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Experimental study of air-core dielectric tube at terahertz frequencies

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ABSTRACT

In this paper, an experimental study of air-core dielectric tube waveguide is proposed at terahertz frequencies. By using the THz time domain measure system, the terahertz dispersion characteristics, loss characteristic and energy focusing characteristic of air-core single-layer and dual-layer dielectric tube are obtained. The results show that this type of air-core dielectric tube can realize low dispersion characteristics. Due to the difference of refractive index between two dielectric materials, stronger energy focusing can be achieved in air-core dual-layer dielectric tube. After the coupling of the THz pulse using the dual-layer dielectric tube waveguide, the THz pulse increased 2.4 times compared with the single-layer dielectric tube waveguide at 1.5 THz.

1. Introduction

Terahertz (THz), locating between the infrared and microwave wave bands in the electromagnetic spectrum, is one of the hot research issues because of its great potential applicability in many scientific and technological fields. The interest in THz technology has strongly increased in the last years with diverse applications in the fields of biotechnology [1,2], spectroscopy [3], imaging [4,5], and so on. Efficient guided THz transmission solutions are still under investigation. Many kinds of THz waveguides have been presented [6–14]. Among them, low-loss and high energy coupling THz waveguide which are of great importance for the practical THz applications. However, THz power is strongly absorbed in most kinds of materials, which gives a challenge to achieve low-loss and high energy coupling THz waveguide. Dry air is the most transparent broadly available transmission medium for THz waves, and then a technically useful waveguide has of course to be materialized in some way. Several polymer fibers have been proposed to reduce the loss and enhance the energy coupling for THz guiding [15–19]. Those research results indicate that the polymer fiber has risen up to be one of the most important candidates of THz waveguides. But it is difficult to fabricate those fibers due to its complex cross sections. Then, a novel polymer tube THz waveguide with low loss is proposed by Chen et al. [20]. The polymer tube has some merits, such as low loss, better confinement, and the ease of fabrication, compared with solid polymer fiber. In [20], the refractive index of the polymer material is assumed to be a low value 1.5. When THz wave propagation along polymer tube, electromagnetic energy distributes in polymer material and the surrounding air region.

To enhance the energy focusing characteristic in air-core dielectric tube waveguide and reduce the radiated interference further, a dual-layer dielectric tube waveguide is proposed to be used at terahertz frequencies. In this paper, the terahertz propagation characteristics of air-core single-layer and dual-layer dielectric tube are demonstrated by using experimental method.

2. Structure

Fig. 1 shows the geometry and refractive index profile of the dual-layer dielectric tube waveguide. ρ_1 is the radius of air core and n_0 is the refractive index of air. ρ_2 is the outer radius of high refractive index dielectric layer and n_2 is the refractive index. ρ_3 is the outer radius of low refractive index dielectric layer and the refractive index is n_1. $d = \rho_2 - \rho_1$ is the thickness of high refractive index dielectric layer and $d' = \rho_3 - \rho_2$ is the thickness of low refractive index dielectric layer.

Fig. 2 shows the pictures of the air-core single-layer and dual-layer dielectric tube. For the single-layer dielectric tube, the dielectric material is Teflon. The length is 10 mm, and $\rho = \rho_3 = 1.5$ mm, $\rho_1 = \rho_2 = 1$ mm, $n = n_1 = 1.43$, the thickness is $d' = 0.5$ mm. And for the dual-layer dielectric tube, the outer dielectric material is Teflon and the inner dielectric material is HDPE. The length is 10 mm, $\rho_1 = 0.5$ mm, $\rho_2 = 1$ mm, $\rho_3 = 1.5$ mm, $n_1 = 1.43$, $n_2 = 1.52$, the thickness is $d = 0.5$ mm and $d' = 0.5$ mm, respectively.

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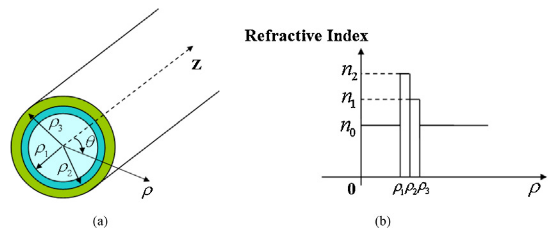

Fig. 1. (a) Geometry of dual-layer dielectric tube waveguide. (b) Refractive index profile of dual-layer dielectric tube waveguide.

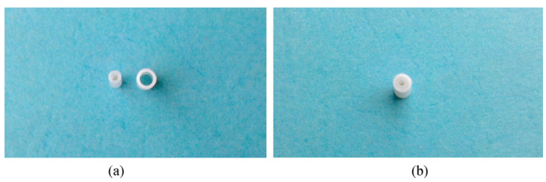

Fig. 2. (a) Air-core single-layer HDPE tube (left) and Teflon tube (right) and (b) air-core dual-layer dielectric tube.

3. Experimental results

Fig. 3 shows the terahertz time domain system. By using the measure system, the experimental results can be obtained, as shown in Fig. 4. Using Fourier transform, the frequency-dependent propagation characteristics of air-core dielectric tube can be obtained, as shown in Fig. 5. Fig. 5 shows the frequency-dependent effective refractive index n_{eff} of air-core dielectric tube. It is clearly seen that at low THz frequency range, especially at 0.1–0.4 THz, the dispersion of the air-core dual-layer dielectric tube waveguide and the single-layer dielectric tube waveguide increases. But with the increase of frequency, the dispersion decreases. The dispersion effect in terms of dh_{eff}/df is more and more flat for this type of waveguide. And the measured data exhibit very good agreement with the simulated results that obtained by using HFSS. The results mean that the air-core dielectric tube can realize low dispersion characteristics.

Fig. 6 shows the normalized H_r magnitude at the end surface of the cylindrical tube with single polymer layer and the cylindrical tube with double polymer layers by using HFSS, which is based on the finite element method. The outer radius of the cylindrical tube with single low refractive index polymer layer (Teflon: $n = 1.43$) is 1 mm, and the thickness of polymer layer is 0.5 mm. The configuration parameters of the cylindrical tube with double polymer layers ($n_0 = 1$, Teflon: $n_1 = 1.43$ and HDPE: $n_2 = 1.52$) are $\rho_1 = 0.5$ mm, $\rho_2 = 1$ mm, $\rho_3 = 1.5$ mm. The radiation frequency is 0.5 THz. As shown in Fig. 6, it can be seen that THz wave is well confined in the high refractive index polymer layer. In terahertz system, low radiated interference is necessary. By using the

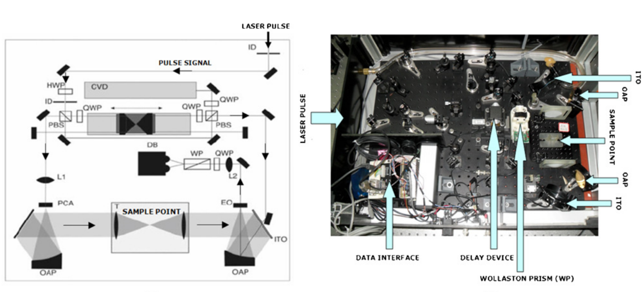

Fig. 3. (a) Schematic of the terahertz time-domain system and (b) picture of the terahertz time-domain system.

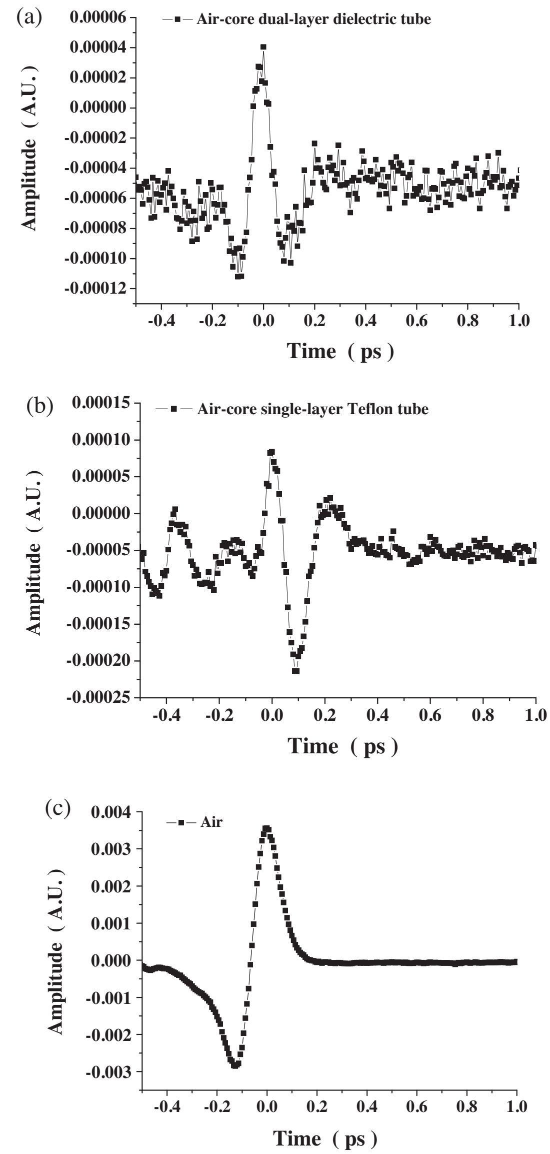

Fig. 4. The experimental results of air-core dielectric tube. (a) The air-core dual-layer dielectric tube; (b) the air-core single-layer Teflon tube and (c) air.

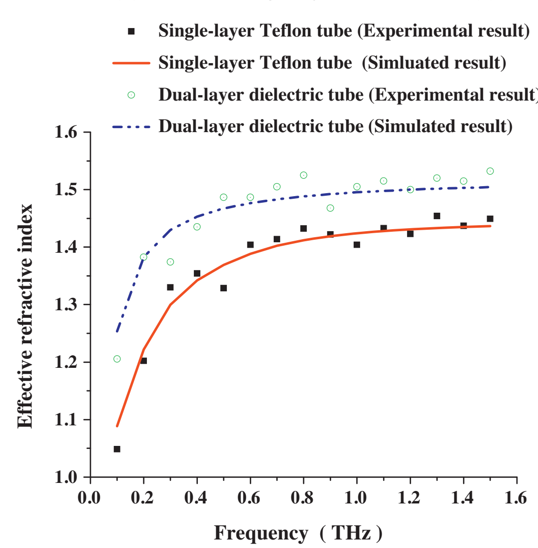

Fig. 5. Frequency-dependent effective index refractive of air-core dielectric tube versus frequency.