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Interactions between semiconductors and planar metamaterials: active infrared metamaterials

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We explore the coupling between metamaterial resonators and different types of thin layers with optical transitions throughout the infrared. Examples are phonon transitions, highly doped semiconductor layers and engineered intersubband transitions in heterostructures. These coupling mechanisms can be exploited for electrical tuning of infrared optical metamaterials.

Planar metamaterials (or "metafilms") offer a promising platform for new types of active optical devices. Resonances in these metamaterial structures can be scaled by geometry and their spectral response is exquisitely sensitive to the local dielectric environment which can be changed using a number of tunable dielectrics [1, 2]. Here we explore the interaction between metamaterial resonators and various dipole resonances and discuss how to harness these for electrical tuning of metamaterials. An example of this strong coupling is shown in Fig. 1: Infrared phonons in dielectrics (such as SiO2) placed in proximity with metamaterial resonators can couple strongly, leading to normal mode splitting similar to vacuum-Rabi splitting that occurs with optical emitters coupled to microcavities. The amount of coupling can be altered through the design of the metamaterial resonators, the proximity of the dielectric layer to the resonator, the dielectric film thickness, and the amount of field overlap with the dielectric layer.[3]

Similar to the phonon case, we can use thin epitaxial layers of either doped semiconductors or engineered optical transitions in semiconductor heterostructures. These layers can be tuned with an applied bias either through depletion of carriers or Stark shifting of optical transitions. I will show several examples that use these semiconductor approaches for electrically tunable metamaterials in the mid IR.

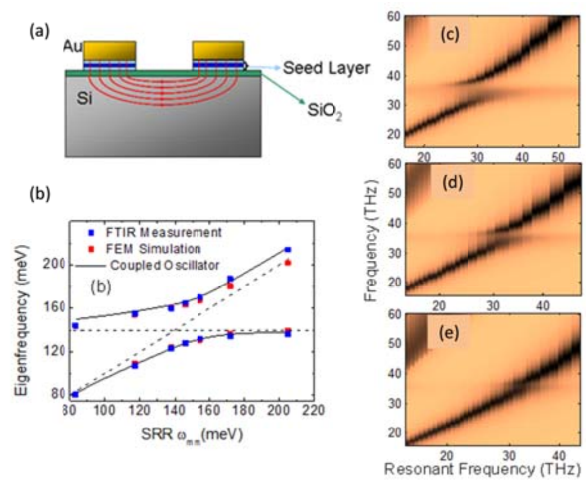

Fig. 1: (a) Schematic cross section showing thin film interface between metallic SRR elements and a thin SiO_2 layer. (b) the measured resonant frequencies of the coupled modes compared to the analytical model for two coupled oscillators. (c-e) Normal mode splitting simulated by FDTD as the SiO_2 layer is displaced from the SRR metamaterial elements: SiO_2 in (c) contact, (d) depth of 50nm, (e) depth=125nm.

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