granular composites. Based on the effective medium approximation, we show that by incorporating metallic magnetic nanoparticles into an appropriate insulating matrix, it may be possible to prepare a composite medium of low eddy current loss which is left-handed for electromagnetic waves propagating in some special direction and polarization in a frequency region near the ferromagnetic resonance frequency.[4,5] This composite may be easier to make on an industrial scale. In addition, its physical properties may be easily tuned by rotating the magnetization locally. The physics involved seems to be different from the original argument.[1,2] In our argument[5], the imaginary part of the dielectric constant of the metal is much larger than the real part, opposite to the original argument. In anisotropic materials so that some of the susceptibilities are negative, the criterion for LHM may not be the same as that for negative refraction.[6] Ansiotropic materials exhibit a richer manifold of anomlous behaviour[6,7,8] and offers more flexibility in apllications.[8] More recently it was found that negative refraction can occur in anisotropic materials where all the susceptibilities are positive.[9] We found that the range of applicability of this effect is much larger than originally thought.[10] S. T. Chui was supported in part by the Office of Naval Research, by the Army Research Laboratory through the Center of Composite Materials at the University of Delaware, by DARPA and by the NSF. [1] J.B.Pendry, A.J.Holden, W.J.Stewart, and I.Youngs, Phys. Rev. Lett 76, 4773 (1996). [2] V.G.Veselago, Sov. Phys. Usp. 10, 509 (1968). [3] D.R.Smith, W.J.Padilla, D.C.Vier, S.C.Nemet-Nasser, S.Schultz, Phys. Rev. Lett. 67, 3578 (2000). [4] S. T. Chui and L. B. Hu, Phys. Rev. B 65, 144407 (2002), [5] S. T. Chui, L. B. Hu and Z. F. Lin, Phys. Lett. A319, 85 (2003). [6] L. B. Hu, S. T. Chui and Z. F. Lin, Phys. Rev. B66, 085108 (2002). [7] V. Lindell and coworkers, Microwave and Opt. Tech Lett. 31, 129 (2001). [8] D. R. Smith and D. Schurig, Phys. Rev. Lett. 90, 077405-1 (2003); D. Schurig and D. R. Smith, Appl. Phys. Lett. 82, 2215 (2003). [9] Y. Zhang, B. Fluegel and A. Mascarenhas, Phys. Rev. Lett. 97, 157404, (2003). [10] Z. F. Lin and S. T. Chui, unpublished.

*Work carried out in collaboration with L. B. Hu, and Z. F. Lin.

Contributed Papers

15:06

S19 2 An $\epsilon < 0$, $\mu < 0$ structure using cladded wires within a ferrimagnetic host GRAEME DEWAR, *University of North Dakota* Structures having simultaneously negative permittivity ϵ and negative permeability μ have generated much interest because light propagating within them exhibits a negative phase velocity. A simple structure predicted to have both $\epsilon < 0$ and $\mu < 0$ can be assembled from a periodic array of conducting wires cladded with a dielectric and having the volume between the wires filled with a non-conducting ferrimagnetic material. The wire structure gives rise to $\epsilon < 0$ over a limited frequency range. The ferrimagnet has $\mu < 0$ over a frequency range which is tunable with an applied magnetic field. The dielectric cladding of the wire prevents the magnetic medium from destroying the $\epsilon < 0$ property of the wire structure. Calculations of the index of refraction for such a structure based on both an approximate and a exact solution of Maxwell's equations are described in this presentation.

15:18

S19 3 A Novel Two-Dimensional Negative Index Metamaterial Suitable for Planar Processing MARK S. WHEELER, J. STEWART AITCHISON, MOHAMMAD MOJAHEDI, *The Edward S. Rogers Sr. Department of Electrical and Computer Engineering* A new negative index metamaterial based on a two-dimensional periodic array of capacitively-loaded metallic scatterers will be described. This structure is used to create a negative effective index of refraction for one polarization of wave incident from free space. The band structure was calculated using the Finite-Difference Time-Domain method, along with the Matrix Pencil Method. A band with backward-wave behaviour was found, with an almost entirely isotropic response. The shape of the structure allows for large capacitance between elements which can be used to tune the response. Since only one structural element is required, this design is a simpler alternative to the split ring resonator and wire metamaterial. The proposed structure is easy to manufacture using planar fabrication processes.

15:30

S19 4 DIELECTRIC PHOTONIC CRYSTALS AS MEDIUM WITH NEGATIVE ELECTRIC PERMITTIVITY AND MAGNETIC PERMEABILITY* ALEXEI EFROS, *Department of Physics, University of Utah* ALEXANDER POKROVSKY, *Department of Physics, University of Utah* About 36 years ago Victor Veselago considered theoretically propagation of the electromagnetic waves in a hypothetical medium, called Left-Handed Medium (LHM) where both electric permittivity e and magnetic permeability m are negative in some frequency range. Since the speed of light $c^2 = c_0^2/\epsilon\mu$ is positive, the electromagnetic waves propagate but they have unusual properties, like negative refraction at the interface with a regular medium. This property is the most interesting because it provides a three-dimensional imaging. The origin of all the properties is opposite directions of energy flux and wave vector. San Diego group has recently observed the negative refraction in the artificial composite system and has claimed that they got a two-dimensional LHM. We show that a two-dimensional photonic crystal (PC) made from a non-magnetic dielectric is a LHM in the sense defined by Veselago. Namely, it has negative values of both the electric permittivity ϵ and the magnetic permeability μ in some frequency range. This follows from a recently proven general theorem. The negative values of ϵ and μ are found by a numerical simulation. Using these values we demonstrate the Veselago lens, a unique optical device predicted by Veselago. An approximate analytical theory is proposed to calculate the values of ϵ and μ from the PC band structure. It gives the results that are close to those obtained by the numerical simulation. The theory explains how a non-zero magnetization arises in a non-magnetic PC.

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15:42

S19 5 Left-Handed-Material-like behavior revealed by arrays of dielectric cylinders ZHEN YE, *Dept. of Physics, National Central University, Chungli, Taiwan 32054, R. O. China* CHAO-HSIEN KUO, *Dept. of Physics, National Central University, Chungli, Taiwan 32054, R.O. China* WAVE PHENOMENA LAB TEAM We investigate the electromagnetic propagation in two-dimensional photonic crystals, formed by parallel dielectric cylinders embedded a uniform medium. The transmission of electro-