Effective Dielectric Constant of Dilute Magnetic Dielectrics

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Abstract

The objective of this paper is to study the electro-magnetic interaction for composite material or dilute magnetic dielectrics (DMD) both from phenomenological and fundamental viewpoints. A simple formula for effective dielectric constant of composite material or DMD is proposed. In presence of magnetic element in the composite the effect of magnetic susceptibility and electromagnetic coupling term is taken into account to describe the dielectric behavior.

1. Introduction

The importance of composite dielectric materials in present day technology has been emphasized in many literatures [1]. In a recent development [2] high frequency dielectric nature of materials has been investigated. In this work a simple form of dielectric behavior of dilute magnetic dielectric (DMD) type composite material is formulated. The effect of inclusion of metallic or magnetic atom in host dielectric is undertaken and modified form of the response ε(ω) is proposed [3].In a DMD system, μ(ω)≠1 The effect magnetic susceptibility is taken into account to describe the overall dielectric behavior under external electro-magnetic (EM) field [4].A coupling term is also arises due to EM interaction in composite material is also considered. In Maxwell's EM field theory both ε(ω) and μ(ω) have their own identity however this proposed theory apparently coupled them to describe an effective dielectric function Φe for a better convenience. The optical absorbance of a non-magnetic material is related to its dielectric function only and for DMD like system it should be related to effective dielectric function, Φe. In this present work UV-VIS spectroscopy on a DMD system is also undertaken. The said analysis is carried out to study the nature of optical absorbance of pure dielectric and DMD composite.

In the following theoretical formulation, experimental result, discussions and conclusions are given.

2. Theory

The dielectric function ε can be expressed in a classical Helmholtz–Drude model [5],

$$\varepsilon_h(\omega) = 1 - \frac{\omega_p^2}{\omega_0^2 - \omega^2 + i\omega\gamma} \qquad (1)$$

Where ω_0 is the resonance frequency and γ is the damping factor.

Frequency dependence of the response function for the metal [4] can be expressed as,

$$\varepsilon_m(\omega) = \frac{\omega_p^2}{\omega^2 + i\omega\tau} \qquad (2)$$

Where ωp is the plasma frequency, Γ is relaxation time.

In case of DMD we have to consider the Debye like spin lattice relaxation, was developed by Gorter and Kronig, given by,

$$\chi_m = \frac{\chi}{1 + i\omega\tau} \qquad (3)$$

For μ≠1, we have combined the spin lattice relaxation effect with the dielectric behavior of composite and a new function Φe is assigned to consider the combine effect. The proposed form of Φe is taken to describe complex refractive index is [5]

$$\eta(\omega) = \sqrt{\varepsilon(\omega)\mu(\omega)} = \sqrt{\phi_e} \qquad (4)$$

Where,

$$\mu(\omega) = 1 + \chi_m(\omega) \qquad (5)$$

$$\phi_e = \left[1 + \chi_m(\omega)\right]\varepsilon_e(\omega) \qquad (6)$$

In a continuous medium of composites with inclusion of magnetic atom the magneto-electric coupling is present in terms of the Tellegen parameters

$$D = \varepsilon E + i\kappa\sqrt{\mu_0\varepsilon_0}H \qquad (7)$$

$$B = -ik\sqrt{\varepsilon_0\mu_0}E + \mu H \qquad (8)$$

where, ε_0 and μ_0 stand for the permittivity and permeability in free space, and denotes the coupling constant used in the Tellegen relations[6].

$$\frac{D}{E} = \varepsilon + \frac{i\kappa H}{c_0 E} \qquad (9)$$

Following E.M. theory, the amplitude of electric and magnetic field are related by,

$$\beta(\omega) = \frac{B_0}{E_0} \qquad (10)$$

In a pure dielectric the contribution $\beta(\omega)$ is very small, and the same is significant in conducting medium.

Hence, the imaginary part of $\varepsilon(\omega)$ which directly related to optical absorbance and is given by

$$\varepsilon_e = \varepsilon + \frac{i\kappa}{c_0}\beta(\omega) \tag{11}$$

Contribution lies Imε and Imμ for real κ.

3. Experiment

In this work a simple DMD system was fabricated by the electro-deposition of Ni atoms over one surface of natural mica sheet (thickness 1.5 mm). Natural mica is a non-magnetic dielectric. The thickness deposited Ni layer was about 1μm. The mentioned specimen was regarded as a DMD system. The UV-VIS absorption spectra of the fabricated DMD specimen was recorded with model 2450 UV-VIS spectrophotometer, Shimadzu, Japan in the range between 225 to 900 nm.

4. Results and Discussions

The experimental result of UV-VIS spectroscopy is shown in Fig.1. It compares absorbance of the pure mica to that of fabricated DMD specimen. The absorbance of the Ni coated mica is greatly modified in presence of magnetic layer on mica sheet. It has been found [7] that in magneto-electric, ferroic and chiral materials the application of magnetic field can produce a dielectric response and the application of an electric field can produce a magnetic response. These cross coupling behaviors can be found to occur in specific material lattices, layered thin films, or by constructing composite materials. When a strong Electric field is applied to a magneto-electric material the structure is slightly distorted, which changes the magnetic moment and therefore cross coupling. The modification of nature of optical absorbance of pure mica shown by graph A in Fig.1. compared to that in DMD system represented B in the Fig. It is purely due to magnetic layer over mica sheet. The overall results obtained are in qualitative agreement.

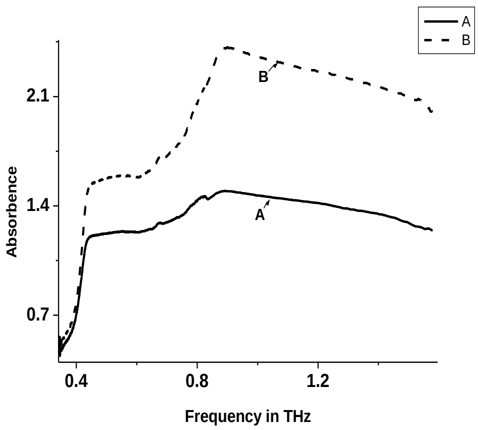

Fig.1.
UV-VIS absorbance spectra for A- pure mica (thickness = 1.5 mm, B-Ni coated composite)

5. Conclusion

The proposed theoretical formulation of DMD like composites and its comparison with experimental result shows a good qualitative agreement. The effective dielectric function may be exploited for DMD composite material to study their optical and electrical behavior.

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7. References

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