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The Transmission Properties of Coated THz Teflon Tube

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Abstract

The S parameters, attenuation characteristics and group delay characteristics of the Teflon tube have been analyzed in the paper. Firstly, the S parameters of metal and polymer tube with the same structure are compared. Then the transmission properties of the simple terahertz Teflon tubes and terahertz Teflon tubes which are coated metal film by three different ways are simulated, and the advantages and disadvantages are contrasted. The S parameters of Teflon tube are more ideal, but it is not plain, the attenuation within the working frequency is less than 10.77dB/m, the group delay is less than 10^{-10}s, coating Teflon tube with film can make S parameters plain. Teflon tube can transmit THz wave effectively, and if the Teflon tube is coated with films, the transmission characteristics can be improved in conclusion.

1. Introduction

Terahertz refers to the frequency 0.1 ~ 10THz (wavelength is 30 ~ 3000μm, 1THz= 10^{12}Hz) within the electromagnetic scope. It overlaps with sub-millimeter wave (SMMW) in the long wave band, and collocates the infrared in short wave band. So THz wave has very special position in the electromagnetic spectrum [1].

With the development of THz radiation source [2] and detection imaging technology [3], its unique advantages and great application prospect have emerged in material science, electronic information, life science, astronomy, atmospheric and environmental monitoring, national security, communications, and other important areas gradually. Limiting the terahertz radiation within a waveguide [4] structure can be better to give play to huge potential advantages of the terahertz in size, performance, and the multi-function. Therefore, THz waveguides are needed urgently.

2. THz Tube with Different Materials

THz energy in free spaces seriously attenuated because of the absorption of vapor and atmospheric scattering [5]. In order to reduce energy loss, a lot of research institutions have carried out the research on THz wave transmission properties. Polymer tube has better loss characteristics than solid waveguide. In addition, it is easy to design and process, the area of the mode field is large. So polymer tube is the new kind of THz waveguide [6].

In this part, three kinds of polymer material are selected to design polymer tube, they are Teflon, polyethylene (PE) and polystyrene (PS), respectively, dielectric constant ε_r are 2.08, 2.25, 2.6. To compare polymer tubes with metal tubes, the metal tubes which was made of Au, Ag, Au, Al with the same geometric size.

The S parameter is analyzed by the finite element method (FEM). As can be seen from the Figure 1, S parameters of polymer tube is superior to metal tubes, the S_{11} parameter of metal tubes are closed to each other within the selected working frequency band. They are all less than -1.3dB (the maximum is -1.275dB, copper), S_{21} parameters are less than 7dB (the maximum is 6.60dB, copper). By comparison, the S parameters of polymer tubes are more ideal, its S_{11} are less than 30dB (the maximum is 39.38dB, PE), and the S_{21} parameters are less than 1dB (the minimum is 0.6dB, PE). The main reason is that the relative dielectric constant of metal is 1, and the relative permeability of Au、Ag、Cu、Al are also similar, and the relative dielectric constant of selected polymer is between 2.0 ~ 2.6, and the dielectric constant of the

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polymer material at terahertz frequency is very high, which can help to obtain the high reflectivity and small loss [7].

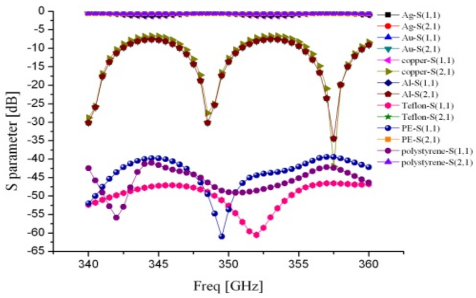

Figure 1. The S Parameters for Tube with Different Metal and Polymer Materials

According to the traditional theory of circular waveguide [8], the main mode of circular waveguide is TE_{11} mode, when the main working mode is just single-mode (TE_{11} mode), the wavelength range as follows:

$$2.62R<\lambda<3.41R$$

There, R is the inner diameter of the circular waveguide.

When the center frequency f = 0.350THz, the corresponding wavelength λ is about 857μm.

Using the work conditions of single mode, we can deduce the range of the waveguide radius:

$$251.349\mu m<R<327.137\mu m,$$

Take the average of the range 289.2μm as the diameter of the initial radius of tube, and the initial values of tube thickness and coating thickness are all $\lambda/4\approx214\mu m$.

3. THz Teflon Tube

There is a roughly 47GHz bandwidth of terahertz communication atmosphere window at the frequency f=0.35THz [9], the working frequency is 0.33THz ~ 0.38THz in this paper.

As Figure 2 shows, 3 mm long Terahertz polymer tube's geometry size, outer diameter is 503.2μm, inner diameter is 289.2μm, the air is filled in the core of tube and the layer of the tube is Teflon.

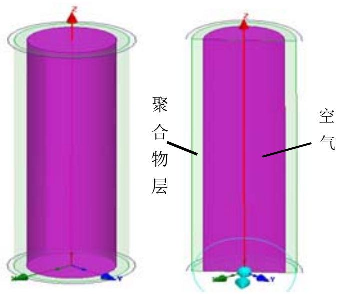

Figure 2. The HFSS Model (left) and Positive Section (right) for the THzTeflon Tube

As shown in Figure 3, the transmission properties of terahertz Teflon tube have been simulated numerically, including the S parameters (shown in Figure 3(a)), the attenuation curves (Figure 3(b)) and group delay (Figure 3(c)).

Propagation constant $\gamma = \alpha + j\beta$, there, α is the attenuation constant and β is the phase constant. In Figure 3(b) re(Gamma) is α, its unit is Np/m, and 1Np/m =(20/ln10)dB/m≈8.686dB/m.

Group Delay (GD) of the waveguide is defined as:

$$\tau = \frac{d\beta}{d\omega} = \frac{\lambda^2}{2\pi c}\frac{d\beta}{d\lambda},$$

There, ω is the angular frequency, λ is the corresponding wavelength, *c* is the speed of light.

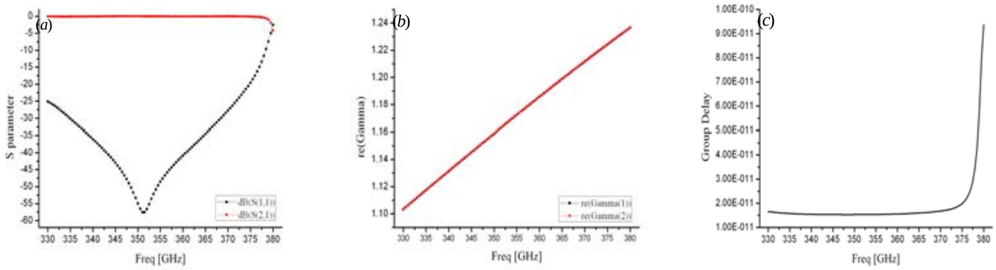

Figure 3. The Transmission Properties of Teflon Tube
(a) S parameters; (b) Attenuation curve; (c) Group delay

Teflon tube's Insertion loss is as low as 4.21dB at center frequency, and the return loss is as low as -57.58dB, but there are large changes within the band, and it is not smooth enough. Within the working frequency band, the attenuation of Teflon tube is less than 1.24Np/m, about 10.77dB/m. For group delay, namely group dispersion is less than 2×10^{-11}s, and it rapidly increased to 9.36×10^{-11}s at 0.380THz.

For the Teflon waveguide, THz wave distribution in the radial is shown in Figure 4. From the electric field and magnetic field distribution, it's easy to see that the field distribution of air core focuses on the tube wall.

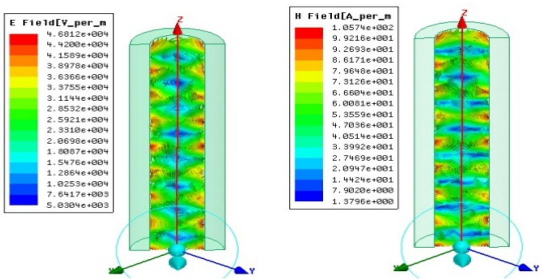

Figure 4. The Field Profile for Single Medium THz Teflon tube: Electric Field (left) and Magnetic Field (right)

4. THz Coated Teflon Tube

In order to improve the transmission properties of Teflon tube, try to coat films on the terahertz Teflon tube [10], and Au, Ag, Cu are commonly used as coating material.

For 3mm-long THz Teflon tube, its relative dielectric constant ε_r is 2.08. Gold, silver, copper, iron and aluminum are usually chosen as the metal coating layer. The inner diameter of tube is 289.2μm, the thickness of Teflon layer and coated metal layer are 214μm, and the core of tube is filled with air. The transmission properties of the coated THz Teflon tube were studied in detail, as shown below.

4.1. The Outer Coating THz Teflon Tube

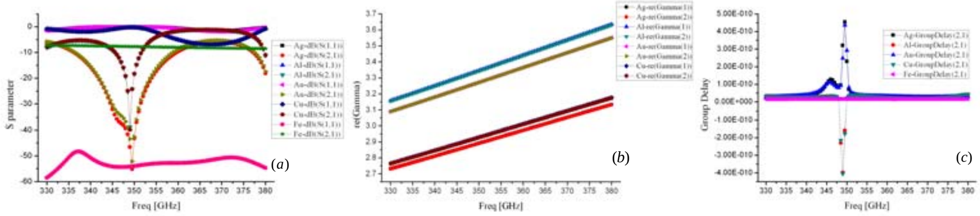

Figure 5. The Transmission Properties of Teflon Tube Outer Coated with Different Metal Materials; (a) S parameters; (b) Attenuation curve; (c) Group delay;

As shown in Figure 5, the transmission properties of THz Teflon tube with outer coating. The S parameters of Teflon tube outer coated under different metals shows in Figure 5(a), Figure 5(b) is the attenuation curve, and the group delay of Teflon tub outer coated with different metals shows in Figure 5(c). S parameter and group delay of THz Teflon tube are poor within the working frequency band. It's easy to find that the attenuation of Teflon tube coated with silver is minimal within the working band, and the coated copper is second.

4.2. The inner coating THz Teflon tube

As shown in Figure 6, the transmission properties of inner coating THz Teflon tube, S parameter of Teflon tube inner coating with different metals shows in Figure 6(a), the attenuation curves shows in Figure 6(b). The insertion loss of Terahertz Teflon tube S_{21} is less than 0.20dB (except iron coating) within the working band, its return loss is less than -30dB, and it tends to be more smooth. Within the working frequency band, the attenuation of Teflon tube is less than 5.2Np/m (about 45.17dB/m), the attenuation for silver coated is still minimal, copper follows.

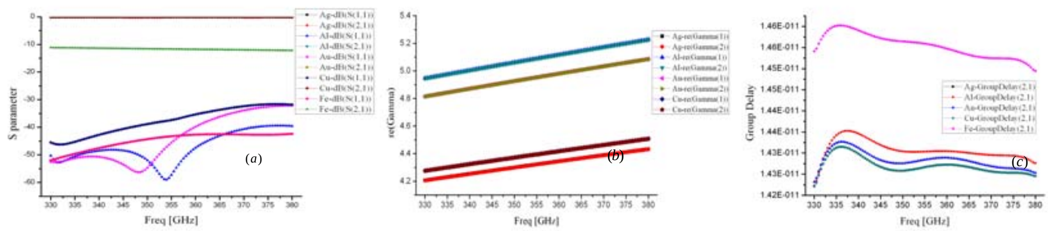

Figure 6. The Transmission Properties of Teflon Tube Inner Coated with Different Metal Materials; (a) S parameters; (b) Attenuation curve; (c) Group delay;

4.3. The Inner and Outer Coating THz Teflon Tube

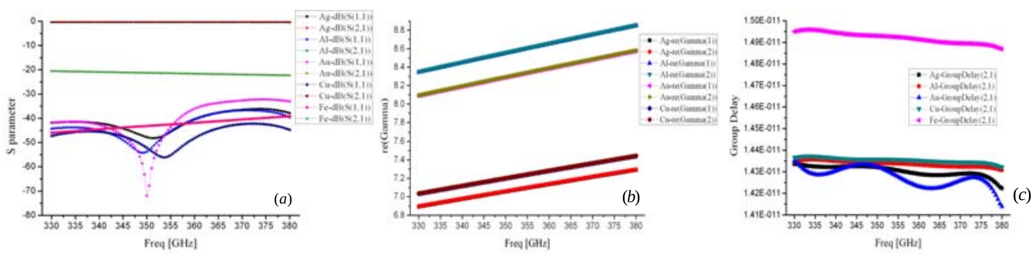

Figure 7. The Transmission Properties of Teflon Tube with Inside and Outside Coated Different Metal Materials; (a) S parameters; (b) Attenuation curve; (c) Group delay;

As shown in Figure 7, it is the transmission properties of inner and outer coated terahertz Teflon tube. Figure 7(a) is S parameters of the Teflon tube inner and outer coating with the different metals, Figure 7(b) is the attenuation curves, Figure 7(c) is the group delay curve. The insertion loss S_{21} of terahertz Teflon tube is less than 0.25dB (except iron coating) within the working frequency band, its return loss S_{11} is less than -32dB, and it tends to be more flat. The attenuation of Teflon tube is greater than 6.8Np/m (about 50.06dB/m) within the working frequency band, and the group delay is less than 1.5×10^{-11}s.

Within the working band, the insertion loss S_{21} is as small as possible. Similarly, the return loss S_{11} is as small as possible. Meanwhile, the attenuation and group delay is as small as possible, as flat as possible as well. Make the comparison of the transmission properties of terahertz Teflon tube among this three coating methods, then it shows that the transmission properties of outer coating THz Teflon tube is the worst, inner and outer coating is last but one. The main reason is that these three coating Teflon tube with the different refractive index distribution and the different reflection interfaces and the structure parameters are need to be further optimized. But the coating can make S parameters more flat. Therefore, terahertz coating Teflon tube can obtain better transmission characteristics.

5. Conclusion

Take the attenuation of terahertz in the open space into account, and in order to transmit the THz (terahertz) wave in the waveguide, terahertz Teflon tube which has the good transmission characteristic is designed and analyzed in this paper. Then the S parameters, attenuation characteristics and group delay characteristics of the Teflon tube also have analyzed in the paper. Compared to the pure metal tube, the transmission properties of terahertz polymer tube is better, its return loss is less than -35dB, and insertion loss is less than 0.3dB. Firstly, the S parameters of metal and polymer tube with the same structure are compared. Then according to the theory of traditional circular waveguides, the geometric parameters of the Teflon tube are determined. Secondly, the transmission properties of the simple terahertz Teflon tubes are analyzed by using HFSS simulation. Finally, the transmission characteristics of terahertz Teflon tubes which are coated metal film by three different ways are simulated, and the advantages and disadvantages are contrasted. The conclusion is that the polymer tube compared to the THz metal tube is more suitable for transmission, the S parameters of Teflon tube are more ideal, but it is not plain; The attenuation within the working frequency is less than 10.77 dB/m; the group delay is less than 10^{-10}s; Coating Teflon tube with film can make S parameters plain. In conclusion, Teflon tube can transmit THz wave effectively, and if the Teflon tube is coated with films, the transmission characteristics can be improved.

Acknowledgement

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References

[1] Yao Jianquan. Introduction of THz-wave and its applications, *Journal of Chongqing University of Posts and Telecommunications (Natural Science Edition)*. 2010; 22(6): 703-707.
[2] FM Zhu, YY Zhang, et al. Subwavelength guiding of terahertz radiation by shallowly corrugated metal surfaces. *Journal of Electromagnetic Waves and Applications*. 2012; 26(1): 120-129.
[3] Zhangfang Hu, Chao Ji, Yuan Luo. SVD-based MEMS dynamic testing technology. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2013; 11(1): 57-62.
[4] Ardavan Rahimian. Modeling and performance of microwave and millimeter wave layered waveguide filters. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2013; 11(7): 3523-3533.
[5] Yang Yihong, Mahboubeh M, Daniel R G. Broadband THz pulse transmission through the atmosphere. *IEEE transactions on terahertz science and technology*. 2011; 1(1): 264-273.
[6] Daru Chen, Haibin Chen. A novel low-loss terahertz waveguide: polymer tube. *Optics express*. 2010; 18(4): 3762-3767.
[7] Benjamin B Yang, Sarah L Katz, Keely JW, et al. A high-Q terahertz resonator for the measurement of electronic properties of conductors and low-loss dielectrics. *IEEE transactions on terahertz science and technology*. 2012; 2(4): 449-459.

[8] Wenting Dong, Jungang Miao. Design of a wide beam millimeter-wave antenna, *IEEE*. *2010 9th international symposium on Antennas Propagation and EM Theory (ISAPE)*. 2010: 33-36.
[9] Radoslaw Piesiewicz, Thomas Kleine-Ostmann, Norman K, et al. Short-range ultra-broadband terahertz communications: concepts and perspectives. *IEEE antennas and propagation magazine*, 2007; 49(6): 24-39.
[10] Chen Daru, Chen Haibin. A novel low-loss terahertz waveguide: polymer tube. *Optics express*. 2010. 18(4): 3762-3767.