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Material Damping in Metal-Dielectric Periodic Optical Structures in Slab Geometry

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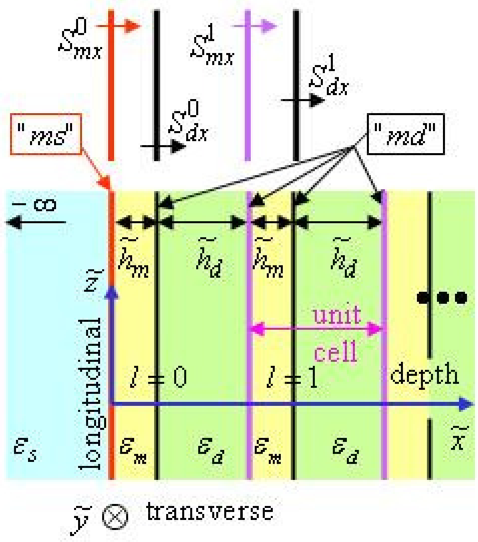
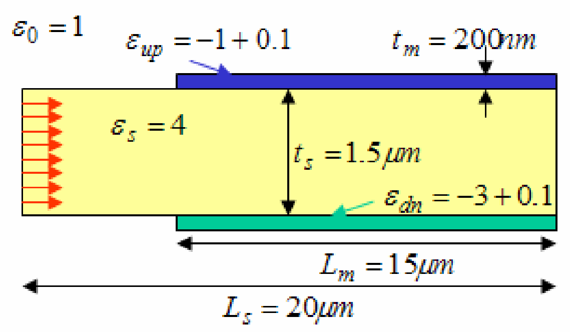
From the viewpoint of implementing nano-photonic devices onto Optical Printed Circuit Board (O-PCB), it is sometimes necessary to assess the performance of periodic photonic devices on a substrate(1) , for instance, silicon. Metal-dielectric (M-D) composite structures receive ever-increasing attention(2), because not only of many well-known characteristics involving surface plasmonic waves, but also of their relevance to the merging science of metamaterials(3). Metal-dielectric composites are useful in guiding and focusing optical waves because of the surface waves established across the M-D interfaces. However, the inherent material damping of metals is a main disadvantage in diminishing the optical energy during propagation. Here, the nature of material damping is examined with respect to surface plasmon resonance (SPR).

For this purpose, a periodic semi-infinite structure is considered in slab geometry as shown in the figure to the right, where the unit cell is composed of metallic and dielectric sublayers(4,5,6). This simple structure has already been analyzed in detail mainly for dielectric-dielectric (D-D) composites(1). When the material damping could not be avoided, it can be at least controlled against its harmful absorption effect. Better yet, the energy-redirection capability due to material damping can be harnessed for useful purposes. To this goal, the structure in the above schematic figure is taken as an example for a thorough analysis of energy flows.



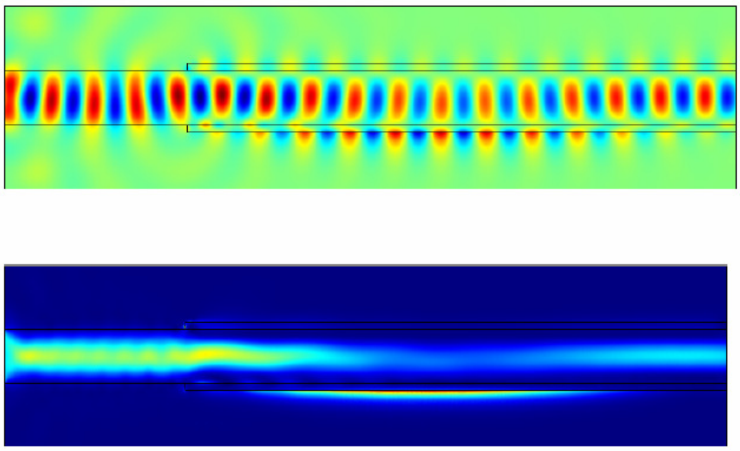
In the longitudinal z-direction (in the above figure), the energy flows in the backward and forward directions in the metallic and dielectric sublayers, respectively. This phenomenon serves as the first step in understanding the left-handed materials and their implantation in the subwavelength imaging in the depth-wise x-direction for point sources(7). When it comes to the application to waveguides, the energy confinement is the desired feature. In this case, the relative amount of energy flows along the substrate and the unit cells are the key issue.

Numerical simulations are also carried out via a finite-element method (FEM) for a number of configurations to assess the possibility of energy redistribution for uniform plane waves, both of finite and infinite widths.



The figure to the left shows the problem definition. The incident waves are of finite height in the medium of $\varepsilon_s = 4$. The two metallic strips are of the same thickness $t_m = 200nm$, but they are assigned different dielectric constants such that $\varepsilon_{up} = -1 + i0.1$; $\varepsilon_{dn} = -3 + i0.1$.

The figure to the right shows the intensity of the electric field (in the upper sub-figure) and the Poynting-vector intensity (in the lower sub-figure). Higher and lower values are associated with reddish and bluish colors, respectively. The unusually high energy flow along the lower metallic strip is evident. TM waves are incident from the left.



By judiciously selecting geometrical dimensions and material properties (in particular, the material damping), it is hoped that desired waveguide characteristics are achieved. The tubular waveguide can be examined for such energy redistribution feature. Another problem under investigation is the SPR for the metallic strips of epsilon-near-zero (ENZ) metals with, for instance, $\varepsilon = -0.1 + i1.5$

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