Coupling between Surface Lattice Resonances and Plasmonic Gap Modes in Arrays of Gold Dimers with Different Geometries

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Motivation

Controlling the optical coupling between the plasmonic resonances in a periodic array of metallic dimers represents unique opportunities for enhancing light-matter interactions, thereby driving many applications ranging from detectors, sensors, data storage, and improved light sources to photovoltaics [1,2]. Here, we study the surface lattice resonance modes supported by square arrays of three different gold dimer nanoantennas geometries (bowties, kissing cylinders, coupled ellipsoids), and their coupling to the gap plasmon modes of the individual dimers.

Au Nanoantennas

On a standard glass coverslip, an Electron Beam Lithography (EBL) method is applied to fabricate 50x50 μm periodic arrays of metallic dimers followed by the deposition of gold (Au) of about 60 nm using evaporation and a standard lift-off process. A 2 nm-thick ITO layer is evaporated prior to Au as an adhesion layer on the glass substrate.

The gap size is found to be between 9 and 15 nm depending on the geometries.

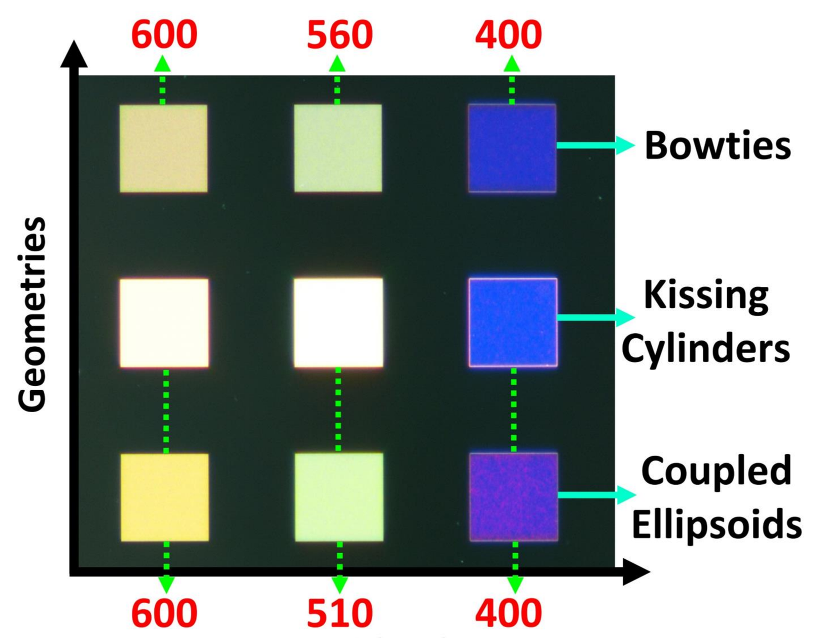

Figure 1: Dark Field Illumination.

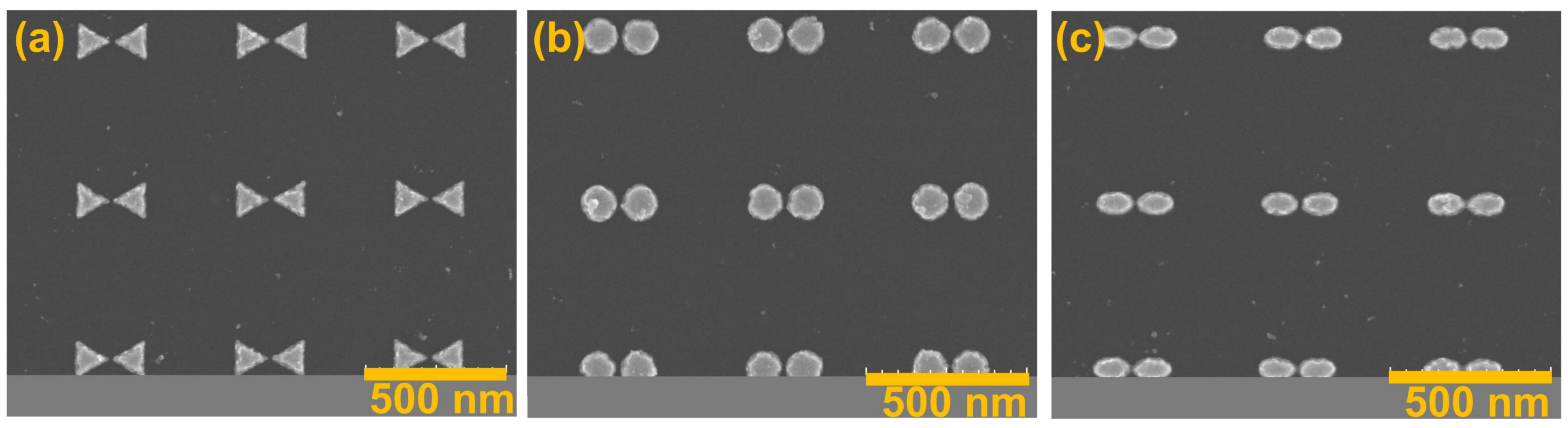

Figure 2: SEM Images of (a) Bowties, (b) Kissing Cylinders and (c) Coupled Ellipsoids nanostructures.

FDTD Simulation

Using numerical FDTD method, the coupling of surface lattice resonances with gap plasmon modes of individual dimers is found which allows reaching significantly high excitation enhancement due to the higher localized electric field intensity.

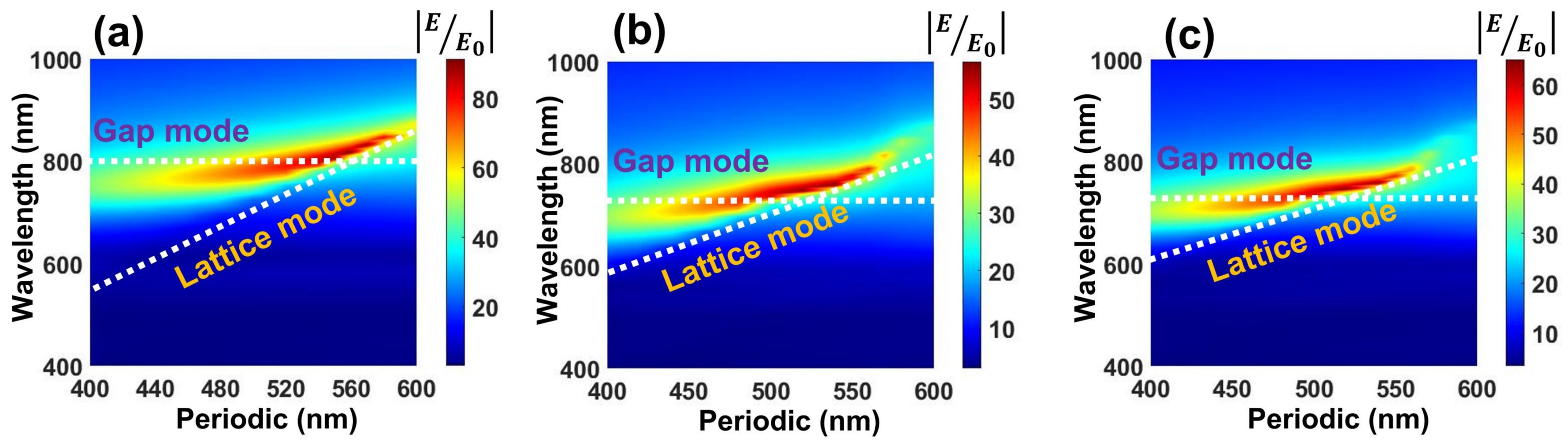

Figure 3: Normalized Electric Field Enhancements of (a) Bowties, (b) Kissing Cylinders and (c) Coupled Ellipsoids Nanoantennas as a function of the wavelength and the period under longitudinal polarization.

- Increasing the lattice period leads to red-shift the position of the diffraction edges* and surface lattice resonances occurs due to diffractive coupling. The resonance peaks become increasingly sharp, yielding a maximum quality factors for arrays of gold dimers, compared to individual dimer.

$* \lambda^{air}_{R-m} = \frac{a}{m}\,[1 \pm sin(\theta)]$

$* \lambda^{sub}_{R-m} = \frac{a}{m}\,[n_s \pm sin(\theta)]$

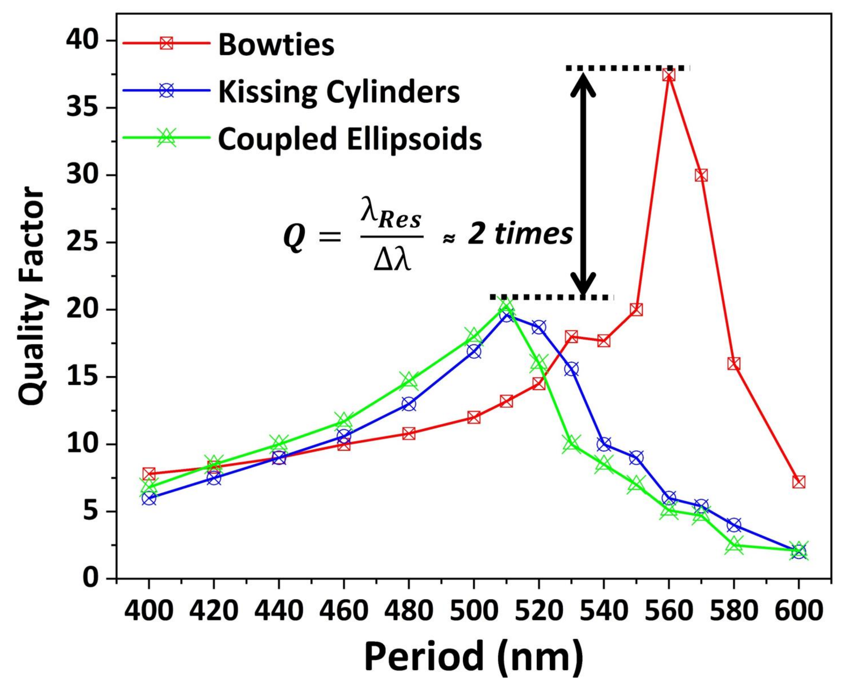

Figure 4: Quality Factor as a function of Period.

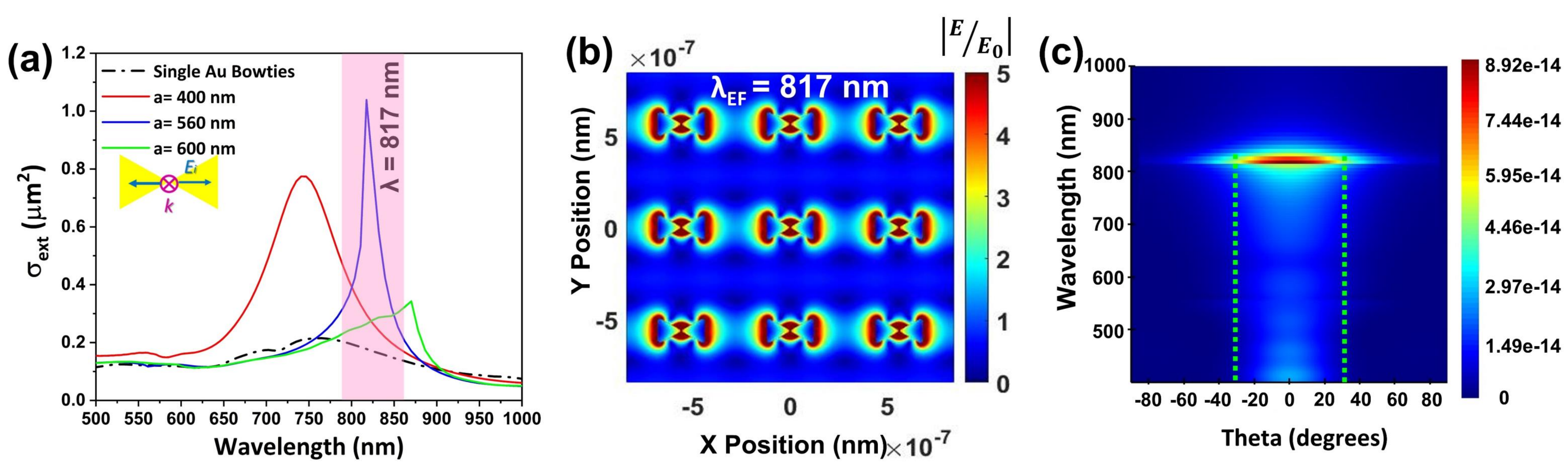

Figure 5: (a) Extinction cross section of arrays of Au bowties, (b) Normalized electric field enhancement which is a direct consequence of the coupling between surface lattice mode and the plasmonic gap mode; and (c) Far-Field projection as a function of wavelength and angle for array of Au bowties (a= 560 nm). The far field is confined within a 25 ° cone of collection with a maximum intensity at the center of the cone.

Experimental Results

Using numerical simulations and experimental validation under two parallel and perpendicular polarizations, a peak is seen in each spectrum and is attributed to the coupling of lattice mode and plasmonic gap mode of arrays of Au dimer nanoantennas.

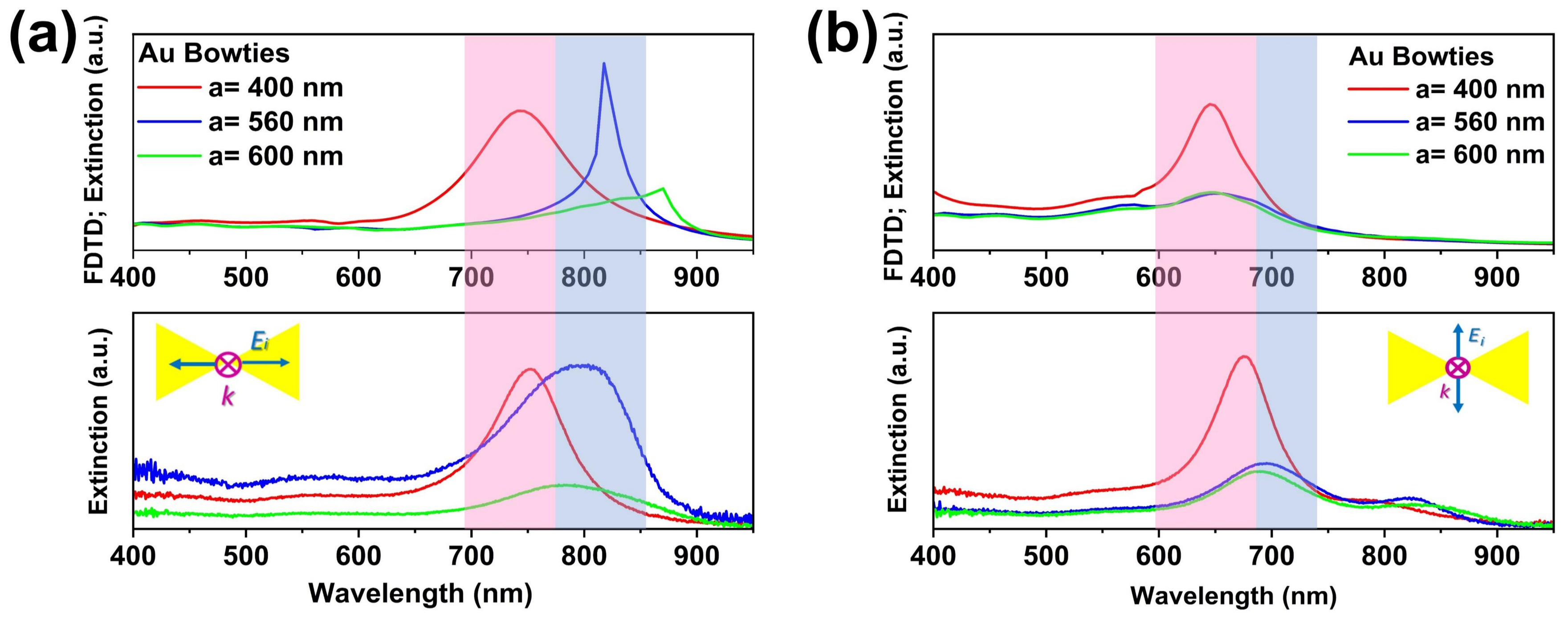

Figure 6: Theoretical and Experimental extinction spectra as a function of wavelength of array of Au bowties under (a) Longitudinal and (b) Transverse polarizations.

- Note that, there is a good agreement between the measured extinction spectra and theoretical results. We attribute the differences that remain to variations of gap size and slanted walls in the experiments (Fig 7), affecting the coupling between the antennas and lattice mode.
- The spectral position and the quality factor of the resonance peaks can be adjusted by changing the geometries of individual nanostructures.

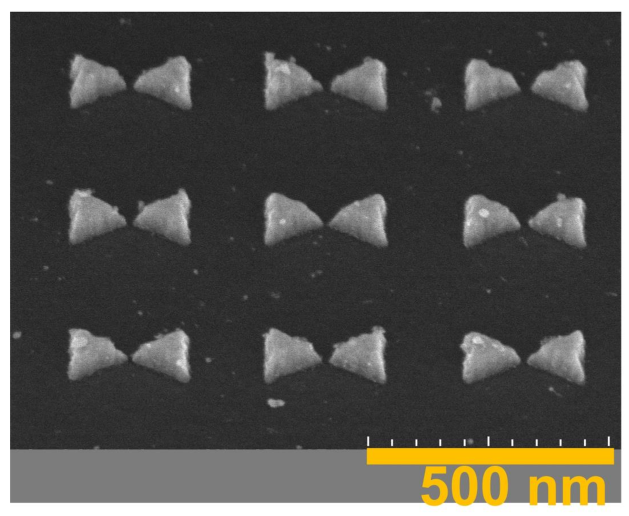

Figure 7: SEM Images of Au Bowties

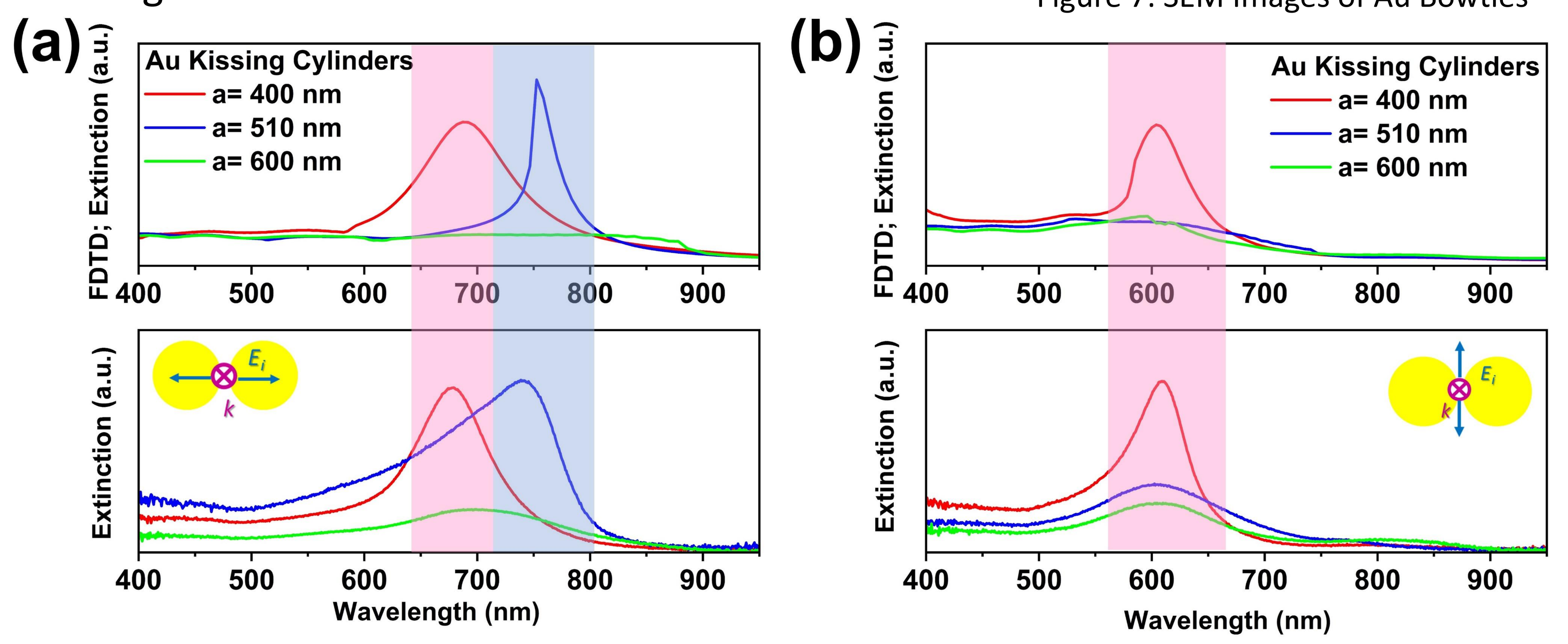

Figure 8: Theoretical and Experimental extinction spectra as a function of wavelength of array of Au kissing cylinders under (a) Longitudinal and (b) Transverse polarizations.

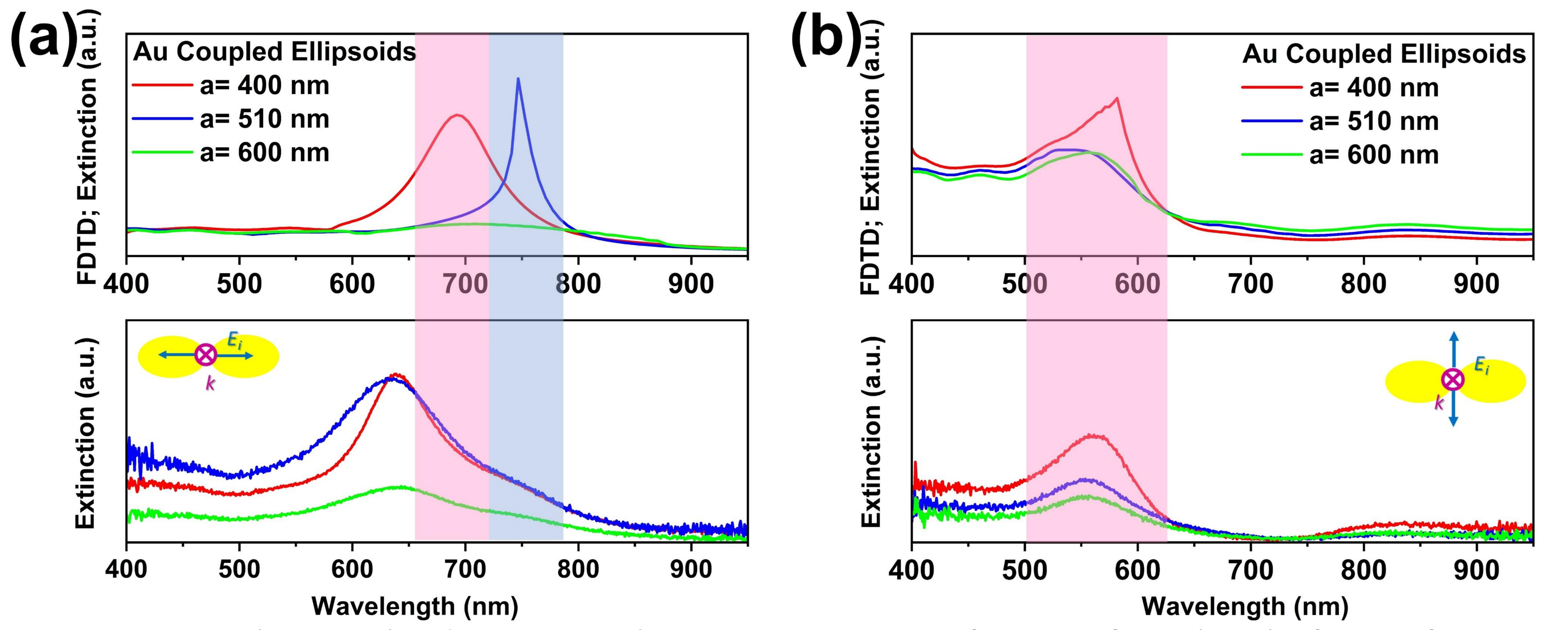

Figure 9: Theoretical and Experimental extinction spectra as a function of wavelength of array of Au coupled ellipsoids under (a) Longitudinal and (b) Transverse polarizations.

Conclusion

The coupling of the gap mode with the lattice mode results:

- Higher localized electric field enhancement in arrays of dimers
- Higher emission enhancement and directivity

References

[1] Kravets, Vasyl G., et al. "Plasmonic surface lattice resonances: a review of properties and applications." Chemical reviews 118.12 (2018): 5912-5951.

[2] Humphrey, A. D., and W. L. Barnes. "Plasmonic surface lattice resonances in arrays of metallic nanoparticle dimers." Journal of Optics 18.3 (2016): 035005.