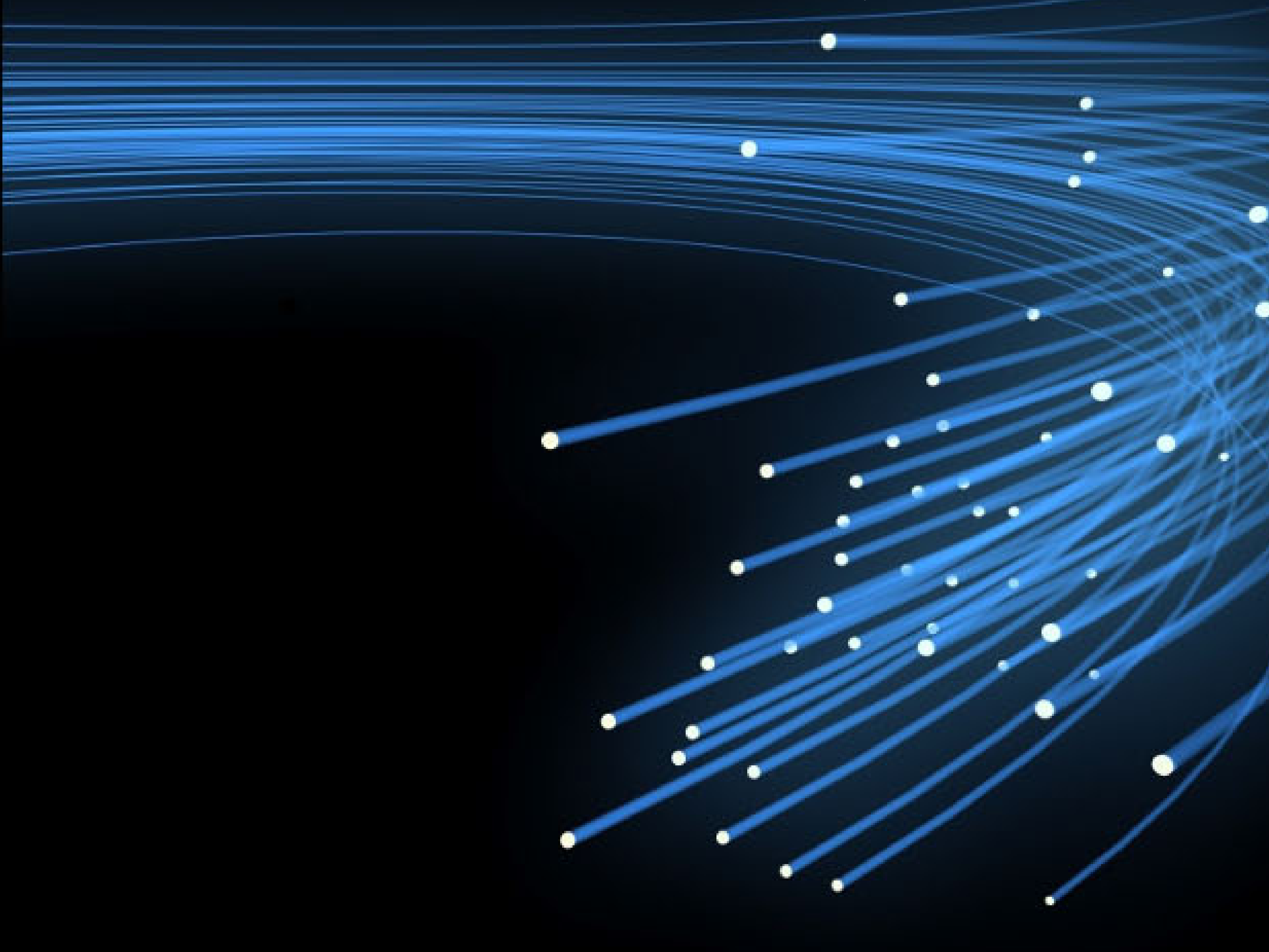
META'14 - Singapore

The 5th International Conference on Metamaterials, Photonic Crystals and Plasmonics



Program

May 20 – 23, 2014
Singapore

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Friday 23rd May, 2014

08:30 - 09:40 — LT22

Session 4A1

Symposium: Resonant Dielectric Nanostructures and Metamaterials IX

Organized by: Boris Luk'yanchuk, Yury Kivshar, Mark Brongersma and Lukas Novotny

Chaired by: Ekmel Ozbay and Francisco Meseguer

08:30 : Keynote talk
Light can push in the wrong way
Kun Ding, Shubo Wang, Jack Ng, C. T. Chan

We present an analytical formula for the optical force acting on a chiral particle. There are chirality dependent terms which couple mechanical linear momentum and optical spin angular momentum. Such chirality induced coupling can serve as a new mechanism to achieve optical pulling force. In addition, it can induce a sideway force that can laterally push particles with opposite chirality to the opposing side of an interface. Our analytical predictions are verified by numerical simulations.

09:00 : Invited talk
Resonant metal-semiconductor nanostructures as building blocks of low-loss negative- and zero-index metamaterials
Ramon Paniagua-Dominguez, Diego Romero-Abujetas, Luis Froufe-Perez, Jose Sanchez-Gil

We propose an isotropic metamaterial with negative electric and magnetic responses in the optical regime, based on hybrid metallo-dielectric core-shell nanowires. The magnetic response stems from the lowest magnetic resonance of the dielectric shell with high refractive index, overlapping with the plasmon resonance of the metal core, responsible for the electric response. Also, the same metamaterial design is shown to yield zero refractive index for a different spectral regime, exhibiting in turn an impedance close to that of vacuum.

09:20 : Invited talk
Metamaterials based on polariton resonances in dielectrics and their combinations with plasmon resonances in metals
Jacob Khurgin

Novel all-dielectric and hybrid metal-dielectric metamaterials based on exciton and phonon polaritons can combine the versatility of metal metamaterials with low losses in dielectrics.

08:30 - 10:00 — LT23

Session 4A2

Analytical and Numerical Modelling I

Chaired by: Mathias Fink and Nicolas Bonod

08:30 : A Bloch mode expansion approach for analyzing quasi-normal modes in open nanophotonic structures
Jakob Rosenkrantz de Lasson, Philip Trost Kristensen, Jesper Mork, Niels Gregersen

Resonant metal-semiconductor nanostructures as building blocks of low-loss negative- and zero-index metamaterials

R. Paniagua-Domínguez, D. R. Abujetas, L. Froufe-Pérez, J. A. Sánchez-Gil*

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Abstract

Here we propose a 2D isotropic metamaterial with negative electric and magnetic responses in the optical regime, based on hybrid metallo-dielectric core-shell nanowires. The magnetic response stems from the lowest magnetic resonance of the dielectric shell with high refractive index (i.e., lossless semiconductor), and can be tuned to coincide with the plasmon resonance of the metal core, responsible for the electric response. Also, the same metamaterial design is shown to yield zero refractive index for a different spectral regime (in connection with overlapping resonances), exhibiting in turn an impedance close to that of vacuum.

1. Introduction

Artificial materials showing electromagnetic properties not attainable in naturally occurring media, the so called metamaterials, are among the most active fields of research in optical and material physics. One of the major challenges found is to obtain truly bulk isotropic negative index metamaterials (NIM) at optical frequencies [1]. In this regard, it has been also shown that metamaterials exhibiting either negligible dielectric permittivity (ENZ) or negligible magnetic permeability (MNZ), thus leading to a negligible refractive index, manifest fascinating optical properties [2]; specially interesting is the case of zero-index metamaterials (ZIM) with similarly small dielectric permittivity and magnetic susceptibility (impedance $Z\sim1$) for obvious reasons.

2. Low-loss negative-index metamaterials

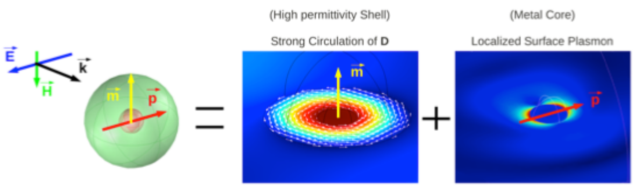

Figure 1: Illustration of the double (electric and magnetic) resonance in core-shell nanospheres [3].

Recently, we reported [3] the possibility to use a certain class of core-shell (CS) nanospheres as building blocks of 3D isotropic NIMs, operating in the near infrared. These CS, made of a metallic core and a high permittivity shell, are doubly-resonant (see Fig. 1), allowing for a spectral overlap of their first electric and magnetic dipolar resonances. Nonetheless, such 3D NIMs exhibit moderate losses, and their fabrication is somewhat challenging.

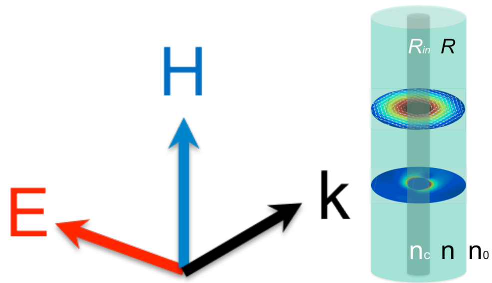

Figure 2: Illustration of the scattering geometry (TE polarization) for a doubly-resonant, single (Ag@Si) core-shell nanowire.

Therefore, we have extended our study to metallo-dielectric core-shell nanowires (NWs), revealing similar properties when incident light wavevector and polarization are both normal to the nanowire axis (see Fig. 2). The metallic core (localized surface plasmon) resonance provides again the negative electric response; the dielectric shell yields a magnetic resonance, which nonetheless does not exhibit a proper magnetic dipolar character. Since the responses do not depend on the interaction between constituents, no particular arrangement is needed to build the metamaterial, which is, moreover, broadly isotropic, though polarization dependent. We study realistic designs with silver in the core, and silicon or germanium in the shell. We show that, for certain geometrical parameters and filling fractions, metamaterials composed by such CS-NWs can have simultaneously negative permittivity and permeability between 1.2-1.5 μm [4]. The resulting metamaterial, at the expense of reduced dimensionality and fixed polarization, then behaves as a 2D isotropic NIM (see Fig. 3) with extremely low losses [4] (f.o.m. up to 200, about one order of magnitude better than previously proposed designs).

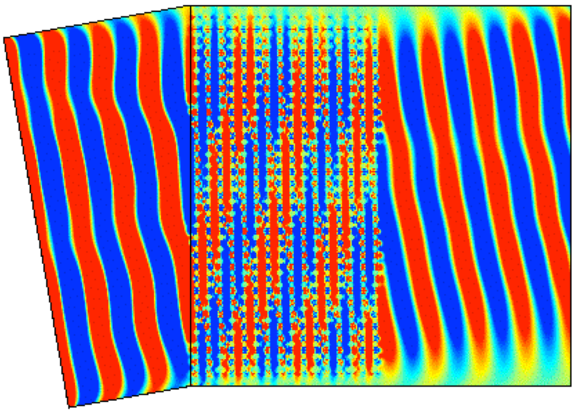

Figure 3: Negative-refraction-index slab made of core-shell (Ag@Si) NWs operating at λ=1.35 μm (TE polarization).

3. Impedance-matched zero-index metamaterials

Moreover, broad spectral regions are also found where the effective index nearly vanishes, while matching vacuum impedance; such zero-index metamaterials are shown to beautifully exhibit the rich phenomenology formally expected. Strictly speaking, unlike for NIMs, no strong resonances are required to achieve such effective ZIM parameters, the only condition being an overlap of the tails of both resonances. Thus we will show [5] that simpler nanostructures, such as solid dielectric cylinders with relatively large refractive index, can actually satisfy such condition in order to behave as a ZIM (see Fig. 4).

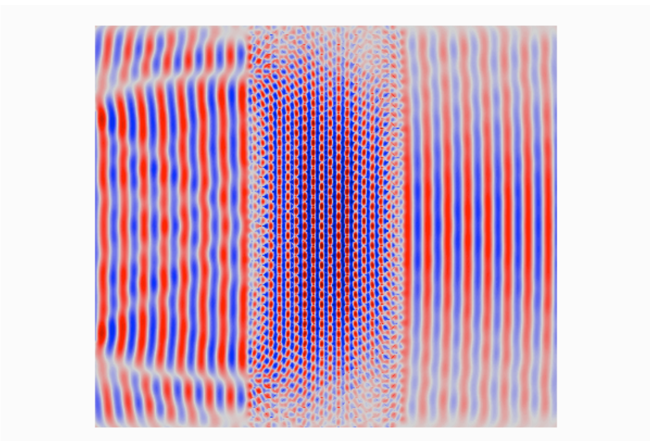

Figure 4: Nearly-zero refraction-index slab made of TiO_2 NWs operating at λ=780 nm (TE polarization).

4. Conclusions

As showed here, metallo-dielectric core-shell nanowires of circular cross section, are very promising candidates as building blocks of highly isotropic, negative index metamaterials operating at optical frequencies, with extremely low losses exhibiting figures of merit f.o.m.~200 (an order of magnitude larger than previously proposed. To further downscale the design into the visible, a nearly lossless semiconductor should be employed. Moreover, the operating physical principles can be applied to obtain negative refraction in completely different ranges of the electromagnetic spectrum (IR and THz) by using appropriate materials. Finally, a similar configuration based on doubly-resonant nanostructures is shown to lead to zero-index metamaterials.

Acknowledgements

The authors acknowledge financial support from the Spanish "Ministerio de Economía y Competitividad" (CSD2008-00066 and FIS2012-31070), and European Social Fund and CSIC (JAE-Pre and JAE-Doc grants).

References

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[2] R.W. Ziolkowski, Propagation in and scattering from a matched metamaterial having a zero index of refraction, *Phys. Rev. E* 70: 046608 (2004).

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[5] R. Paniagua-Domínguez, D. R. Abujetas, L. S. Froufe, J. A. Sánchez-Gil, preprint.