Mid-IR Selective Thermal Emission and Strong Coupling

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Abstract: We demonstrate strongly selective mid-infrared absorption and thermal emission from structured thin-films. Near-perfect absorption (and strongly selective thermal emission) is obtained for wavelengths between 5-9µm. Strong-coupling between optical and material resonances is observed as an anti-crossing of the absorption spectra of these two resonances. Our results are compared to numerical simulations, as well as a straightforward analytical model, with good agreement between experiments and model.

The mid-infrared (mid-IR), as the spectral range where all finite temperature biological and mechanical objects emit thermal radiation, and where numerous molecular species have strong vibrational absorption resonances, is of significant importance for both security and sensing applications. The design of materials with engineered absorption resonances, which, by Kirchoff’s Law, should give strongly selective emission at the design resonance upon thermal excitation, allows for the control of the spectral character of the material’s thermal emission. Designed as a thin film coating, these structures can be applied to grey-body emitters to shift the grey-body thermal emission into predetermined spectral bands, altering their appearance on a thermal imaging system. A beneficial consequence of the thin-film architecture is the strong confinement of incident mid-IR light to the subwavelength vertical dimension of the engineered photonic structure. With this strong confinement comes the potential for enhanced direct detection of molecular resonances.

Our structures consist, from the bottom up, of a metal ground-plane, a thin dielectric layer, and a patterned top metal layer (Fig. 1). The dimension of the patterning determines the resonant wavelength of the structure, while the thickness of the dielectric layer determines the strength of the absorption resonance. Samples with varying dielectric thickness and top metal pattern dimensions were fabricated for this work. Samples were characterized by reflection and emission spectroscopy, as a function of polarization, and emission angle [1]. Strongly selective thermal emission was obtained, and compared to a calibrated blackbody source. A distinct splitting was observed at wavelengths spectrally coincident with an absorption resonance in our dielectric. A series of samples were fabricated moving the designed resonance through the material absorption resonance and an anti-crossing of the two absorption spectra was observed, indicative of a strong coupling between the two resonances [2].

The strong spectral resonances and confinement of incident light, as well as the ease of fabrication for these structures, may offer a potential avenue towards thermal cloaking films and/or enhanced sensitivity mid-IR sensors.

Fig. 1. (i) (a) TM and (b) TE polarized emission spectra from 1D patterned structure as a function of emission angle (c) COMSOL simulations of experiment in (b). (ii) (a) Schematic and SEM of structure with 2D patterned discs (b) Reflection and thermal emission for structure with designed resonance far from material resonance. (iii) (a) Experimental and (b) 3D COMSOL simulations of structures in (ii-(a)) as the optical resonance shifts through the dielectric material absorption resonance.

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References