Microwave properties of diluted composites made of magnetic wires with giant magneto impedance effect

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MICROWAVE PROPERTIES OF DILUTED COMPOSITES MADE OF MAGNETIC WIRES WITH GIANT MAGNETO IMPEDANCE EFFECT

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Introduction

The possibility of engineering microwave composites with new and attractive properties has attracted considerable attention, since the pioneering work of Pendry [1] and Smith [2]. These composites have a negative refraction index due to a negative permeability and permittivity. They are denominated either left-handed materials, negative index materials or metamaterials. The negative permittivity properties are commonly achieved through a wire media consisting of an array of wires.

We report here significant advances on wire media based on magnetic microwires. We have established the theoretical description of wire media made of magnetic wires, supported by experimental results [3]. In particular, we show that there is a close link between the Giant Magneto Impedance Effect (GMI) in individual wires, and the free-space microwave properties of the composite wire media. As a consequence, the extended knowledge on GMI materials and effects developed in recent years may be readily used to design wire media with new dielectric properties. For example, the demonstration of composites with tuneable dielectric constant under a static magnetic field is easily described using the GMI approach.

Experimental details and results

Lattices of continuous parallel wires have been manufactured using several types of amorphous glass-coated CoFeSiB microwires with different magnetic properties. The size of the lattices are 300mmx300mm. Free-space reflection and transmission microwave measurements have been performed to determine the effective permittivity of these composites, in a configuration sketched on Fig. 1. The permittivity of a wire media made of wires with an axial magnetization is reported in fig. 2. Unlike traditional metallic lattices [1], the dielectric response is clearly resonant. Large negative permittivities are obtained in the 4.5 to 11 GHz range. In contrast, wire media made using wires with circumferential magnetization exhibit properties similar to that of metallic non magnetic wire media.

Analytical model

An electric field is produced by the microwire in response to the incident plane wave. The effective permittivity of the wire media is the ratio of the spatial average of electrical displacement <D>, over the spatial average of the electric field <E>. <D> is essentially affected by the conductivity of the wire over the skin depth. This leads to a factor in the expression of the effective permittivity that is dependent on the ratio of the microwave impedance over DC resistance. This is the same quantity that can be measured through GMI experiments. <E> is affected by the long range radiation of the different wires in the whole space, leading to a factor similar to that established for metallic non magnetic wires.

The effective permittivity of the wire media is shown to be :

$$\varepsilon_{eff}=(1-f)\varepsilon_m+f\frac{\sigma_0}{j\omega\varepsilon_0\frac{Z}{R_{dc}}\left(1+j\omega\frac{\mu_0\sigma_0 f}{2\pi}\frac{R_{dc}}{Z}A\right)} \qquad (1)$$

where Z/R_{dc} is the GMI ratio, A an area only dependent on the geometry, f the volume fraction of wire and σ_0 the conductivity of the wire. A comparison between theory and measurements is reported in fig. 2. A good agreement is achieved.

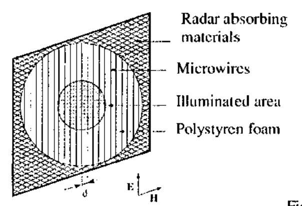

Figure 1 : wire medium and polarization of interest.

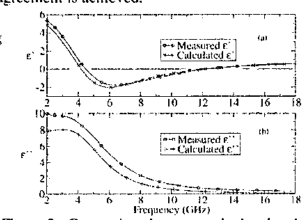

Figure 2 : Comparison between calculated and measured permittivity of a wire medium. The magnetostriction coefficient of the alloy is positive.

Dielectric response tuned using a static magnetic field

It has been demonstrated that the permittivity of these composites can be tuned by applying a static magnetic field. Permittivity measurements performed in a transmission line are reported on fig. (4).

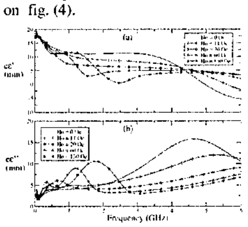

Figure 4 : Permittivity measurements of the composite in coaxial line. A static magnetic field is applied parallel to the wires, ranging from 0 Oe to 130 Oe.

References

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