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

Extinction cross-section [μm²]

Extinction cross-section [μm²]

Model

E field

~ λ

Electromagnetic & Acoustic Materials
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

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

Resonant frequency dependent on size and shape
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.

$k_g = \frac{2\pi}{a}$
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?

\[ \vec{p}_{\text{arr}} = \alpha^* \vec{E}_{\text{inc}} \]
\[ \alpha^* = \frac{1}{1/\alpha - S} \]

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

\( S \) also complex

(array size 50 micron x 50 micron)
\[ \alpha^* = \frac{1}{1/\alpha - S} \]

Resonance position mainly determined by crossing points of real parts.

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

(model run for 400x400 particles) (smoothed using cubic spline)
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**

- Image of a square lattice with a scale bar indicating 500 nm.

**Model**

- Graphs showing extinction cross-section and real and imaginary parts of the S matrix vs. wavelength for isolated particles and particles in an array.

- Graphs for different wavelengths (500 nm to 900 nm) and different values of extinction cross-section.
Triangular lattice

Experiment

Model
Honeycomb lattice

Experiment

Model

- Real S
- Imag S
- Real (1/α)
- Imag (1/α)

Extinction cross-section [µm²]

- Isolated particle
- Particle in array

Extinction

Wavelength [nm]
Comparison of lattices

Experiment

Model (S factor)
Polarization sensitivity

Square

Triangular

Honeycomb

Wavelength [nm]

Extinction

500 nm

500 nm

500 nm
Rectangular lattice

\[ a_y = 480 \text{ nm} \]

\[ a_x = 370 \text{ nm} \]

Experiment vs. Model

Extinction vs. Wavelength

- Isolated single particle
- Array x pol
- Array y pol
Rectangular lattice

![Graph showing extinction vs. wavelength for different lattice parameters. The graphs illustrate the variation of extinction with wavelength for different lattice constants, showing peaks at specific wavelengths.](image)

- **a_x** = 370 nm
- **a_x** = 480 nm
- **a_x** = 520 nm

**a_y** = 480 nm

Wavelength [nm]:
- 500
- 550
- 600
- 650
- 700
- 750
- 800
- 850
- 900
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

**Extinction vs. Wavelength**

- **E_x**
- **FWHM < 9 nm**
- **Q > 80**

Inset: 500 nm scale bar

Wavelength [nm] vs. Extinction graph

- **0** to **0.45** Extinction
- **500** to **900** Wavelength [nm]
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