Transformation optics for plasmonics

P. A. Huidobro, M. L. Nesterov, L. Martín-Moreno, F. J. García-Vidal

Departamento de Física Teórica de Materia Condensada, Facultad de Ciencias, Universidad Autónoma de Madrid, Campus Cantoblanco, Ctra. Colmenar, Km.15., Madrid, Spain.
paloma.arroyo@uam.es

A new strategy to control the flow of surface plasmon polaritons (SPPs) at metallic surfaces is presented. It is based on the application of the concept of Transformation Optics (TO), a theoretical frame proposed [1,2] as a general technique to design complex electromagnetic (EM) media with unusual properties. TO provides us with expressions for the dielectric permittivity tensor, ε, and the magnetic permeability tensor, μ, that need to be implemented in order to obtain a medium with a designed functionality.

Practical realizations of the idea of TO include the construction of a two-dimensional cylindrical invisibility cloak for EM plane waves and the construction of broad-band ground-plane cloaks [3] in the microwave [4] and optical [5,6] regimes. These experiments made use of metamaterials, [7] artificially structured materials made up of subwavelength constituents and designed to implement a prescribed response to EM fields. Besides, a wide variety of applications other than cloaking has been recently presented, including beam shifters and beam dividers [8], or lenses with subwavelength resolution [9].

On the other hand, one of the main goals in Plasmonics is to control the flow of light at a metal surface by means of the SPPs that decorate a metal-dielectric interface. In our work [10], we present a new strategy to tackle this problem by showing that the TO framework can be applied to mold the propagation of SPPs at a metal surface. We develop a general methodology for the design of Transformation-Optical devices for SPPs, based on the use of TO to devise the optical parameters that need to be implemented in order to obtained the desired functionality. Then, we show that a simplified version of the TO recipe in which the optical parameters are implemented only in the dielectric on top of the metal surface leads to quasi-perfect functionalities. We analyze, for proof-of-principle purposes, three representative examples with different functionalities: a beam shifter (see Fig. 1), a cylindrical cloak (see Fig. 2) and a ground-plane cloak (see Fig. 3).

References

[1] Pendry, J. B.; Schurig, D. and Smith, D. R., Science **312** (2006) 1780-1782.
[2] Leonhardt, U., Science **312** (2006) 1777-1780.
[3] Li, J. and Pendry, J. B., Phys. Rev. Lett. **101** (2008) 203901.
[4] Liu, R.; Ji, C.; Mock, J. J.; Chin, J. Y.; Cui, T. J. and Smith, D. R., Science **323** (2009) 366-369.
[5] Valentine, J.; Li, J.; Zentgraf, T.; Bartal, G. and Zhang, X., Nat. Mater. **8** (2009) 568-571.
[6] Gabrielli, L. H.; Cardenas, J.; Pointras, C. B. and Lipson, M., Nat. Photonics, **43** (2009) 461-463.
[7] Ziolkowski, R. W. and Engheta N., Metamaterials: Physics and Engineering Explorations, IEEE Press, John Wiley & Sons, Inc. (2006).
[8] Rahm, M.; Cummer, S. A.; Schurig, D.; Pendry, J. B. and Smith, D. R., Phys. Rev. Lett. **100** (2008) 063903.
[9] Schurig, D.; Pendry, J. B.; and Smith, D. R., Opt. Express **15** (2007) 14772-14782.
[10] Huidobro, P. A.; Nesterov, M. L.; Martín-Moreno, L. and García-Vidal, F. J., submitted (2010).

Figures

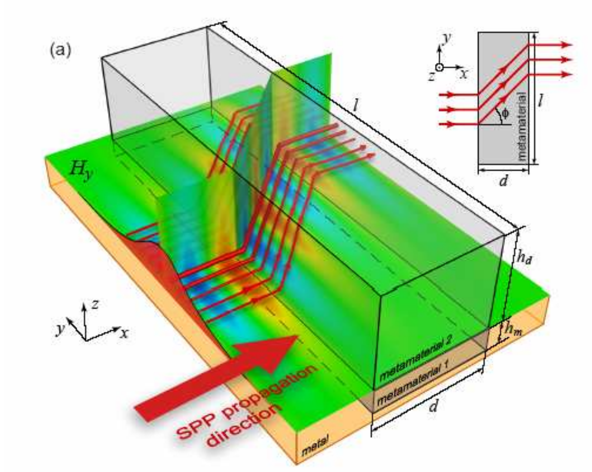

Figure 1: SPP at 1.5 μm travelling along a gold-vacuum interface and entering into a 3D beam shifter. The color map represents the normalized magnetic field pattern and the red lines are power flow streamlines. The beam shifter is constituted by two rectangular metamaterials with inplane dimensions 2.5 μm x 10 μm and thicknesses h_d = 6 μm in the dielectric side and h_m = 50 nm in the metal side. The inset of the figure shows the basic geometry from a top view.

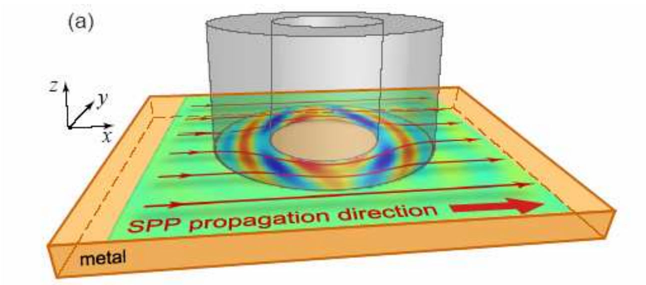

Figure 2: Schematic picture showing of a 3D cylindrical cloak for an SPP travelling through a gold-vacuum interface. The cylindrical region in the dielectric side comprised between the inner radius a = 1.5 μm and the outer radius b=2a and 6 μm high constitutes the metamaterial were the TO parameters are implemented. The color map at the metal surface is the normalized scattered magnetic field for a SPP at 1.5 μm.

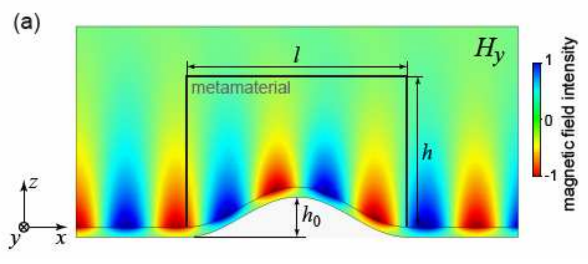

Figure 3: Two-dimensional ground-plane cloak for a SPP at 600nm that travels in the x-direction along a gold surface. The cloaked object is a cos2-shaped gold bump, 1250 nm long and with a height of h0 = 200 nm. The metamaterial acting as the cloak is 750 nm high. The color map shows the normalized magnetic field pattern.