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An Experimental Study of Reflection and Transmission of Absorption Materials for EM Wave with Chirality

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INTRODUCTION

Recently, it is required to develop EM wave absorber. We are interested in the chiral medium as the new absorption materials for EM wave. A chiral object is defined as a three-dimensional body that cannot be brought into congruence with its mirror image by translation and rotation. The object exhibits the property of handedness and lacks bilateral symmetry. Some examples of chiral objects are the wire helix, the Moebius strip, and certain winding vegetation. A chiral medium can be constructed by embedding chiral objects, and an irregular tetrahedron in a non-chiral dielectric or other medium, that can be modeled by collection of uniformly distributed, randomly oriented chiral objects [1]. The chiral media have long been known in optics under the common name of optically active materials. With modern advances in polymer science, one may make chiral materials even for the microwave region. The media exhibit interesting properties of polarization birefringence and circular dichroism. Thus the scattering of electromagnetic waves by layered chiral media has been of great interest from both the theoretical and practical points of view [2]. However it is not found for the absorption materials for EM wave with chirality.

In this paper, we made samples of chiral materials in microwave frequencies.A transversely polarized time-harmonic electromagnetic plane wave which is incident on chiral slab is considered. Reflection and transmission characteristics of the chiral and dielectric media are measured in 20[MHz]-1[GHz] frequency range. Furthermore frequency characteristics of reflection and transmission are numerically obtained by using complex dielectric constants which are computed from results. These measured results are compared with theoretical results for many samples.

FORMULATION

Consider a plane monochromatic wave of any arbitrary polarization incident from a dielectric medium upon chiral slab, as shown in Fig.1. The chiral medium is characterized by the following constitutive relations [3]:

$$D = \varepsilon E - j\kappa H \qquad (1)$$
$$B = \mu H + j\kappa E \qquad (2)$$

where κ is a real quantity and called the chirality parameter.

Inside the chiral medium there are two modes of propagation: a right-circularly polarized wave (wave number k_1) and a left-circularly polarized wave (wave number k_2). The wave numbers k_1 and k_2 are given by

$$k_1 = \omega\mu\kappa + \sqrt{\omega^2\mu^2\kappa^2 + k^2} \qquad (3)$$
$$k_2 = -\omega\mu\kappa + \sqrt{\omega^2\mu^2\kappa^2 + k^2} \qquad (4)$$

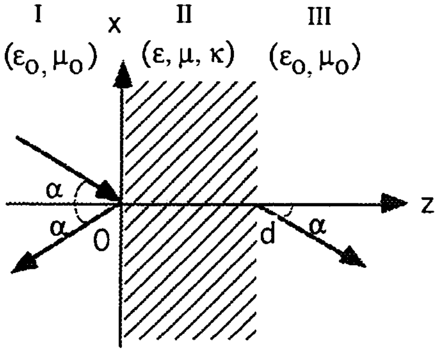


Fig.1 Geometry of chiral slab.

where $k = \omega\sqrt{\mu\varepsilon}$, and ε and μ are the permittivity and the permeability of the chiral medium, respectivery.

The incident electric field can be written as

$$E_i = E_{0i} \cdot exp\{\mathrm{j} k_0 (z\cos\alpha - x\sin\alpha)\} \tag{5}$$

where

$$E_{0i} = E_{is} u_y + E_{ip}(\cos\alpha u_x + \sin\alpha u_z) \tag{6}$$

where $\mathbf{u}_x, \mathbf{u}_y$ and $\mathbf{u}_z$ are unit vectors and k_0 is a wave number of free space. Note that the subscripts s and p refer to the perpendicular and parallel components of an electric field vector [4].

And the reflection electric field can be written as

$$E_r = E_{0r} \cdot exp\{-\mathrm{j} k_0 (z\cos\alpha - x\sin\alpha)\} \tag{7}$$

where

$$E_{0r} = E_{rs} u_y + E_{rp}(\cos\alpha u_x - \sin\alpha u_z) \tag{8}$$

The electric field inside a chiral medium is represented as a sum of a right-circularly polarized wave and a left-circularly polarized wave. Thus, in the chiral slab, there are two right-circularly polarized plane waves and two left-circularly polarized plane waves propagating toward the interfaces z=0 and z=d.

$$\mathbf{E}_c^+ = \mathbf{E}_{c1}^+ \cdot \exp\{\mathrm{j} k_1 (z\cos\alpha_1 - x\sin\alpha_1)\} + \mathbf{E}_{c2}^+ \cdot \exp\{\mathrm{j} k_2 (z\cos\alpha_2 - x\sin\alpha_2)\} \tag{9}$$

$$\mathbf{E}_c^- = \mathbf{E}_{c1}^- \cdot \exp\{-\mathrm{j} k_1 (z\cos\alpha_1 + x\sin\alpha_1)\} + \mathbf{E}_{c2}^- \cdot \exp\{-\mathrm{j} k_2 (z\cos\alpha_2 + x\sin\alpha_2)\} \tag{10}$$

where

$$E_{c1}^+ = E_{c1}^+(\cos\alpha_1 u_x + \sin\alpha_1 u_z + \mathrm{j} u_y) \tag{11}$$

$$E_{c2}^+ = E_{c2}^+(\cos\alpha_2 u_x + \sin\alpha_2 u_z - \mathrm{j} u_y) \tag{12}$$

$$E_{c1}^- = E_{c1}^-(\cos\alpha_1 u_x - \sin\alpha_1 u_z + \mathrm{j} u_y) \tag{13}$$

$$E_{c2}^- = E_{c2}^-(\cos\alpha_2 u_x - \sin\alpha_2 u_z - \mathrm{j} u_y) \tag{14}$$

And the transmission electric field can be written as

$$E_t = E_{0t} \cdot exp\{\mathrm{j} k_0 (z\cos\alpha - x\sin\alpha)\} \tag{15}$$

where

$$E_{0t} = E_{ts} u_y + E_{tp}(\cos\alpha u_x + \sin\alpha u_z) \tag{16}$$

Applying the boundary conditions at the two interfaces of the chiral slab,

$$\begin{bmatrix} E_{is} \\ E_{ip} \\ E_{rs} \\ E_{rp} \end{bmatrix} = [A] \begin{bmatrix} E_{ts} \\ E_{tp} \end{bmatrix} \tag{17}$$

is obtained, where $[A]$ is a 4×2 matrix. We can get the amplitudes of the reflected and transmitted waves outside the slab:

$$E_{rs} = \frac{B_2 E_{is} + B_3 E_{ip}}{B_1} \tag{18}$$

$$E_{rp} = \frac{B_4 E_{is} + B_5 E_{ip}}{B_1} \tag{19}$$

$$E_{ts} = \frac{A_{32} E_{is} - A_{12} E_{ip}}{B_1} \tag{20}$$

$$E_{tp} = -\frac{A_{31} E_{is} - A_{11} E_{ip}}{B_1} \tag{21}$$

where A_{ij} is a component of the matrix $[A]$. The reflection and transmission powers are given by

$$P_r = P_{rs} + P_{rp} \tag{22}$$

$$P_t = P_{ts} + P_{tp} \tag{23}$$

where

$$P_{rs} = |E_{rs}|^2 \tag{24}$$

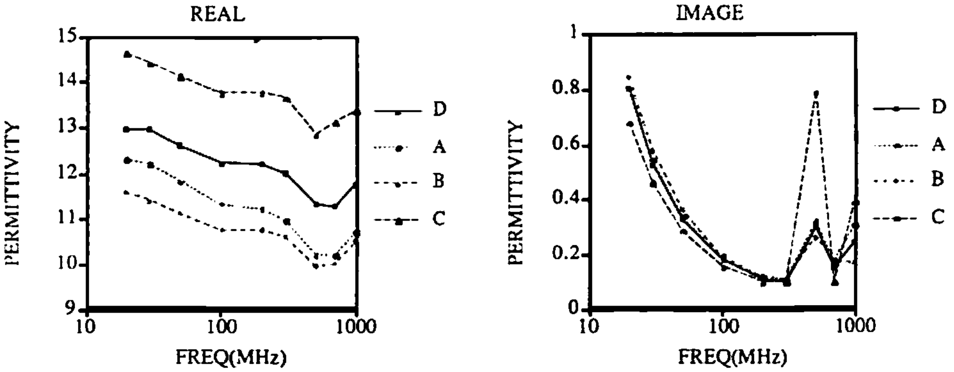
$$P_{rp} = |E_{rp}|^2 \tag{25}$$

$$P_{ts} = |E_{ts}|^2 \tag{26}$$

$$P_{tp} = |E_{tp}|^2 \tag{27}.$$

NUMERICAL RESULTS

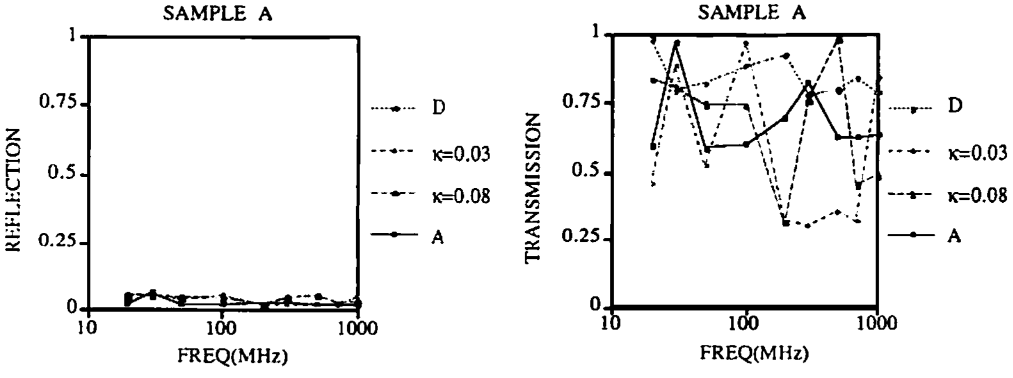
The chiral slab under test is made of copper helices, embedded in epoxy matrix. Helices are both randomly oriented and distributed. Samples are three types of volume for chiral objects (samples A, B and C) and non-chiral sample (sample D). Reflection and transmission coefficients of samples are measured by using the network analyzer. From the results, we obtained dielectric constants of the samples, as shown in Fig.2.



(a) Real part (b) imagenaly part

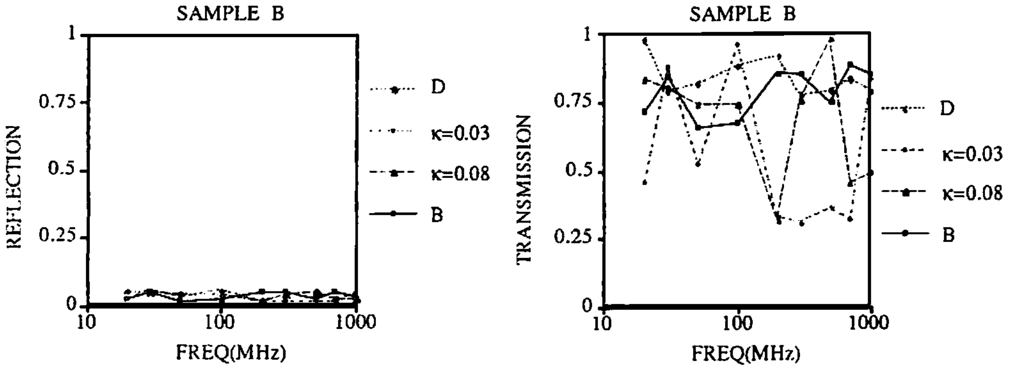
Fig.2 dielectric constans

From Fig.2(a), real parts of dielectric constants of chiral media (samples A and D) are smaller than non-chiral medium (sample D). On the other hand, the value of sample C is larger than one of sample D. Imaginary parts of dielectric constants of samples are almost same over all frequencies, Fig.2(b), but there is a little different around a frequency in sample C.



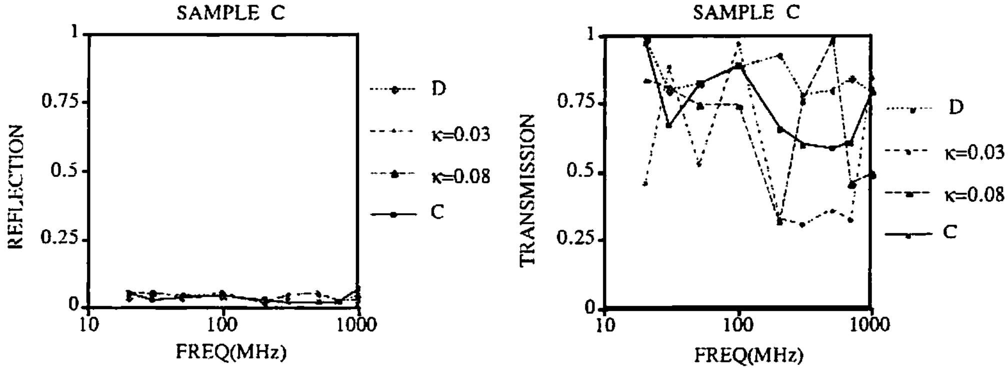
(a) Reflection characteristics (b) Transmission characteristics

Fig.3 Sample A



(a) Reflection characteristics (b) Transmission characteristics

Fig.4 Sample B



(a) Reflection characteristics (b) Transmission characteristics

Fig.5 Sample C

Frequency characteristics of reflection and transmission coefficients of samples are shown in Figs.3, 4 and 5. And they were computed by using values of dielectric constants in non-chiral media. From Fig.3, the reflection characteristic of sample A is not different from that of sample D. But the transmission characteristic of the sample A is a little different from that of sample D over all frequency range characteristics.But we can not distinguish the chiral parameter from other results in Fig.3. From Fig.4, the reflection characteristic of sample B is almost same as that of sample D and the transmission characteristic of sample B is similar to that of sample D. However in the low frequency range, it is a little different from sample D. Also, the reflection characteristic of sample C is similar to that of samples A, B, and D from Fig.5. The transmission characteristic of sample C is same as sample D in the low frequency range. From the result, it is difficult to obtain the chiral parameter.

CONCLUSION

We made samples of chiral materials and measured reflection and transmission characteristics, and found dielectric constants of samples. From results, we found that the chiral medium is useful to absorption materials, and that reflection and transmission characteristics change in accordance with subtle oriented chiral objects.

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