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# Electron Photoemission Enhancement from Collective Effects in Plasmonic Nanoparticle Arrays

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Plasmonic nanostructures show great promise in the design of advanced photovoltaic devices [1,2]. In particular, enhanced photoelectron emission from plasmonic nanoparticles can increase solar cell efficiency, putting forth a new concept of photoconductive metamaterials [3]. Still, most current studies are focused on single plasmonic nanoparticles and nanoantennas [2,3].

In contrast, plasmonic nanoparticle *arrays* are known to feature *collective* lattice effects resulting from coherent interference of individual particle excitations. When the response of an individual particle is spectrally close to a lattice plasmon mode and Rayleigh anomaly, the energy of evanescent diffractive orders is coupled into the array [4], giving rise to a Fano-like profile in transmission coefficients and strong enhancement of local fields [5]. Here we report that it can result in increased photoemission at the nanoparticles surface. This effect can further improve performance of photovoltaic devices, and can be useful in the design of new narrow-band frequency- and polarization-selective photodetectors.

We consider an array of gold nanodisks with radius 25 nm and thickness 18 nm, embedded in a GaAs matrix ($n_{GaAs} = 3.6$). Such nanodisks exhibit a localized surface plasmon (SP) resonance near 1 eV, which is below the gap for GaAs but above the work function for the Au/GaAs interface. Thus, the enhanced field at the SP resonance can facilitate photoemission from the disks [2,3].

Rather than considering a square lattice where the effects of the individual particles are dominant [3], we study a rectangular lattice with dimensions $a_x \times a_y$, with $a_y$ fixed at 100 nm to keep the lattice relatively dense, and $a_x$ varied between 100 and 400 nm to bring the Rayleigh anomaly wavelength ($\lambda_{RA} = a_x n_{GaAs}$) close to the wavelength of the SP resonance.

Our numerical simulations (carried out in CST Microwave Studio) show that for normally incident light polarized along the $x$-axis, the response of the array is still dominated by the particle SP, as in the dense array [2,3]. However, for light polarized along the $y$-axis, lattice effects are pronounced. We see zero absorption at $\lambda_{RA}$ (dots in Fig. 1a), where higher-order diffraction appears [4]. We also see a strong enhancement of the SP response, marked by a sharp peak in the absorption spectra and apparently associated with the interaction of a narrow-band lattice resonance with a broader one from the individual particle. The absorption peak follows $\lambda_{RA}$ and acquires a Fano shape. Note that the strongest local fields are observed in the vicinity of the nanodisk surface. Enhanced photoemission from the particle into the surrounding medium is thus expected. The photocurrent depends on the normal component of the electric field integrated across the disk surface: $J \propto \oint |E_n|^2 \, dS$ [3].

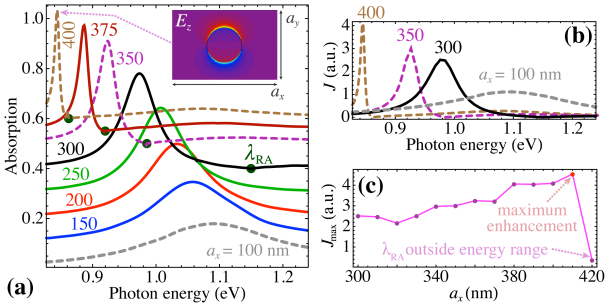


**Fig. 1**: (a) Calculated absorption spectra of nanodisk lattices with varying lattice constant $a_x$. The inset shows the local field enhancement at the absorption peak. (b) Spectral dependence of $J$ through one face of the nanodisk. (c) Maximum photoemission enhancement $J_{max}(a_x)$.

Calculations reveal that a sharper resonance is accompanied by a maximum in the photocurrent (Fig. 1b). Comparing the peak value of $J$ for different $a_x$ shows that the photoemission enhancement is greater for larger $a_x$ due to the contribution of collective lattice effects. As an example, increasing $a_x$ from 300 to 400 nm nearly doubles the peak value of $J$ (Fig. 1c).

The results obtained can be used to boost the efficiency of solar cells, particularly in the frequency range where the incident photon energy is not sufficient for the direct photoelectric effect. In addition, increased photoemission from narrow lattice-enhanced resonances in nanoparticle arrays can render them useful as photodetectors with highly selective and tunable spectral response.

**References:**

[1] H. Atwater and A. Polman, *Nat. Mater.* **9**, 205 (2010).
[2] M. W. Knight *et al*., *Science* **332**, 702 (2011).
[3] A. Novitsky *et al*, *Prog. Photovolt.: Res. Appl.*, DOI: 10.1002/pip.2278 (2012).
[4] A. G. Nikitin *et al*, *Opt. Express* **20**, 27941 (2012).
[5] W. Zhou and T. Odom, *Nat. Nanotech.* **6**, 423 (2011).