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Symmetry-Broken Metamaterial Absorbers: Ultrahigh-Q Couplers for Launching Directional Surface Plasmon Waves

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The concept of a metamaterial (MM) absorber utilizes an array of suitably-designed periodic metal-insulator-metal (MIM) patterns to reduce reflection of radiation from a surface at a resonant frequency. With an optically-thick lower metal ground plane yielding zero transmission, and reflection reduced toward zero, such an MM is claimed to be perfectly absorbing. In the language of RF technology, the reflection is identically zero when the impedance of the MIM pattern is matched to that of the incident medium, usually air.

Considering this phenomenon in more depth, one finds that freely-propagating photons are first coupled into surface plasmon polaritons (SPP), whose energy is then dissipated into heat due to Drude heating in the metal and/or dielectric loss in the insulator layer. The generated SPPs can propagate along the metal/insulator interfaces in the form of surface plasmon waves, or can form standing (localized) waves due to the symmetry and periodicity of the MIM structure. So far in the literature, MM absorbers are designed on symmetric MIM patterns. The symmetry of these patterns causes the generated SPPs to form standing waves, yielding localized surface plasmons (LSP). The small effective cavity size for the LSP is also the main reason for the relatively low Q factors observed for current MM resonant absorbers [1].

Here, we propose symmetry-broken MIM patterns that, instead of localizing the SPPs, cause them to travel along a preferred direction. At the resonance frequency where the impedance of the MM surface matches that of air, these devices bend the incident light 90 degrees, without reflecting back to the incident direction, yielding a quasi-perfect absorber. This phenomenon can be regarded as an extreme case of the recently published work by Pfeiffer and Grbic on wave front tailoring with reflectionless MM sheets [2]. Due to the considerably larger effective cavity size of the propagating SPPs, the symmetry-broken MM patterns can have much larger Q-factors than their symmetric counterparts. We demonstrate the above phenomena in both experiment and simulations in the optical and infrared regions. These novel, asymmetric SPP couplers have the advantage of high coupling efficiency (theoretically reaching 100%), good directionality and large quality factor.

[1] X. Liu, T. Starr, A. F. Starr, and W. J. Padilla, Phys. Rev. Lett. 104, 207403 (2010).

[2] C. Pfeifer and A. Grbic, Phys. Rev. Lett. 110, 197401 (2013).