Circuit Modeling of Nanoantenna Enabled Detectors

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Improving infrared detectors' sensitivity is an essential step for future applications, including satellite- and terrestrial-based systems, photovoltaics, etc. Mercury cadmium telluride (MCT) is the active material used in current detectors. It is common knowledge that MCT-based detectors are approaching their fundamental signal-to-noise limitations as predicted by the empirical Rule 07. Infrared detectors based on superlattice absorbers are emerging as capable competitors to MCT detectors because of the advances in growth quality that have improved both dark current characteristics and minority carrier lifetimes. In particular, the noise performance of infrared detectors can be improved through utilization of thinner detector layers that reduce noise currents arising from thermally generated electron-hole pairs. However, many infrared detector materials suffer from weak optical absorption; thus, thinning the detector layer can lead to incomplete absorption of the incoming infrared photons, further reducing detector quantum efficiency. Here, we show how subwavelength metallic nanoantennas can be used to boost the efficiency of photon absorption for thin detector layers, thereby achieving overall enhanced detector performance.

We show that the detection enhancement arises from a combination of resonantly enhanced near-field absorption and impedance matched coupling of external plane waves to the metal-backed detector layer. Starting from a transmission line analysis of the admittance of a metal-backed detector layer, the detection performance can be improved through primarily capacitive or primarily inductive nanoantenna array designs. We show how our hybrid analytic/numerical approach allows us to determine the dimensions of the nanoantenna array that will lead to optimal absorption in the detector layer. We will present numerical simulations of the performance of nanoantenna-enhanced infrared detectors based on realistic thicknesses and optical constants of the detector layer, and compare them with published experimental data. In particular, we will show that ~70% of the incoming infrared energy can be absorbed in a detector layer whose single pass absorption is only ~10%. We will also present analytical and numerical analyses that address another important consideration in the nanoantenna approach: maximizing the absorption in the detector layer while simultaneously minimizing the parasitic absorption due to ohmic currents in the metal nanoantenna structure.

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