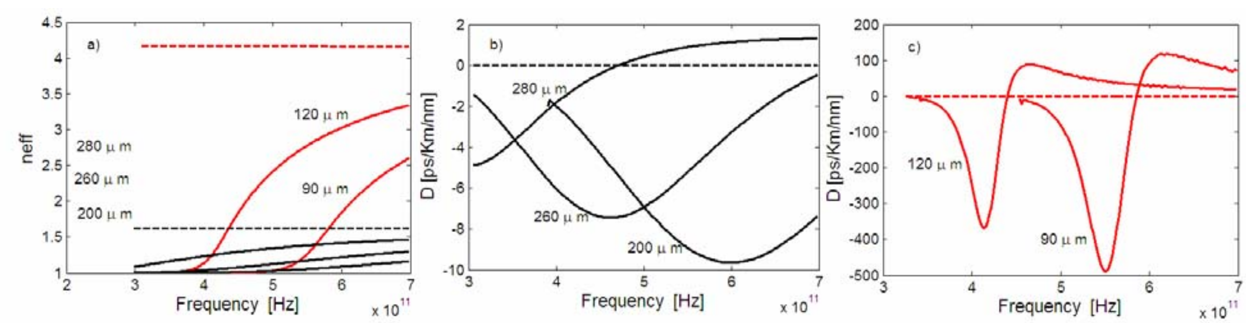

Figure 5. (a) Effective refractive indices, (b) dispersion curves for PMMA, and (c) dispersion curves for Bismuth glass microwires. For all curves red and black curves are Bismuth and PMMA respectively.

Figure 5 (a) indicates that at low frequency (high wavelength) most of the field is relatively outside for all the microwire, and hence the effective refractive index approaches the refractive index of air i.e., n=1. However, for high frequencies, the fields are confined within the rod and depending on the refractive index of the rod and its diameter, the effective refractive index approaches that of the rod material. It is also clear that due to the huge contrast between the refractive index of air and Bismuth glass, this glass should have overall larger dispersion than that of PMMA as it is shown in Fig.5 (b) and (c). However, for both PMMA and Bismuth the dispersions approach to below 10 ps.$km^{-1}nm^{-1}$, as the frequency decreases. It should be noted that in both Fig. 5 (b) and (c), as the diameter decreases the beginning of the dispersion curve shifts towards higher frequencies hence it is possible to achieve both low dispersion and minimum effective loss. For example, a dispersion of ~ -2 ps $km^{-1}nm^{-1}$ can be achieved for a 124 μm PMMA at frequency 0.5 THz, corresponding to the minimum loss in Fig. 4.

3. Conclusion

We have investigated the loss and dispersion properties of microwires; dielectric wires with dimensions (in micrometer range) much less than terahertz wavelength, and shown the parameter regime for low loss and dispersion of these waveguides for terahertz transmission. The details of our results will be presented.

4. Refrences

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