COMPLEX PERMITTIVITY AND PERMEABILITY OF CARBON NANOTUBES AT 26-40GHZ

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Introduction

Nano materials are increasingly receiving recognition as practical structural and functional materials with good prospect, and have been developed extensively in recent years. Since the discovery in 1991[1], carbon nanotubes have attracted more and more interest for their distinguished properties and promising future applications. Carbon nanotubes are of great interest for many reasons. For example, they can be used as supports for metal catalysts. As tubular structures, they have unusual capillary properties. Mechanically, carbon nanotubes are significantly stiffer than currently commercially available carbon fibers, and can therefore be used to strengthen composite materials or atomic force microscope tips. Theoretical calculations of their electronic structure indicate that single-walled carbon nanotubes are either metallic conductors, or semiconductors, depending on the diameter and helicity of the individual tubes. Because of their mesoscopic structure, carbon nanotubes may exhibit quantum effects arising from their small diameter (≤10nm). The preparation and properties of carbon nanotubes have been studied efficiently [1-5]. However, to our knowledge, little data on the complex permittivity and permeability of the carbon nanotube has been reported, especially at high frequencies. In this paper the complex permittivity and permeability of the carbon nanotube imbedded in paraffin wax have been investigated at 26-40GHz.

Experimental

The carbon nanotubes were prepared by catalytic decompose of benzene using floating transition method at 1100~1200℃. Benzene was used as carbon source and iron as catalyst with sulfur.

The complex permittivity and permeability of carbon nanotubes imbedded in paraffin wax were measured by the method, which is based on measurements of the reflection and transmission moduli between 26 GHz and 40GHz, in the fundamental waveguide mode, using rectangular samples set in a brass holder which fills the rectangular waveguide. After calibrated with an intermediate of a short circuit and blank holder, reflection and transmission coefficients were obtained with the help of an automated measuring system (HP8510B network analyzer). Both the real and imaginary parts of the permittivity and permeability were calculated. The carbon nanotubes were dispersed in melting paraffin wax, and then the mixtures were cast into molds. Commercially available paraffin wax was used. Because the melting point of paraffin wax is low(~60 ℃), the task of mixing liquid paraffin wax with the carbon nanotubes is simply a matter of blending the desired volumes of the two constituents in a suitable container until a uniform consistency is obtained. To prepare samples for testing, rectangular waveguide sections were filled carefully to prevent void formation. The sample consisted of 5 wt% carbon nanotubes and 90 wt% paraffin wax.

Results and Discussion

Fig.1 shows the TEM image of carbon nanotubes. The TEM image reveals that the carbon nanotubes are straight with diameter 30~80 nm, internal diameter 10~50 nm and length 50~100 μ m.

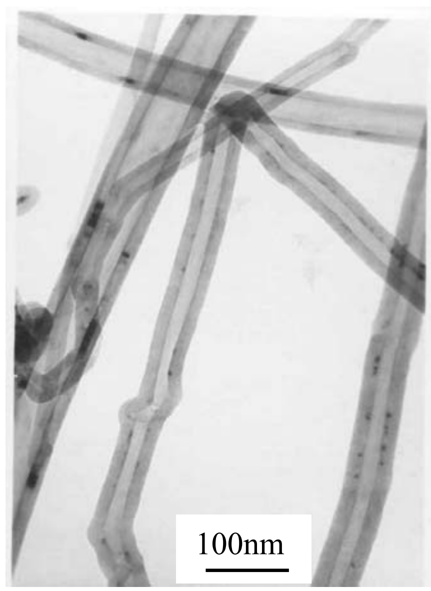

Figure 1. TEM image of carbon nanotubes

Electrical properties can be determined at various frequencies [6,7]. The interaction between electromagnetic waves and condensed matter can be described by using complex permittivity, ε_r ($\varepsilon_r=\varepsilon'+i\varepsilon''$, where ε' is the real part, ε'' the imaginary part), and conductivity, σ_r. The relation between the real part of the (polarization) conductivity $\sigma'(\omega)$ and the imaginary part of the permittivity $\varepsilon''(\omega)$ is $\sigma'(\omega)=\omega\, \varepsilon''(\omega)$, where ω is the angular frequency.

The real part (ε') of complex permittivity of the carbon nanotube imbedded in paraffin wax ranges from 13.27 to 14.62, and the imaginary part (ε''), 11.60 to 8.02 at the frequency range of 26-40GHz. The loss tangent (or dissipation factor), $tg\delta_\varepsilon$ ($\varepsilon''/\varepsilon'$) ranges from 0.58 to 0.80 (Figure 2). The real part (μ') of permeability of the carbon nanotube imbedded in paraffin wax ranges from 1.07 to 1.19, and the imaginary part

(μ''), 0.01 to 0.07. The loss tangent $tg\delta_\mu$ (μ''/μ') ranges from 0.01 to 0.06 (Figure 3). This is due to the special structure of carbon nanotubes and existence of catalyst of Fe, Fe_3C and FeS.

The idea of theoretically predicting the permittivity of a composite materials has been a source of continuing interest since the late 1800's [7-9]. Authors have constructed theoretical models to predict ε_r by approaching the problem with the fundamental equations of electrodynamics scattering methods or with pure mathematical models. Despite these efforts, a universal theory capable of theoretically predict the permittivity of a composite material has not been established [7]. The MG theory presented in 1904 by J. C. Maxwell Garnet is considered to be the fundamental theory for predicting the permittivity of a composite material [8]. Although the MG theory has been used extensively to study the complex index of refraction of metal-insulator composites at optical frequencies, little work regarding the microwave permittivity of composite materials has been done. K. Bober's results indicate that Maxwell Garnet theory's ability to model ε' is effective only for nickel zinc ferrite composites, and the accuracy of the method to predict the permittivity of a mixture gradually diminish with increasing the permittivity of the powder suspended in the matrix. MG theory is unable to model ε'' for any of the composites at microwave frequencies. Second-order polynomials dependent only f (volume filling factor) are utilized to theoretically predict ε' and ε'' for the composite materials [7]. It can be seen that ε' and ε'' of the pure carbon nanotube are higher than 100. According to Bober's results [7], second-order polynomials dependent only f can be utilized to theoretically predict ε' and ε'' for the composite materials composed of carbon nanotube and dielectric materials.

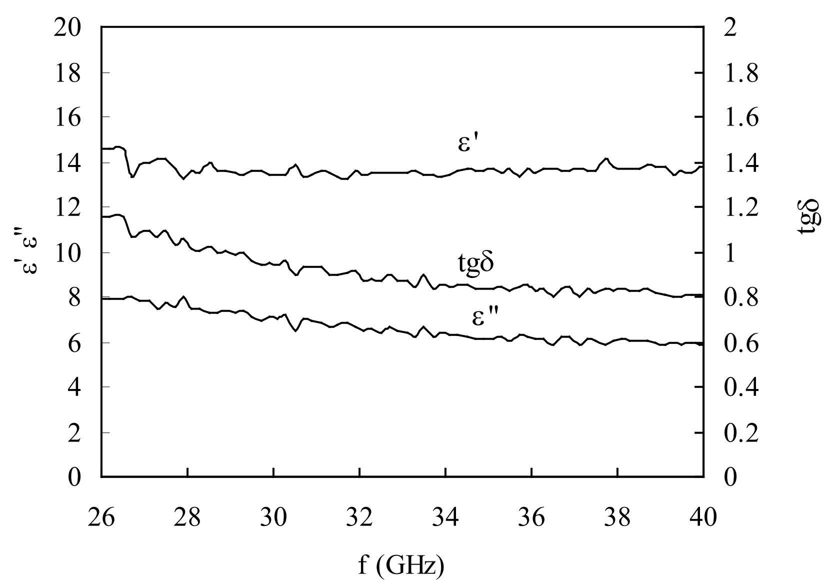

Figure 2. ε' and ε'' of carbon nanotubes imbedded in paraffin wax

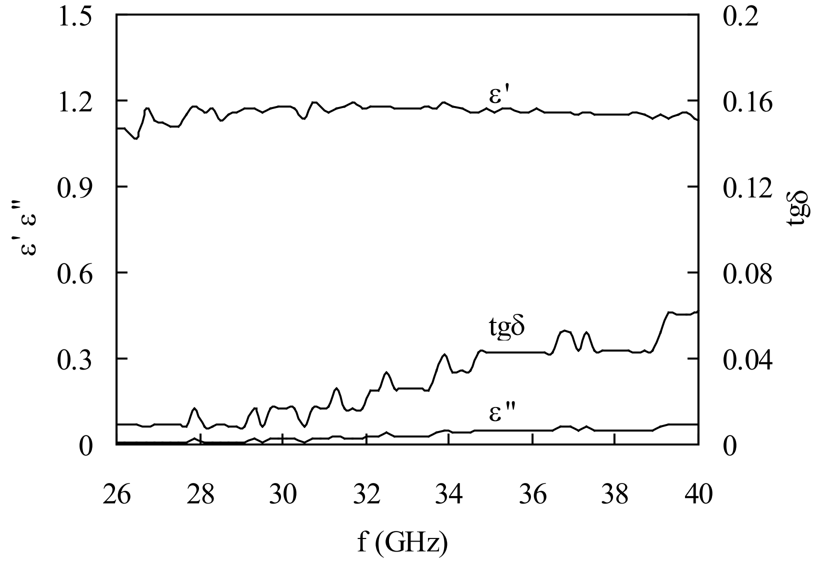

Figure 3. μ′ and μ″ of carbon nanotubes imbedded in paraffin wax

Conclusions

The ε′ of the carbon nanotube imbedded in paraffin wax ranges from 13.27 to 14.62, and ε″, from 11.60 to 8.02 at the frequency range of 26-40GHz. The μ′ of the carbon nanotube imbedded in paraffin wax ranges from 1.07 to 1.19, and μ″, 0.01 to 0.07. This is due to the special structure of carbon nanotubes and existence of catalyst of Fe, Fe_3C and FeS. The ε′ and ε″ of the pure carbon nanotube are higher than 100.

References

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