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CREOL UCF

Wide-band Spectral Control of Au Nanoparticle Plasmon Resonances on a Thermally and Chemically Robust Sensing Platform

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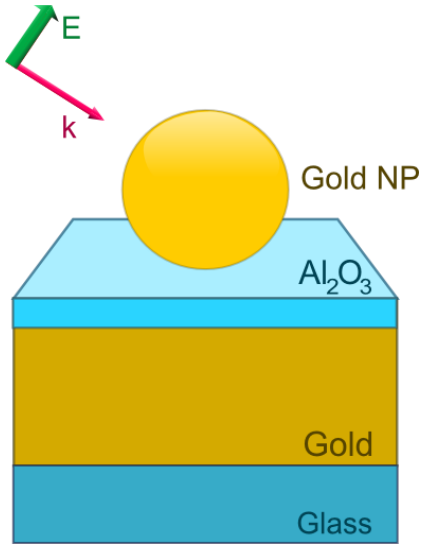
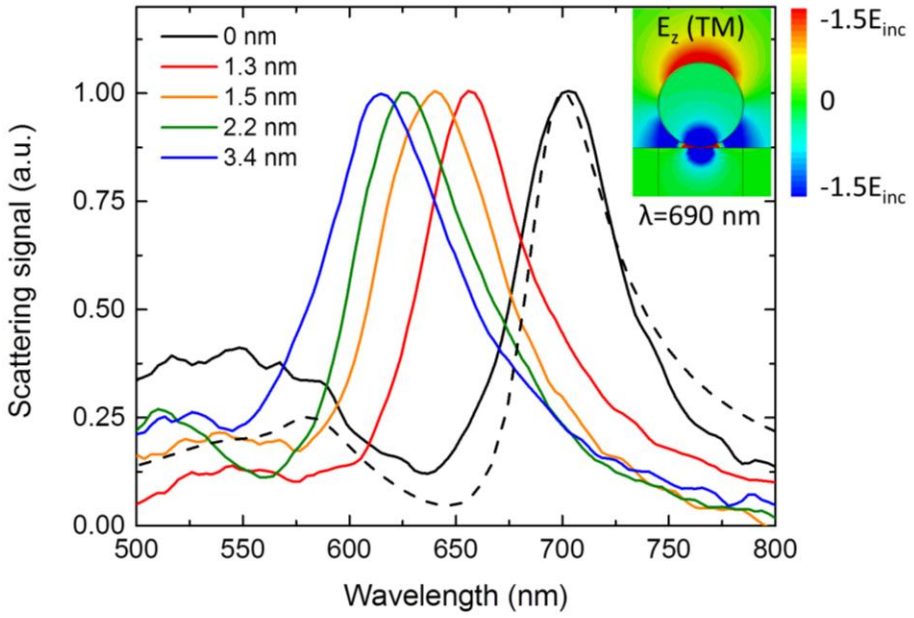
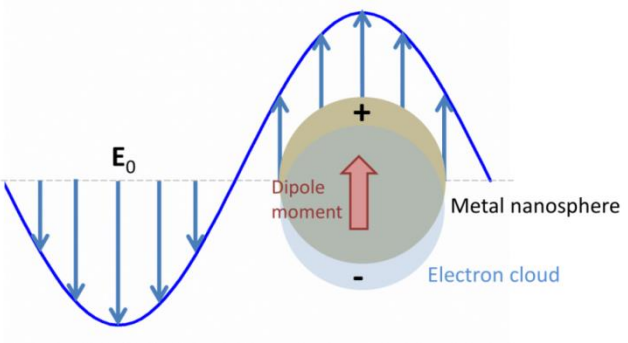
CREOL, the College of Optics and Photonics, UCF, Orlando, FL, USA





Introduction

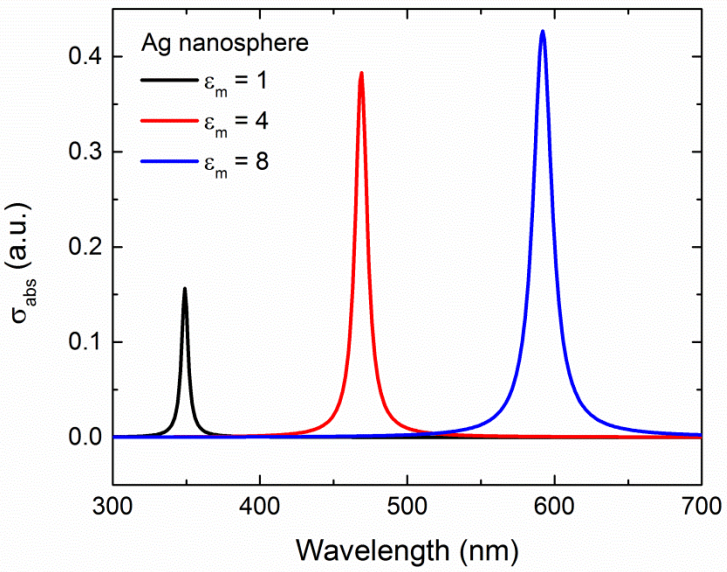
- Localized Surface Plasmon Resonance (LSPR)
  - Provide a strong field enhancement
  - Application:
    SERS, non-linear enhancement, solar cell, etc.

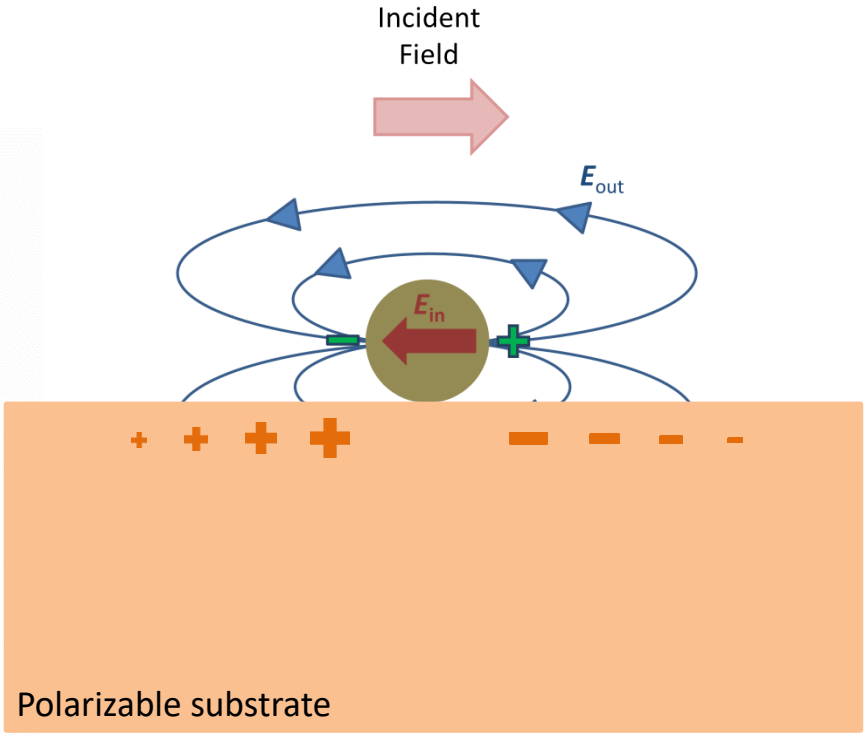


Introduction

- 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

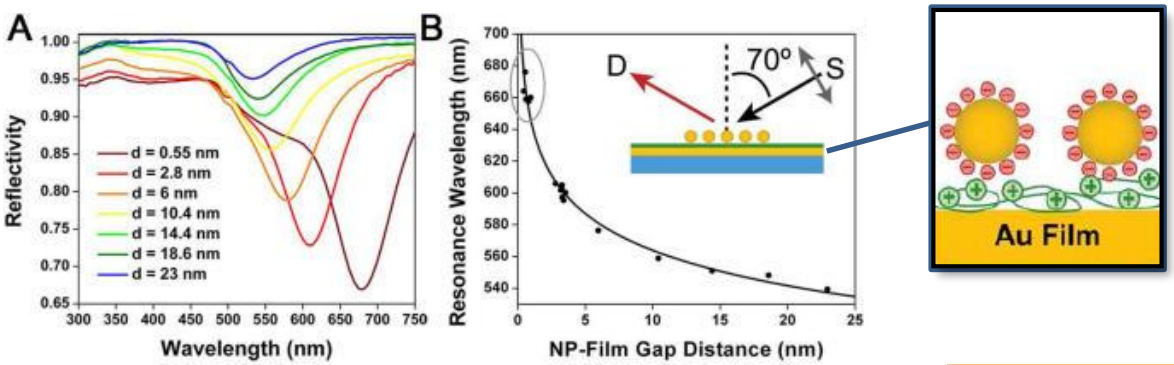




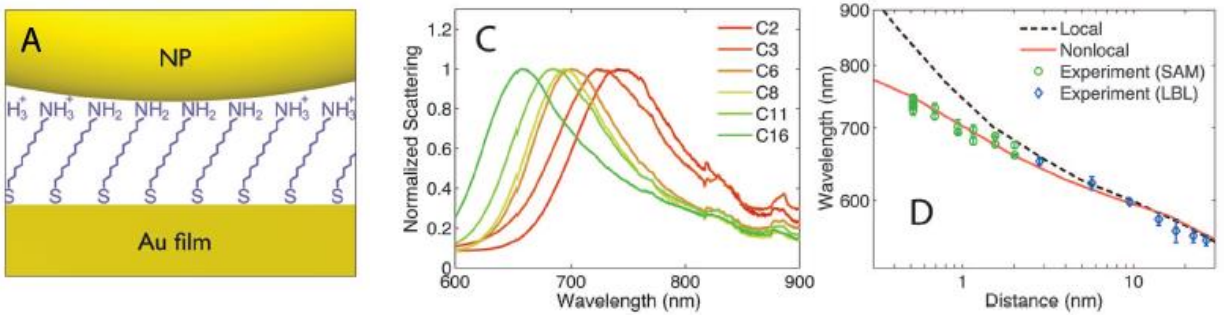
Substrate based Resonance Tuning

- Controlling particle-substrate interaction
  - Using Organic layers –
    e.g. polyelectrolyte (PE) layers, amine-terminated alkanethiol

J. J. Mock, et al. Nano Lett. 2012, 12(4), pp 1757−1764



C. Ciraci, et al. Science 2012, 337, pp 1072−1074

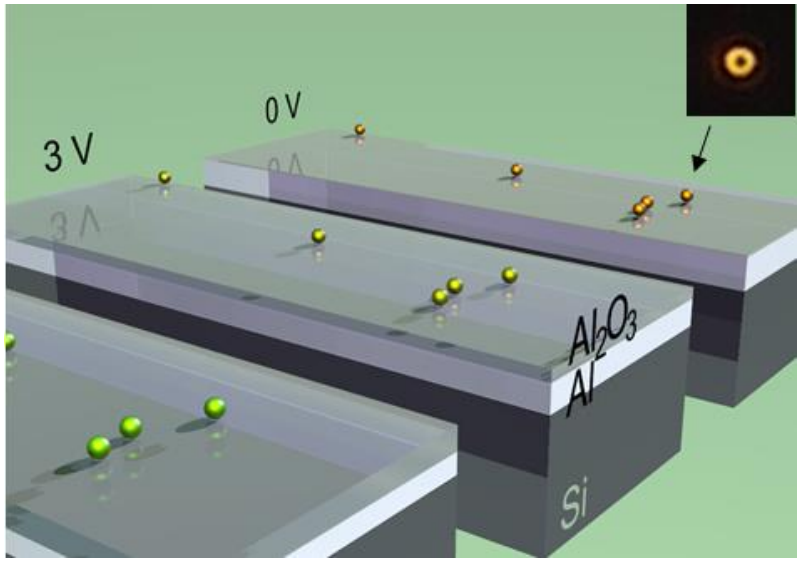


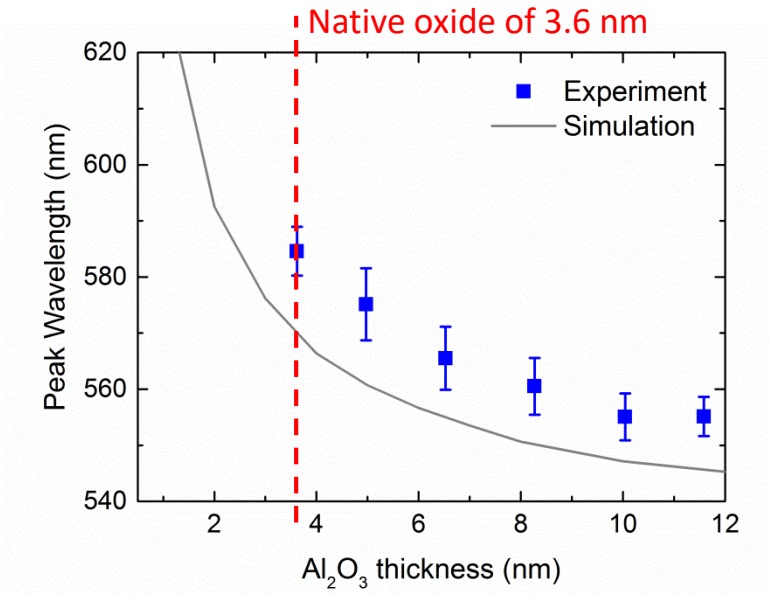
- Challenges: background signal, thermal/chemically stability

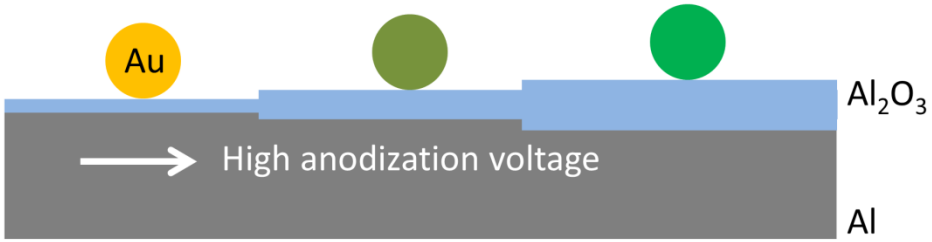
Substrate based Resonance Tuning

- Controlling particle-substrate interaction
  - Single particle resonance tuning using metal oxide film

C. Lumdee, et al. ACS Nano 2012, 6(7), pp 6301−6307





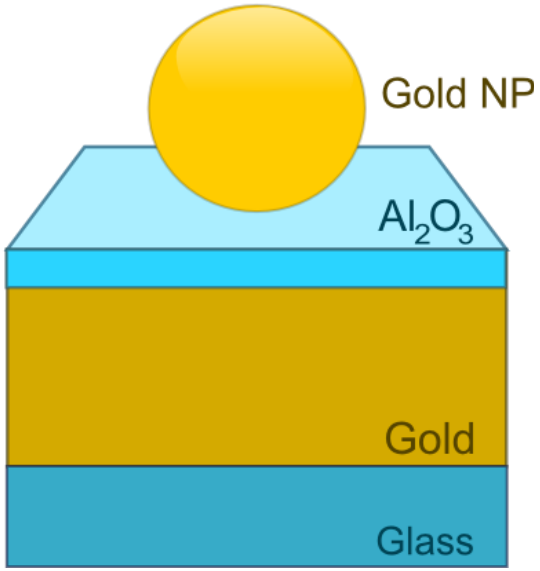


- Challenges: small resonance tuning range

Gold nanoparticle on Al_2O_3 coated gold film

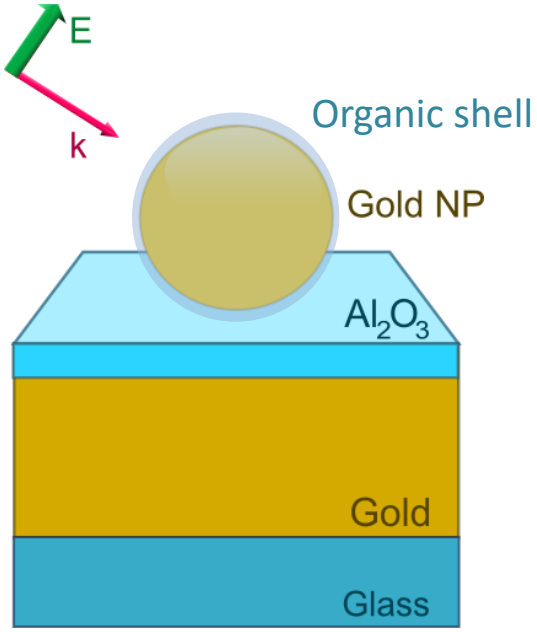
- Challenges:
  - background signal, thermal/chemically stability
  - small resonance tuning range

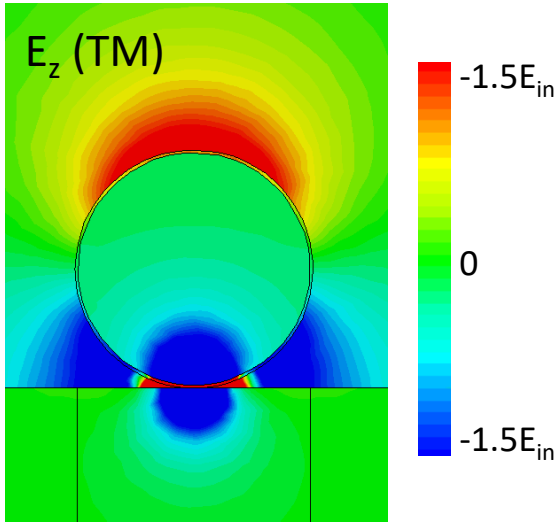
- Proposed system:
  - Gold nanosphere and Al_2O_3 → stable, no background
  - Spacer layer < native Al_2O_3



Numerical Simulation

- Gold nanoparticle (60 nm diameter) on Al_2O_3 coated gold film
  - Frequency domain finite integration technique (CST microwave studio®)
  - Dipole moment summation $\vec{\mu}_{NP} = \epsilon_0 \int_V \chi \vec{E}(\vec{r}) d\vec{r}$
  - Assume electric dipole radiation $I_{scat} \alpha |\vec{\mu}_{NP}|^2 \omega^4$

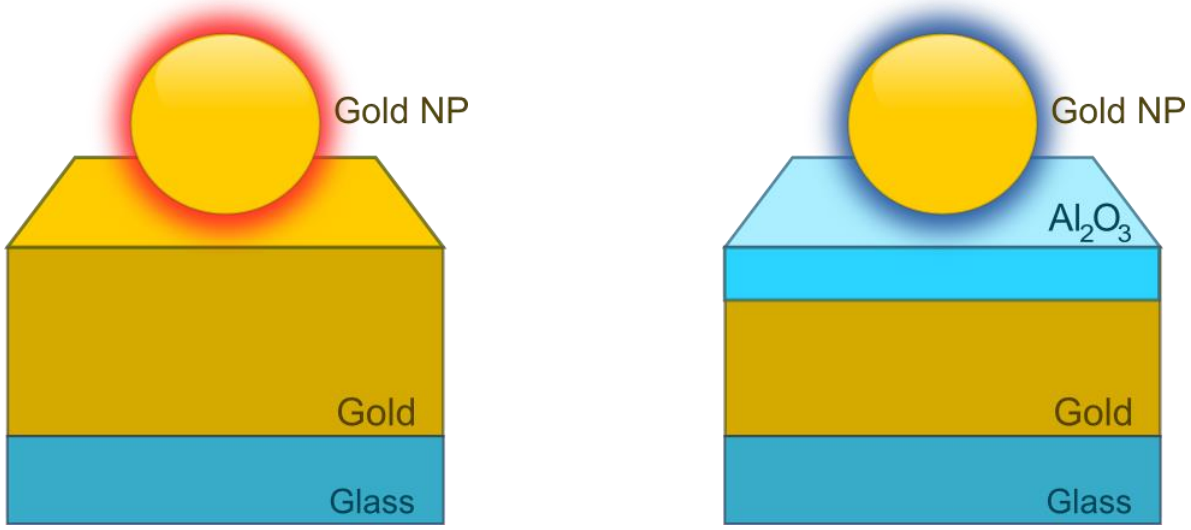




λ=690 nm

Numerical Simulation

- Gold nanoparticle (60 nm diameter) on Al_2O_3 coated gold film
  - AuNP on gold films without and 4 nm Al_2O_3 coating
  - Multi-resonance modes
  - Tuning range ~ 100 nm



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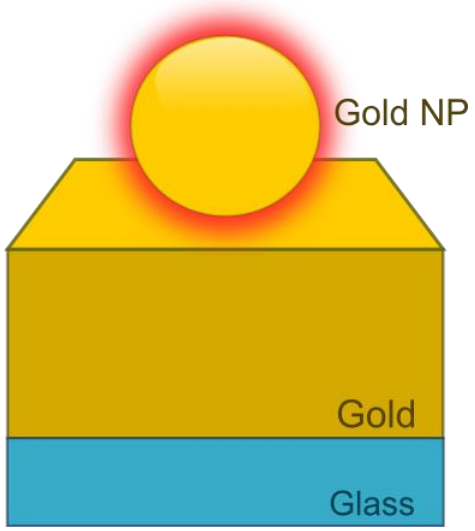

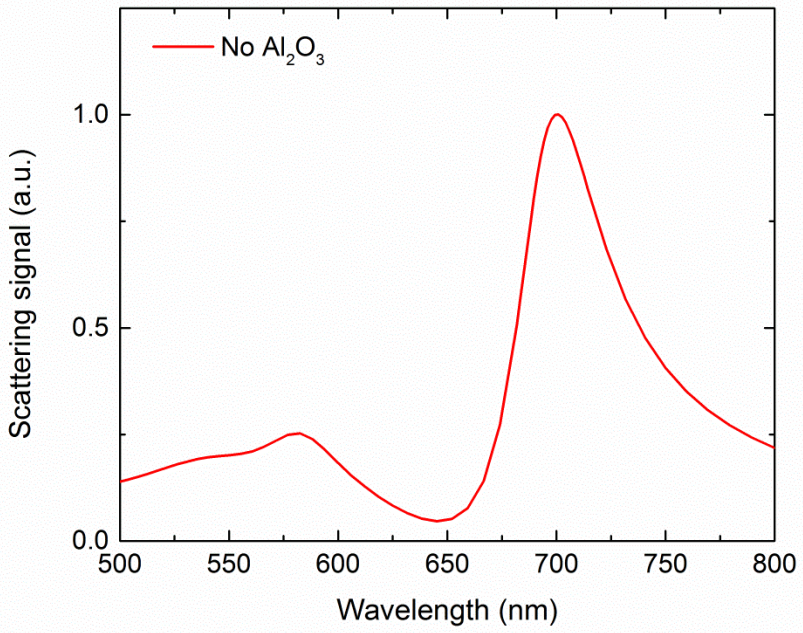

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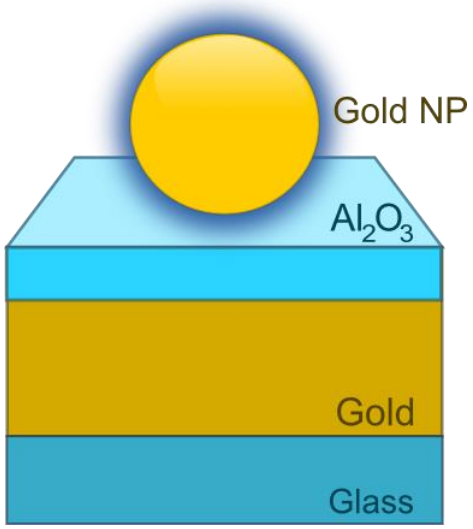
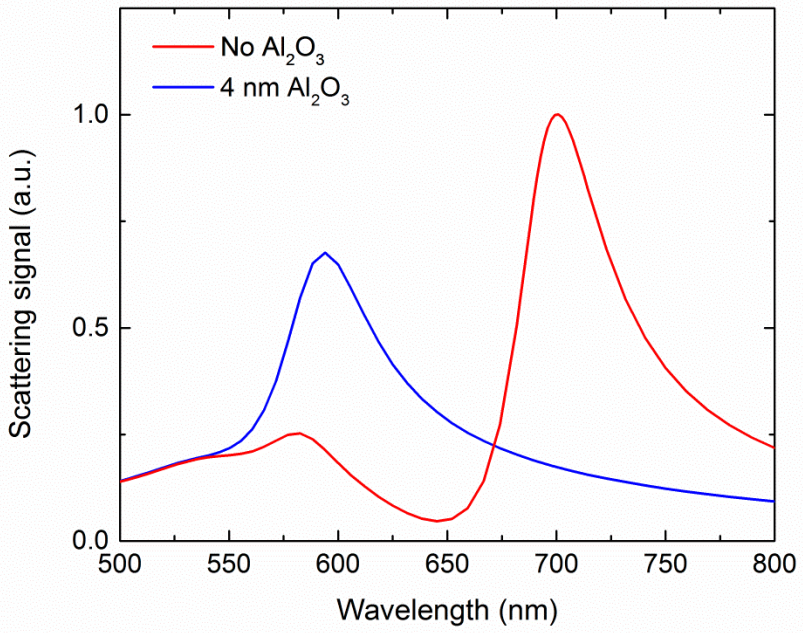
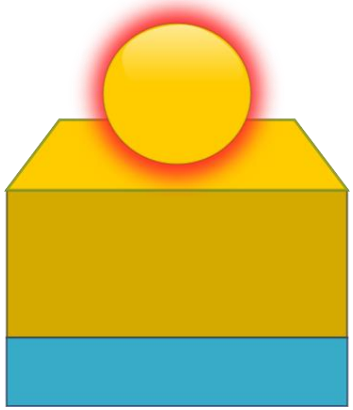


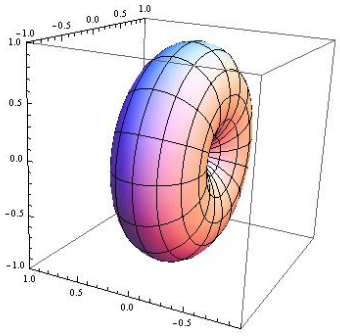


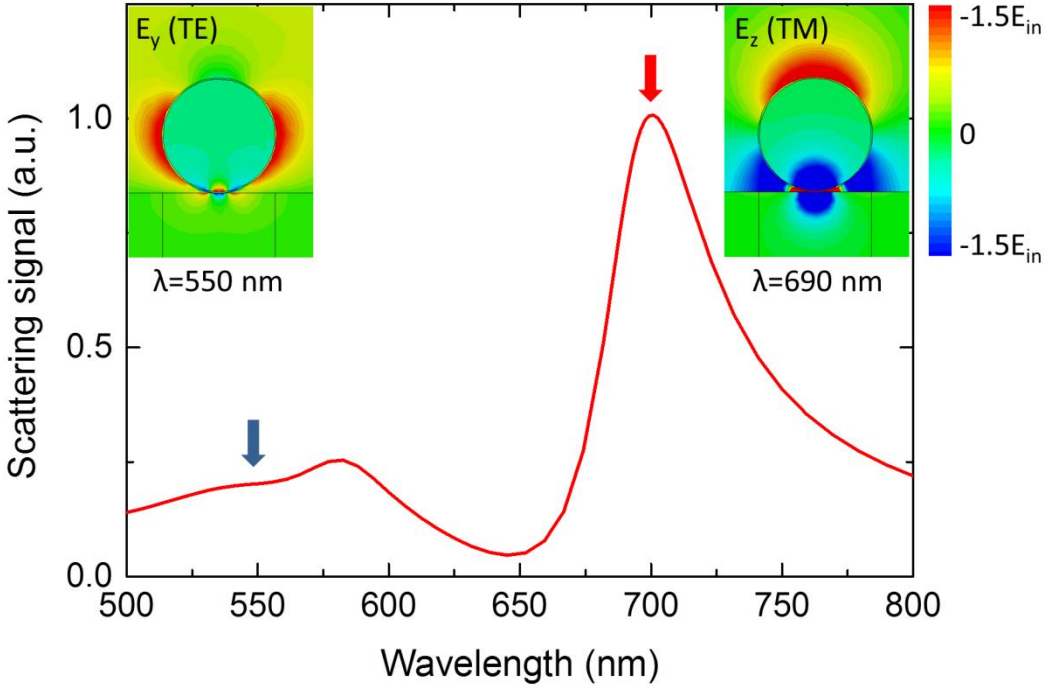
Numerical Simulation

- Resonance modes
  - Lateral mode – weak coupling
  - Vertical mode – stronger coupling
    → redshift, strong enhancement

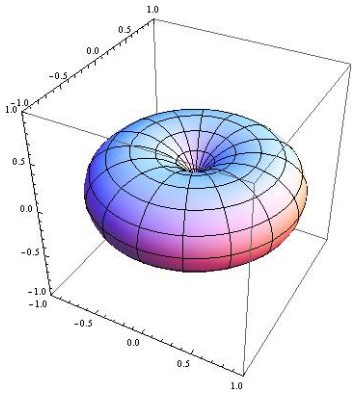


Lateral (x and y) dipole oscillation



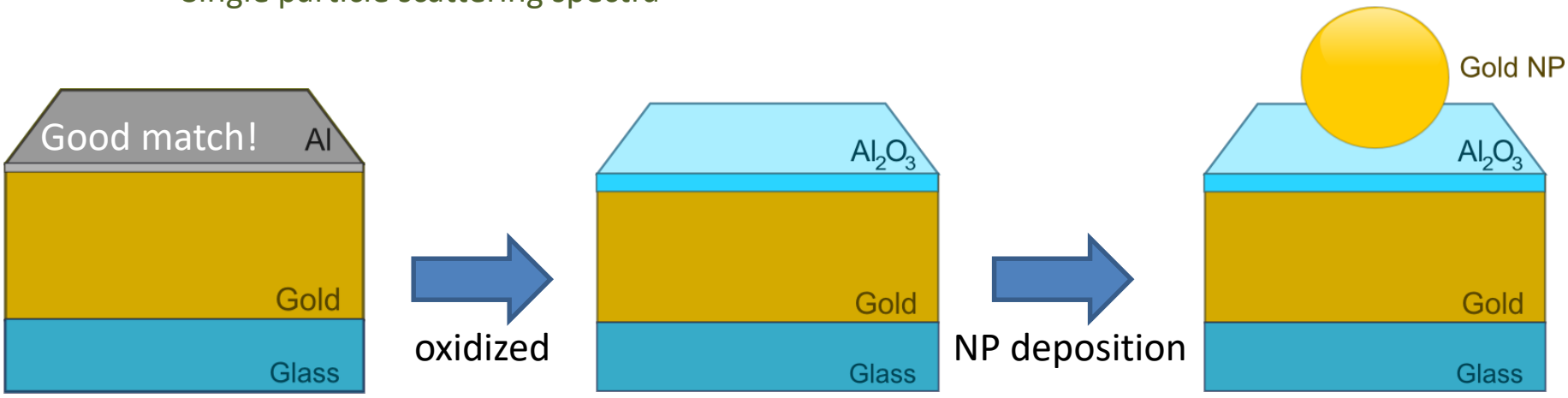


Vertical (z) dipole oscillation



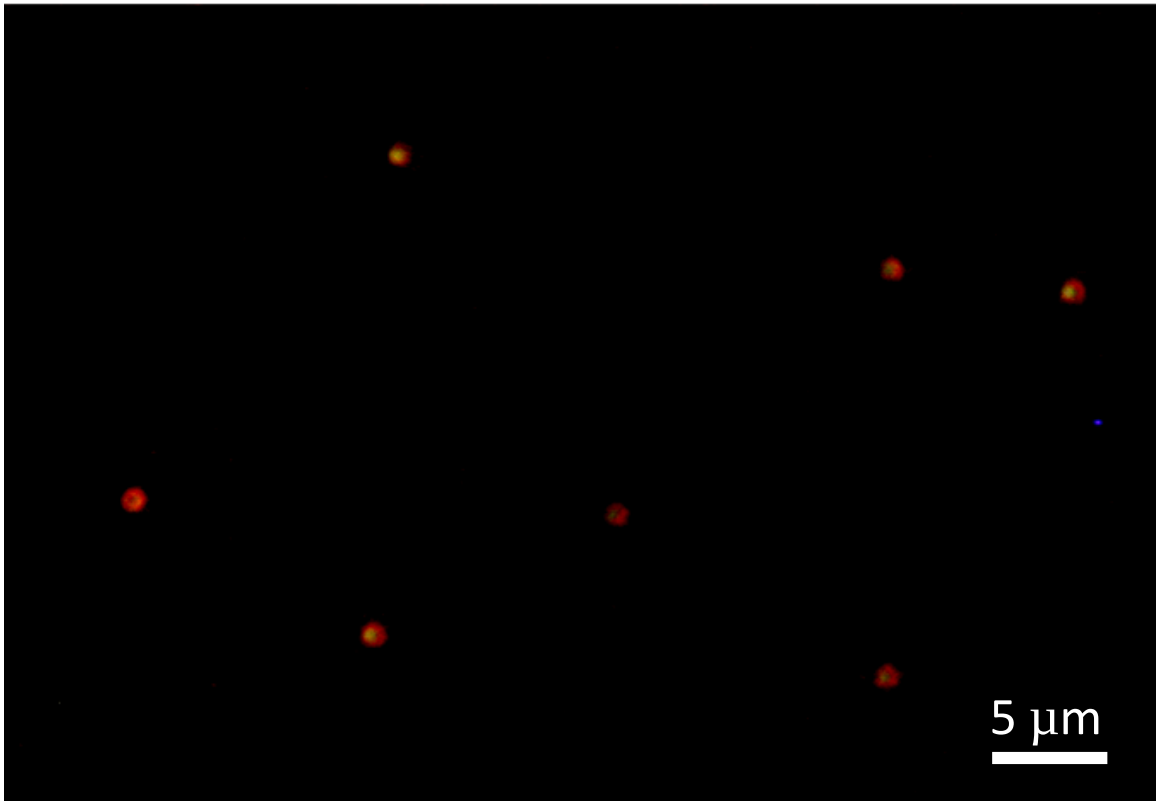
Experimental Process

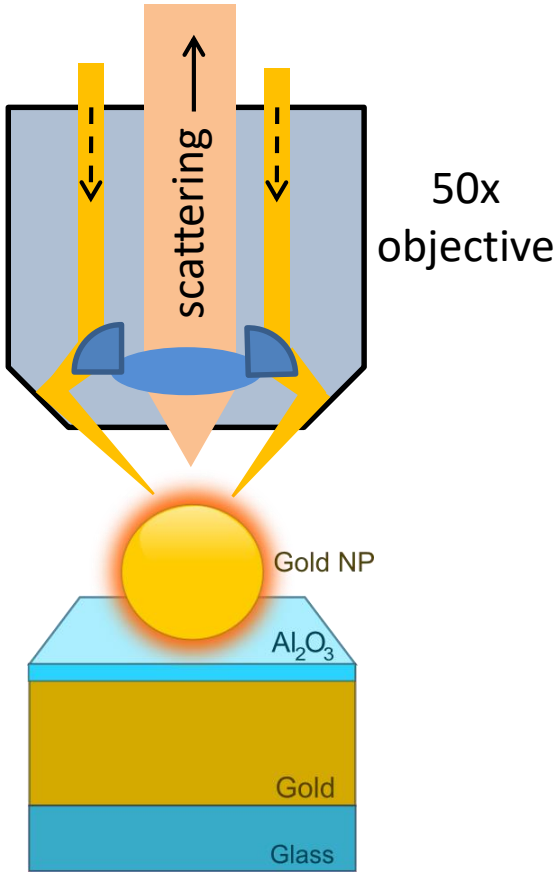
- Simulation
  - Resonance tuning range ~100 nm, two resonance modes
- Sample
  - A thin Al layer on top of a Au film (base pressure < 10^{-5} mbar)
  - The Al film gets oxidized entirely → Al_2O_3 coating layer
  - Au nanoparticles deposition
- Measurements
  - Ellipsometry → Al_2O_3 thicknesses,
  - Darkfield microscopy images,
  - Single particle scattering spectra



Dark-field Microscopy Images

- Dark-field microscopy
  - Canon EOS 450D digital camera
    - Well separated scatterers

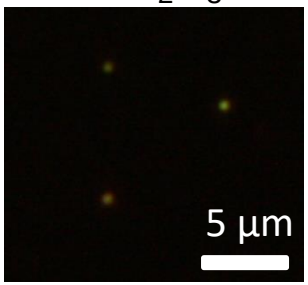


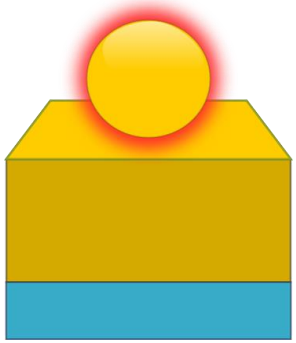


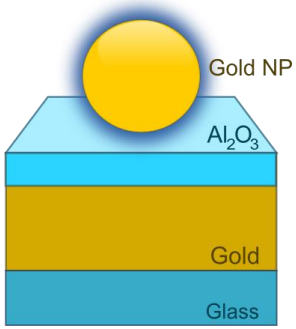
Dark-field Microscopy Images

- Dark-field microscopy
  - Canon EOS 450D digital camera
    - **Green** central and **Red** ring scattering

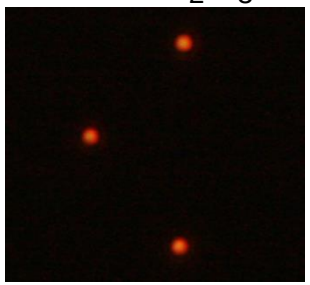
0 nm Al_2O_3







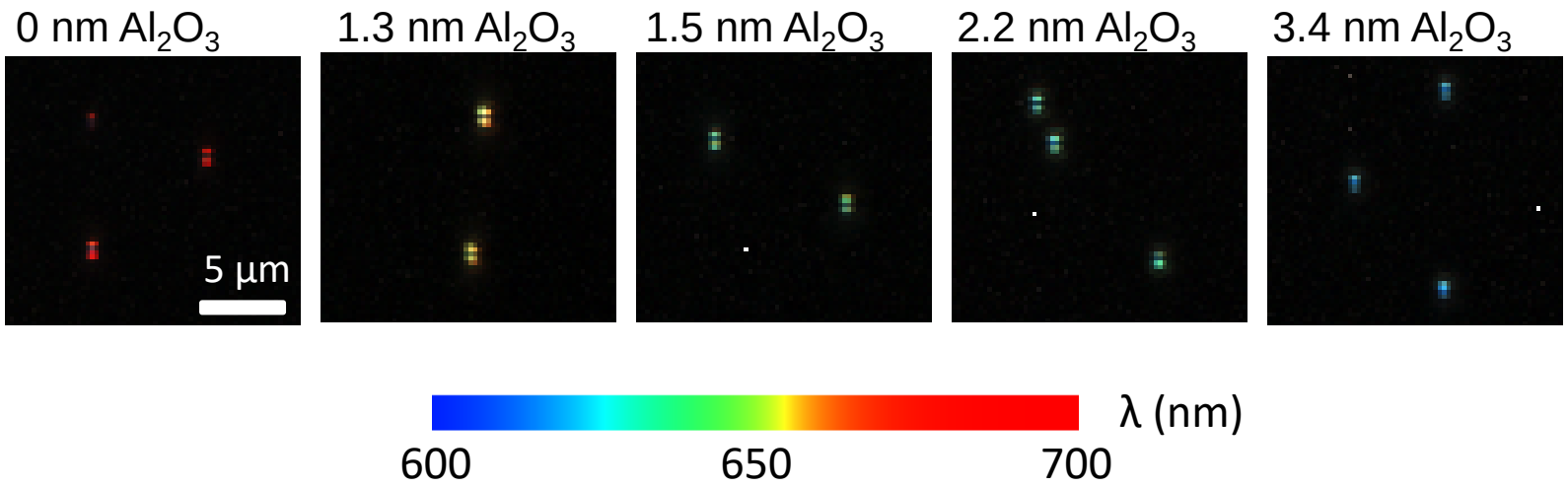
3.4 nm Al_2O_3



Not what we expected!!!

Dark-field Microscopy Images

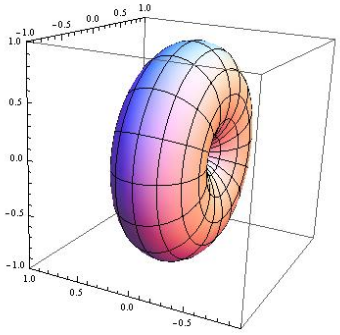
- Dark-field microscopy
  - Canon EOS 450D digital camera
    - **Green** central and **Red** ring scattering
  - HSi-440C Hyperspectral Imaging System (Gooch & Housego)

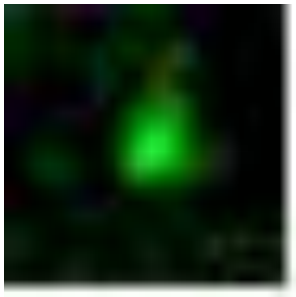


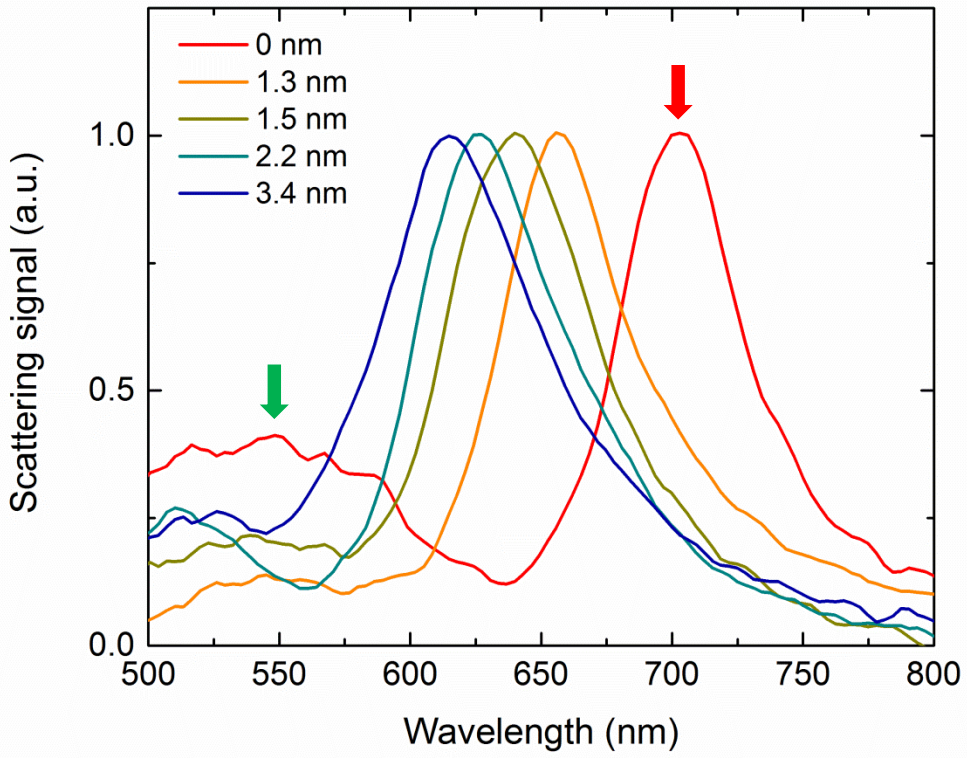
Single Particle Scattering Spectra

- Measured single particle scattering spectra
  - Resonance tuning range ~ 90 nm
  - Two resonance modes (at least)

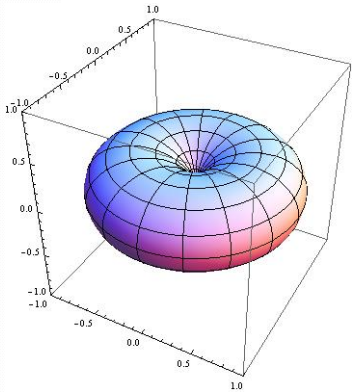
Lateral (x and y) dipole oscillation

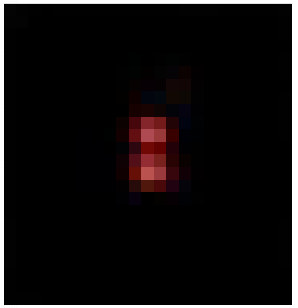






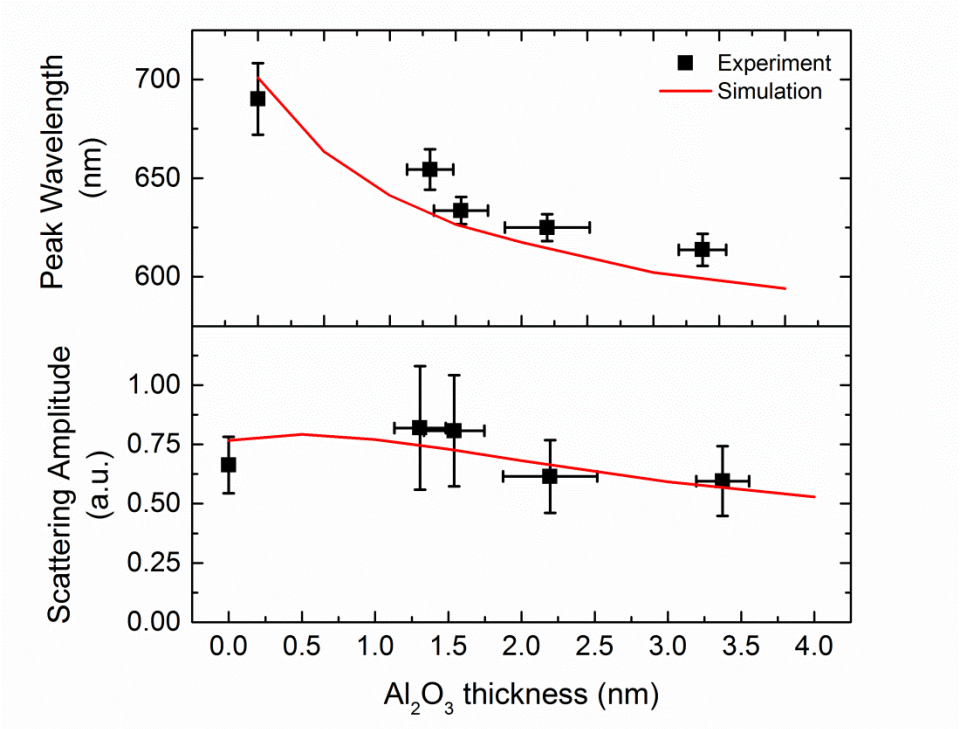
Vertical (z) dipole oscillation





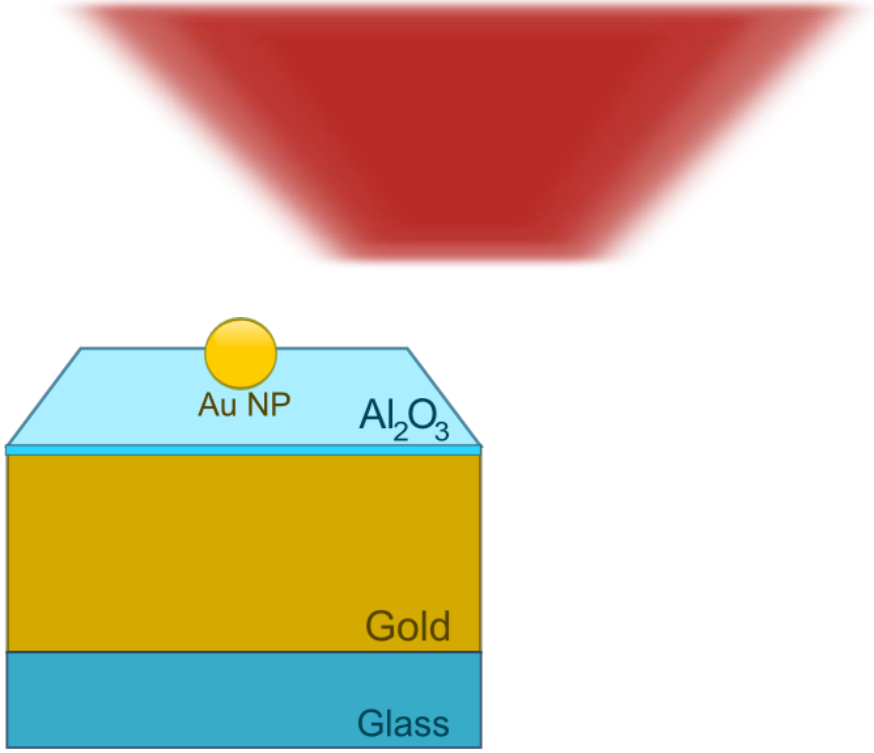
Single Particle Scattering Spectra

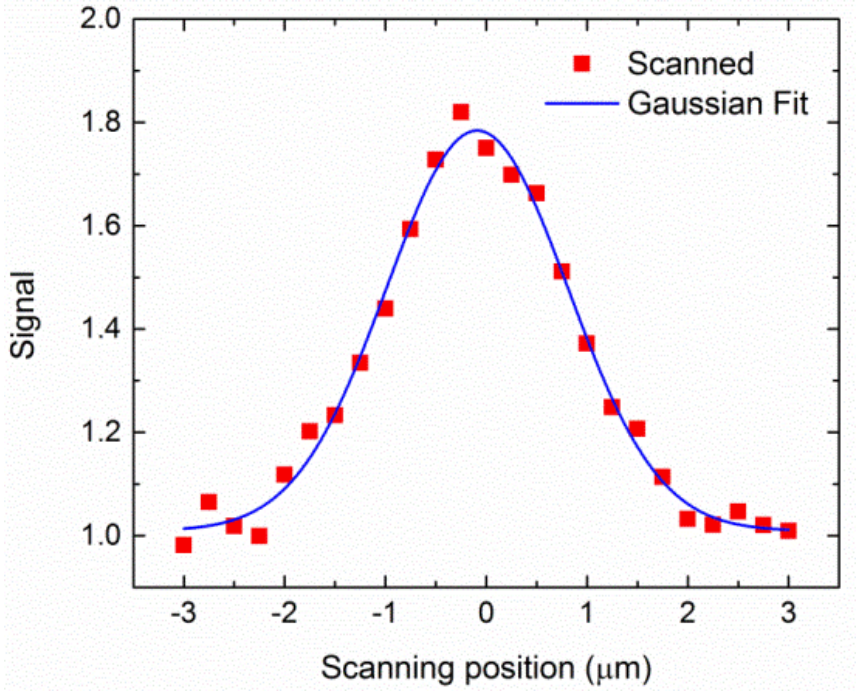
- Simulation and measurement (~100 nanoparticles)
  - Scattering peak wavelength – ~100 nm resonance shifting
  - Scattering peak strength – quite stable, slowly gets weaker after Al_2O_3 > 2 nm



Laser Heating and Stability

- Particle probing and alignment
  - Align the NP to the center of the beam by near-field probing
  - Laser irradiation: TM polarization, 15° angle of incidence

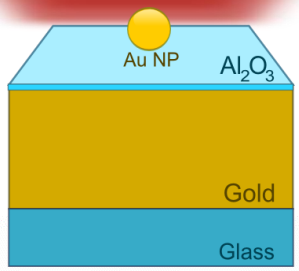


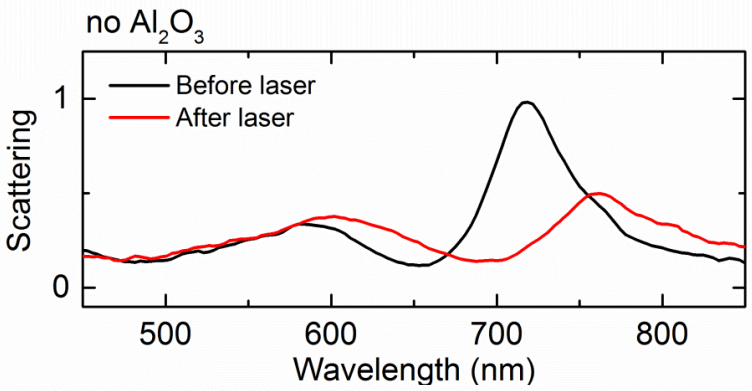


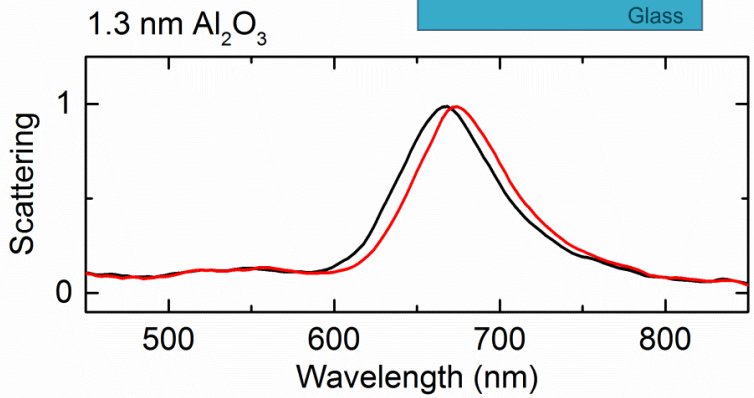
Laser Heating and Stability

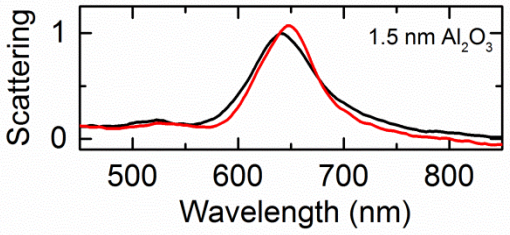
- Observation
  - No Al_2O_3 → spectrum drifts upon irradiation
  - with Al_2O_3 → survive the irradiation

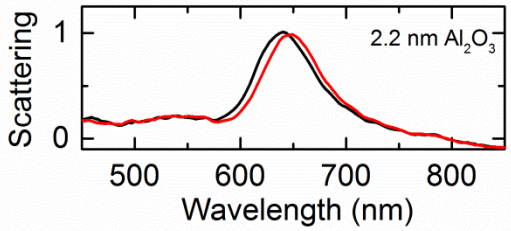
peak irradiance ~100 W/mm²

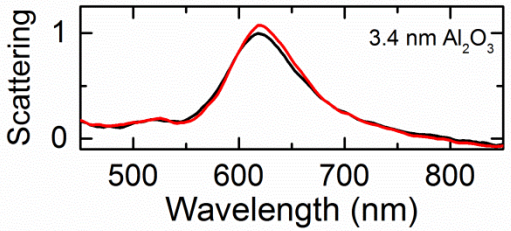








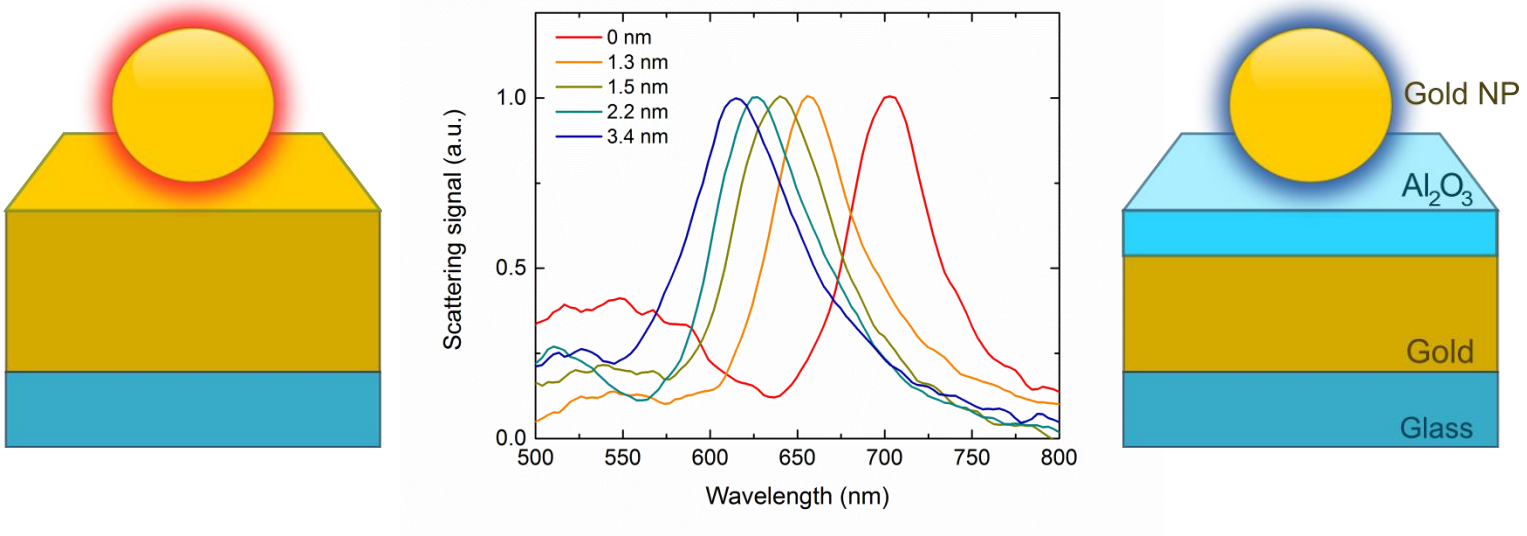




Summary

- Al_2O_3 coated gold film

  → Tuning range ~100 nm **(3 times improvement)**



Summary

- Al_2O_3 coated gold film

Challenges solved!

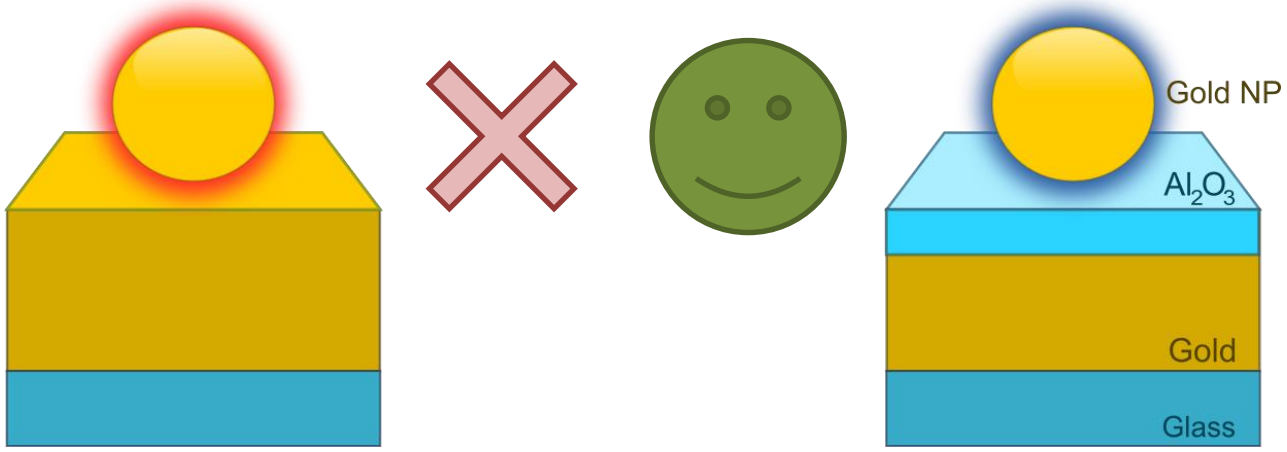
Just accepted – Journal of Physical Chemistry C
DOI: 10.1021/jp4056522

→ Tuning range ~100 nm **(3 times improvement)**

→ Irradiation tolerance > polymer based substrate tuning

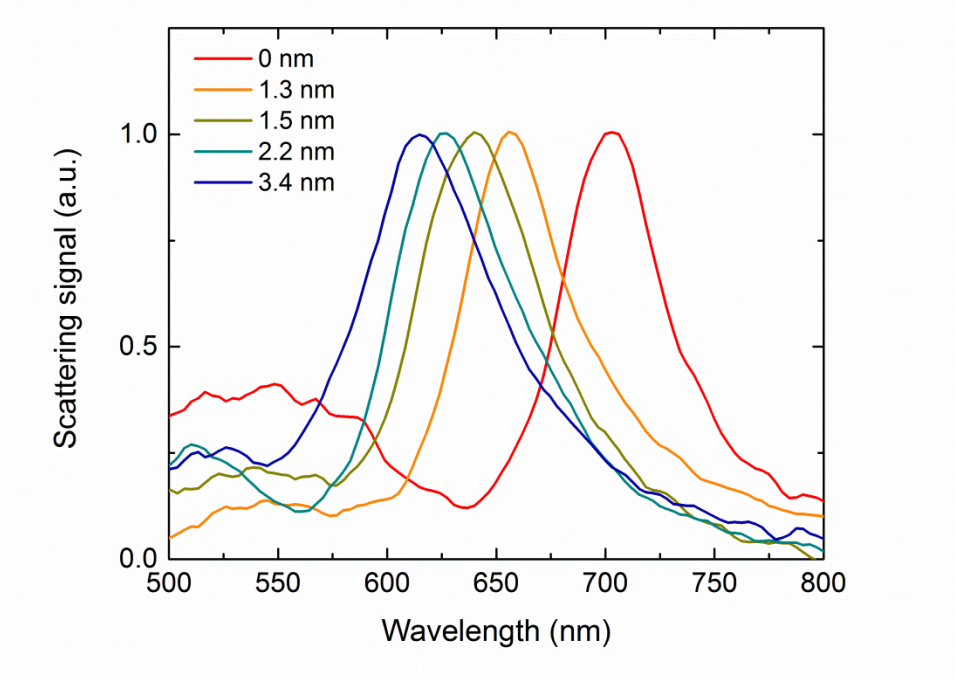
→ No organic background --- good for sensing application

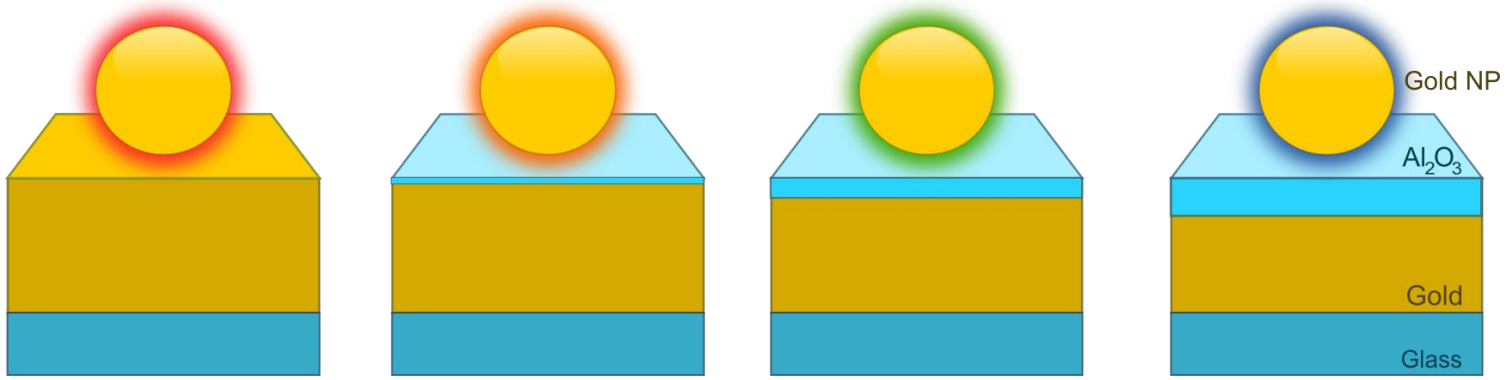
Laser irradiation



Thank you!

- Q & A


0 nm
1.3 nm
1.5 nm
2.2 nm
3.4 nm
Scattering signal (a.u.)
1.0
0.5
0.0
500
550
600
650
700
750
800
Wavelength (nm)


Gold NP
Al_2O_3
Gold
Glass