Negative refraction, perfect lenses, invisibility and metamaterials. The state after twelve years

Manuel Nieto-Vesperinas
Instituto de Ciencia de Materiales de Madrid, C.S.I.C.

http://www.icmm.csic.es/MNV/

November 27, 2012
Using tiny wires and fishnet structures, researchers at the University of California, Berkeley, have found new ways to bend light backward, something that never occurs in nature.

This technology could lead to microscopes able to peer more deeply and clearly into living cells. And the same kind of structures might one day be adapted to bend light in other unnatural ways, creating a Harry Potter-like invisibility cloak.
METAMATERIAL CONCEPT:

Harnessing light:

Take advantage of new techniques to growing and ensembling micro and nano-structures to play with electromagnetic waves and light, their wavefronts and directions of propagation by introducing appropriate geometry on propagation = built in convenient variations of macroscopic constitutive parameters $\varepsilon$ and $\mu$.

-Artificial dielectrics, (W.E. Kock, 1948), radar, microwaves.
Examples of metamaterials. Left: giant gyrotropic power. Right: slow light

Zheludev et al.


Dielectric
d= 1.5 mm

Copper film thickness: 35 µm
W= 0.4 mm
L= 53 mm
4.5–7.0 GHz (λ = 4.3–6.7 cm).
**Title:** Fundamentals of Nanoscale and Emergent Effects and Engineered Devices

**Description:** The Fundamentals of Nanoscale and Emergent Effects and Engineered Devices program seeks to understand and exploit physical phenomena for developing more efficient and powerful devices. This includes developing devices and structures to enable controllable photonic devices at multiple wavelengths, engineering palladium microstructures with large deuterium loadings to study absorption thermodynamics and effects, enabling real-time detection as well as analysis of signals and molecules and origin of emergent behavior in correlated electron devices, and developing stabilization and scale-up methods to fabricate high pressure crystal structures at low pressures. Arrays of engineered nanoscale devices will result in an order of magnitude (10 to 100 times) reduction in the time required for analysis and identification of known and unknown (engineered) molecules. This program will develop novel nanomaterials for exquisitely precise purification of materials, enabling such diverse applications as oxygen generation and desalination, ultra-high sensitivity magnetic sensors, and correlated electron effects such as superconductivity. This program will compare the phenomenology of various biological, physical and social systems and abstract the common features that are responsible for their properties of self-organization, emergent behavior, and physical intelligence.

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<td>16.745</td>
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**Title:** Nanoscale/Bio-inspired and MetaMaterials

**Description:** The research in this thrust area exploits advances in nanoscale and bio-inspired materials, including computationally based materials science, in order to develop unique microstructures and material properties. This area also includes efforts to develop the underlying physics for the behavior of materials whose properties have been engineered at the nanoscale level (metamaterials) and materials exhibiting a permanent electric charge (charged matter).

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**UNCLASSIFIED**

Exhibit R-2, RDT&E Budget Item Justification: PB 2013 Defense Advanced Research Projects Agency

**DATE:** February 2012

**APPROPRIATION/BUDGET ACTIVITY**
0400: Research, Development, Test & Evaluation, Defense-Wide
BA 2: Applied Research

**R-1 ITEM NOMENCLATURE**
PE 0602115E: BIOMEDICAL TECHNOLOGY

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**C. Accomplishments/Planned Programs ($ in Millions)**

<p>| Title: Autonomous Diagnostics to Enable Prevention and Therapeutics (ADEPT)* |
|---------------------------------|-------|-------|-------|
| Description: *Previously funded in Synthetic Biology in PE 0601101E, Project TRS-01 |
| The overarching goal of the Autonomous Diagnostics to Enable Prevention and Therapeutics (ADEPT) program is to increase our ability to rapidly respond to a disease or threat and improve individual readiness and total force health protection by providing centralized laboratory capabilities at non-tertiary care settings. ADEPT will focus on the development of Ribonucleic Acid (RNA)-based vaccines, potentially eliminating the time and labor required for traditional manufacture of a vaccine while at the same time improving efficacy. ADEPT will also focus on advanced development of key elements for simple-to-operate diagnostic devices. A companion basic research effort is budgeted in PE 0601117E, Project MED-01. |</p>
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**FY 2012 Plans:**

PE 0602115E: BIOMEDICAL TECHNOLOGY
Defense Advanced Research Projects Agency

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**Unclassified**

Page 3 of 11

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Exhibit R-2A, RDT&E Project Justification: PB 2013 Defense Advanced Research Projects Agency

**DATE:** February 2012

**APPROPRIATION/BUDGET ACTIVITY**
0400: Research, Development, Test & Evaluation, Defense-Wide
BA 2: Applied Research

**R-1 ITEM NOMENCLATURE**
PE 0602702E: TACTICAL TECHNOLOGY

**PROJECT**
TT-03: NAVAL WARFARE TECHNOLOGY

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**Title: Tactically Expandable Maritime Platform (TEMP)**

**Description:** The Tactically Expandable Maritime Platform (TEMP) concept, an outgrowth of the ACTUV program, seeks to develop and demonstrate macroscopic integrated systems built up from International Organization for Standardization (ISO) modular technologies that can be operated from unmodified commercial container ships and deliver credible naval capability for high priority missions. TEMP will develop critical enabling modular technologies and evaluate the feasible range of naval missions that can be serviced from this highly flexible and cost effective unconventional force structure model. An initial mission to be explored will be the modular sea depot concept to enable a remote unmanned refueling capability for small craft; enabling independent operation from host ships. TEMP will also evaluate a Humanitarian Assistance and Disaster Relief (HA/DR) mission, engineering a modular first responder capability that allows the rapid force closure capability of TEMP to deliver immediate lifesaving operations in the hours and days following a disaster event, prior to the time that conventional platforms and organizations are able to respond.

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**DARPA**

http://www.google.es/url?
sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CCEQFjAA&url=http%3A%2F%2Fwww.darpa.mil%2FWorkArea%2FDownloadAsset.aspx%3Fid%3D2147484865&ei=mCGpUILoIpSRhQfq5YCoAQ&usg=AFQjCNF5FYEcO9HPUxK1Hsr1vV-q1kmmPQ&sig2=SRjD_3xqh7UKS64SHnd-Zw
Re $\varepsilon < 0$, Re $\mu < 0$, $n = \sqrt{\varepsilon \mu} < 0$

$\text{Rot } E = -(1/c) \partial B / \partial t$

$k \times E = (\omega/c) \mu H$

$\text{Rot } H = (1/c) \partial D / \partial t$

$k \times H = - (\omega/c) \varepsilon E$

Energy flow:

$S = (c/4\pi) E \times H$

Ordinary medium

Left-handed material (LHM)
Negative refraction:

Other phenomena:
Reversal of Cerenkov and Doppler effects.
Reversal of radiation pressure (still controversial)
Some ancestors...:

Mandel'shtam L I Zh. Eksp. Teor. Fiz. 15 475 (1945)

the group velocity of the wave packet

\[ v_g = \frac{d\omega(k)}{dk} = \frac{k}{k} \frac{d\omega(k)}{dk} \]

is codirected with either \( k \) or \( -k \), depending on the sign of \( d\omega(k)/dk \).
Phase conjugation of a plane electromagnetic wave at an interface

M. NIETO-VESPERINAS

Department of Physics and Astronomy and The Institute of Optics,
The University of Rochester, Rochester, New York 14627, U.S.A.

Rediscovered by:
- S. Maslovski, S. Tretyakov,
- J. B. Pendry, et al.
  Time Reversal and Negative Refraction
  Science 322, 71 (2008)

Figure 2. Comparison of ordinary (dashed arrows) and phase-conjugate (continuous arrows) reflection and refraction.
Magnetism from Conductors and Enhanced Nonlinear Phenomena

J. B. Pendry, A. J. Holden, D. J. Robbins, and W. J. Stewart, Member, IEEE
The new idea (with permission of antennists):

- Magnetism induced by an incident electromagnetic wave, or light, in the elements ("meta-atoms") of a fabricated composite material.

- Seek behavior of the composite as an EFFECTIVE CONTINUOUS medium at the excitation frequencies.
Condition for $\text{Re} \mu < 0$:

Near resonant frequency $\omega_{\text{res}}$

Incident wavelength $\lambda = 30$ mm

Unit cell $a = 5$ mm

Estimated effective refractive index $n_{\text{eff}} = -2.7$

Effective wavelength $\lambda_{\text{eff}} = 11$ mm

Effective medium??

Composite Medium with Simultaneously Negative Permeability and Permittivity

Department of Physics, University of California, San Diego, 9500 Gilman Drive, La Jolla, California 92093-0319
(Received 2 December 1999)

Experimental Verification of a Negative Index of Refraction

R. A. Shelby, D. R. Smith, S. Schultz

5165 citas   Google scholar

-METAL-LIKE LOSSES

-NO CONTINUOUS MEDIUM
The logic of quantum mechanics
Author(s): Birkhoff, G; von Neumann, J
Source: ANNALS OF MATHEMATICS
Volume: 37
Pages: 823-843
DOI: 10.2307/196862
Published: 1936
Times Cited: 762 (from Web of Science)
A terrific application of LHMs?


(evanescent wave amplification, and hence, recovery with unlimited detail).
Negative Refraction Makes a Perfect Lens

J. B. Pendry
Condensed Matter Theory Group, The Blackett Laboratory, Imperial College, London SW7 2BZ, United Kingdom
(Received 25 April 2000)

-Involves infinite energy.

-Only physical with absorption. But then, far from “perfect”.

6510 citas
Predicciones de Thomson Reuters para los Premios Nobel de 2012

http://francisthemulenews.wordpress.com/2012/09/22/predicciones-de-thomson-reuters-para-los-premios-nobel-de-2012/

http://sciencewatch.com/

HALL OF CITATION LAUREATES

Sir John B. Pendry
FRS, Professor of Theoretical Solid State Physics and Head of the Condensed Matter Theory Group, Imperial College of Science and Technology, London, UK

David R. Smith
William Bevan Professor of Electrical and Computer Engineering and Director of the Center for Metamaterial and Integrated Plasmonics, Duke University, Durham, NC, USA
PROBLEMS AND PATHOLOGIES:


...explica Katie Pennicott, directora del servicio de noticias Physics Web... Sin embargo, el científico británico John Pendry, del Imperial College, mantiene sus simulaciones, que indican que se puede producir refracción *negativa* en delgadas láminas de plata... Afirma que... G. y N-V... hicieron mal los cálculos...
But "perfect lens" negated by Veselago himself


Heat and Light
Does negative refraction really exist?
Here evanescent component:

\[ \exp[|k_z|(z-z_0)] \]

THE "PERFECT LENS":

ANALOGIC INVERSE DIFFRACTION FILTER
Resolution of image:

\[ \Delta y = \frac{\pi}{k_y^{(c)}} \]

I.e., absorption \( n_2 \) as small as:

\[ n_2 < 2 \exp[-4\pi (z_0/\lambda) \sqrt{s_c^2 - 1}] \]

\[ k_y^{(c)} = k_0 s_c \]


Logarithmic dependence.
Requires exponential decrease in data uncertainty to obtain linear increase in resolution

Ultimately, why is the performance of the SLAB SUPERLENS so sensitive to absorption?

(M.N-V., unpublished)
Transport of Information

\[ \Delta \Omega = \cos \theta \sin \theta \Delta \theta \Delta \phi = \Delta \rho \Delta q \]

\[ W = \Delta x \Delta y \]


G. Toraldo di Francia, *JOSA*, 1969

**Shannon number of degrees of freedom:**

Invariant at any plane \( z = \text{const} \) of propagation

\[ \mathcal{N} = \frac{W \Delta \rho \Delta q}{\lambda^2} = \frac{W \Delta \Omega}{\lambda^2} \]

**Huygens’ principle**
The “perfect lens” is an analogic inverse propagator: (Signal recovery after propagation as an inverse problem)

\[ U = \mathbf{K} f \]

\[ \lambda_n \varphi_n = \mathbf{K} \varphi_n \]

\[ U = \sum_{n=0}^{\infty} g_n \varphi_n \]

\[ f = \sum_{n=0}^{\infty} f_n \varphi_n \]

\[ g_n = f_n \lambda_n \]

\[ \tilde{f} = [\mathbf{K}^\dagger \mathbf{K} + \mu \mathbf{L}^\dagger \mathbf{L}]^{-1} \mathbf{K}^\dagger U \]

\[ \| U - \mathbf{K} \tilde{f} \| \leq \varepsilon \]

\[ \delta = \| \tilde{f} - f \| \quad \delta \sim \ln \varepsilon^{-1} \]

\[ \tilde{f}_n = \frac{\lambda_n}{\lambda_n^2 + \mu \beta_n^2} g_n \]

This implies that in order to get an error of \( \delta \sim c^{-1} \) as low as \( \varepsilon \sim \exp(-c) \) is required
That the diffraction limit is not a fundamentally unbreakable one can also be seen from a purely formal standpoint. The Fourier transform of a finite twodimensional source is an analytic function of the spatial frequencies $k_x$, $k_y$ and, if this function is given in any finite region of the $k_x k_y$ plane, it can be determined over the entire plane. In particular, there is no upper limit to the spatial frequencies at which this function can, in principle, be determined and, therefore, no limit, in principle, to resolution.
There are two basic theorems:

-The Divine Theorem: Analyticity allows data extrapolation.

-The Diabolic Theorem: Extrapolation is highly unstable.


In developing active gain-assisted metamaterials, the main goal is the compensation of losses that dampen the coupled oscillations of electrons and light (known as plasmons) in the nanostructures. These losses render photonic negative-index media useless. One solution is to combine metamaterials with electrically and optically pumped gain media such as semiconductor quantum dots (2), semiconductor quantum wells, and organic dyes (3) embedded into the metal nanostructures.
Perfect imaging without negative refraction

Ulf Leonhardt
School of Physics and Astronomy, University of St Andrews, North Haugh, St Andrews KY16 9SS, UK
E-mail: ulf@st-andrews.ac.uk

Figure 3. Fish-eye mirror. (A) A mirror at the Equator of the sphere creates the illusion that light rays, shown in red, perform complete great circles, whereas in reality they are reflected. Picture (B) shows light rays emitted from one point on the plane in the stereographic projection performed by Maxwell's fish eye. The reflected rays from an arbitrary point all meet at the corresponding image point.
It is true that perfect imaging with positive refraction is hotly debated—just have a look at the December 1st News and Views Forum of Nature—but so was negative refraction itself around 2002. This debate is mostly a fair, healthy scientific discussion that has helped clarify the issues. I learned a lot from replying to comments or even to comments on replies to comments. I am most grateful to my colleagues for taking the trouble of causing trouble. This is all in the interest of science. However, partly there are also nonscientific arguments caused by vested interests. Much money was invested on negative refraction with little return. So, ironically, the most vicious are those who have experienced the debate on negative refraction first hand. They ought to know that in the long run science always wins.

Ulf Leonhardt
University of St Andrews, U.K.
A distinguished professor of electromagnetics and antenna theory with a radical viewpoint:

Science has always been plagued by occasional hype or misdirected work, witness the N-ray of a previous century that purported to image soft tissues. Unsupported science has appeared in force in recent years in the area

APPENDIX A
The Paper Rejected in 2003

“On Negative $\mu_1$ and $\varepsilon_1$: Fact and Fiction.”
APPENDIX D
Can Negative Refraction Be Observed Using a Wedge of Lossy Material?

D.1 INTRODUCTION

Throughout this book we have steadfastly claimed that a negative index of refraction does not seem possible. However, a recent paper by Sanz et al. [1] showed that a glass wedge with loss but without negative parameters could produce negative refraction at 320 nm. García and Nieto-Vesperinas [2] showed analytically that below negative index media (NIM) lattice, cutoff $\epsilon$ is imaginary and losses dominate. These papers inspired R. C. Hansen to investigate the possibility of a negative index of refraction at microwave frequencies [3]. He exposed a dielectric wedge of very lossy material to an incident field produced by a linear array of isotropic line sources parallel to the wedge edge and spaced $\lambda/4$ to avoid grating lobe complications. Calculation of the field transmitted seems to indicate that a negative index of refraction is possible.

The purpose of this appendix is to show that significant fields in the negative sector can indeed be obtained using a wedge of very lossy material. However, as we show, it is not caused by negative refraction but probably by a broadening of the beam transmitted. We start our investigation by reviewing certain fundamentals.


Using tiny wires and fishnet structures, researchers at the University of California, Berkeley, have found new ways to bend light backward, something that never occurs in nature.

This technology could lead to microscopes able to peer more deeply and clearly into living cells. And the same kind of structures might one day be adapted to bend light in other unnatural ways, creating a Harry Potter-like invisibility cloak.
Three-dimensional optical metamaterial with a negative refractive index

Jason Valentine¹*, Shuang Zhang¹*, Thomas Zentgraf¹*, Erick Ulin-Avila¹, Dentcho A. Genov¹, Guy Bartal¹ & Xiang Zhang¹,²

Figure 1 | Diagram and SEM image of fabricated fishnet structure. a, Diagram of the 21-layer fishnet structure with a unit cell of \( p = 860 \) nm, \( a = 565 \) nm and \( b = 265 \) nm. b, SEM image of the 21-layer fishnet structure with the side etched, showing the cross-section. The structure consists of alternating layers of 30 nm silver (Ag) and 50 nm magnesium fluoride (MgF₂), and the dimensions of the structure correspond to the diagram in a. The inset shows a cross-section of the pattern taken at a 45° angle. The sidewall angle is 4.3° and was found to have a minor effect on the transmittance curve according to simulation.
Sample:
10 functional layers of 80 nm each.
Total thickness of sample at transmittance peak: 20 $\lambda$.

Figure of merit:
$-\text{Re}(n)/|\text{Im}(n)|$
Transformation optics

New coordinates in terms of the old:

\[ u(x, y, z), \ v(x, y, z), \ w(x, y, z) \]

\[ \tilde{\varepsilon}_{uu} = \varepsilon_{uu} \frac{Q_u Q_v Q_w}{Q_u^2}, \quad \tilde{\mu}_{uu} = \mu_{uu} \frac{Q_u Q_v Q_w}{Q_u^2} \]

\[ Q_u^2 = \left( \frac{\partial x}{\partial u} \right)^2 + \left( \frac{\partial y}{\partial u} \right)^2 + \left( \frac{\partial z}{\partial u} \right)^2 \]

Euclidean metrics
Free space

Riemann metrics
Metamaterial space
Metamaterial Electromagnetic Cloak at Microwave Frequencies


1Department of Electrical and Computer Engineering, Duke University, Box 90291, Durham, NC 27708, USA. 2Department of Physics, The Blackett Laboratory, Imperial College, London SW7 2AZ, UK. 3SensorMetrix, San Diego, CA, USA.

*To whom correspondence should be addressed. E-mail: drsmith@ee.duke.edu

Eikonal approximation for design
Metamateriales y nanotecnología: el camino hacia la invisibilidad

MIGUEL ÁNGEL CAMPOS 2012-11-06
But research findings over the past decade have shown us how to develop artificially structured “metamaterials” — in which tiny electrical circuits serve as the building blocks in much the same way that atoms and molecules provide the structure of natural substances. By changing the geometry and other parameters of those circuits, we can give these materials properties beyond what nature offers, letting us simultaneously manipulate both the electric and magnetic aspects of light in striking harmony.

This year, with one such metamaterial, we built the world’s first invisibility cloak capable of managing both components of light.

A full-parameter unidirectional metamaterial cloak for microwaves
Nathan Landy & David R. Smith

Published online 11 November 2012
The price of the carpet transformation is that an object can be effectively cloaked only for a narrow range of observation angles about the axis of the transformation.
Measured electric field data for free space, the cloak and a copper cylinder at the optimum cloaking frequency of 10.2 GHz.
7. Conclusions

In conclusion, we have discussed how non-local response is required for true cloaking of a volume. In “quasi-cloaking”, where the sources depend only on local values of the wave, the cloaking can be detected through the distorted transmission of a pulse of length comparable to or shorter than the volume (or by another signal of similar bandwidth). Because materials all have local response, no “invisible paint” is possible for true, causal cloaking. Even quasi-cloaking does, however, apparently give good invisibility to reflective probing.

We have shown how to achieve true cloaking based on wave measurement, giving a general formula, applicable in principle for any kind of linear wave, for how the necessary surface sources should be calculated. We have verified the concept with fully causal simulations for scalar waves. Cloaking for slowly propagating (e.g., acoustic) classical waves has no problems in principle, though cloaking for broad-band electromagnetic waves in a vacuum is challenging because there is little or no additional time available for any calculations or extra propagation. We have discussed also how any schemes that rely on measurement or that have to make up for losses should be detectable with a quantum transmission probe.
Negative refraction with photonic crystals


- Superlensing with photonic crystals has not been demonstrated.
- The conclusions by Pendry, Joannopoulos, Soukoulis, Ozbay et al. aren’t correct.

See

“NEGATIVE AND ANOMALOUS REFRACTION IN METAMATERIALS AND PHOTONIC CRYSTALS”.
The quest for magnetic plasmons at optical frequencies

Andrea Alù\textsuperscript{1,2}, and Nader Engheta\textsuperscript{1,*}

\textsuperscript{1}University of Pennsylvania, Department of Electrical and Systems Engineering, 200 South 33\textsuperscript{rd} Street, Philadelphia, PA 19104, U.S.A.
\textsuperscript{2}University of Texas at Austin, Department of Electrical and Computer Engineering, 1 University Station C0803, Austin, TX 78712-0240, U.S.A.
TRATADO DE ELECTRICIDAD Y MAGNETISMO
CURSO DE FÍSICA DEL ÉTER PARA FÍSICOS, QUÍMICOS Y ELECTROTÉCNICOS
POR EL PROF. GUSTAVO MIE
TRADUCCIÓN DE LA SEGUNDA EDICIÓN ALEmana
POR JOSÉ M.ª VIDAL LLENAS
Profesor de Física de la Universidad de Barcelona
Y MERCEDES POTAU DE VIDAL
Licenciada en Química

MANUEL MARÍN, EDITOR
Pza. de E., 273. - Barcelona
1944
1. Beiträge zur Optik trüber Medien, speziell kolloidaler Metalllösungen; von Gustav Mie.

1. Die mannigfachen Färben der Metalle im kolloidalen Zustand haben im Laufe der Zeiten recht verschiedenartige Deutungen erfahren. Früher neigte man sehr zu der Meinung, daß die betreffenden Metalle (besonders das Silber) in mehreren verschieden gefärbten Modifikationen aufräten. Später ist die Meinung aufgekommen, daß die Farben auf optischer Resonanz beruhten. Diese Meinung ist besonders eingehend von F. Ehrenhaft \(^1\) begründet worden. Endlich hat neuerdings J. C. Maxwell-Garnett \(^2\) nachgewiesen, daß sich die Farben von kolloidalen Metallen, wenn die suspendierten Partikelchen des Metalles sehr klein sind, aus der Theorie, die L. Lorenz \(^3\) für optisch inhomogene Medien entwickelt hat, einwandfrei erklären lassen. Die Theorie ergibt für eine feine Metallsuspension, in denen die Dimensionen der Teilchen im Vergleich zur Wellenlänge und außerdem zu ihren gegenseitigen Entfernungen sehr klein sind, eine ganz bestimmte Absorptionskurve, die sich aus den optischen Konstanten des Metalles vorher berechnen läßt und demnach, obwohl sie durchaus verschieden von der Absorptionskurve des soliden Metalles verläuft, doch gar nichts mit Resonanz in dem Sinne, in dem dieses Wort von Ehrenhaft, Wood u. a. gebraucht wird, zu tun hat. So konnte Maxwell-Garnett unter anderem die rote Farbe vieler Goldlösungen, die Ehrenhaft als Resonanz-

---

Low losses?
Optical response features of Si-nanoparticle arrays

Andrey B. Evlyukhin,1,2,* Carsten Reinhardt,1 Andreas Seidel,1 Boris S. Luk’yanchuk,3 and Boris N. Chichkov1
1 Laser Zentrum Hannover e.V., Hollerithallee 8, D-30419 Hannover, Germany
2 Kama State Academy of Engineering and Economics, 423810 Naberezhnye Chelny, Russia
3 Data Storage Institute (DSI), Agency for Science, Technology and Research, DSI Building, 5 Engineering Drive 1,
117608 Singapore, Singapore
(Received 29 March 2010; published 8 July 2010)

Strong magnetic response of submicron Silicon particles in the infrared

A. García-Etxarri ,1 R. Gómez-Medina,2 L. S. Froufe-Pérez,2 C. López,2 L. Chantada,3 F. Scheffold,3 J. Aizpurua,1
M. Nieto-Vesperinas 2 and J. J. Sáenz1,4

14 March 2011 / Vol. 19, No. 6 / OPTICS EXPRESS 4815
Fig. 3. Scattering cross-section $\sigma_S$ versus the wavelength $\lambda$ for a 230nm Si sphere (the refraction index $m = 3.5$ is constant and real in this wavelength range). The contribution of each term in the Mie expansion is also shown. The green line corresponds to the magnetic dipole contribution.
Kerker coherence and Fano resonance anomalous scattering

Magnetic and electric coherence in forward- and back-scattered electromagnetic waves by a single dielectric subwavelength sphere

J.M. Geffrin¹, B. García-Cámara², R. Gómez-Medina⁴, P. Albella⁵, L.S. Froufe-Pérez⁶, C. Eyraud¹, A. Litman¹, R. Vaillon⁷, F. González³, M. Nieto-Vesperinas⁸, J.J. Sáenz⁴,⁵ & F. Moreno³

Kerker and Fano effects.
Magnetic light

Arseniy I. Kuznetsov¹, Andrey E. Miroshnichenko², Yuan Hsing Fu¹, JingBo Zhang¹ & Boris Luk’yanchuk¹

¹Data Storage Institute, 5 Engineering Drive 1, 117608, Singapore, ²Nonlinear Physics Centre, Centre for Ultrahigh-bandwidth Devices for Optical Systems (CUDOS), Research School of Physics and Engineering, Australian National University, Canberra, 0200, Australia.

Figure 1 | Schematic representation of electric and magnetic field distribution inside a metallic split-ring resonator (a) and a high-refractive index dielectric nanoparticle (b) at magnetic resonance wavelength.
Fano resonances in nanoscale structures

Andrey E. Miroshnichenko et al..

Probing the Magnetic Field of Light at Optical Frequencies

M. Burresi, D. van Oosten, T. Kampfrath, H. Schoenmaker, R. Heideman, A. Leinse, L. Kuipers

550 23 OCTOBER 2009 VOL 326 SCIENCE www.sciencemag.org

Demonstration of Magnetic Dipole Resonances of Dielectric Nanospheres in the Visible Region

Andrey B. Evlyukhin, Sergey M. Novikov, Urs Zywietz, René Lynge Eriksen, Carsten Reinhardt, Sergey I. Bozhevolnyi, and Boris N. Chichkov
Broadband Unidirectional Scattering by Magneto-Electric Core—Shell Nanoparticles

Wei Liu, Andrey E. Miroshnichenko, Dragomir N. Neshev, and Yuri S. Kivshar*

Nonlinear Physics Centre, Centre for Ultrahigh-Bandwidth Devices for Optical Systems (CUDOS), Research School of Physics and Engineering, Australian National University, Canberra, ACT 0200, Australia
Composites of resonant dielectric rods: A test of their behavior as metamaterial refractive elements

F.J. Valdivia-Valero, M. Nieto-Vesperinas

Instituto de Ciencia de Materiales de Madrid, C.S.I.C., Campus de Cantoblanco, 28049 Madrid, Spain

Available online 19 May 2012

Homogeneous medium (a) Max: 1.164V/m

Cylinders crystal (a) Max: 2.00V/m

Min: -1.086V/m Min: -2.00V/m
Si rods at random positions

- Transmittivity depends on sample shape
- There is no effective medium
- There are huge scattering losses
- No improvement over previous designs
THE REALISTIC PERIOD OF METAMATERIALS?

Thermophotovoltaic Solar Cell

Design of Nanostructured Solar Cells Using Coupled Optical and Electrical Modeling

Michael G. Deceglie, Vivian E. Ferry, A. Paul Alivisatos, and Harry A. Atwater

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Broadband light management using low-Q whispering gallery modes in spherical nanoshells

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Field theory for generalized bidirectional reflectivity: derivation of Helmholtz’s reciprocity principle and Kirchhoff’s law

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Taming the Blackbody with Infrared Metamaterials as Selective Thermal Emitters

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Comparison between the experimental absorptivity and emissivity.

Negative index

Metamaterials

Cloaking

The metamaterials bubble
The financial derivatives bubble

USD 1 trillion = USD 1000,000,000,000 = 1 billion
The “subprimes”
... the majority of the stock trades in the United States are being made by computers, capable of buying and selling thousands of different securities in the time it takes you to blink an eye.

...high-speed or high-frequency trading — known as H.F.T. — was the biggest new thing to hit Wall Street trading, and in the minds of many, the most disruptive. On any given day, this lightning-quick, computer-driven form of trading accounts for half of all of the business transacted on the nation’s stock markets.

Critics say H.F.T. has contributed to the hair-raising flash crashes and computer hiccups that seem to roil the markets with alarming frequency.
-En junio de 2011, el valor total nominal de los derivados (swaps, futuros, opciones, credit default swaps CDS por defecto de crédito, IRS Interest Rate Swaps), en circulación en el mundo ascendía a USD 708 billones, alrededor de 12 veces el PIB mundial.

-En los EE.UU. el total es de unos 248 billones de dólares (1 billón = 1 millón de millones).

A pesar de que sólo tienen el 35% de los derivados financieros mundiales, los EE.UU. tienen la mayor parte de los swaps de incumplimiento crediticio, o el 48% de todo el mundo,

Cuatro bancos USA representan el 94% de esa cantidad: JP Morgan Chase (78 billones de dólares), Citibank (56 billones de dólares), Bank of America (US $ 53 billones de dólares) y Goldman Sachs (48 billones de dólares).

F.e.:

JPMorgan Chase & Co. -NYSE, Market Capitalization: USD 163,000 millions
Derivative exposure. US banks.

$100 notes

The White House

THE END