Theory of absorption-induced transparency

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1.- Introduction
Recent experiments [Hutchinson, O’Carroll, Schwartz, Genet, and Ebbesen, Angew. Chem. Int. Ed. 50, 2085 (2011)] have demonstrated that optical transmission through an array of subwavelength holes in a metal film can be enhanced by the intentional presence of dyes in the system. As the transmission maximum occurs spectrally close to the absorption resonances of the dyes, this phenomenon was christened “absorption induced transparency”. Here, a theoretical study on absorption induced transparency is presented. The results show that the appearance of transmission maxima requires that the absorptive fills the holes and that it occurs also for single holes. Furthermore, it is shown that the transmission process is nonresonant, being composed by a sequential passage of the electromagnetic field through the hole. Finally, the physical origin of the phenomenon is depicted to be nonplasmonic, which implies that absorption induced transparency should also occur at the infrared or terahertz frequency regimes.

2.- Absorption-induced transparency: Experiments

(a) Absorption induced transparency (AIT), roughly speaking, is an extraordinary optical transmission (EOT) peak seen in the transmission spectrum of a holey metal film when a molecular dye is deposited on top of it [1]. As the AIT peak spectral location appears unexpectedly close to one of the absorption energies of the molecules (b), transmission can only be possible through a strong modification of the propagation constant of holes, $k_{\text{eff}}$, as we have recently demonstrated [2].

3.- Absorption-induced transparency: Theory

(a) Absorption spectra for an optically thick silver film calculated with the Finite-Difference Time-Domain (FDTD) method. The system is illuminated at normal incidence from the top interface. Two configurations are considered: (i) no absorber present (black line) and (ii) the presence of an absorbing overlayer (blue line), with the refractive index represented in the inset (Lorentz function), and (iii) no overlayer is present (black line).

4.- Transmission process

For a two-dimensional array of holes, the transmission $T$ and $R$ of light through an absorptive-nanometallic film can be given by

$$T = |\rho|^2 \approx 1 - \frac{z_{\text{eff}}}{1 + z_{\text{eff}}} = \mu_{\text{eff}}^2 \frac{k_z^2}{k_o^2},$$

$$R = |\rho|^2 \approx 1 - \frac{z_{\text{eff}}}{1 + z_{\text{eff}}},$$

where $z_{\text{eff}} = \frac{\mu_{\text{eff}}^2}{k_o^2}$.

5.- Effective medium approach

$\mu_{\text{eff}} = \frac{S'}{S} = \text{cte}$

$\varepsilon_{\text{eff}} = \left( \varepsilon_{\text{host}} - \frac{Q^2\Delta\varepsilon}{\omega^2 - \Omega^2 + i\epsilon\alpha} \right) \frac{\omega^2}{\omega_p^2} S^2$

6.- References