Plasmonic Surface Lattice Resonances for Different Lattice Symmetries

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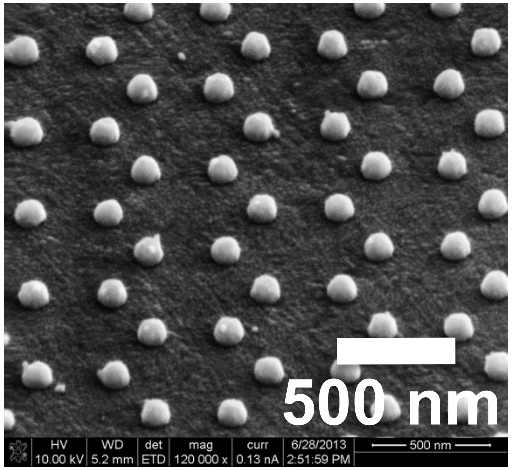
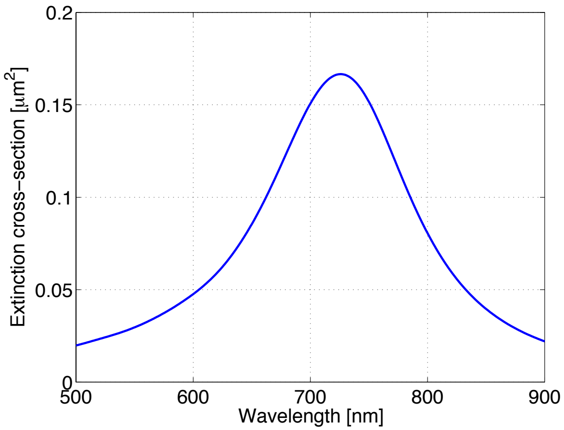
Outline of talk

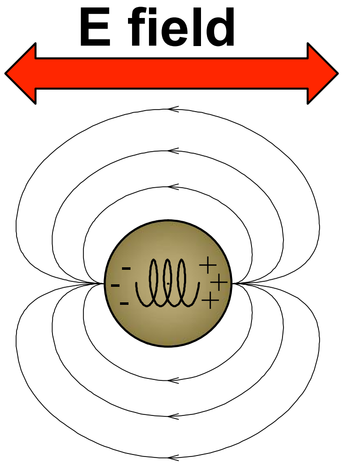
- Single plasmonic particle vs. particle array: optical response
- Experimental techniques
  - Fabrication
  - Optical characterization
- Results
  - Square, triangular and honeycomb lattices
  - Rectangular lattices
- Conclusion / future work



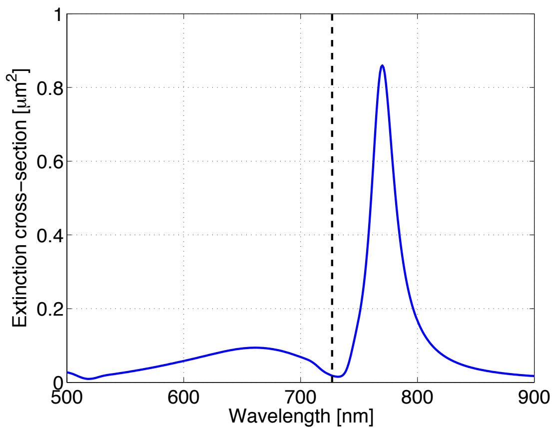
Single particle vs. array

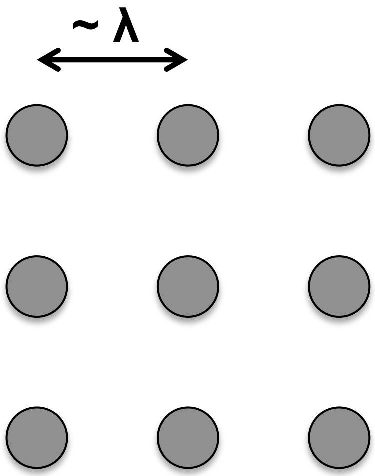
Model





Model





Single particle response

Quasistatic

$$\vec{p} = \alpha \vec{E}$$

$$\alpha(\omega)_{\text{static}} = 4\pi a^3 \left(\frac{\varepsilon(\omega) - \varepsilon_s}{\varepsilon(\omega) + 2\varepsilon_s} \right)$$

$$\sigma_{\text{abs}} = k\,\text{Im}(\alpha)$$

$$\sigma_{\text{scat}} = \frac{k^4}{6\pi} |\alpha|^2$$

$\varepsilon(\omega)$ is complex, $\alpha(\omega)$ is complex

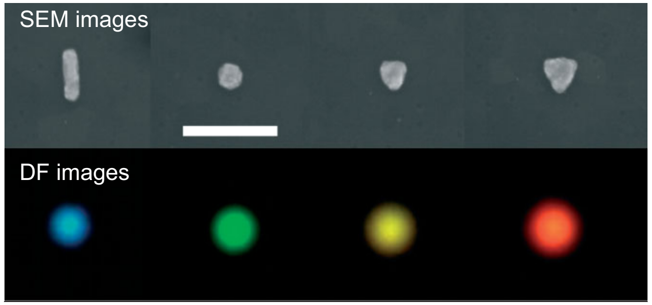
Modified long wavelength approximation

$$\alpha_{\text{MLWA}} = \frac{\alpha_{\text{static}}}{1 - \frac{k^2}{a}\alpha_{\text{static}} - i\frac{2}{3}k^3\alpha_{\text{static}}}$$

⇩

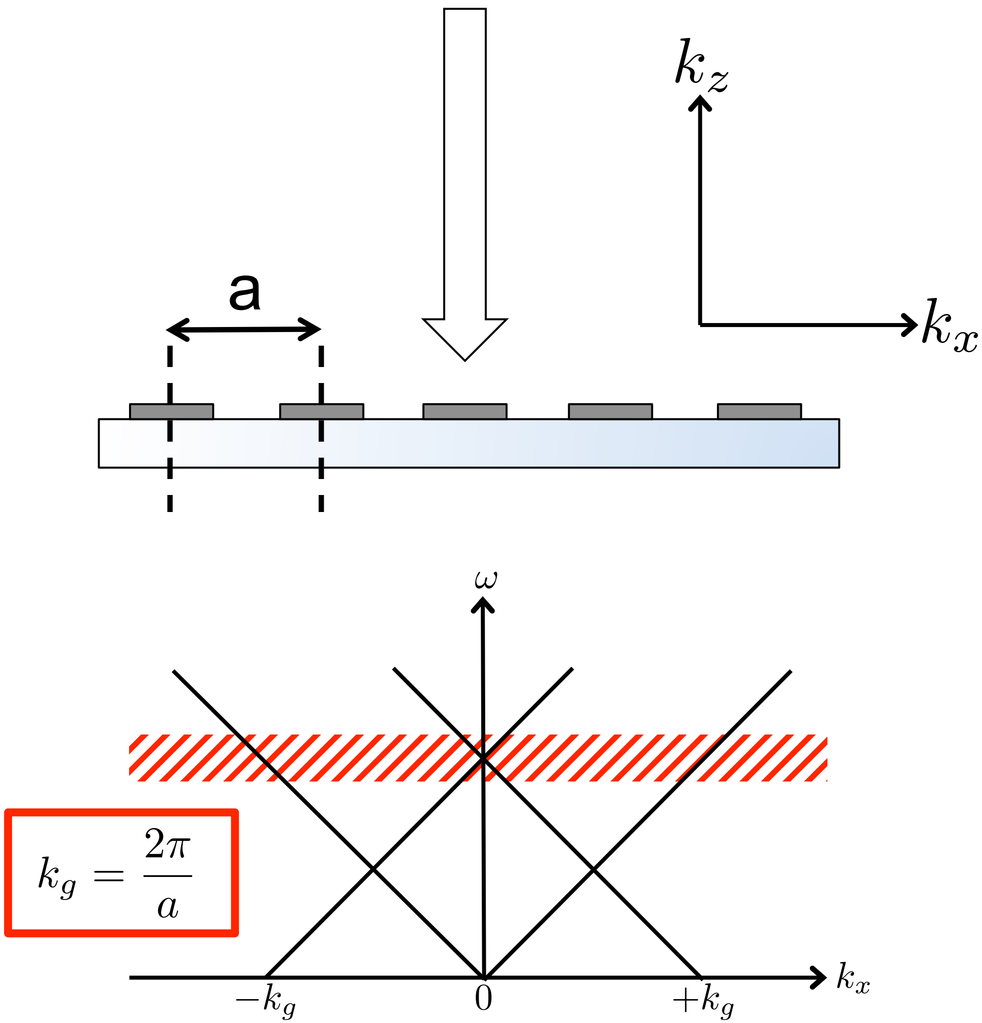
Resonant frequency dependent on size and shape

Scale bar 300 nm



W.A. Murray and W.L. Barnes, *Plasmonic Materials*, Adv. Mater. **19,** 3771–3782 (2007)

Array of particles



- Array acts as a grating.
- Resonantly scattered light in phase with each one of the oscillating dipoles.
- E field that each particle experiences is different to isolated particle.

How does array alter response?

$$\vec{p}_{\text{single}} = \alpha \vec{E}_{\text{inc}}$$

$$\vec{p}_{\text{arr}} = \frac{1}{(1/\alpha - S)} \vec{E}_{\text{inc}}$$

SLRs occur when

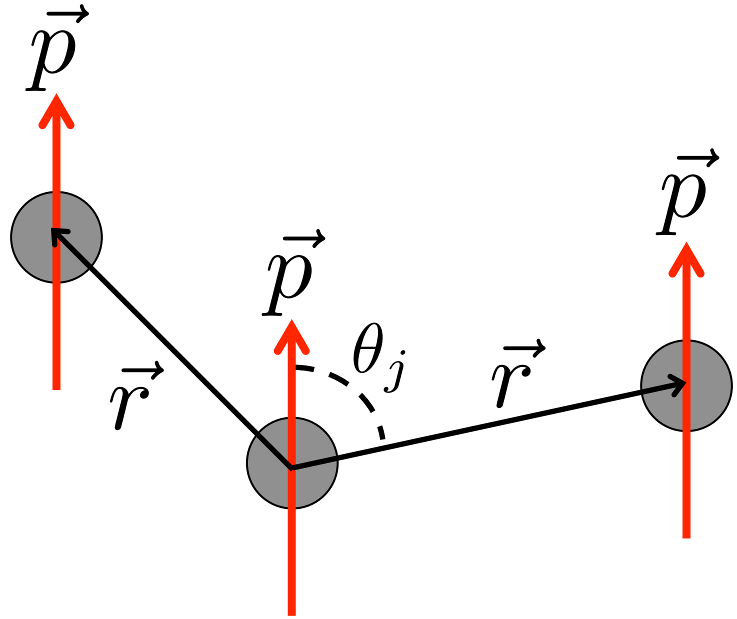
$$\frac{1}{\alpha} = S$$

How does *S* depend on lattice?

$$\vec{p}_{\text{arr}} = \alpha^{*} \vec{E}_{\text{inc}}$$

S factor

$$\alpha^* = \frac{1}{1/\alpha - S}$$



$$S = \sum_j \exp(ikr_j) \left[\frac{(1 - ikr_j)(3\cos^2\theta_j - 1)}{r_j^3} + \frac{k^2 \sin^2\theta_j}{r_j} \right]$$

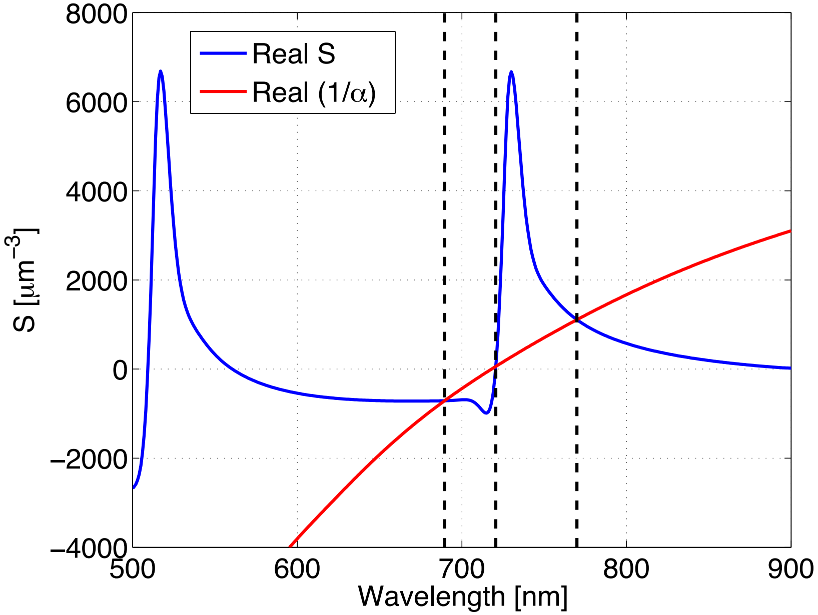
S also complex

(array size 50 micron x 50 micron)

S factor

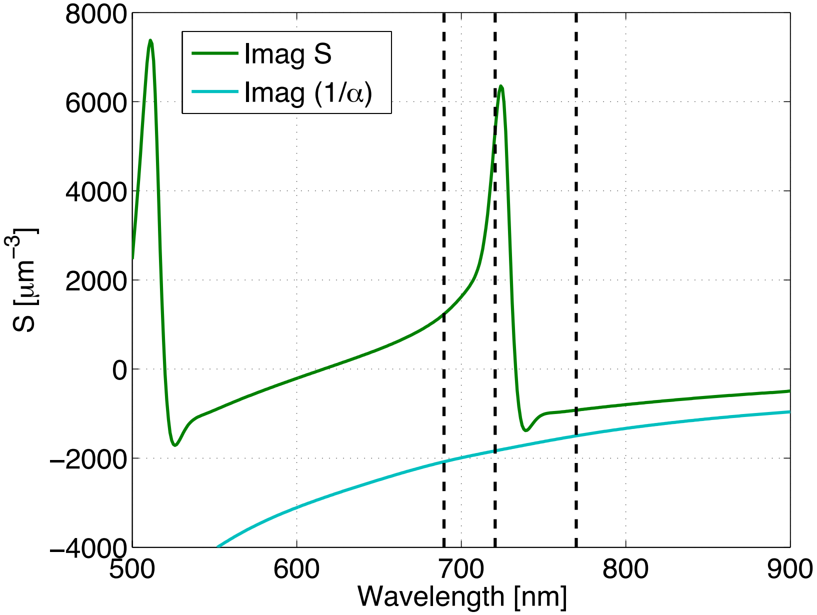
$$\alpha^* = \frac{1}{1/\alpha - S}$$

Resonance position mainly determined by crossing points of real parts.



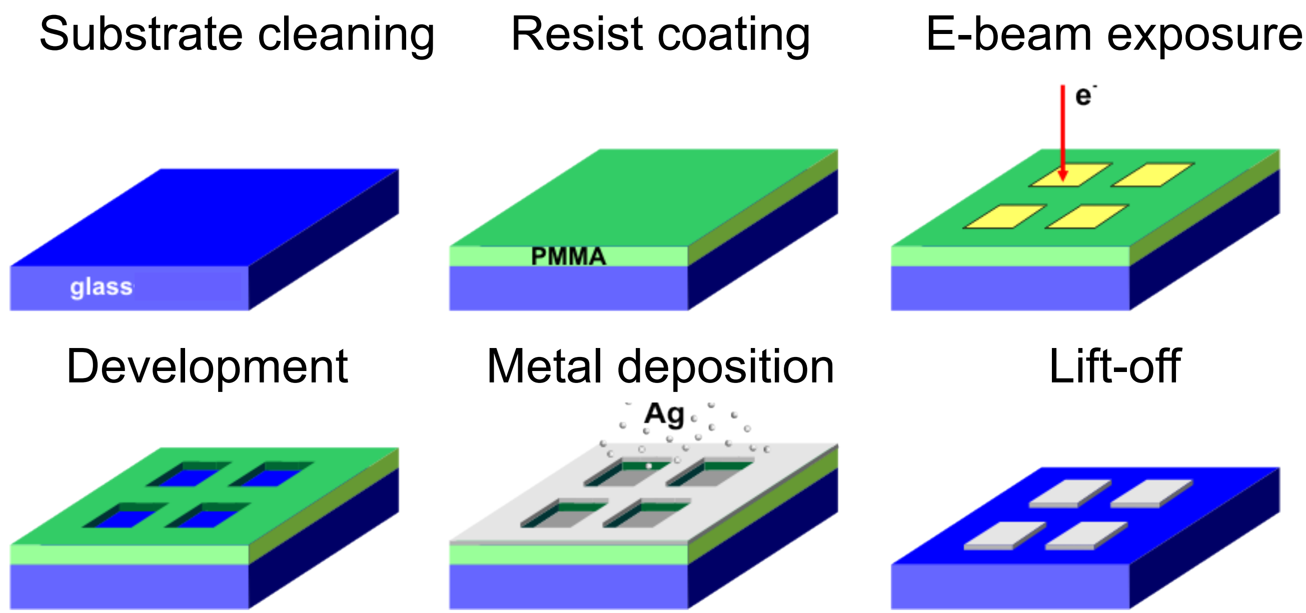
(model run for 400x400 particles)

Strength and width of resonance determined by difference between imaginary parts.



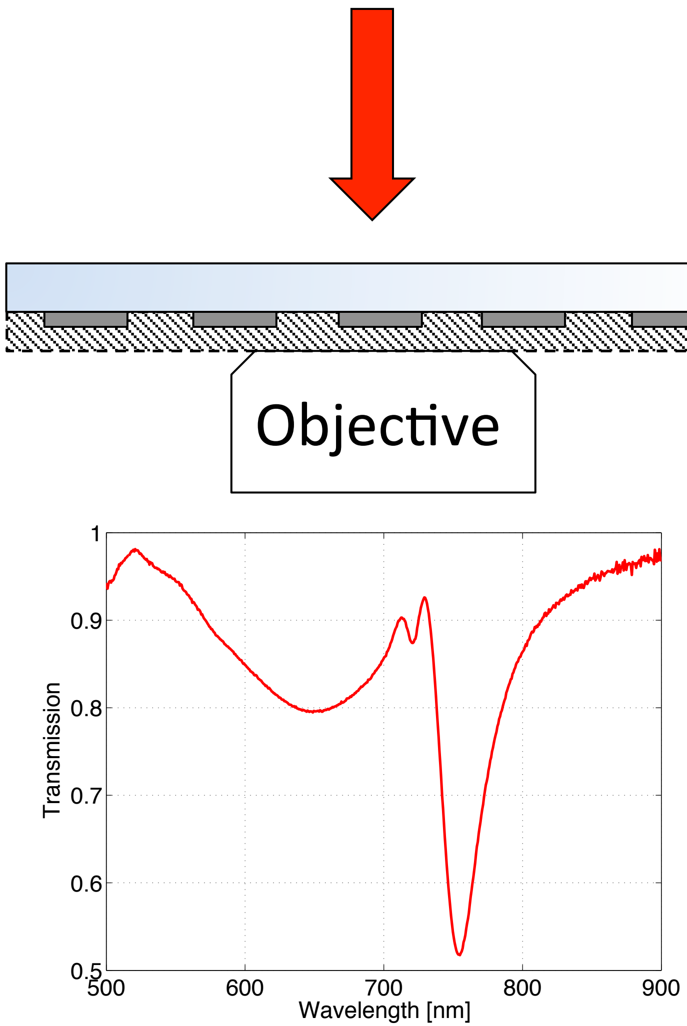
(smoothed using cubic spline)

Fabrication



Arrays written with a write field of 50 micron x 50 micron.

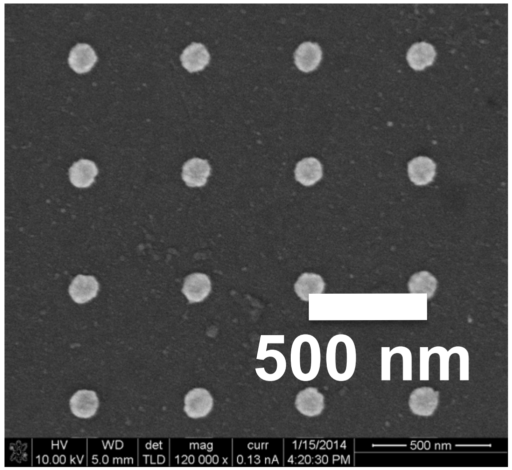
Optical characterization

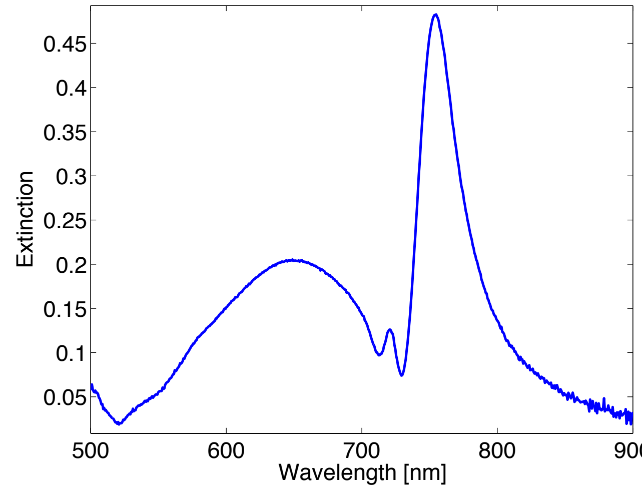


- Index matched to give homogeneous environment.
- Incident beam divergence of < 1°.
- 30 micron diameter illumination spot size. (arrays are 50 micron x 50 micron).
- Long-pass filter to eliminate second order diffraction.

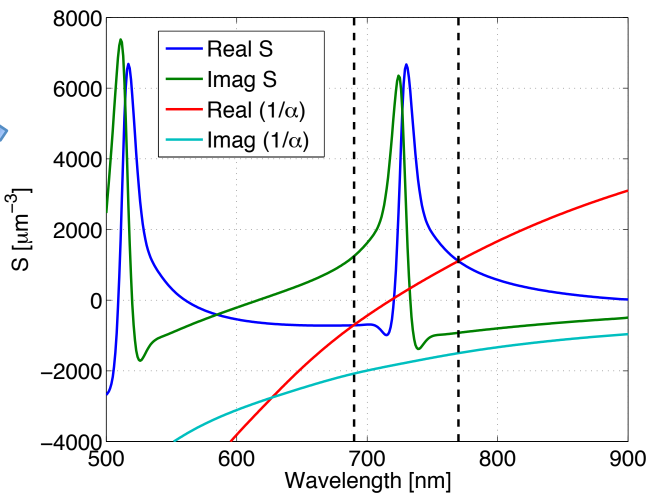
Square lattice

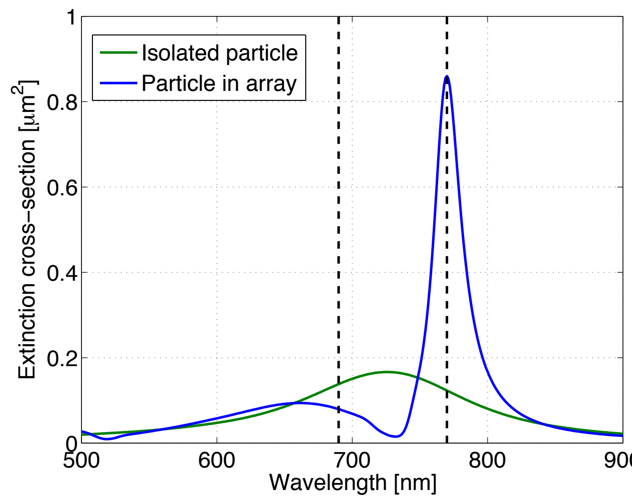
Experiment





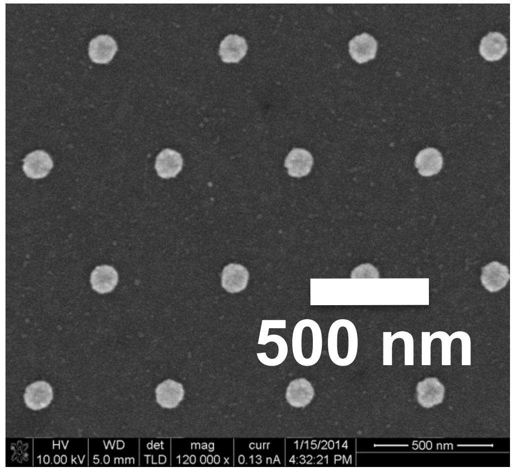
Model

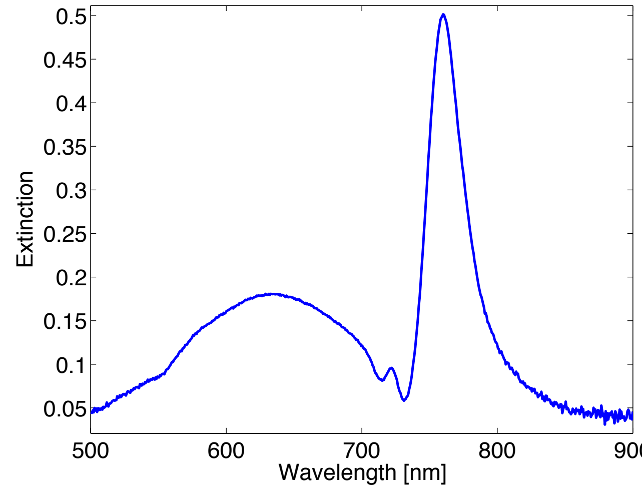




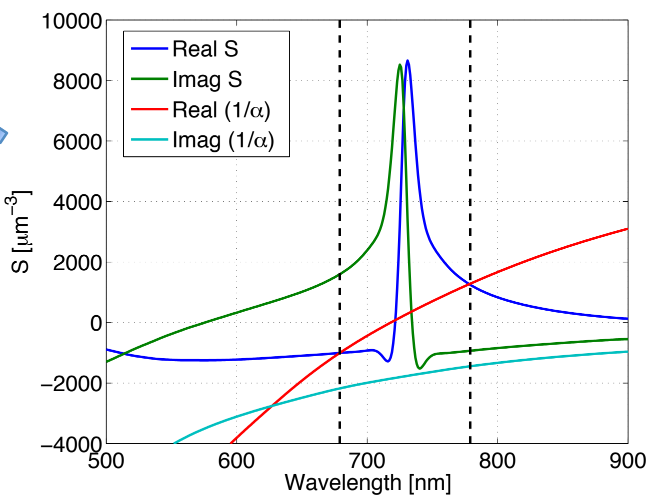
Triangular lattice

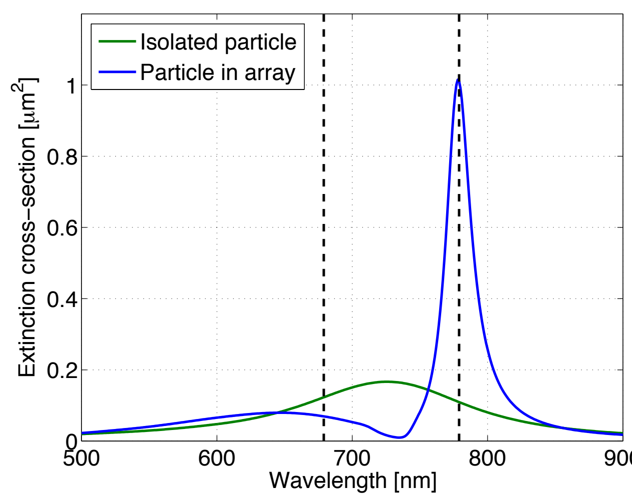
Experiment





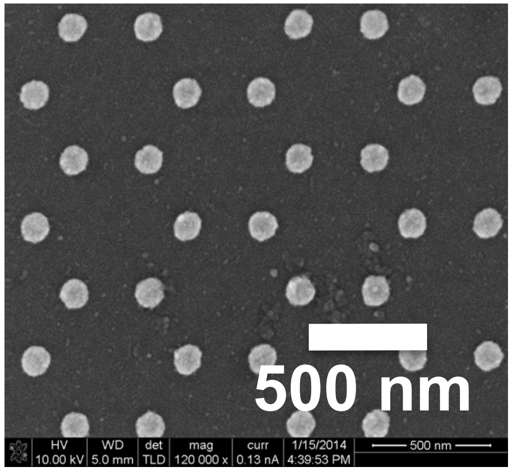
Model

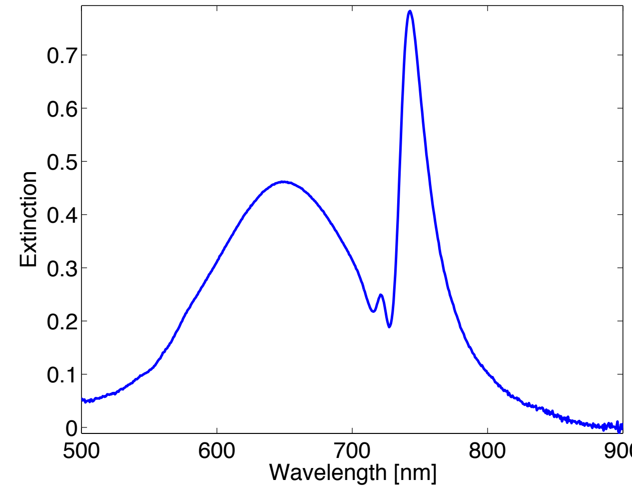




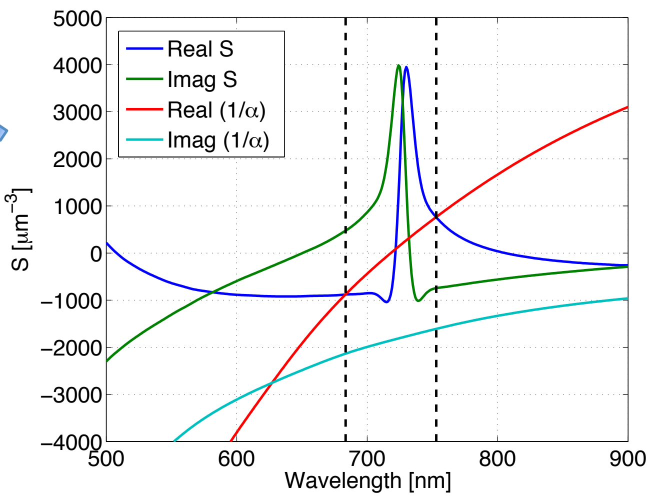
Honeycomb lattice

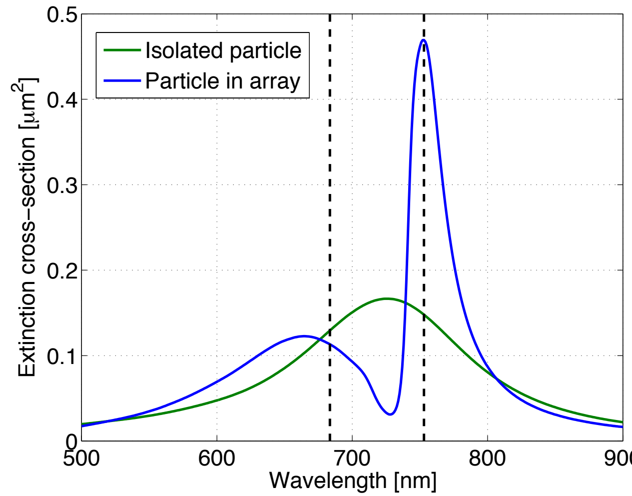
Experiment



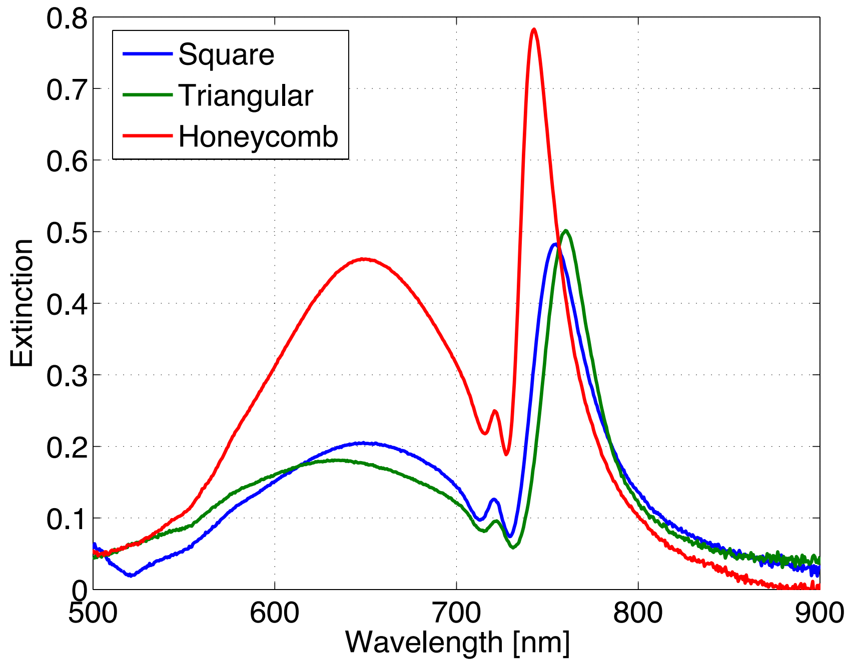


Model

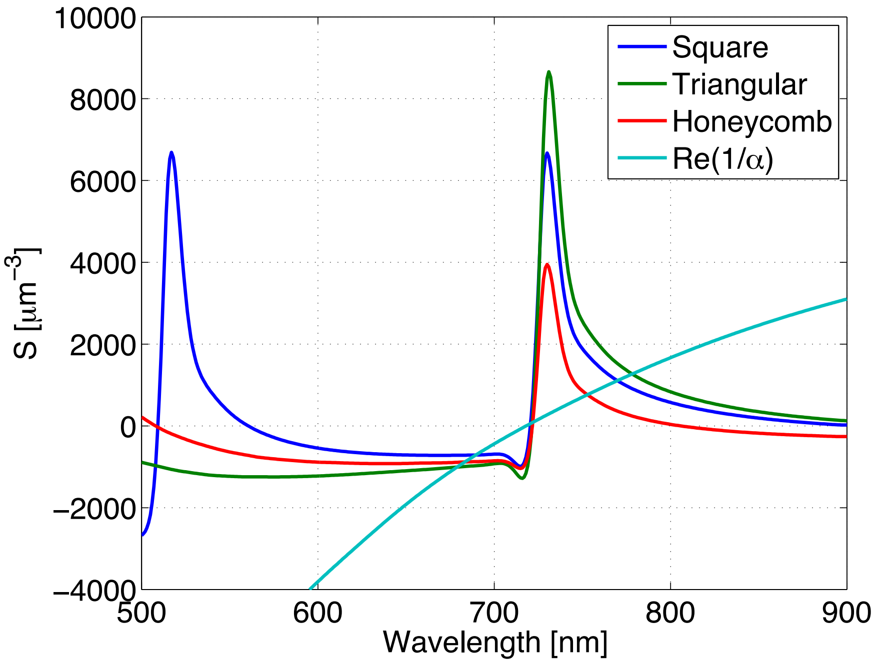




Comparison of lattices



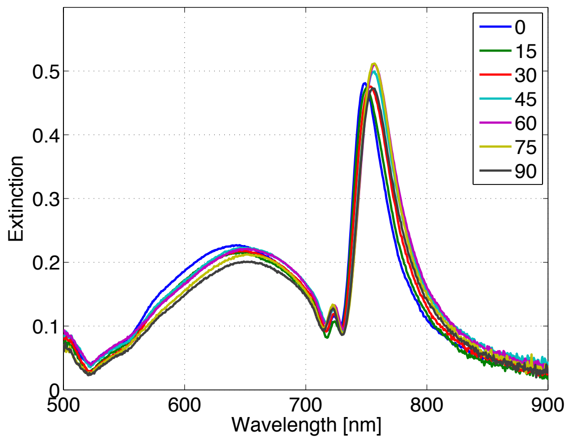
Experiment

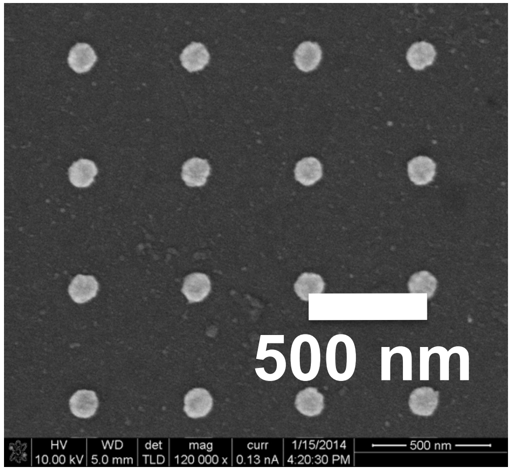


Model (*S* factor)

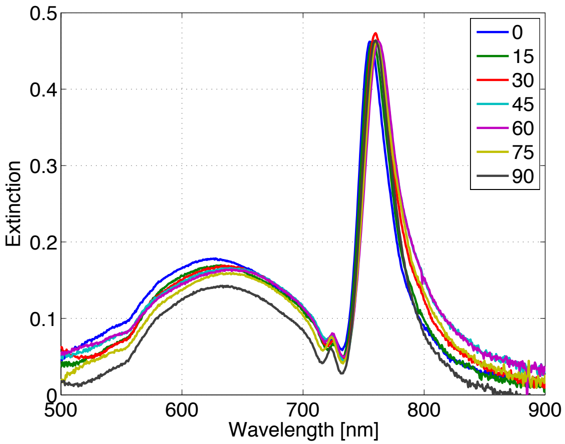
Polarization sensitivity

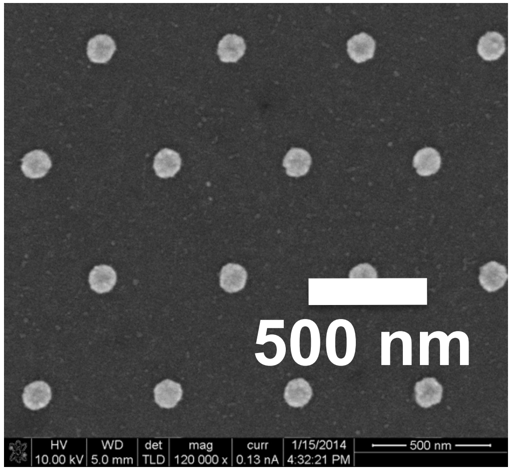
Square



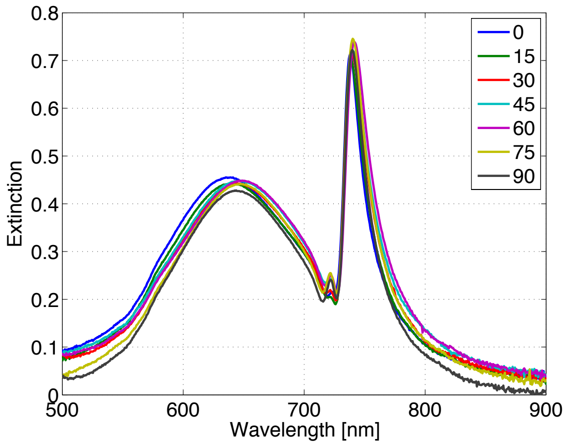


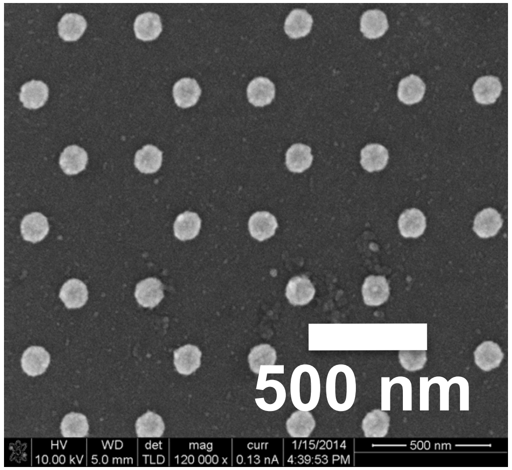
Triangular





Honeycomb





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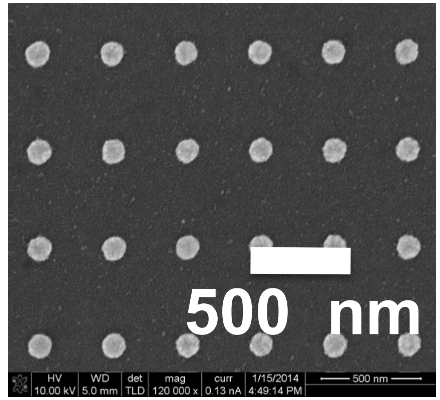
Rectangular lattice



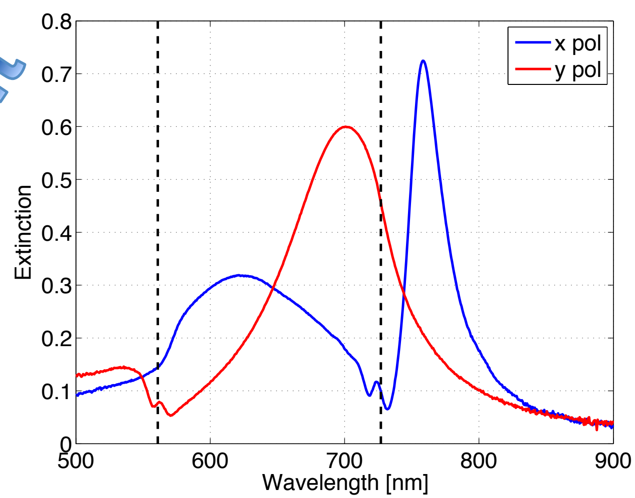
a_y=480 nm

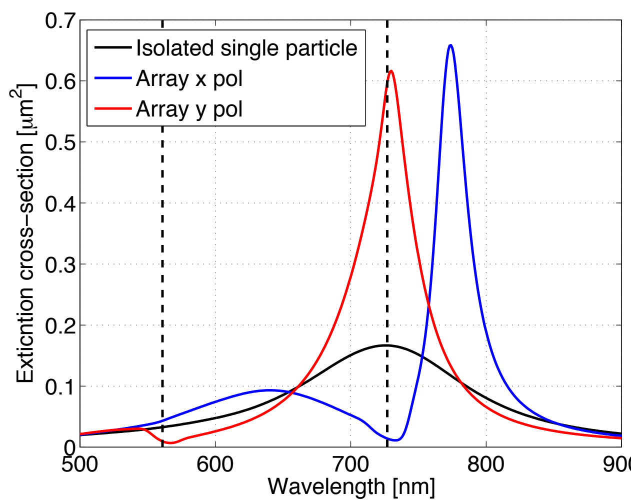
E_y

E_x

a_x=370 nm

Experiment





Model

Electromagnetic & Acoustic Materials

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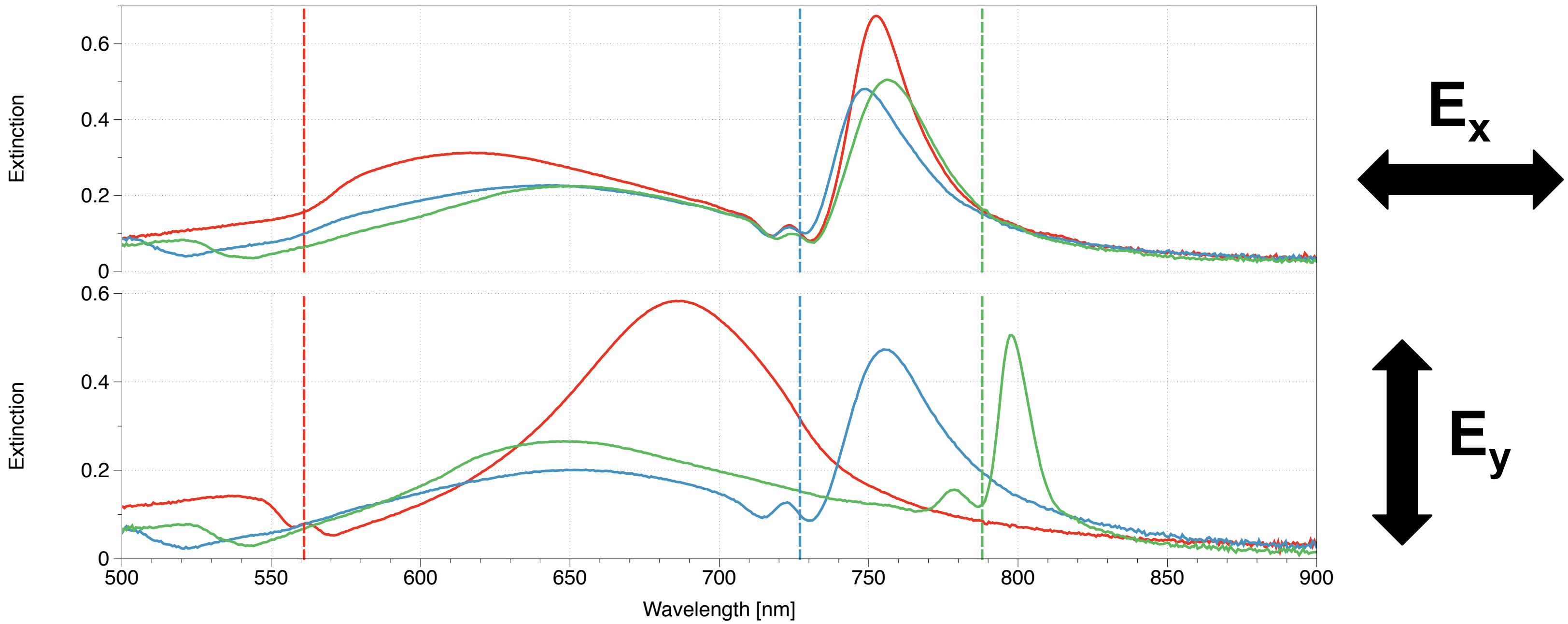
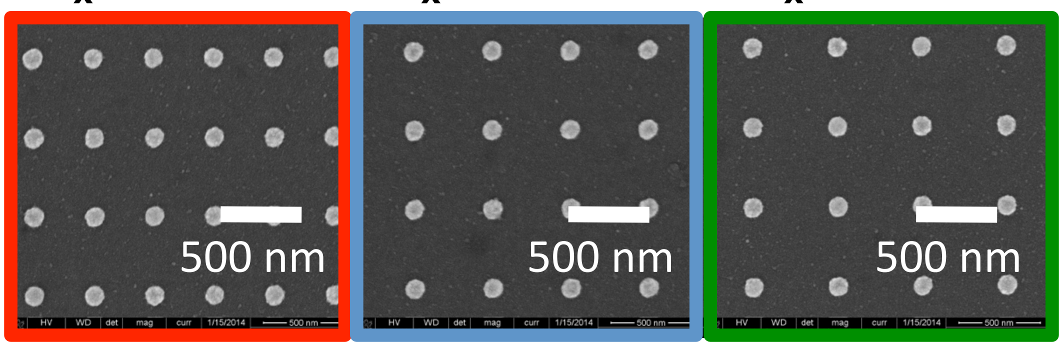
Rectangular lattice



a_x=370 nm | a_x=480 nm | a_x=520 nm

a_y=480 nm



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Conclusion / future work

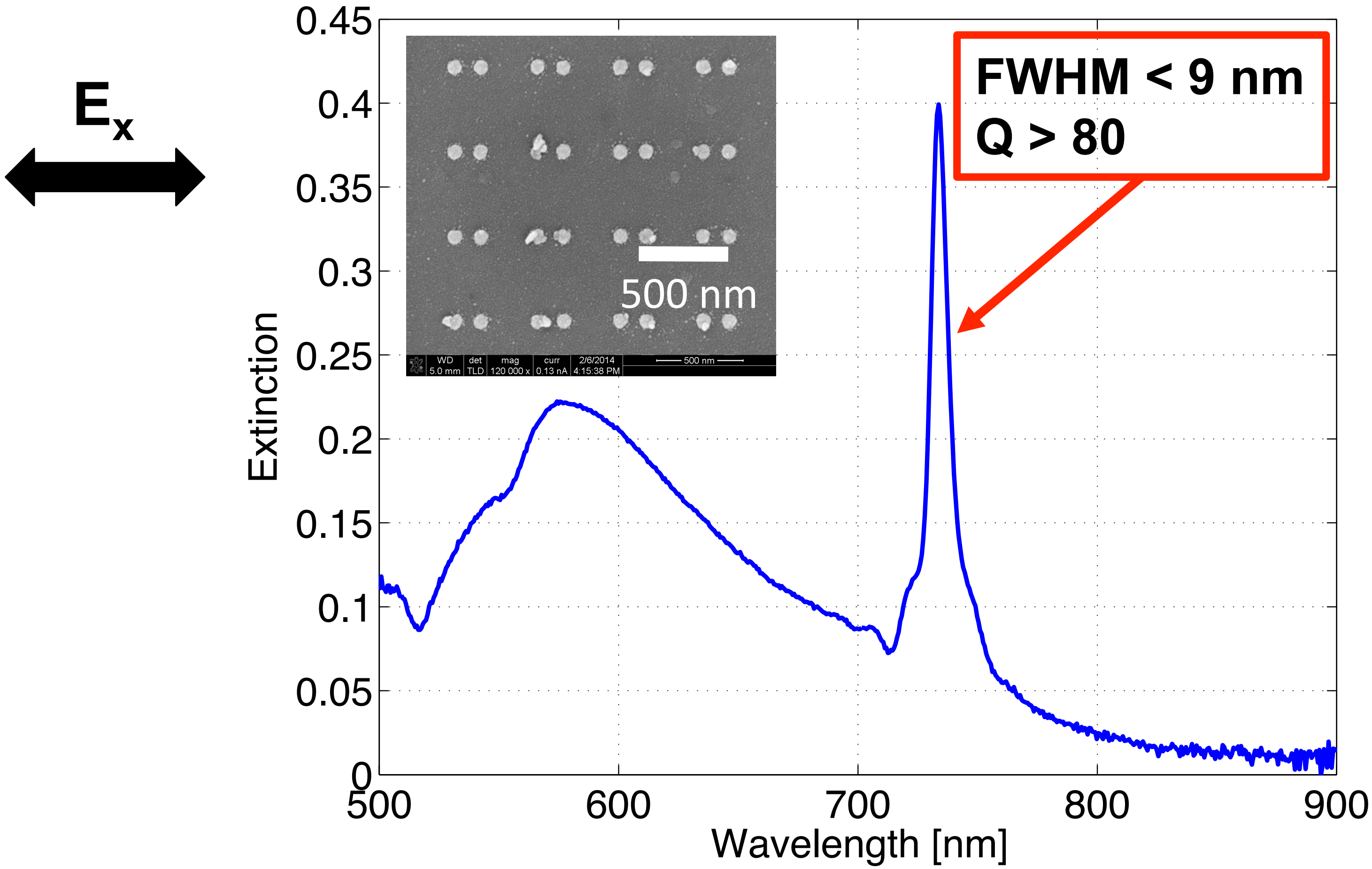
Conclusion

- Successfully fabricated arrays of metallic nanoparticles and modelled their optical response using a simple coupled-dipole model.
- Shown that square, triangular and honeycomb lattices exhibit SLRs and that their optical response is independent of the polarization.
- Confirmed using a rectangular array that particles mainly couple together in the direction orthogonal to the applied electric field.

Future work

- Change basis of lattice.

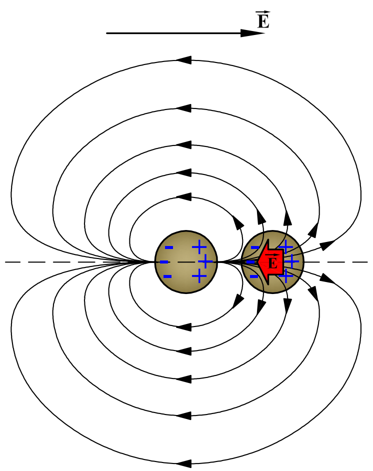
Conclusion / future work



Two particles

Parallel polarization

- E-field from neighbouring nanoparticle is in *opposite* direction to internal field of nanoparticle
- *Reduced* restoring force
- LSPR red-shifted



Perpendicular polarization

- E-field from neighbouring nanoparticle is in *same* direction to internal field of nanoparticle
- *Increased* restoring force
- LSPR blue-shifted