Study of the Anomalous Reflection From the Ultra-thin Metallic Nano-strip Antenna

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Abstract

Introduction: A metal film whose thickness is smaller than the skin depth, is of high transmission in the visible and half-transparent in the near infrared. However, when the film is divided into discrete nano-strips (i.e. array), an enhanced anomalous reflection and suppressed transmission take place. It was reported that this phenomenon is attributed to the Localize Surface Plasmon Resonance (LSPR) supported by an individual strip antenna[1, 2]. But the exact physics behind is still not well understood. To study this anomalous phenomenon, we employed the Wave Optics Module in COMSOL Multiphysics® to simulate and analyze the optical property of the ultra-thin metallic nano-strip antenna. A theory model is presented on the basis of the simulation results. This work is published on Journal of the Optical Society of America B[3].
COMSOL Multiphysics: We first simulate the optical modulation property of a single ultra-thin gold nano-strip antenna (surrounded by air) with Wave Optics Module. The scattered field from the antenna is calculated under the illumination of a homogenous background plane wave. The simulation area is show in Fig.1(a), where the outer rectangles form the perfect match layer (PML). The gold antenna is in the middle and is surrounded by a rectangle. The rectangle is used to calculate the backward (through boundary 1) and forward (through boundary 2) power escaping from the single nano-strip. The phase of the current in the strip is also extracted with function "arg()". The dispersion relation of gold is taken from literature and is applied in the model with an interpolation function. The permittivity and permeability of air are 1.
Results: The spectra are shown in Fig.1(b) as purple and blue curves. The phase of the incident magnetic field and the current density at the strip center is also extracted from the simulation. It is indicated that the forward propagating energy reaches almost zero (3.7%) at λ=1408 nm. The phase of the current density is 0 at this wavelength, which is the same as the phase of the incident field. Since the forward scattered magnetic field is in anti-phase with the current in the strip, the scattered field interference destructively with the incident field in the forward direction, resulting in a transmission minimum. Figure 1(c) shows the superposition of the incident and scattered magnetic field.
Conclusion: We investigated the anomalous scattering property of a single nano-strip. The suppressed forward scattering of a single ultra-thin metallic nano-strip is attributed to the phase matching between the displacement current and the incident field, which leads to the destructive interference between the background and resonant scattering in the forward direction. The simulation results help us to peer into the physical principle hidden behind the anomalous phenomenon.

Reference

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[2] S. Xiao, et. al. , "Nearly zero transmission through periodically modulated ultrathin metal films," Appl. Phys. Lett. 97, 071116 (2010).
[3] D. Hu, et. al. , "Anomalous reflection in the ultra-thin nano-strip antenna induced by incident field and displacement current phase matching," JOSA B 32, 1369-1376 (2015).

Figures used in the abstract

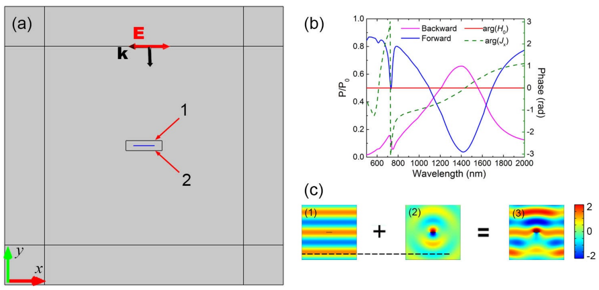

Figure 1: Fig.1. (a). Schematic of the simulation areas. (b). Left axis: plots of forward and backward power spectra related to the nano-strip shown in (a). Right axis: phase of incident magnetic field (H0) and current density (Jx) at strip center point. (c). Normalized magnetic field distribution of a stand-alone strip for λ=1408 nm. 1-3 show incident field, scattered field and total field, respectively.

Figure 2

Figure 3

Figure 4