Localized magnetic plasmons in all-dielectric structures.

L. S. Froufe-Pérez[1], R. Paniagua-Domínguez[2], J. J. Sáenz[3], and J. A. Sánchez-Gil[4]

[1] Physics Department, University of Fribourg, Chemin du Musée 3 CH-1700 Fribourg, Switzerland.
[2] Data Storage Institute, Agency for Science, Technology and Research, Singapore.
[3] Donostia International Physics Center (DIPC), Donostia-San Sebastián. Spain.
[4] Instituto de Estructura de la Materia, Consejo Superior de Investigaciones Científicas, Spain.

luis.froufe@unifr.ch

Abstract. The natural magnetic response is negligible for the majority of materials at high frequencies. Materials exhibiting prescribed permeability and permittivity would open routes towards extraordinary applications. Probably, one of the best known such materials are negative refractive index (NRI) ones, first studied by Veselago [1], where simultaneous $\varepsilon=-1$ and $\mu=-1$ lead to a refractive index $n=-1$.
Proposals for actual realizations of such materials [2, 3] can be considered as the origin of modern metamaterials technology. One of the main goals is designing structures presenting an effective magnetic response $\mu_{eff}\neq 1$ with all $\mu=1$ blocks. Many of the practical implementations and theoretical designs are based on resonant metal structures [4], which are suitable for this purpose at the expense of presenting a strong absorption. Nevertheless, single scatterers as simple as a high refractive index (HRI) sphere can support strong magnetic resonances [5], under certain conditions, the coherent superposition of scattered EM waves by dipole electric and magnetic resonances by a single object leads to a strong inhibition or enhancement of either backward or forward scattering by a single scatterer. These conditions, first discovered by Kerker and coworkers [6] for dielectric spheres with $\mu\neq 1$, can be achieved also with nonmagnetic HRI all parameters are chosen appropriately [7].
We propose and theoretically study in this paper [8] a metamaterial made of nonmagnetic HRI scatterers whose effective magnetic permeability is negative while its effective electrical permittivity is comparable to that of the host medium.
Our system is a collection of monodisperse homogeneous nonmagnetic HRI spheres. The size, refractive index and density of scatterers is chosen in such a way that the effective permeability $\mu_{eff}\neq 1$, can be prescribed to tailor the magnetic response of the system.
Localized plasmon resonances encountered in metallic spheres with $\varepsilon\approx-2$ and $\mu\approx 1$, have a magnetic counterpart in spheres with $\mu\approx-2$ and $\varepsilon\approx 1$. In this work we design a metamaterial such that, when carved in a spherical shape with the appropriate radius, a "metasphere", it clearly supports a localized magnetic plasmon resonance that can be identified with the magnetic dipole scattering channel of the Mie theory for a sphere of the same radius as the metasphere and $\mu\approx-2$, $\varepsilon\approx 1$. In this way, our metamaterial effectively behaves as a "magnetic metal" supporting localized magnetic plasmons.
We derive approximate, though universal, conditions for the occurrence of such magnetic plasmon phenomena, revealing that available materials and geometrical parameters enable it for a wide spectral regime from microwave to near infrared and even visible for geometries other than the spherical. This effective medium together with our design rules paves the way towards realistic plasmonic $\mu<0$ structures, unlocking a whole new quadrant of the ε-μ plane.

References

[1] V. G. Veselago, Sov. Phys. Usp. (Engl. Transl.), **10** (1968) 509.
[2] J. B. Pendry, Phys. Rev. Lett., **85** (2000) 3966.
[3] D. R. Smith, W. J. Padilla, D. C. Vier, S. C. Nemat-Nasser, and S. Schultz, Phys. Rev. Lett., **84** (2000) 4184.
[4] R. Paniagua-Domínguez, F. López-Tejeira, R. Marqués, and J. A. Sánchez-Gil, New J. Phys., **13** (2011) 123017.
[5] A. García-Etxarri, R. Gómez-Medina, L. S. Froufe-Pérez, C. López, L. Chantada, F. Scheffold, J. Aizpurua, M. Nieto-Vesperinas, and J. J. Sáenz, Opt. Express, **19 (**2011) 4815.
[6] M. Kerker, D.S. Wang, and L. Giles, J. Opt. Soc. Am., **73** (1983) 765.
[7] J. M. Geffrin, B. García-Cámara, R. Gómez-Medina, P. Albella, L. S. Froufe-Pérez, C. Eyraud, A. Litman, R. Vaillon, F. González, M. Nieto-Vesperinas, J. J. Sáenz, and F. Moreno, Nat. Commun., **3** (2012) 1171.
[8] R. Paniagua-Domínguez, L. S. Froufe-Pérez, J. J. Sáenz, and J. A. Sánchez-Gil, Phys. Rev. B, Vol. **91** (2015) 235120.