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INVESTIGATION OF LIGHT PROPAGATION THROUGH HYPERBOLIC METAMATERIALS FOR HIGH REFLECTANCE CONTRAST APPLICATIONS

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Abstract:This paper is intended to give an investigation on the switchable reflection modulationprospects of silver air based hyperbolic metamaterial operating in mid-IR frequencies. By modulating its design via variation of the fill fraction, both the longitudinal and transverse permittivities when plotted versus wavelength show a decrease(increase) in their real(imaginary)parts.However the distinct pattern noted here is that the permittivity in case of longitudinal propagation exhibits a steeper change, whereas it's a flattening change with respect to wavelength,when there is anascending variation of fill fraction. Further, the reflectance modulation is obtained in the IR regime with the varying fill fraction. Also,the influence of the incidence angle on the reflectance is investigated to obtain a sharp edge filter.

Keywords: Hyperbolic metamaterial, Reflectance, Permittivity

1.INTRODUCTION

Hyperbolic metamaterials offer a versatile multi-functional platform to realizeefficient modern photonic devices, including switches, filters, absorbers, and modulators [1–6]. They are the fabricated, not naturally existing,-dielectric multilayer structures which workin the plasmonic resonant frequency and terahertz regime. With the principal component either permittivity or permeability being opposite to one another, it is the metasurfaceswhich makes them superior over the existing right handed materials, wherein they allow the manipulation of any incoming signal that comes in to contact with them. HMMs are the choice forhigh efficiency and at the same time the low-voltage requiring candidates for multifunctional infrared modulation devices. Hence researchers have shown interest in this area leading to a plethora of numerical modelling and simulation works in HMMs for tunable device applications. In this work, we demonstrate a switchable reflection modulator operating in mid-IR frequencies using hyperbolic metamaterial based on mulitlayered diluted silver with dielectric. The effect of filling fraction over the longitudinal and transverse permittivity is studied employing effective medium theory and the reflectance study is carried out employing transfer matrix approach. It is shown that the increase in the fill fraction can lead to blue shift in the reflectance. The observed features of Ag/dielectric-based multilayered hyperbolic metamaterial would be very helpful in establishing these HMMs as switchable reflection modulator with wide range of novel applications in active optoelectronic systems as a very operative / effective edge or narrow-band filter in the regime of infrared frequencies.

2.1 MODELLING AND ANALYSIS

HMM is dispersive in nature, and the effective permittivity of the HMM has been determined by utilizing a combinatorial approach of effective medium theory with Drude model [7] wherein the permittivity of the bulk layer is deduced. The multilayered HMM structures can be designed by alternating periodic arrangement of metal and dielectric. We have considered the HMM layer as diluted Ag with dielectric, and the longitudinal and transverse permittivities can be calculated by employing the effective medium theory [8]:

$$\varepsilon_{longi} = \varepsilon_m(\lambda)f + \varepsilon_d(1- \lambda)$$

$$\varepsilon_{trans}=1/(f/\varepsilon_m(\lambda)+1-f/\varepsilon_d)$$

ε_m isthe permittivity of silver metal (deduced by the Lorentz–Drude model) and εd is the permittivity of the dielectric medium. The filling factor of silver is denoted by f in unit volume.f = wm/wm +wd where wm is the metallic strip width and wd , the dielectric strip widthin nanometer. The permittivity of the metal considered here i.e., silver is obtained from Drude model as follows

$\varepsilon m = 1 - \lambda^2 \lambda_{co}^2 / \lambda_{pl}^2 (\lambda_{co} + i\lambda)$

Where $\lambda_{pl}$is the plasma wavelength and $\lambda_{co}$is the collision wavelength for silver which are 1.4541 $\times 10^{-7}$ and 17.6140 $\times 10^{-6}$respectively.The permittivity of the dielectric layer is εd=1.The permittivity tensor is nondiagonal with

$\varepsilon zz = \varepsilon_{longi} \sin 2\varphi + \varepsilon_{trans} \cos 2\varphi$

$\varepsilon xz = \varepsilon zx = (\varepsilon_{trans} - \varepsilon_{longi}) \sin\varphi\cos\varphi$.

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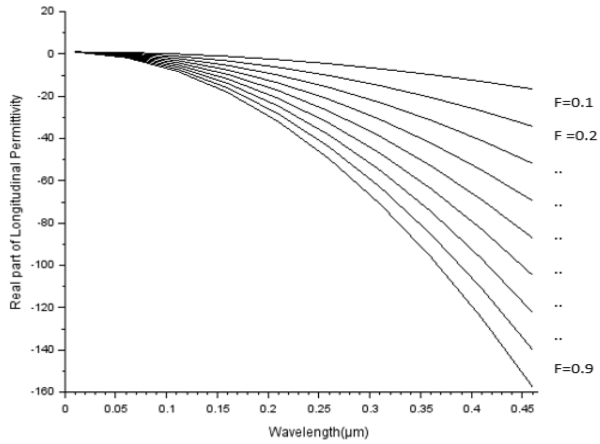


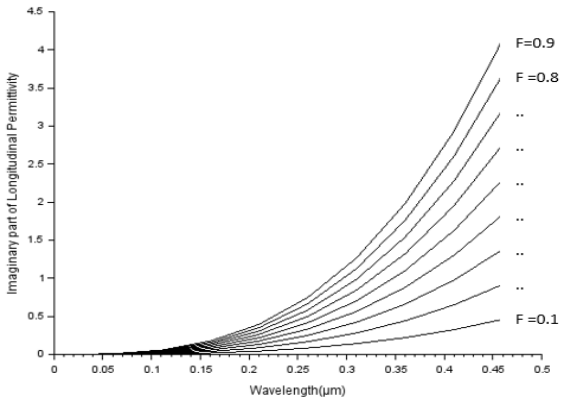
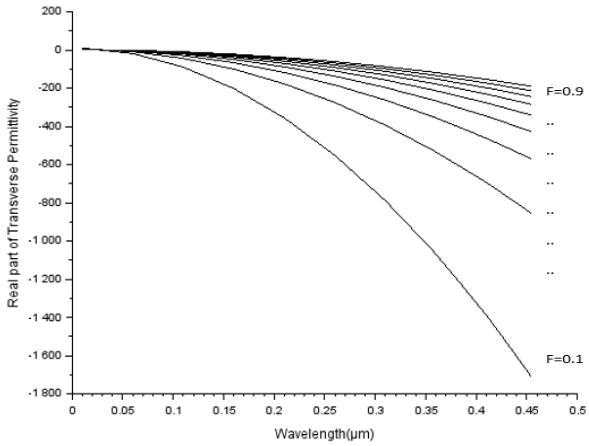


Fig.1 *Real and imaginary parts of longitudinal permittivity vs wavelength for different values of filling fraction.*

The wavelength dependence of the longitudinal and transverse permittivities are analysed for various values of fill fraction and dependence obtained using scilab codes. The permittivity both longitudinal and transverse is shown to exhibit a steep change, but the pattern is distinct. As the fill fraction is increased, a decrease(increase) seems to get steeper in the real (Imaginary) part of longitudinal permittivity. Whereas in the transverse permittivity, the increase in the fill fraction leads to the flattening of the decrease (increase) /increase in their real(imaginary)parts .Thus the ascending fill fraction leads to steeper change in longitudinal permittiviy, whereas it's a flattening one in transverse permittivity



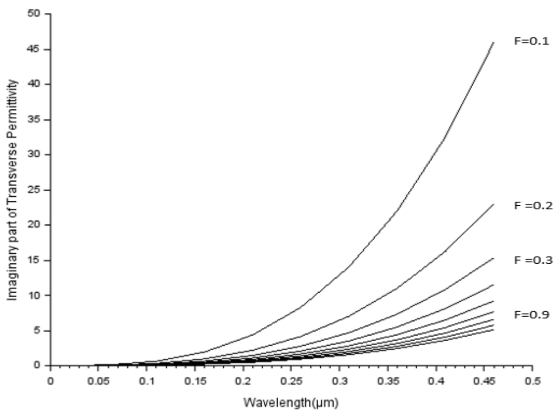


Fig.2 *Real and imaginary parts of transverse permittivity vs wavelength for different values of filling fraction.*

2.2 Transfer Matrix Approach

In our multilayered HMM made of silver and dielectric, the propagation of electromagnetic or acoustic waves could be examined with the help of transfer matrix method[9]. It is carried out by using maxwells equation for obtaining transmission coefficient. In the present study of silver air based HMMs the resultant traansfer matrix is expressed as

$$T = \begin{matrix} m11 & m12 \\ m21 & m22 \end{matrix} =$$

$$\begin{matrix} \cos(\alpha 2wHMM) & -j/q2 \sin(\alpha 2wHMM) \\ -jq2 \sin \alpha 2wHMM) & \cos(\alpha 2wHMM) \end{matrix}$$

$\alpha 1 = (\varepsilon xz(\lambda) / \varepsilon zz\lambda) * kx$

$\alpha 2=(\omega/c) * q\ (\varepsilon_{longi(}(\lambda)\varepsilon_{trans}(\lambda)\ \varepsilon zz(\lambda) - \sin^2(\theta)/\varepsilon zz(\lambda)^2$

$q2 = (\varepsilon zz(\omega)\alpha 2)/(\ \varepsilon 0\omega\varepsilon_{longi}\varepsilon_{trans})$

The reflectance is calculated from the coefficient of reflection given by

$Rp = (m11 + m12qN)q1 - (m21 + m22qN)(m11 + m12qN)q1 + (m21 + m22qN)$

Here q1 and qn are the first and nth layer of the proposed structure. The substrate is chosen as glass with refractive index ng =3.7 and upper layer as air with inbetween HMM structure of silver and dielectric .As the reflectance versus wavelength is analysed for various values of the fillfraction, it is visible that as the fill fraction is increased, implying the width of the metallic layer being increased, the reflectance shifts towards the lesser wavelength , i.e, it gets blue shifted.

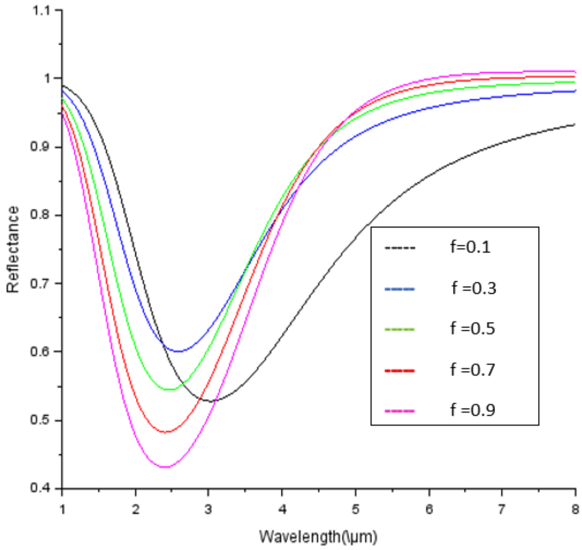


Fig.3*Reflectance plotted versus wavelength for various values of fill fraction .*

Also as the reflectance is studies for various angles of incidence, it is seen that as φ is increased the reflectance is blue shifted. Also the reflectance minimum creeps up.

3.CONCLUSION

Diluted silver with dielectric based multilayered HMMs are consideredin this work and employing a combinatorial approach with effective medium theory and transfer matrix method, a numerical simulation study of the variation of permittivity tensor and reflectance with variation of fill fraction and angle of incidence are studied. This study would be beneficial in proving the efficiency of Ag /dielectric HMMs as tunable reflection modulatorsuitable inIR frequency applications.

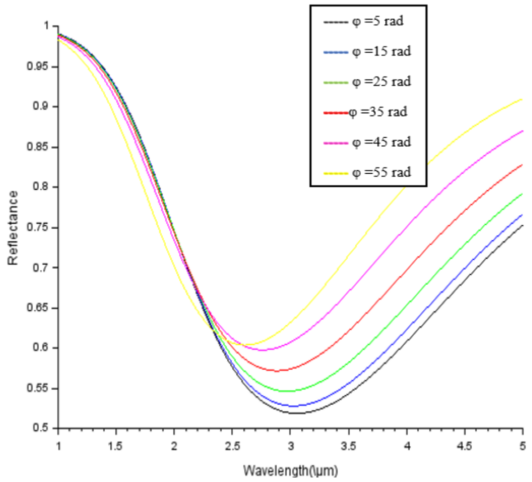


Fig.3*Reflectance plotted versus wavelength for various angles of incidence .*

REFERENCES

1. N. I. Zheludev and Y. X. Kivshar, "From metamaterials to metadevices," Nat. Mater. **11**(11), 917–924 (2012

2. I. V. Shadrivov, M. Lapine, and Y. S. Kivshar, *Nonlinear, Tunable and Active Metamaterials* (Springer Series in Materials Science, 2015).

3. R. Kowerdziej, L. Jaroszewicz, M. Olifierczuk, and J. Parka, "Experimental study on terahertz metamaterial embedded in nematic liquid crystal," Appl. Phys. Lett. **106**(9), 092905 (2015).

4. R. Kowerdziej, M. Olifierczuk, and J. Parka, "Thermally induced tunability of terahertz metamaterial by using a specially designed nematic liquid crystal mixture," Opt. Express **26**(3), 2443–2452 (2018).

5. R. Kowerdziej, T. Stańczyk, and J. Parka, "Electromagnetic simulations of tunable terahertz metamaterial infiltrated w ith highly birefringent nematic liquid crystal," Liq. Cryst. **42**(4), 430–434 (2015).

6. R. Kowerdziej, J. Parka, and J. Krupka, "Experimental study of thermally controlled metamaterial containing a liquid crystal layer at microwave frequencies," Liq. Cryst. **38**(6), 743–747 (2011).

7.K. V. Sreekanth, A. De Luca, and G. Strangi, "Negative refraction in graphene-based hyperbolic metamaterials" J Appl. Phys. 103, 064302 (2008).

8.M. A. Baqir, Ali Farmani, T. Fatima, M. R. Raza, S. F. Shaukat, and Ali Mir , "Nanoscale, tunable, and highly sensitive biosensor utilizing hyperbolic metamaterials Bibliography 43 in the near-infrared range" Appl. Opt.57,9447(2018)