Session 1P2
Electromagnetic Theory and Design on the Optical Dispersive Materials, Invisible Cloak and Photonic Crystals

A New Novel GL Isotropic Invisible Cloak without Exceeding Light Speed Wave in Outer Layer of the Double Layer Cloak

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Abstract— A more exciting breakthrough progress is that we discovered and propose a isotropic EM invisible cloak without exceeding light speed violation in this paper. The GL EM isotropic cloak is installed in outer layer of our double cloak. The GL isotropic invisible cloak in this paper and anisotropic invisible cloaks in our paper ArXiv 1050.3999 in May 2010 and paper in piers 2011 are complete new cloak and totally different from Pendry's cloak and Ulf's cloak in 2011. The dielectric and permeanbility of GL EM cloak in this paper are large than one. The refractive index of the GL cloak material, $n(r)$, is large than one or equal to one. The traditional geometry optical ray tracing method can not be used for explaining our GL isotropic and anisotropic cloak. When EM wave propagates in our GL cloak, an extensive Femate Principle is satisfied. Our GL isotropic cloak in this paper and anisotropic cloaks in ArXiv 1050.3999 in May 2010 are created from our unconventional GL EM cloak modeling and inversion that are proposed here. By searching in a distinctive class of the rational function of (h), $h = r - R_1$, the GL EM cloak modeling and inversion create GL EM isotropic invisible cloak class without exceeding light speed. The GL EM cloaks can be practicable by using conventional optical materials. The properties of our GL EM cloak and their proofs are presented by using GL modeling and inversion in this paper. The novel EM wave propagation and front branching in the GL cloak by GL EM modeling are presented in this paper. The EM wave front propagation in GL cloak is behind of the front in free space. At time steps $118dt$, in the GL cloak, the wave front is curved as a crescent like and propagates slower than the light in free space. At the time step $120dt$, the EM wave inside of the GL EM cloak propagates slower than light speed, moreover, its two crescent front peaks intersect at a front branching point. At the front branching point, the front is split to two fronts. The novel front branching and crescent like wave propagation are displayed in figures in this paper. We propose a new GL EM isotropic invisibility cloak as follows and its novel invisible properties without exceeding light speed are shown in references [1–3].

$$\varepsilon_r(r)=\mu_r(r)=\frac{R_2}{\sqrt{r-R_1}\sqrt{G_2\left(R_1,R_2,R_2-r\right)}}+\frac{4\left(R_2-2R_1\right)\sqrt{(r-R_1)}R_2}{\left(G_2\left(R_1,R_2,R_2-r\right)\right)^{\frac{3}{2}}F_2\left(R_1,R_2,(R_2-r)\right)}, \quad (1)$$

where

$$\begin{aligned} G_2(R_1,R_2,R_2-r) &= 3R_2-4R_1+\sqrt{R_2^2+16(R_2-R_1)(R_2-r)-8R_2(R_2-r)}, \\ F_2(R_1,R_2,R_2-r) &= \sqrt{R_2^2+16(R_2-R_1)(R_2-r)-8R_2(R_2-r)}, \end{aligned} \quad (2)$$

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Lossy Gradient Index Metamaterial with General Periodic Permeability and Permittivity: The Case of Constant Impedance throughout the Structure

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Abstract— We utilize an exact analytical approach to investigate the electromagnetic wave propagation across an infinite metamaterial composite with general periodic gradient effective permittivity and permeability. A remarkably simple direct solution for the field distribution is obtained for an arbitrary periodic variation of complex refractive index across the structure. The calculation is done for the case of constant impedance across the structure. Arbitrary temporal dispersion and losses are allowed and the model is generally applicable to inhomogeneous and anisotropic media simultaneously containing positive and negative refractive index constituents as long as the effective medium approximation is valid.

Electromagnetic metamaterials (MM) are a new paradigm in electromagnetics and (nano) plasmonics. They may be defined as artificial composites with electromagnetic properties not readily found in nature. A special class of MMs are the negative refractive index metamaterials (NRM or NIM), also known as the left-handed materials (LHM). LHM are typically produced using subwavelength "particles" or "atoms" with negative effective relative permittivity and permeability as their structural units. The novel and often counter-intuitive properties of the LHM, which include negative index of refraction (and, hence, negative phase velocity), inverse Doppler effect, radiation tension instead of pressure, etc. resulted in numerous proposed applications. These include superlenses and hyperlenses that enable imaging far below the diffraction limit, resonant cavities and waveguides with geometrical dimensions even orders of magnitude smaller than the operating wavelength, as well as invisibility cloaks and transformation optics.

A majority of cases considers structures with constant refractive index within the MM structure and abrupt interfaces with the surrounding positive index material ("right-handed" media, RHM). There is however a practical interest for metamaterials with spatially varying refractive index and with gradual transition from the RHM to LHM and vice versa, since many real-world applications would benefit from such structures. Graded refractive index is interesting for transformation optics and hyperlenses, and a class of the invisibility cloaks using spherically graded MM has been described. Various other proposed applications of graded metamaterials include beam shaping and directing, enhancement of nonlinear effects, superlenses, etc..

As far as the authors are informed, the first papers dedicated to gradient refractive index LHM were published in 2005. Exact analytical approaches to some special cases of graded index metamaterial structures have been developed by the present authors in a number of papers, and are of special interest, since they ensures fast, simple and direct route to the determination of the field distribution and the calculation of the scattering parameters within such materials. In this paper, we present an exact analytical solution of Helmholtz equation for the propagation of electromagnetic waves through a lossy gradient metamaterial structure with an arbitrary periodic permeability and permittivity for the case of constant impedance throughout the structure. We illustrate the obtained general results by considering a few special cases including the case of constant material parameters and abrupt transitions.

Monolithic Silicon-based Gauss to J_0-Bessel-Gauss Beam Converter

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Abstract— We report on the first Si-based graded refractive index structure to realize conversion of Gaussian beams to J_0-Bessel-Gauss beams. Production of near-Bessel beams has been explored in recent years by different techniques like holograms, phase elements and plasmons (1; 2; 3). Although these methods yielded high quality beams they are potentially complicated when integrated with other photonic integrated circuits (PICs) elements. Hence, the need for an integrated and compatible solution to realize on-chip conversions of beam profiles. In our work we explore a theoretical device in which the refractive index profile and dimensions were tailored to produce silicon technology compatible near Bessel beam converter. Our device consists of a rectangular Si slab, width (w) and length (l) of 20 μm and 200 μm, respectively. The refractive index is tailored in both directions ranging from 1 (air) to 3.5 (Silicon) in controllable steps. To solve the inverse problem we implemented a hybrid technique based on transformation optics and variational methods. Two-dimensional Beam Propagation method (2D-BPM) was used to simulate the beam characteristics in the device. The near and far field studies showed that the proposed device transform an impinging Gauss beam with spot size of 10 μm into a J_0-Bessel-Gauss beam after 200 μm transmission, with 5% loss and a beam divergence of 2%. An optimization of the refractive index profile yielded a J_0-Bessel-Gauss beam coupling into a 0.5 μm wide waveguide with $n = 2.5$ at a coupling loss of 1%. Such self-healing beam, where the beam stays undisturbed after passing through nanoscopic objects, may be potentially useful in photonic-based microfluidic applications. Additionally, our technique can be extended to produce other non-linear beams. Further details will be presented in the final manuscript.

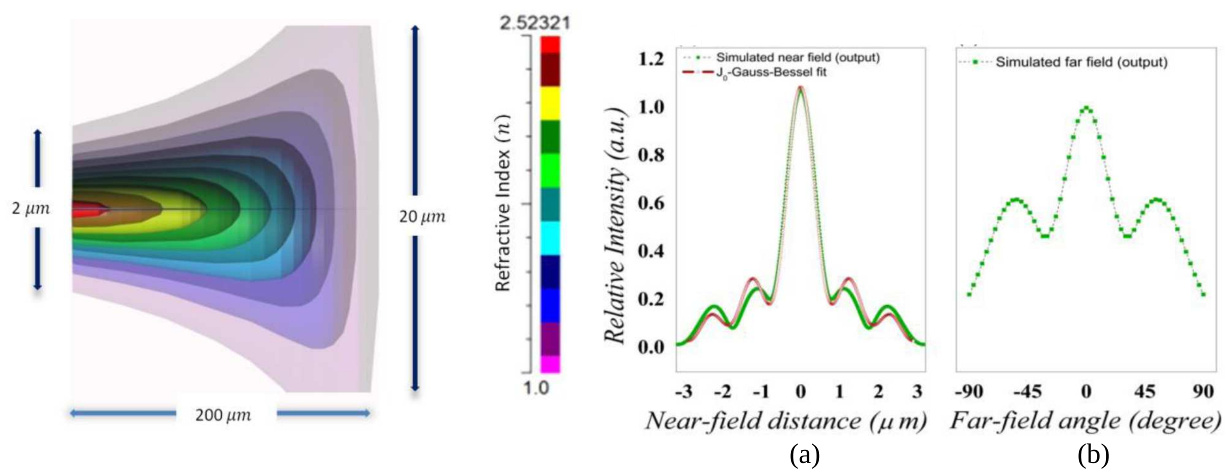

Figure 1: Proposed slab convertor structure (left), the device has 11 controllable refractive index steps. (a) The resulting beam (right) after a propagation of is a Bessel-Gauss beam, (b) the far-field profile is also of the Bessel-Gauss form.

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A New Tunable Metamaterial Using Low-loss Ferrofluid and Its Application on Lens Antenna

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Abstract— We present a new kind of tunable metamaterial using a low-loss ferrofluid, which is well suited for RF and microwave device applications. The ferrofluid is prepared by homogeneously dispersing magnetite (Fe_3O_4) nanoparticles in a low-loss mixture of organic solvents at microwave frequencies such as N, N-Dimethyl aniline, acetonitrile and benzene. Continuously tunable permittivity of the matrix can be achieved by controlling the concentration of different liquid components in the mixture. The impedance matching with free space and the loss tangent is substantially improved by the monodispersion of the magnetic nanoparticles with diameters between 10 and 20 nm. By using a dielectric probe kit and a network analyzer, the permittivity of the ferrofluid was retrieved in the range of 8 and 12 GHz. The measured data revealed a tunable range of permittivities from 2.3 to 25.8 with a loss tangent of 0.01 to 0.02 and an optimal relative characteristic impedance of 1.4. Based on the ferrofluid presented above, a low-loss lens antenna with a spacial refractive index distribution was designed to realize the tunable radiation angle of microwave beams.

Fabrication of Gradient index 3D Photonic Crystals Structure in Metamaterial

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Abstract— A broadband and low-loss graded index (GRIN) 3D photonic crystals (PCs) structure in the metamaterial regime is proposed in the present research. The 3D isofrequency contours are approximately spherical in long-wavelength limit, which leads to nearly isotropic electromagnetic properties. By gradually varying the constitutive parameters of the PCs, the complex spatial distribution of the refractive index profile desgined for controlling electromagnetic fields can be fulfilled.

A carpetcloak and a 3D omnidirectional electromagnetic absorber (elctromagnetic blackhole), which employed the GRIN 3D PCs structure operating in the metamaterial regime were fabricated by stereolithography using photocurable resin. The nonresonant property of the sub-wavelength PCs unit cell resulted in a very broad bandwith and relatively low loss. Their eletromagnetic properties were stuied experimentally both in 2D and 3D cases, and agreed well with the simulation results, demonstrating a low-cost and rapid manufacturing method for the realization of pratical cloak and 3D "elctromagnetic blackhole".

Azimuthal Directive Emission Realized by Transformation Optics Concept

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Abstract— Transformation optics is a mathematical tool that consists in generating a new transformed space from an initial one where solutions of Maxwell's equations are known. It offers an unconventional strategy to the design of novel class metamaterial devices, such as invisibility cloaks [1–3], waveguides transition and bends [4–8], Luneberg lenses [9] and ultra-directive antennas [10–12]. Using the idea of wave manipulation through transformation optics, we demonstrate numerically and experimentally a way to create an azimuthal directive emission from quasi omnidirectional sources such as microstrip patch antennas or monopoles. The manipulation is enabled by composite metamaterials that realize a space coordinate transformation in the radiation zone of the latter source. It is shown that a plane source radiating in the elevation plane can be transformed into an azimuthal radiative element by modifying the electromagnetic properties of the space around it. For a physical prototype fabrication, we have simplified the calculated material parameters through a parameter reduction procedure. The relevant electromagnetic parameters found are therefore μ_{zz}, $\varepsilon_{\theta\theta}$ and ε_{rr}. We maintained $\varepsilon_{\theta\theta}$ and μ_{zz} constant and hence the new set of coordinates is as follows:

$$\begin{cases} \varepsilon_{rr} = \left(\frac{1}{br}\right)^2 \div 1.7 \\ \varepsilon_{\theta\theta} = 2.8 \\ \mu_{zz} = 1.7 \end{cases}$$

The fabricated prototype is then composed of 30 identical layers where each layer is divided in 10 unit cells. The cells are composed of respectively SRRs [13] and ELCs [14] to secure μ_{zz} and ε_{rr}. $\varepsilon_{\theta\theta}$ is produced by a host medium, which is a commercially available resin. Near-field cartography and far-field pattern measurements performed on the fabricated prototype agree qualitatively with Finite Element Method (FEM) simulations. The results obtained confirm the bending of electromagnetic waves to create the azimuthal emission. This idea can find various applications in novel antenna design techniques for aeronautical and transport domains.

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Quasi-perfect Isotropic Emission Realized by Coordinate Transformation

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Abstract— Transformation optics is a mathematical tool that consists in generating a new transformed space from an initial one where solutions of Maxwell's equations are known. It offers an unconventional strategy to the design of novel class metamaterial devices, such as invisibility cloaks [1–3], waveguides transition and bends [4–8], Luneberg lenses [9] and ultra-directive antennas [10–12]. Using the idea of wave manipulation via transformation optics, we propose a way to create a quasi-perfect isotropic emission from a directional one. The manipulation is enabled by composite metamaterials that correspond to a space stretching around the source. The expansion procedure is further followed by a compression so as to secure a good impedance matching with free space. It is shown that the directive radiation of a plane source larger than the operating wavelength can be transformed into an isotropic one by modifying the electromagnetic properties of the space around it. A set of parameters allowing practical realization of the proposed device is defined. At the center of the transformed space, ε and μ present very low values ($\ll 1$). Consequently, light velocity and the corresponding wavelength are much higher than in vacuum. The width of the plane source then appears very small compared to wavelength and the source can then be regarded as a radiating wire, which is in fact an isotropic source. Numerical simulations using Finite Element Method (FEM) are performed to illustrate the proposed coordinate transformation. This idea, which consists in strongly reducing the apparent size of a radiating source, can find various applications in novel antenna design techniques.

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High Energy Particals and Nanostructures Physics

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Abstract— Demands for the continuous increase in the data storage density bring the challenge to overcome physical limits for currently used magnetic recording media. Magnetic nano structures are subjects of growing interest because of their potential applications in high density magnetic recording media and their original magnetic properties. Over the past several decades, amorphous and more recently nano-crystalline materials have been investigated for applications in magnetic devices. The benefits found in the nano-crystalline alloys is from their chemical and structural variations on a nano-scale which are important for developing optimal magnetic devices with high properties.

Research on Potential Use of Nanomaterials and Properties in Astrophysics

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Abstract— When the physical dimensions of a system become comparable to the interatomic spacing, strong modifications of the intrinsic magnetic properties (ordering temperature, magnetic anisotropy, spontaneous magnetization) are expected. Micromagnetic modeling of the behavior of a nanostructured film beautifully describes the magnetization process, but requires a high calculational effort and long computation times. Furthermore, it is difficult to predict changes of the macroscopic physical behaviour due to variation of parameters. Phenomenological models, on the other hand, are very useful to simulate the behaviour of the magnetic material under the influence of varying parameters, especially when the parameters are based on physical constants.

Nano Particle Thermal Stability and Natural Subnanostructures

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Abstract— Magnetic nano particle thermal stability calculation is essential for development of patterned ultra high magnetic storage media. The use of reliable model (like: Energetic Model (EM) in the predication of non linear ferromagnetic materials properties, wich may depend also on direction and history of magnetization) is very important. EM simulation of hysteresis opens a very big opportunities to calculate values of parameters which we then use directly for interpretation of the stability condition of stored information on a nano magnetic structure. The main idea behind that is to change the direction of the applied field H and then see the stability conditions on a given nano bit volume. The value of the fBS depends strongly on Ku and the volume of the nano structure which holds the stored magnetic information (a what socalled nano bit or nano dot). Research and development teams in companies implementing nano-technology are gaining more and more importance in the field of sensor systems and material science.