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Epsilon-Near-Zero Modes in Thin Films

Salvatore Campione[1,2], Igal Brener[1,2], and Francois Marquier[3]
[1]*Center for Integrated Nanotechnologies, Sandia National Laboratories, P.O. Box 5800, Albuquerque, NM, 87185, USA*
[2]*Sandia National Laboratories, P.O. Box 5800, Albuquerque, NM, 87185, USA*
[3]*Laboratoire Charles Fabry, Institut d Optique, CNRS–Univ Paris-Sud, Campus Polytechnique, RD128, 91127 Palaiseau Cedex, France*

Thin metallic films can support short- and long-range surface plasmon modes [1]. When the film thickness is much smaller than the skin depth, the long-range surface plasmon dispersion can reach the plasma frequency, where the metal dielectric constant vanishes. Around this frequency, under plane wave incidence, the *z*-component of the electric field becomes dramatically large when compared to the in-plane components. Moreover, it presents also a constant profile within the film. This peculiar behavior, due to the very small value of the dielectric constant, makes us refer to as epsilon-near-zero (ENZ) mode the long-range surface plasmon in this dispersion region.

We analyze thoroughly the ENZ mode characteristics, and we demonstrate that the following properties:

(i) The ENZ mode dispersion relation can be approximated by a linear relation between the angular frequency ω and the wave vector $k_{//}$.

(ii) The ENZ electric field inside the film increases when the thickness d decreases, and is proportional to $1/d$.

(iii) The ENZ mode exists only for a given range of thicknesses/frequencies. A good rule of thumb is $d < \lambda_P/50$ where $\lambda_P = 2\pi c/\omega_P$ is the plasma wavelength, or more generally, the wavelength for which the film dielectric constant vanishes.

(iv) This behavior is not limited to the simple case of a Drude layer surrounded by free space. We find it consistently for a wide range of structures, as for example a thin glass layer deposited on gold [2]. In that work, the ENZ frequency is related to the longitudinal phonon frequency in the glass.

These features allow us to understand which material systems can support an ENZ mode and under which conditions. This paves the way to very interesting possibilities, particularly in semiconductors, where very thin layers can be easily fabricated, and opens up possibilities in many applications, such as directional perfect absorption, ultrafast voltage-tunable strong coupling with metamaterials, electro-optical modulation, and ultrafast thermal emission.

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[2] S. Vassant, J. P. Hugonin, F. Marquier, and J. J. Greffet, *Opt. Express* **20**, 23971 (2012)