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Nonmagnetic negative refractive index media based on chalcogenide glasses

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Abstract: We report in this work the study of the permittivity and the losses in non-linear nonmagnetic negative refractive index media. We analyze the permittivity and the losses dependence on the inclusion number of the particles used in the suggested media that is made by interlacing plasmonic metallic particles and a dielectric. We show that the exhibition of a negative permittivity in these strongly anisotropic media depends not only on the inclusion number of the particles and the frequency range but also on the oscillation frequency of free electrons in the metal which plays the major role. We finally suggest the use of supraconductor nanoparticles in the design of metal dielectric structures as a very promising route to create metamaterials, mainly in Chalcogenide glass as they provide low losses, high quality with non-linearity in fabrication.

Keywords: Superconductor particles, NIM materials, Chalcogenide glass, Maxwell Garnett Theory

1 Introduction

Numerous theoretical investigations and experimental findings[1,2,3] have shown the existence of a novel class of micro-structurally-organized materials that can be identified by a real-world negative magnetic permeability and real-world negative dielectric permittivity in the microwave frequency range. These substances are also known as double-negative substances, negative refractory substances, or left-handed metamaterials (LHMs). Such materials have pertinent non linear optical properties[4,5,6], for instance the kerr effect[7], slow light propagation[7,8], among other applications. The creation of bulk, multilayered, negative-index plasmonic structures has lately made significant strides [9,10]. Due to a near-field interaction, the EM energy is coherently steered through a collection of widely spaced metal nanoparticles. Surface plasmons (SP), which support collective electronic excitation and have resonance frequencies that depend on the particle's size and shape are widely known to exist in metals. Building substantially anisotropic media, especially uniaxial anisotropic materials with differing permittivity tensor component signs parallel and transverse, is a promising approach to create metamaterials [11,12]. Layered superconductors have only lately been recognized as extremely anisotropic materials that can exhibit negative refractive indices over a broad frequency range [13]. We can combine plasmonic or polar particles (which provide the negative permittivity) with dielectric medium to achieve the significant optical anisotropy. The composite structure often accommodates plane-wave-like modes if the characteristic size of inhomogeneities and their typical separation are significantly lower than the wavelength of incident radiation.

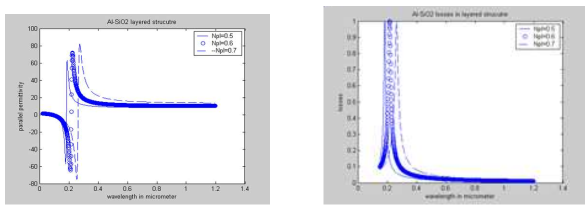

Fig. 1: : the parallel permittivity of a Al-SiO2 layered structure and the losses for different inclusions number are reported in the figure 1 (a) and (b) respectively.

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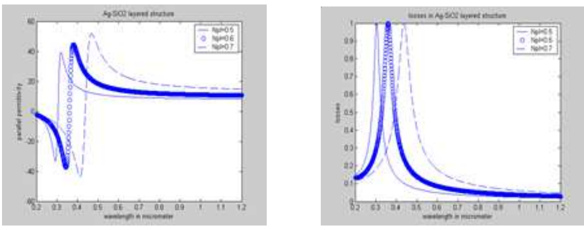

Fig. 2: : the parallel permittivity of a Ag-SiO2 layered structure and the losses for different inclusions number are reported in the figure 1 (a) and (b) respectively.

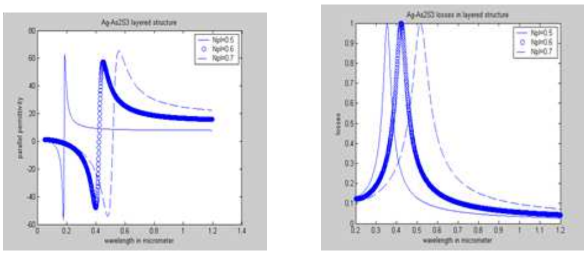

Fig. 3: :(a) parallel permittivity, (b) Losses

2 The model

We consider the Maxwell Garnett Model for dielectric mixture containing conducting particles, the composite medium is assumed to be composed of small particles of radius $a \ll \Lambda$ and dielectric permittivity ε_i randomly embedded in another bulk medium with dielectric permittivity ε_h[14]. The EM properties of the plane-wave-like modes can be described in terms of the effective dielectric constant as: ε_{eff}=ε_h ((1+2f)ε_i+2ε_h (1-f))/(ε_i (1-f)+ε_h ((2+f)) Since the effects described originate from the averaged (effective medium) properties of metamaterials, the desired response does not require any periodicity of the particle arrangement and only the average concentration has to be controlled [14]. The volume filling fraction of the included particles is taken to be: f=4π(a^3)N/3 N is the number density of spheres particles. In this Case Continuity of electric fields components throughout the system lead to[15]: $\varepsilon_{parallel}$=N_{pl} ε_{pl}+(1-N_{pl})ε_{pl} for layered structure

$\varepsilon_{perpendicular}$=($\varepsilon_d$ ε_{pl})/(N_{pl} ε_d+(1-N_{pl}) ε_{pl}) for wired structure.

We also explain the kinetic theory and the transport properties of electrons in materials (especially metals) by the Drude model. It gives mainly the electronic equation of motion, as well as a linear relationship between the current J and the electric field E . In the Drude Model the permittivity is assumed to be a Complex number as: (the permittivity)

$$\varepsilon = \varepsilon\prime + i\varepsilon'' \qquad (1)$$

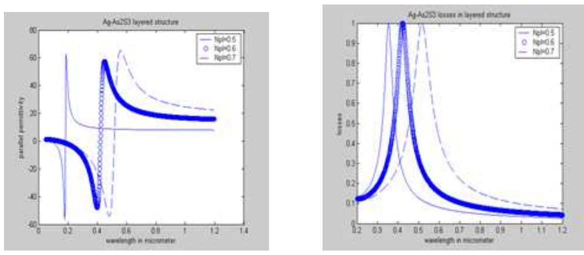

Fig. 4: a) parallel permittivity, b) losses only for Npl=0.7, the Ag-As2S3 has a negative permittivity around 500nm

The permittivity depends on the frequency oscillation of free electrons and we have:

$$\varepsilon_i(j) = (\varepsilon_\infty - \varepsilon_p^2)/((\omega(\omega + i\tau))) \qquad (2)$$

.

For the case of Ag and Al, the ε_∞ =1 and ε_p is the electrons oscillation frequency losses and permittivity in nano-plasmonic materials: layered structures

2.1 wired structures

Permittivity of a wired structure Ag-As2S3 for different N_{pl}=0.05 for the low peak curve, and N_{pl}=0.5 for the highest peak curve. The third curve is obtained for N_{pl}=0.5 and ω_p =2.5 ev (Metal-As2S3). The low oscillation frequency ω_p is used to check the metal permittivity dependence on its electron frequency oscillation.

2.2 Losses in wired structure Ag-As2S3

We report here, the study of the losses of Silver-As2S3 as function of the inclusions, the minimum peak curve is for N_{pl}=0.07, the medium peak is for N_{pl}=0.03 and the highest is for N_{pl}=0.04. The best minimum losses was found for N_{pl}=0.04. From another side, we studied the losses and permittivity in nanoplasmonic materials: layered structures for the Ag-As2S3. Hence, we investigated the permittivity and losses of Silver-As2S3 as function of the inclusions. Therefore, we observed a shift in the peaks is noticed as we increase the inclusions number. The same was observed the curve of the permittivity in layered Silver-As2S3 as function of the inclusions. A shift in the losses peaks is also noticed as we increase the inclusions number. Finally we concluded that the permittivity depends on inelastic losses process.

2.3 Towards the use of superconductor nanoparticles embedded in Chalcogenide glass

Since ω_p has a great effect on the losses, we virtually tried to use supra-conductor particles embedded in the

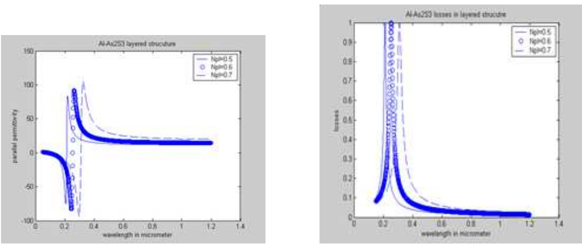

Fig. 5: : a) parallel permittivity, b) losses

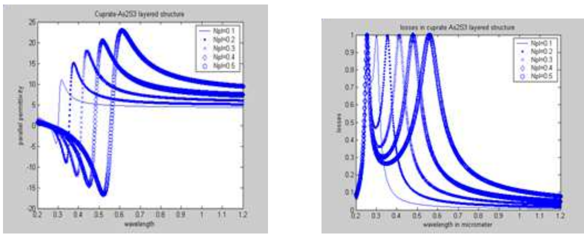

Fig. 6: Permittivity of a wired structure Ag-As2S3 for different Npl=0.05 for the low peak curve, and Npl=0.5 for the highest peak curve.

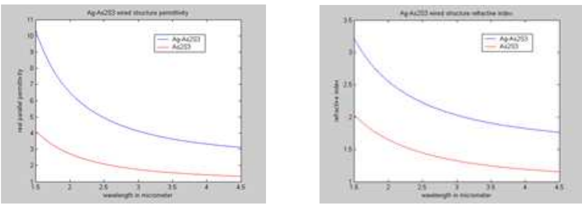

Fig. 7: losses for wired structure Ag-As2S3 for different inclusions number

chalcogenide layered structure, hence we report in the following figure the real part of the permittivity in terms of the wavelength. The different curves present the epsilon real part of a layered structure supraconductor chalcogenide NIM. From right to left ,we notice a shift in the peaks as the plasma frequency decreases. All the minimums are in the visible range. The chalcogenide glass is a good candidate to realize experimentally low losses. Based on the Maxwell Garnett Model for dielectric mixture containing conducting particles, we consider a composite medium assumed to be composed of small particles of radius $a \ll \Lambda$ and dielectric permittivity ε_i randomly embedded in another bulk medium with dielectric permittivity ε_h. A theoretical device made by interlacing plasmonic and dielectric such as Ag As2S3, Ag polymer, Ag Sio2, Al As2S3, Al polymer, Al Sio2 were studied by us and we reported the losses as well as the permittivity study for both wired and layered structure as function of different inclusions number, wavelength and as function of free electrons oscillation frequency.

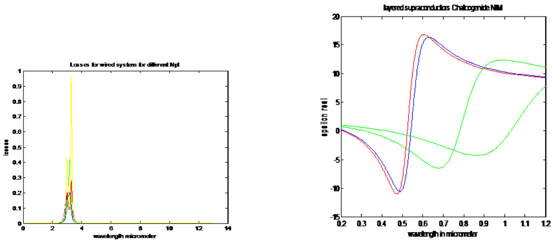

Fig. 8: The permittivity in terms of the wavelength. The different colors are used for different plasma frequencies

The curves show that in both cases wired and layered structured the negative permittivity depends on the inclusions number of the conducting particles and the frequency range. In all the cases we noticed that the plasma frequency of free electrons considered by the Drude model play the major effect in getting a negative permittivity, as low as the plasma frequency as negative as the permittivity in a more wide frequency range.

As supra conductor particles have low plasma frequency, we suggest the use of supraconductor particles embedded in chalcogenide glass for the design of non magnetic refractive index media mainly layered. The choice of Chalcogenide Glass is crucial as these materials are well known [16] by having very high non linearity, good quality and low losses. The work done by[17,18] demonstrated that supraconductor particles could theoretically be used to the design of nonmagnetic composites especially layered structures, however they are very lossy.

3 Conclusion

A theoretical study of the permittivity and the losses in non magnetic negative refractive index nanoplasmonic structures, shows that by varying concentration of inclusions it is possible to form the desirable frequency where the permittivity is negative and the losses are low. The negative permittivity propriety depends not only on the inclusion number of the particles and the frequency range but also on the oscillation frequency of free electrons in the metal. Their for we suggest the use of supraconductors nanoparticles in the design of metal dielectric structures as a very promising route to create metamaterials, mainly in ChG as they provide low losses, high quality with ultra-nonlinearity in fabrication[16].

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