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Couple ϵ, μ Behaviour Study by the Electromagnetic Response of the Composite PVC/ Fe_3O_4 by Time Domain Spectroscopy and Measurements at 10 GHz Versus the Applied Magnetic Field

A.M. Bottreau, A. Boutaudon, R. Sardos* and A. Merzouki**

Laboratoire PIOM, URA 1506, ENSCPB, Université de Bordeaux I, avenue Pey Berland, BP. 108, 33402 Talence cedex, France

* 37 rue de Patay, 33000 Bordeaux, France

*** Institut d'Électronique de l'Université de Sétif, 19000 Sétif, Algérie

Abstract: Using the time domain spectroscopy (TDS) and a 10 GHz three waves reflecto - interferometer (TWRI) with an applied magnetic field, we have measured $\epsilon\mu$ as a function of the volumetric fraction of the composite material PVC- Fe_3O_4 . The experimental results are compared to several mixing laws. Further, the moment expansion of the scattering matrix up to fifth order enables us to determine the size parameter as a function of the volumetric fraction.

1. INTRODUCTION.

In the general case, the modelisation of the electromagnetic behaviour of heterogeneous media obliges us to use a dielectric and magnetic model media since the propagation coefficient γ is a function of $(\epsilon\mu)^{1/4}$. We use a composite PVC / Fe_3O_4 , which presents a ferrimagnetic resonance to vary the permeability by applying a variable magnetic field which results in a great number of $\epsilon\mu$ couples.

2. EXPERIMENTAL RESULTS

The permittivity versus the volumetric fraction (V) was determined without magnetic field by TDS. To study the permeability variation versus the magnetic field (B from 0 to 5500 gauss) and V, we have used a TWRI already published [1, 2].

On figure 1 and 2 only the real and imaginary part of the product of $\epsilon\mu$ are shown.

Figure 1: Variation of the real part of $\epsilon\mu$ versus volumetric fraction and applied magnetic field B

Figure 2: Variation of the imaginary part of $\epsilon\mu$ versus volumetric fraction and applied magnetic field B

3. INTERPRETATION OF THE EXPERIMENTAL RESULTS

In fact, the studied material is a ternary mixture: PVC, Fe_3O_4 et Air. Yet, if we plot the ternary diagram representing the volumetric fraction (Figure 3), the points obtained with different compounds are aligned, which means we can consider the medium as a binary mixture: PVC+ Air and Fe_3O_4 + Air. Both permittivity and permeability have been measured for each volumetric fraction and over the whole magnetic field range. With this working hypothesis, we have systematically made an analysis of different mixing laws which are more adapted to this material. Knowing $\epsilon\mu$, we have

calculated the volumetric fraction (V_c). Then, when one of the laws is verified, V_c is situated in a bisector plane of the 3D plot representation : V , B , V_c . Two of them are of a great interest: Hanai law (Figure 3) which leads to a mean quadratic residue $\sigma = 6 \cdot 10^{-2}$ and Lichtenecker law (figure 4) which leads to $\sigma = 2,7 \cdot 10^{-2}$.

Figure 3: Ternary diagram of three volumetric fractions

Figure 4: Lichtenecker law $V_c = f(V, B)$

Carrying on with this study, we have made an expansion of the Mie law to the fifth order, which in the case of an effective medium hypothesis leads for retro-diffused field with $V_i = 4\pi/3 \int n_i(r) r^3 dr$ and $k_i = [\omega/c]^5 / 30 \int n_i(r) r^5 dr$ to:

$$\sum_{i=1}^N \left[V_i \frac{\varepsilon \mu_i - \varepsilon \mu}{\varepsilon \mu_i + 2\varepsilon \mu} + k_i (\varepsilon \mu_i - \varepsilon \mu) \left[18 \frac{\varepsilon \mu (\varepsilon \mu_i - 2\varepsilon \mu)}{(\varepsilon \mu_i + 2\varepsilon \mu)^2} - 1 - 5 \frac{\varepsilon \mu}{2\varepsilon \mu_i + 3\varepsilon \mu} \right] \right] = 0$$

Knowing V_i , ε , μ_i and μ , we have calculated the fifth order coefficients k_i (figure 5 and 6) which confirms what was obtained by electron microscopy where an aggregation of PVC was observed when V tends towards zero and an aggregation of Fe_3O_4 when V tends towards 1. In the microwave range, this new analyse of the electromagnetic behaviour of composite materials with the effective medium hypothesis, allows one to better understand the internal structure of the material, by looking at the evolution of the 5th order term.

Figure 5: $k_{(PVC)} = f(B, 1-V)$

Figure 6: $k_{(Fe3O4)} = f(B, V)$

4. CONCLUSION.

In this paper, we have shown the advantage of using a ternary diagram for the material definition, and we have also shown the advantage presented by the development of the fifth order of the Mie's diffusion laws to show the formation of aggregates.

Références.

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