Anomalous band formation of transmission through terahertz nanoantennas

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The transmission properties of electromagnetic (EM) waves through subwavelength hole arrays have been studied in a wide spectral range from terahertz to visible frequencies.[1-4] It was soon found that the resonance peak position of rectangular hole is close to the cut off wavelength of the hole waveguide and the transmission cross-section at resonance is proportional to λ_{res}^2.[5] A close analogy is shown in an isolated atom, whose resonant cross section is also proportional to λ_{res}^2. Close-packing atoms with periods much smaller than λ_{res} bring profound change to their spectral properties, eventually forming band structure (Fig. 1(a)). Here, it is natural to construct an atomic-solid analogue of the aperture array, to create new properties and functionalities, which would have impact upon other metamaterials whose properties will also change with ultra-close-packing.

We have fabricated periodic array of rectangular holes, with a length l=100 μm and widths around w=200 nm, perforated on a 100 nm thick Au film onto a Si substrate (see Fig. 1(b)). The horizontal period, d, is varied from 2 to 200 μm. As seen in Fig. 1(c), the normalized-to-area transmitted amplitude decrease as d is reduced when d < 100 μm. However, the linewidth and the resonant peak position do not show a monotonic behavior as the period is changed, which contrast to what is expected from a band formation of periodic systems in solid state physics. To explain the physical origin of the observations, we investigated the EM coupling between two holes, G_{01}. The real part of the total coupling, $S=\Sigma G_{01}$, affects the spectral location of the resonance while the linewidth is governed by the imaginary part [5]. An oscillatory and slow decaying trend of the coupling term results in the non-monotonic behavior of transmission properties (see Fig. 1(d)).

In conclusion, we have shown anomalous band formation of transmission through terahertz nanoantennas, depending on the period of the array. We report that the non-monotonic behavior of transmission properties is due to the oscillating behavior of EM coupling between the holes.

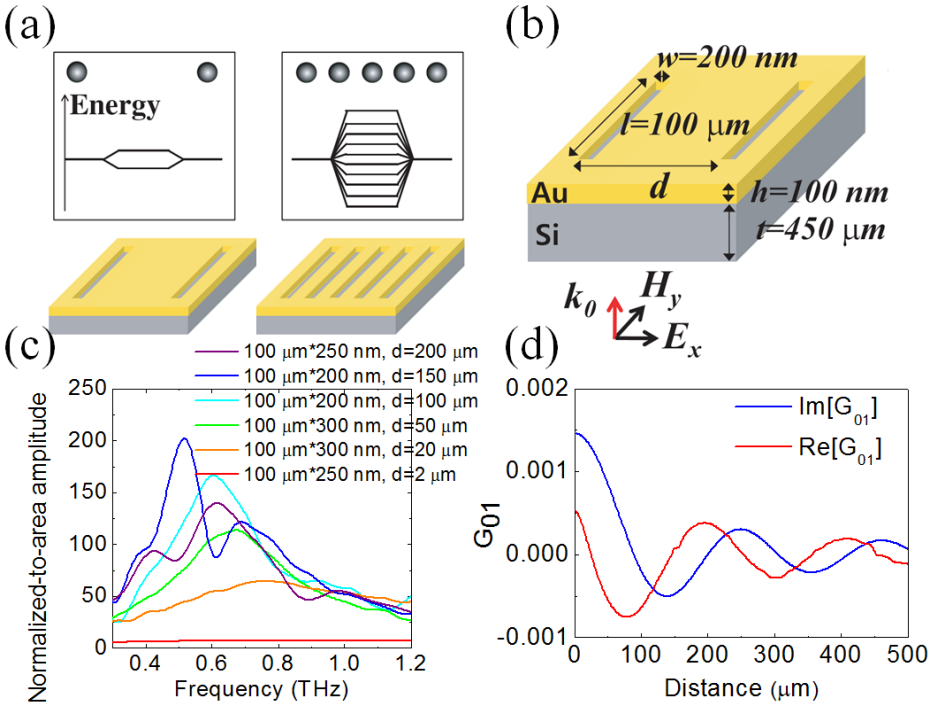

Figure 1 (a) Schematic of band formation in solid state physics and the photonic analogue analyzed in this work. (b) Schematic of a periodic array of rectangular holes. (c) Normalized-to-area transmitted amplitudes with varying the periods from d=2 μm to d=200 μm. (d) Imaginary and real parts of the EM coupling between two holes, G_{01}.

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