Voltage Controlled Nanoparticle Plasmon Resonance Tuning through Anodization

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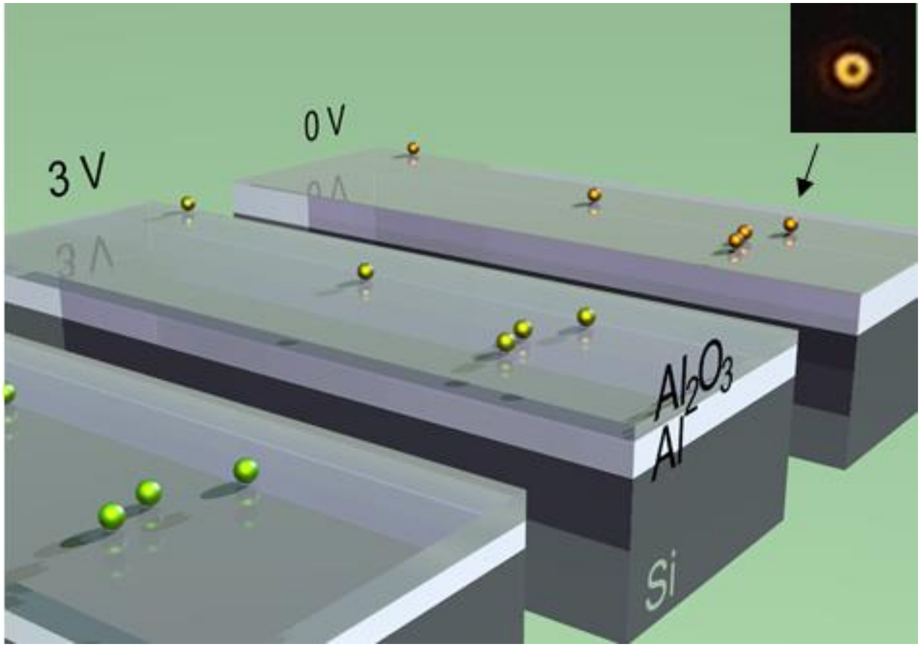
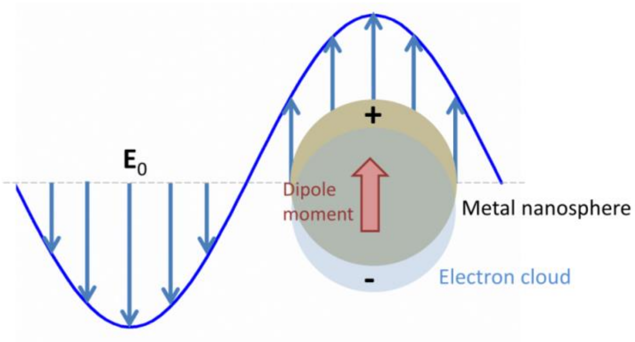


Introduction

- Localized Surface Plasmon Resonance (LSPR)
  - Provide a strong field enhancement
  - Application:

    SERS, non-linear enhancement, solar cell, etc.

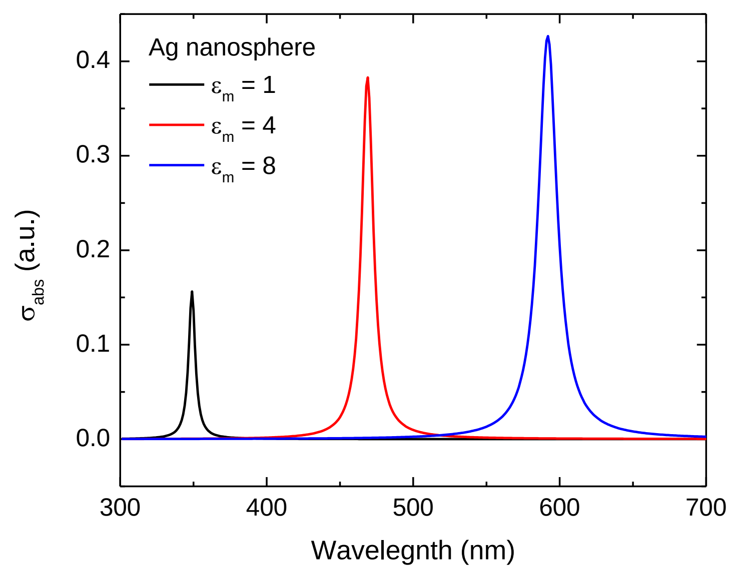


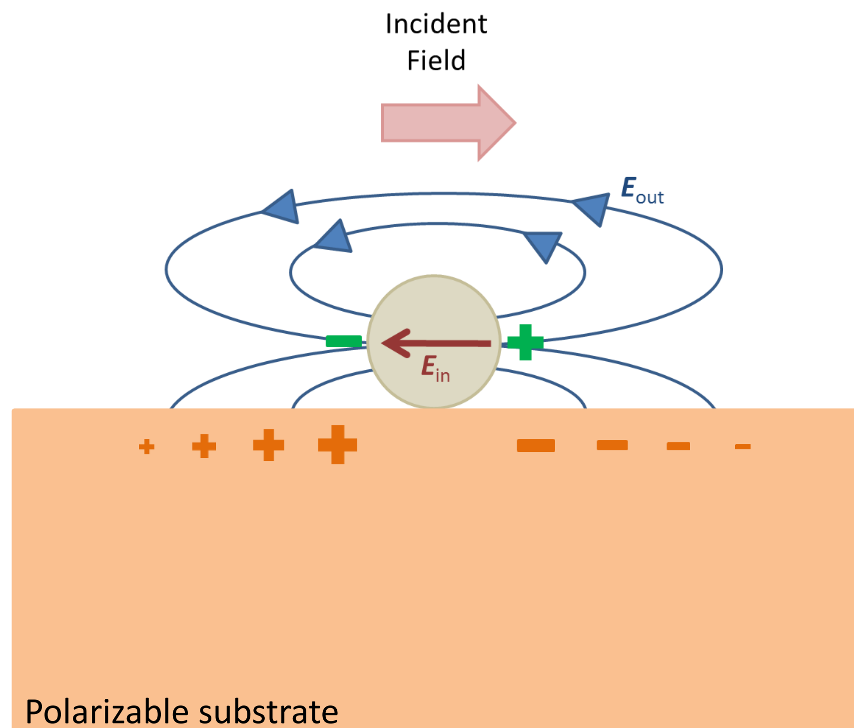
Introduction

- Localized Surface Plasmon Resonance (LSPR)
  - Provide a strong field enhancement
  - Application:

    SERS, non-linear enhancement, solar cell, etc.

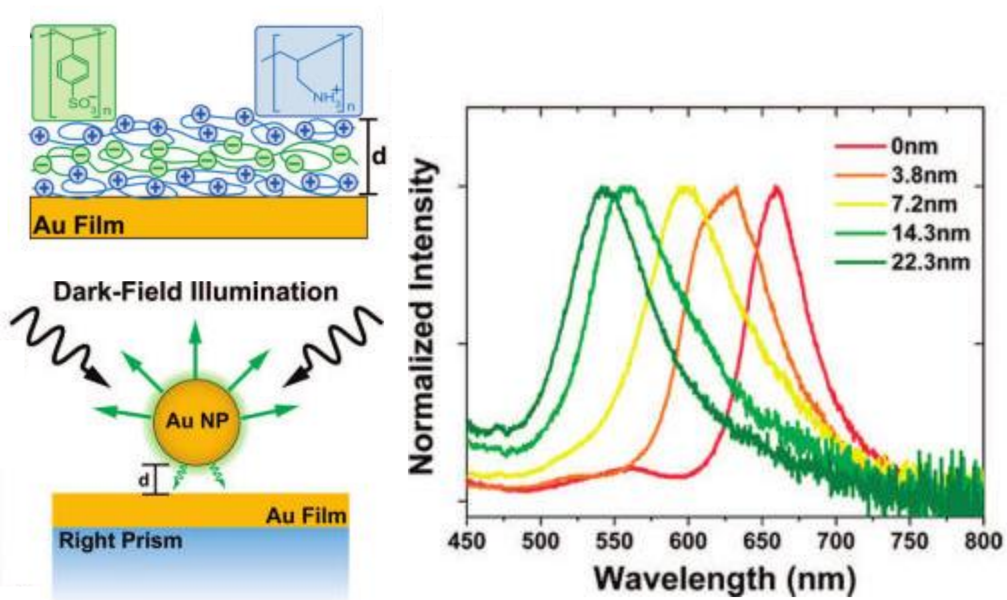
- Plasmon Resonance Tuning
  - Resonance wavelength is crucial

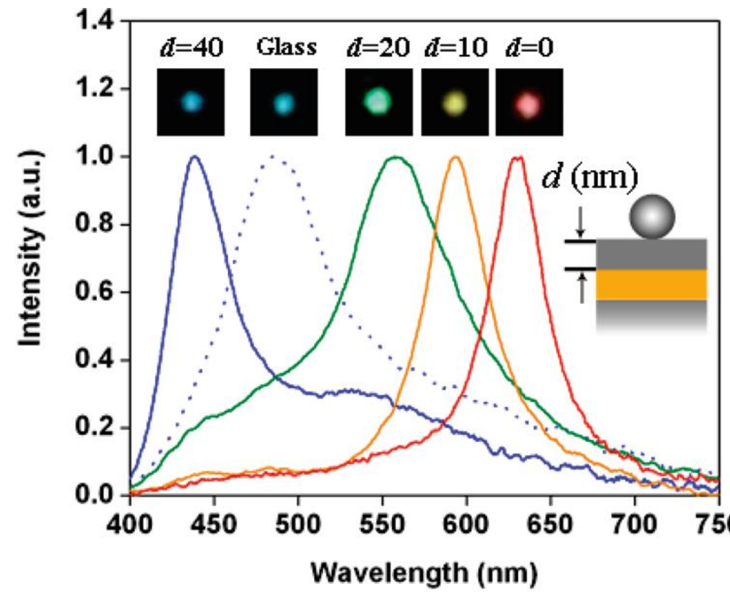




Substrate based Resonance Tuning

- Controlling particle-substrate interaction
  - Two single particle resonance tuning examples:





J. J. Mock, et al. Nano Lett. 2008, 8, 2245–2252

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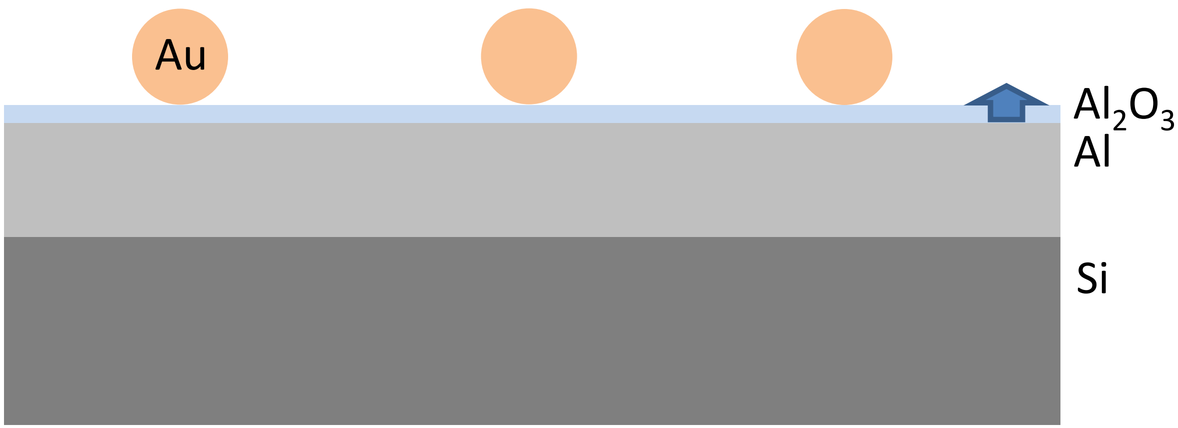
- Challenges: fixed resonance, thermal stability?, layer adhesive?

Gold nanoparticle on Aluminum film

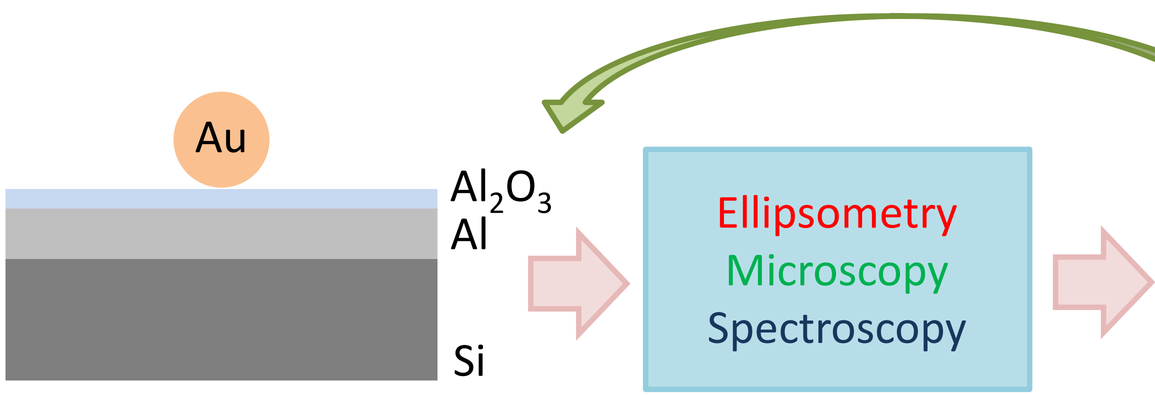
- Challenges: fixed resonance, thermal stability?, layer adhesive?
- Goals: tunable resonance, thermally stable, good adhesion
- Proposed system:
  - Gold nanoparticles on an aluminum film
  - Au provides resonance in visible with high stability
  - Al high plasma frequency, voltage controlled growth of a stable Al_2O_3 spacer layer

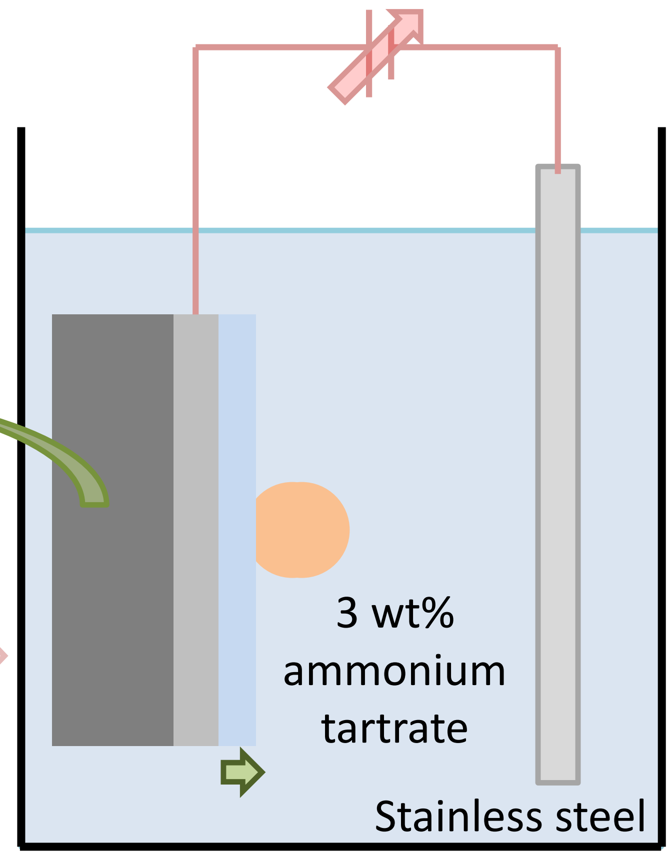


Voltage controlled resonance tuning !

Experimental Process

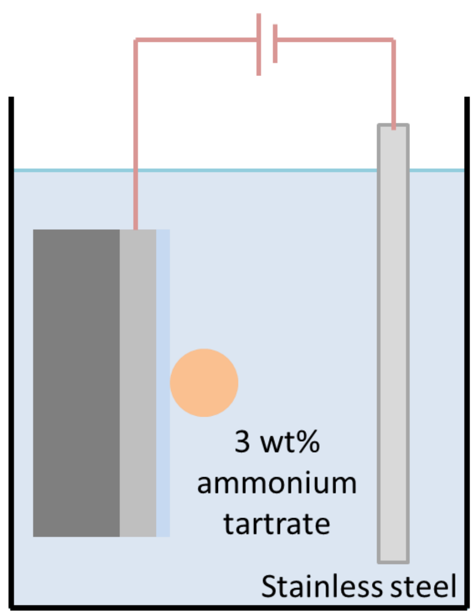
- Sample
  - 100 nm Al film on silicon wafer (with native Al_2O_3 layer)
  - 60 nm diameter Au nanoparticles were deposited on the substrate
- Ellipsometry, microscopy, and spectroscopy
  - Measure Al_2O_3 thicknesses
  - Scattering images,
  - Scattering spectra,
- Anodization
  - Voltage controlled Al_2O_3 thickness

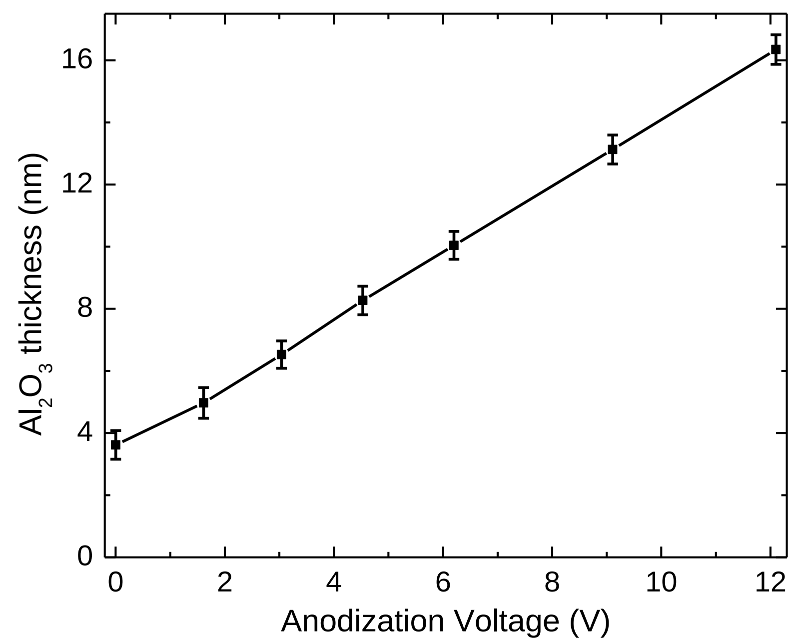




Measurement results

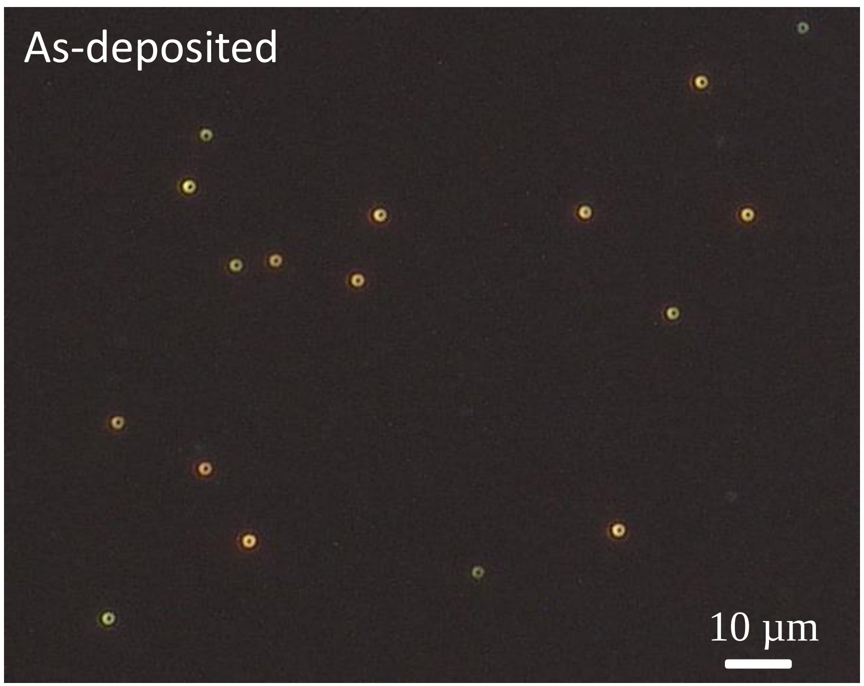
- Ellipsometry
  - Linearly voltage controlled Al_2O_3 thickness → voltage controlled interaction

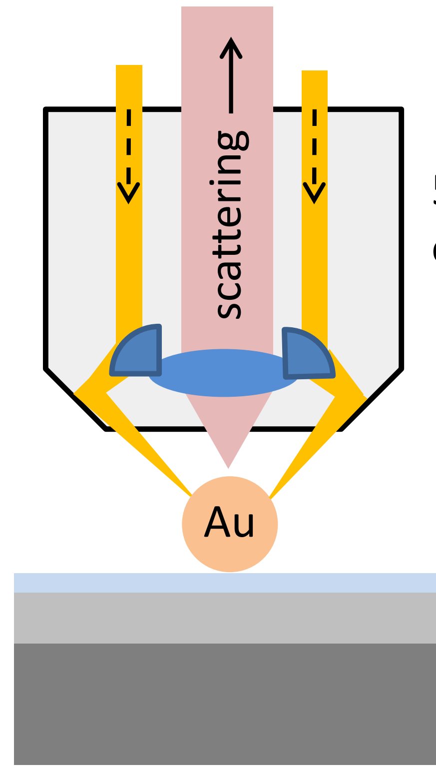




Measurement results

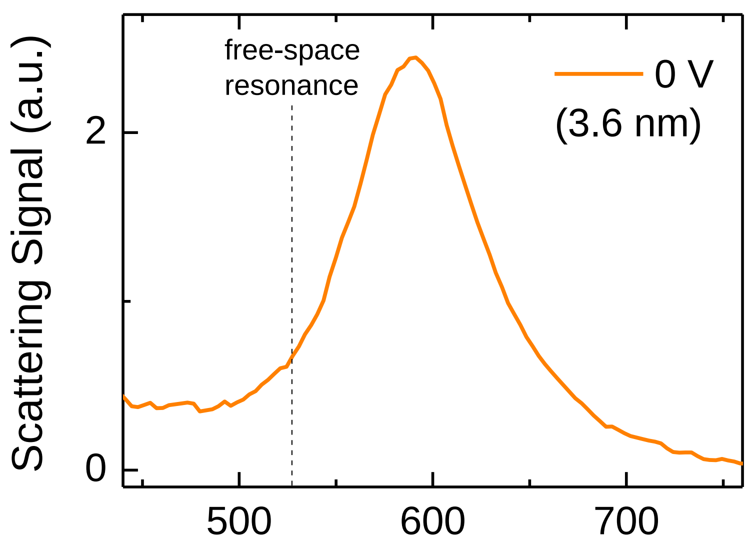
- Ellipsometry
  - Linearly voltage controlled Al_2O_3 thickness → voltage controlled interaction
- Dark-field microscopy
  - Well separated, ring-shaped images



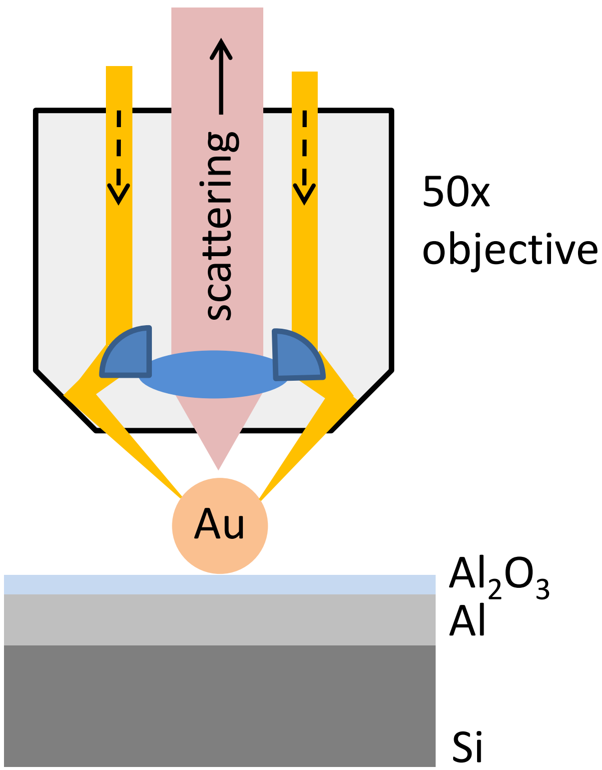


Measurement results

- Ellipsometry
  - Linearly voltage controlled Al_2O_3 thickness → voltage controlled interaction
- Dark-field microscopy
  - Well separated, ring-shaped images
- Single particle spectroscopy
  - Red-shift compared to a free-space resonance

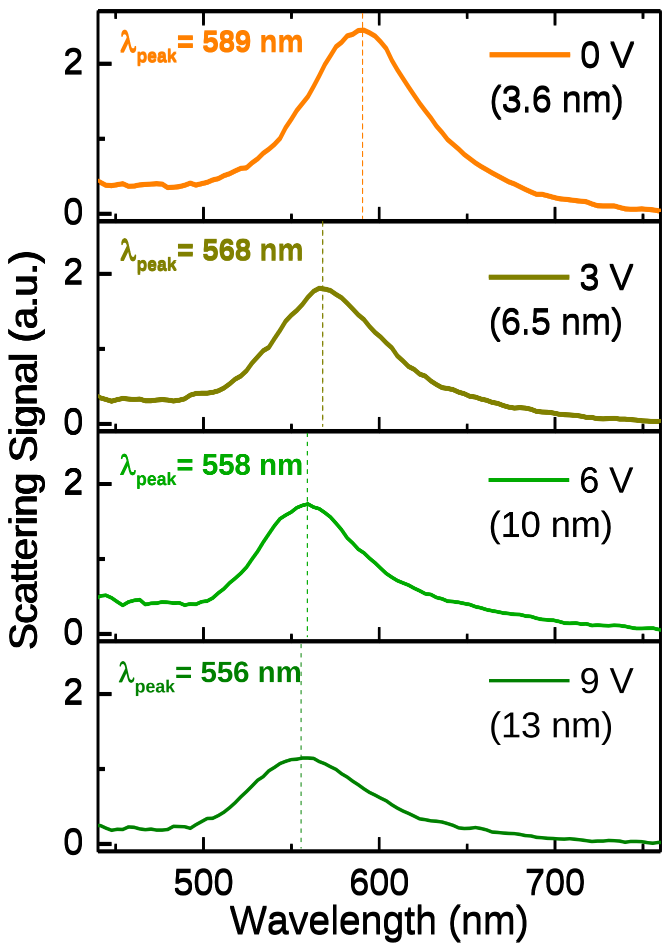


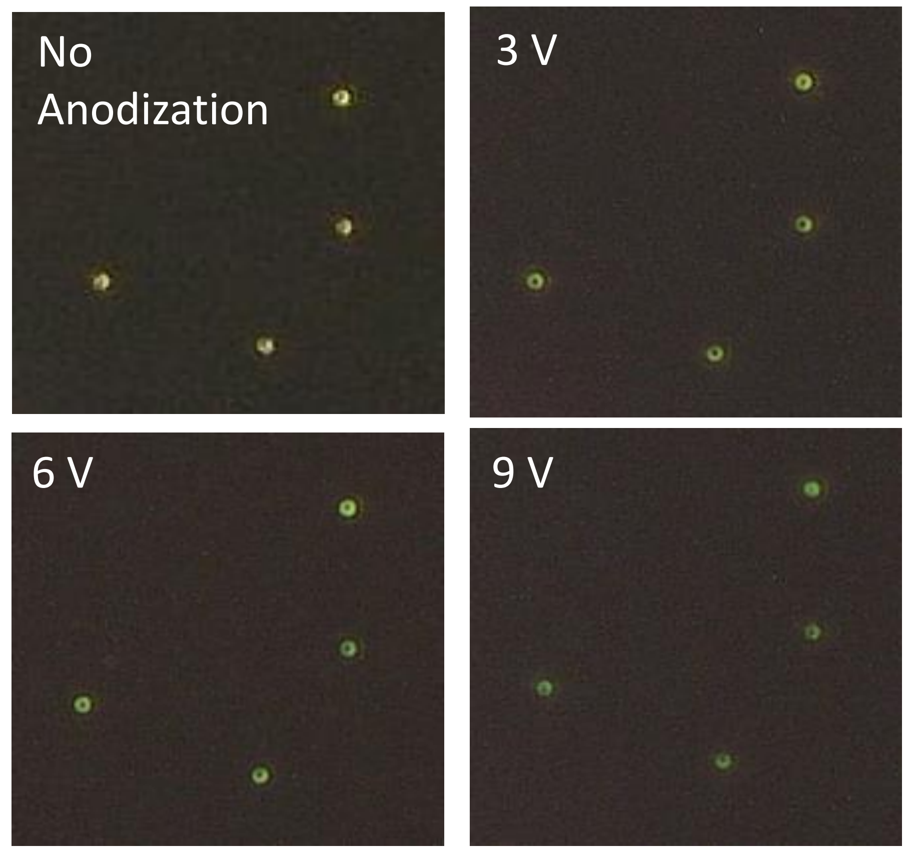
$I_{SC} = (I_{NP} - I_{REF})/I_{IN}$



Measurement results

- Same set of the gold nanoparticles
  - Resonances blue-shift, reduce scattering



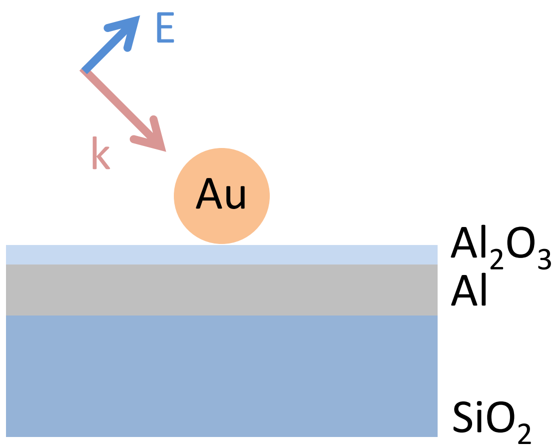


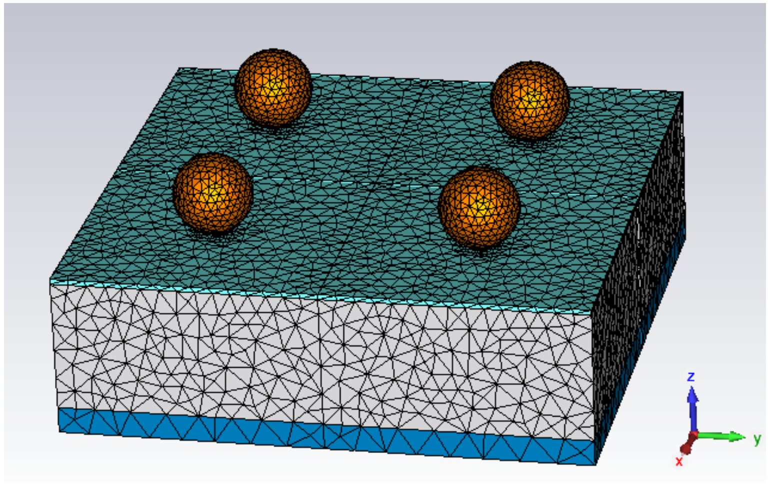
Simulation

- Simulation was conducted based on the experimental structure replacing Si with SiO_2

- Incident angle in the simulations was set at 53° to the surface normal

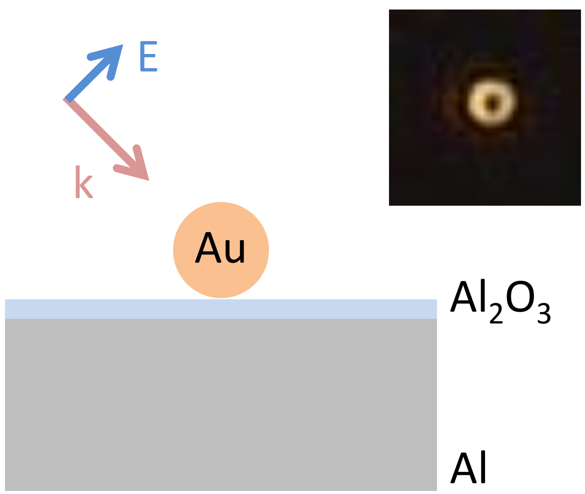
- Three-dimensional frequency domain electromagnetic simulation
  Unit cell boundaries with 200 nm lattice spacing



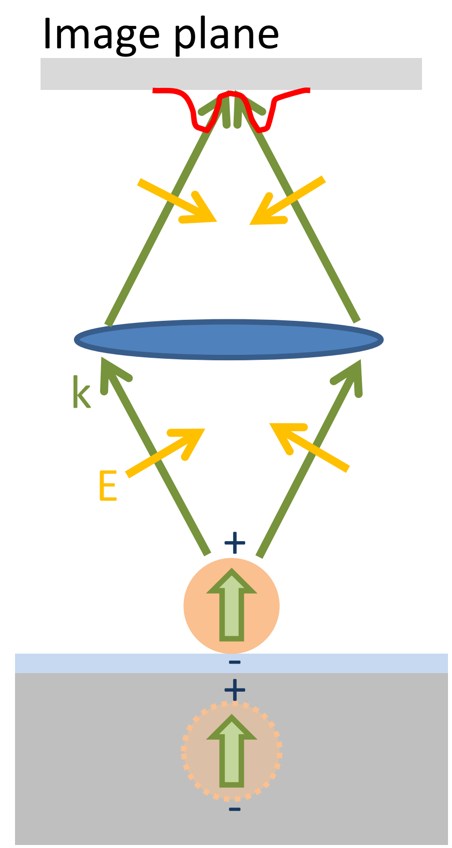


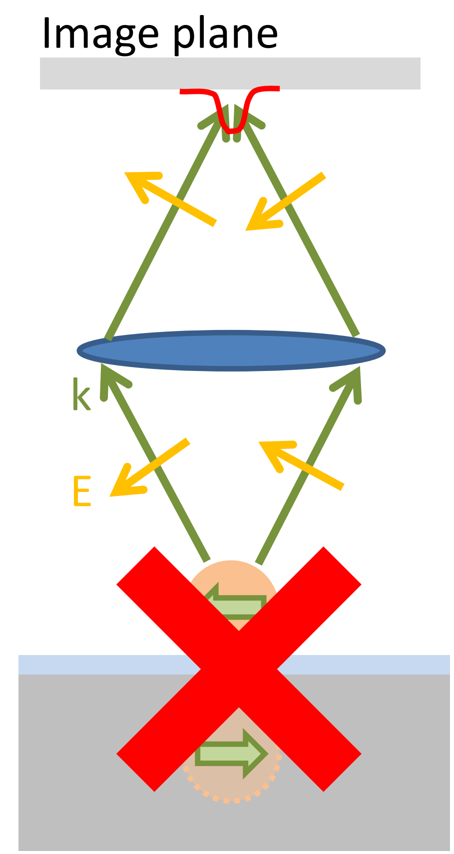
Simulation

- Ring-shape scattering pattern observed in a dark field microscopy image suggests a vertical electric dipole oscillation



Net dipole → Bright
Quadrupole → Dark

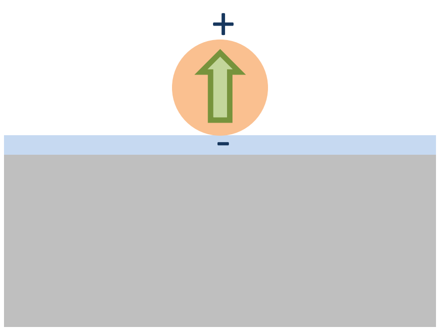




Simulation

- Ring-shape scattering pattern observed in a dark field microscopy image suggests a vertical electric dipole oscillation

- Scattering spectra were calculated using a dipole radiation model



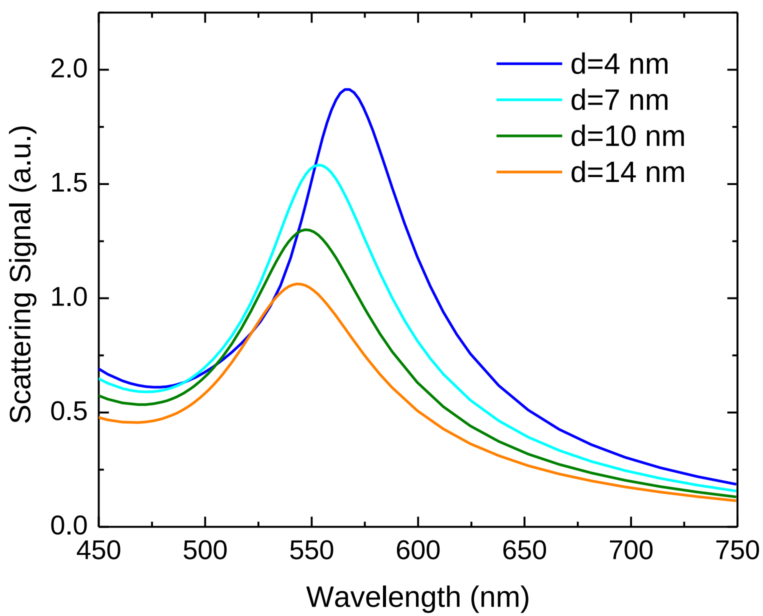
$$P_{rad} \propto |\mu_z|^2 \omega^4$$

$$\mu_z = \epsilon_0 \chi_{Au} < E_z > \times Vol$$

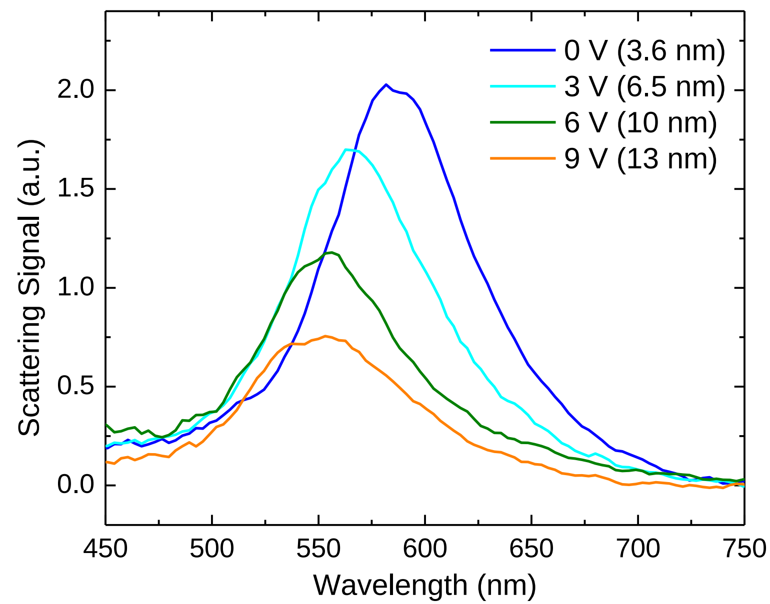
Tuning Results

- Calculated scattering spectra show the same tuning trend as observed in the experiment

- The resonances show blue-shift and decreasing in scattering intensity as Al_2O_3 thickness increases



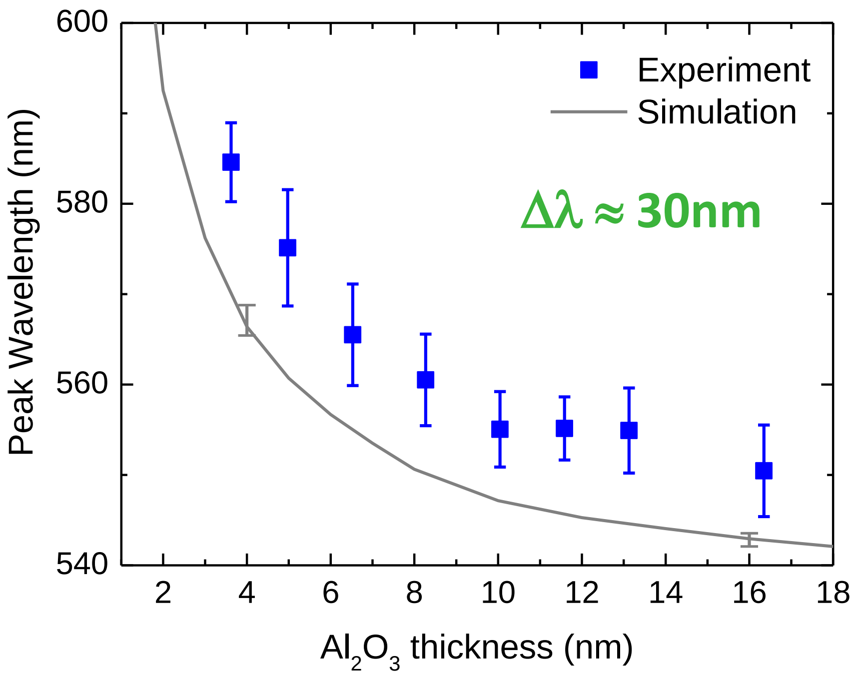
Simulation

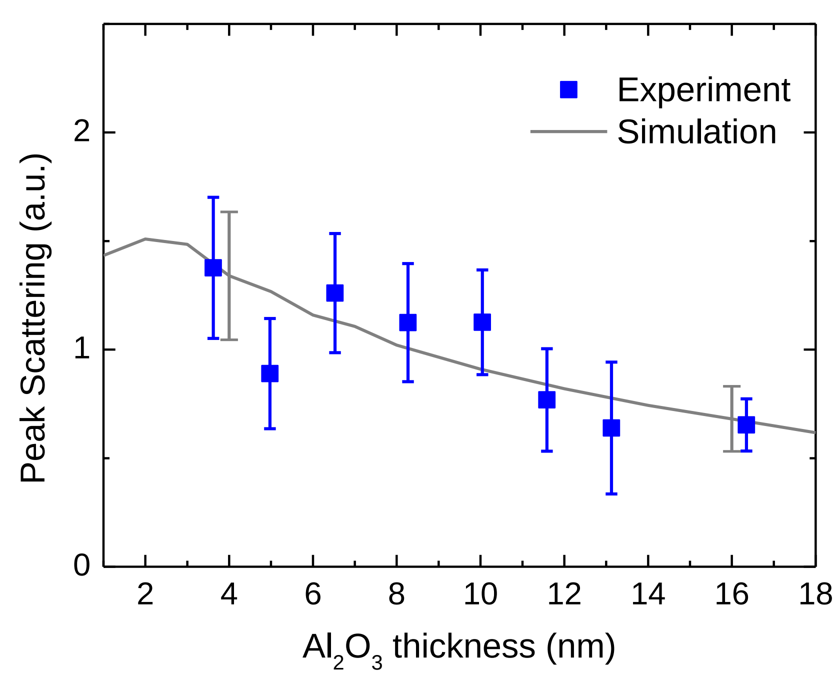


Experiment

Tuning Results

- Observed: ~30 nm resonance blue-shift upon increasing Al_2O_3 thickness
- 50 % change in brightness observed
- Small particle to particle variation, possibly due to size, faceting, local residues





C. Lumdee, et al. ACS Nano 2012, 6, 6301−6307

Conclusion

- Resonance tuning: single gold nanoparticles on anodized Al film
- Expect: high chemical and thermal stability system
- Voltage controlled resonance tuning
- Single particle tracking → post-deposition tuning
- Selective electric dipole oscillation
- Blue-shift and reduced scattering spectra
- Confirm with numerical calculations