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Effects of Wavelength Variation on Localized Photoemission in Triangular Gold Antennas

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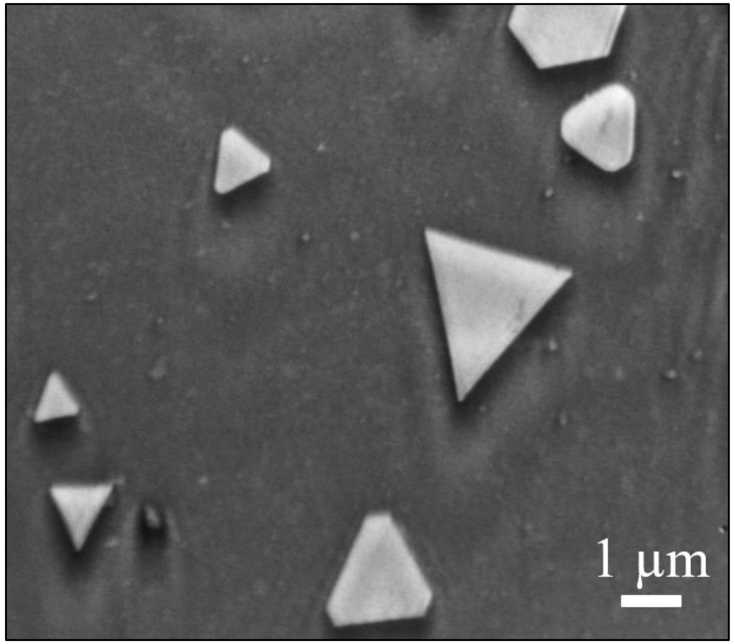
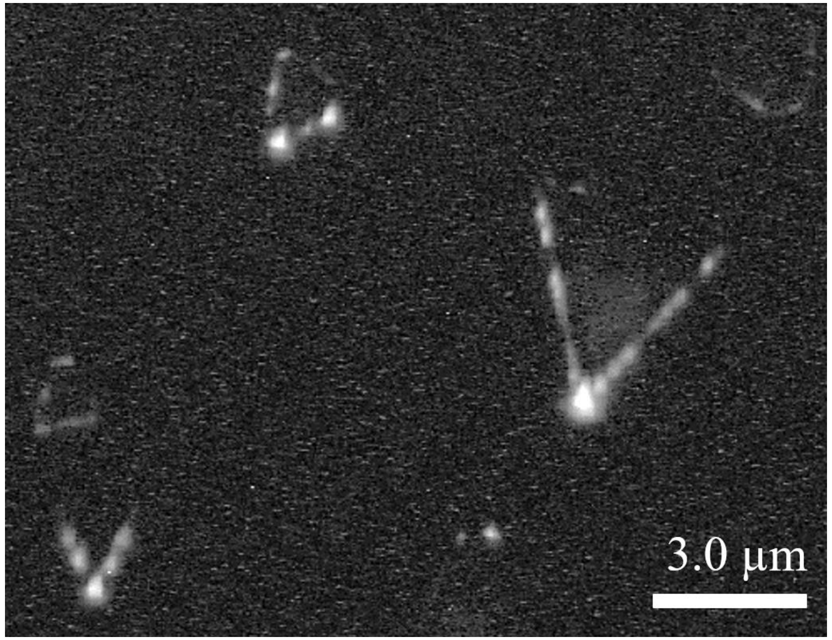
Motivation

- Prior work at PSU observed interesting optical responses from triangular gold structures using a photoemission electron microscopy (PEEM).



PEEM micrograph of an array of gold microstructures excited with 244 nm continuous-wave light incident at $\theta = 60°$. Micrograph provided by Dr. Robert C. Word. (Reference 1)



PEEM Micrograph of the same region excited with 800 nm pulsed light incident at $\theta = 60°$. Micrograph provided by Dr. Robert Word. (Reference 2)

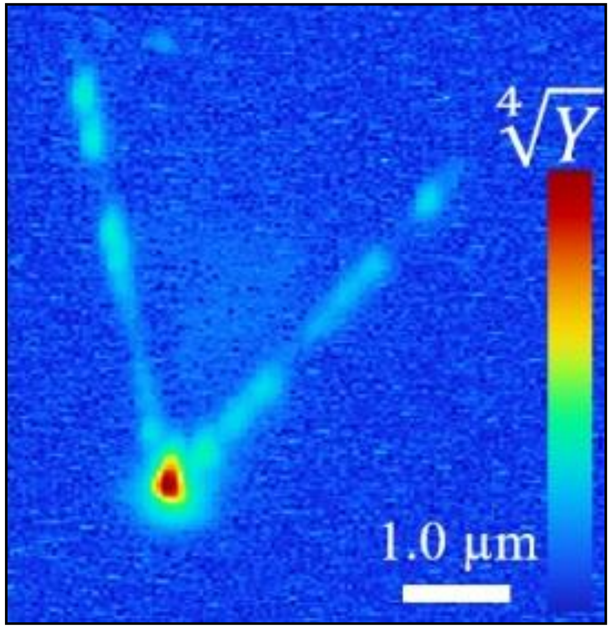
Project Overview

- Recreate optical effects seen in PEEM in computer modeling.
- Explain the underlying and overall optical responses

  (theory and simulation).
- Evaluate dependencies of the optical responses on the:
  a) Polarization of the incident laser

     (i.e. orientation of the electric field of the light)

  b) Wavelength of the incident laser (i.e. energy of the light)

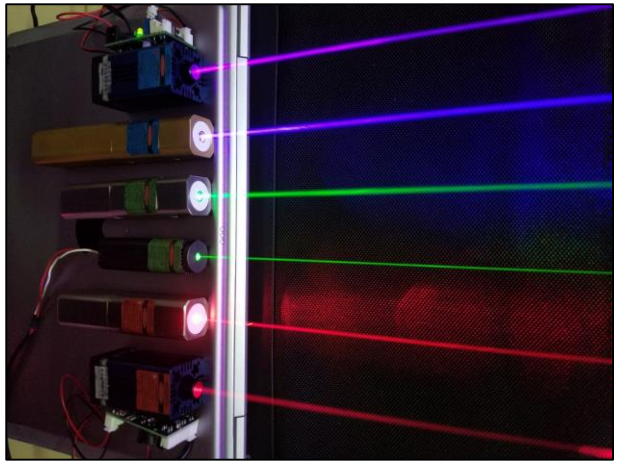


PEEM Micrograph of a gold triangle excited with 800 nm pulsed light incident at $\theta = 60°$. Digitally magnified and colorized. (Reference 2)

Introduction

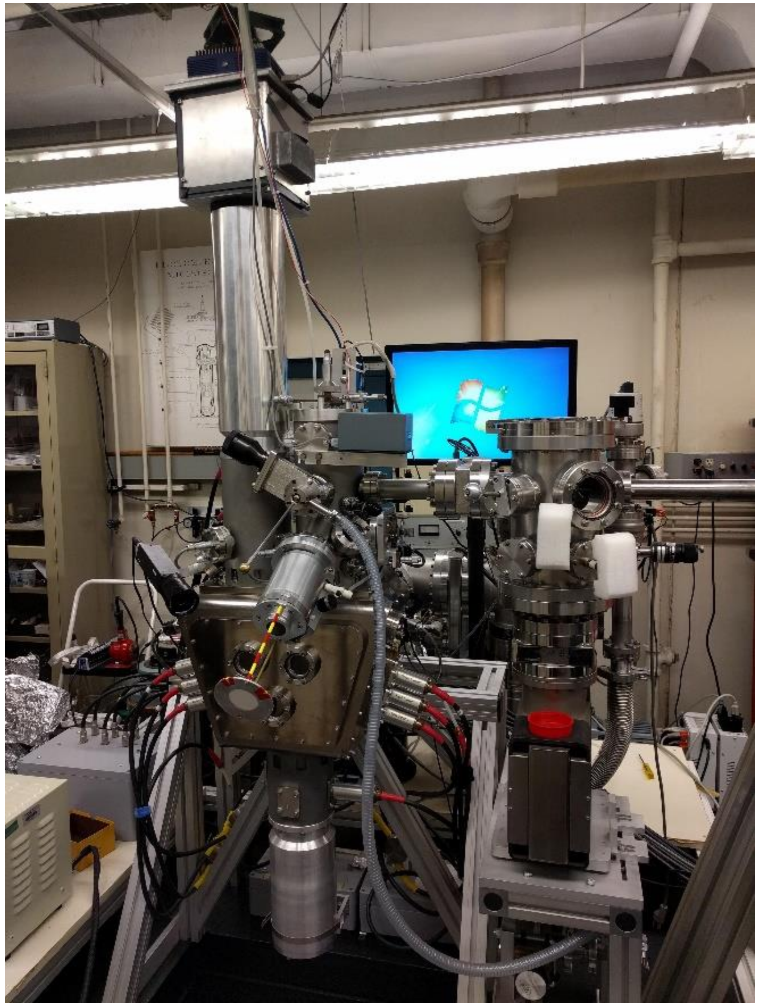
- Advancements in fabrication methods enable the straightforward creation of micron- and nanometer-sized devices and structures.
- Modern laser technology enables the creation of optical devices.
- Optical devices have been utilized in a wide range of applications, including: light localization, microscopy, phototherapy, and sensors.

Zeiss Orion NanoFab (Reference 3)


Various lasers (Reference 4)

Photoemission Electron Microscope (PEEM)

- A sample is placed within a high-vacuum environment.
- A high-powered laser is incident onto the sample, which will cause electrons to be ejected from the material (through the photoelectric effect)
- These photoemitted electrons are collected and used to form and acquire a digital image.
- PSU: Best demonstrated resolution of 5 nm.



Könenkamp Nanophotonics Lab PEEM.
(Reference 1)

Sample Details

- Thin, triangular gold platelets are deposited on a simple planar stack of an insulator (ITO) on top of glass.
- Gold platelets:
  - Single-crystalline
  - 50 – 100 nm in thickness
  - Most are ~2 – 5 um in length

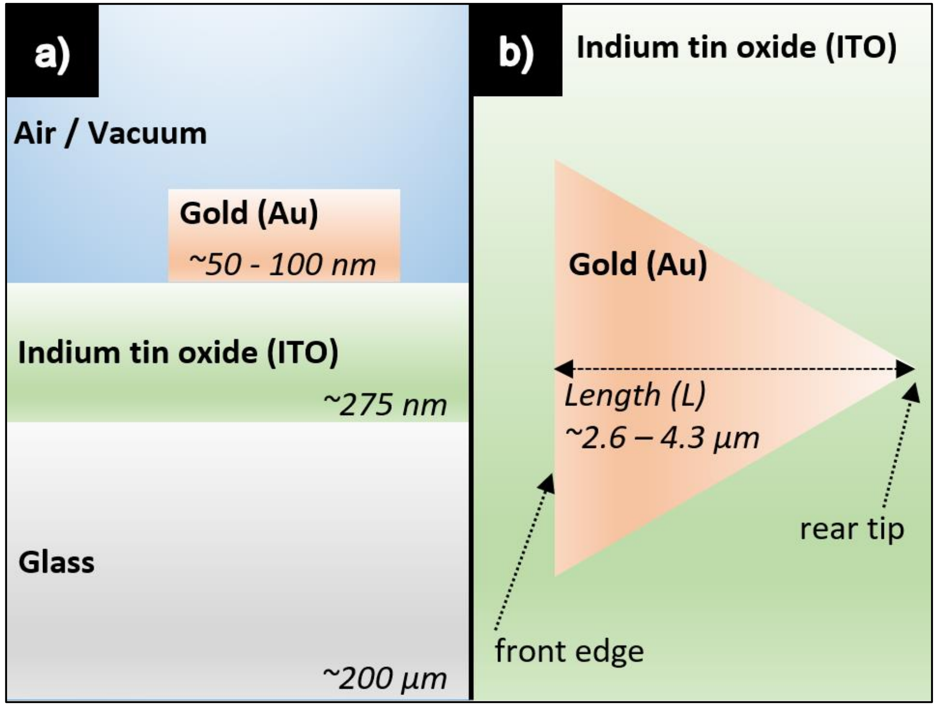


Image not to scale.
(a) Cross-sectional view
(b) Top-down view
(Refence 2)

Experimental Setup

- For this work:

  Oblique incidence: 60° (directly from above)

  or

  Normal incidence: 0° (via transmission from below)

  λ = 800 nm (wavelength of incident laser)

  (Simulation: λ = ~600 nm : 1 μm)

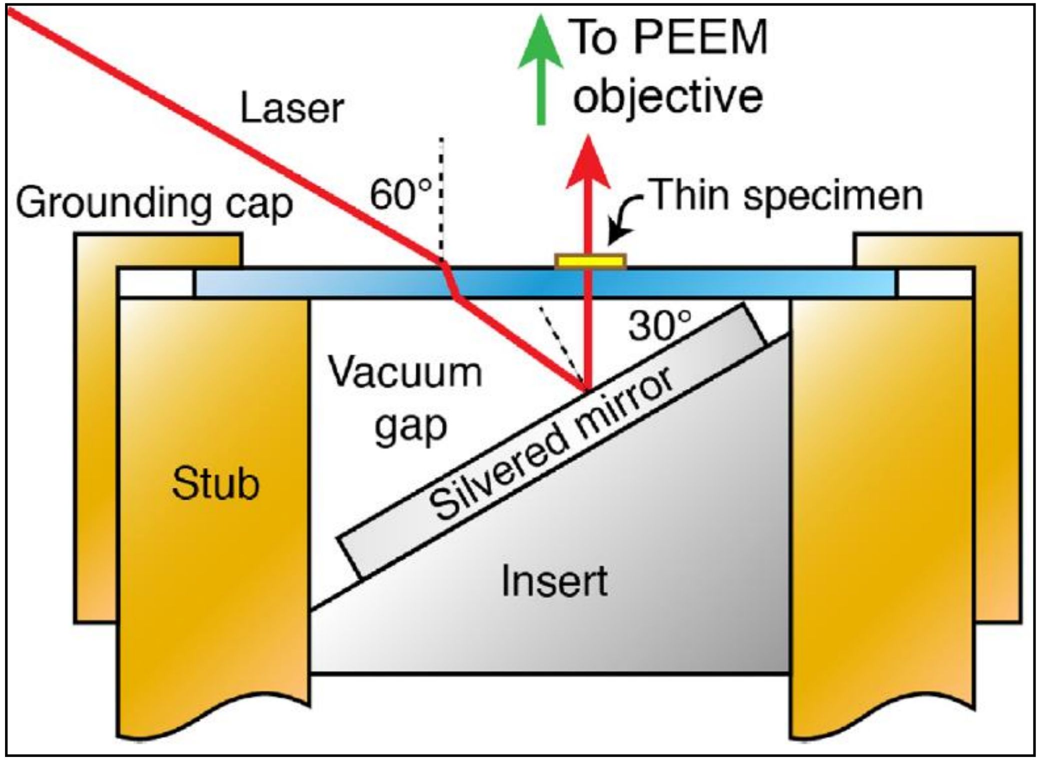


Illustration of the PEEM specimen stub, depicting oblique (from above) and normal (below) incidence. (Reference 5)

- Image reprinted with permission from *Photonic and plasmonic surface field distributions characterized with normal- and oblique-incidence multi-photon PEEM*, by R.C. Word and R. Könenkamp, Ultramicroscopy, vol. 183, pp. 1139-1351, 2017.

Experimental Results

- PEEM micrographs were obtained for transverse magnetic (TM) polarizations at an oblique angle from above the sample.
  - Localized photoemission is seen primarily at the rear tip region and along the edges.
- PEEM micrographs were obtained at a normal incidence from below the sample.
  - Localized photoemission is seen along the edges.

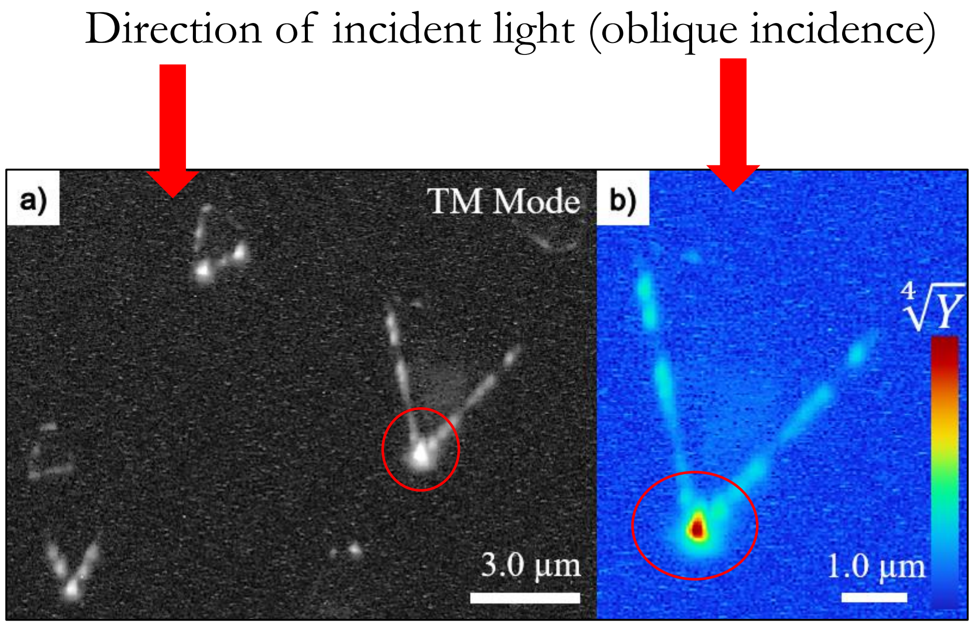
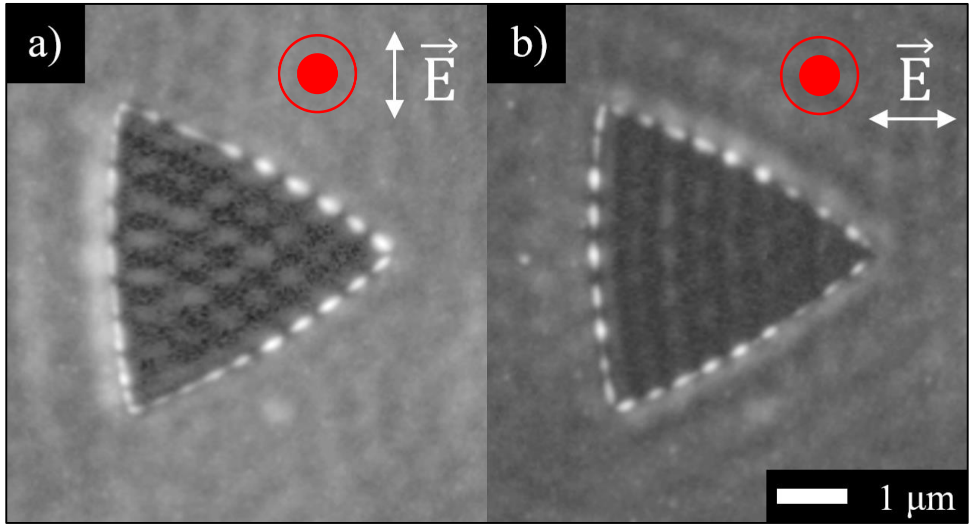


Image (b) is digitally magnified and colored from (a). (Reference 2)

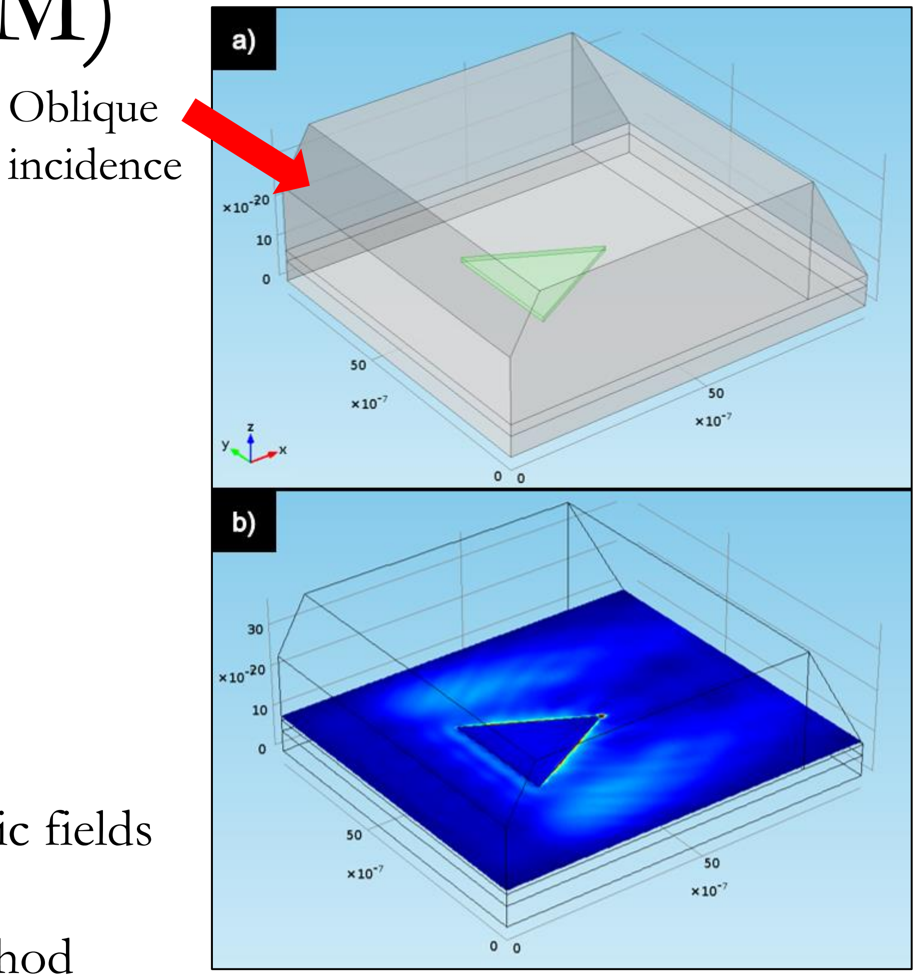


Normal incidence PEEM micrographs. (Reference 5)

- Adapted with permission from *Photonic and plasmonic surface field distributions characterized with normal- and oblique-incidence multi-photon PEEM*, by R.C. Word and R. Könenkamp, Ultramicroscopy, vol. 183, pp. 1139-1351, 2017.

Finite Element Modeling (FEM)

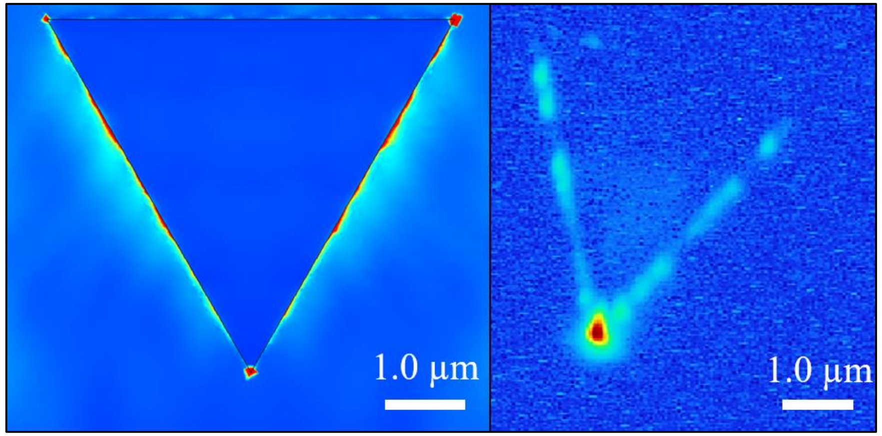
- COMSOL Multiphysics is used to model the PEEM setup:
  - Recreate PEEM experiment in a 2D- or 3D-model.
    - Assign optical material properties to each layer
    - Specify a light source (i.e. laser)
    - Define boundary conditions
  - COMSOL will calculate the (time-averaged) electromagnetic fields for each point within the model using a finite-element method (FEM) analysis technique.



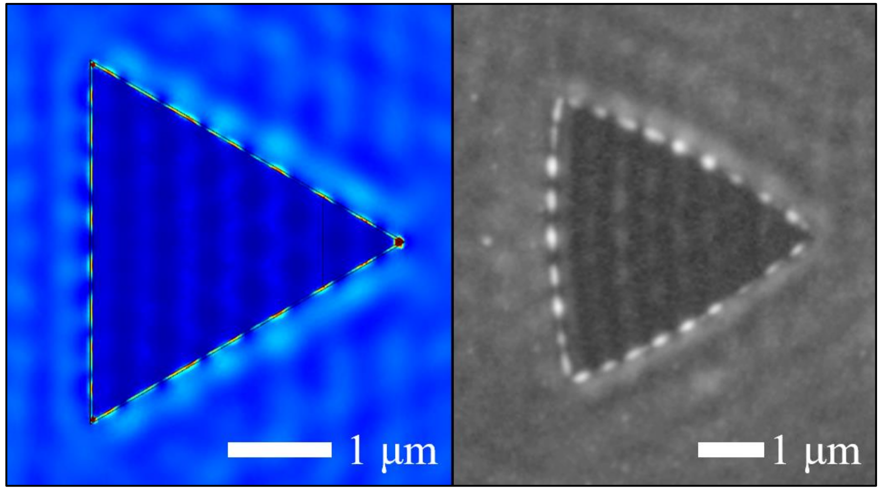
COMSOL Multiphysics 3D Model:
(a) Au region highlighted in green
(b) Simulated $|E|^2$ at the surface of the Au layer.
(Reference 2)

Results: Simulation vs. Experiment

- For oblique incidence, the simulations have approximately reproduced the optical responses seen in PEEM:
  - Strong rear tip photoemission
  - Less intense emission along the exterior edges
  - No visible surface interference patterning
- For normal incidence, simulations have closely reproduced the PEEM optical responses:
  - Strong, periodic photoemission along the exterior edges
  - Distinctive interference patterning within the Au layer



(Reference 1)



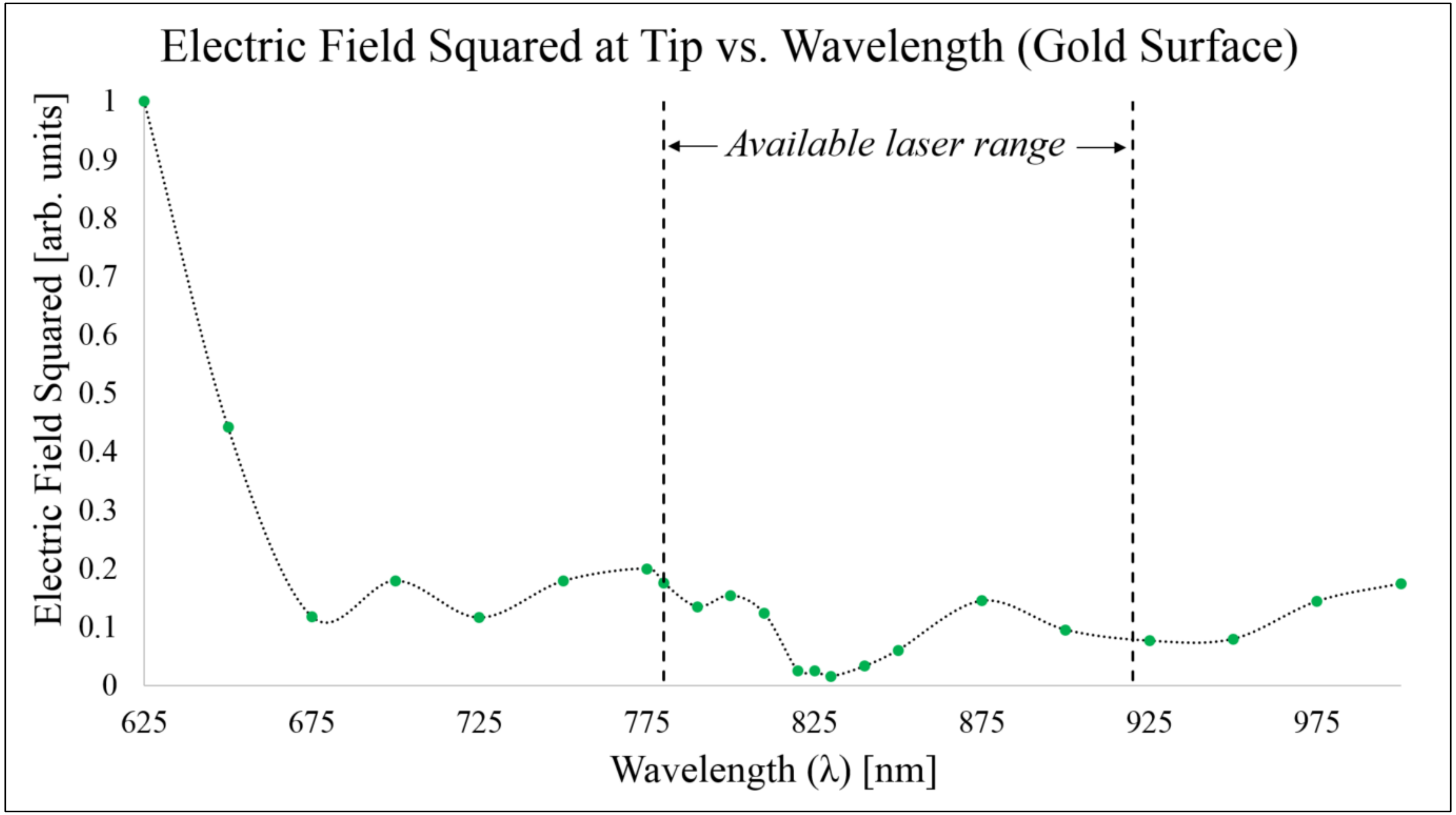
(Reference 1)

Analysis: Wavelength Dependence (λ)

- Quantitative comparison:
  λ = {625 nm : 1 μm}

$|E|^2$ for {625 nm : 1 μm}

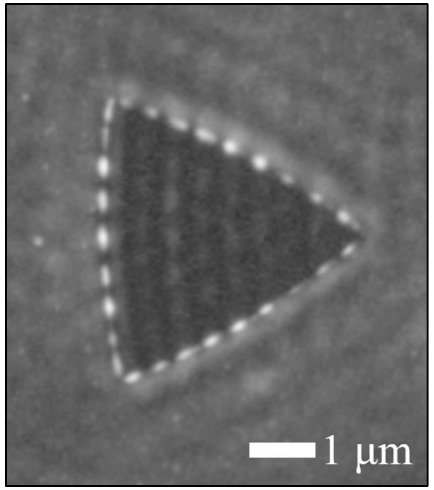
= ~**{125 : 2}**



Graph of the simulated time-averaged $|\vec{E}|^2$ at the gold surface of the rear tip vs. wavelength for a 3 μm long gold platelet exposed to obliquely incident light (θ = 60°) for λ = {625 nm : 1 μm}. (Reference 1)

Conclusion

- PEEM imaging of gold nano-platelets is a powerful tool for characterizing optical responses with sub-wavelength resolution.
- Combined with FEM based modeling, detailed quantitative analysis can be performed.
- In this work, we have demonstrated:
  - Strong, localized photoemission within a region far smaller than the wavelength of the incident light (< 250 nm vs. 800 nm).
  - Wavelength adjustment at readily available optical frequencies is highly effective and feasible for controlling photoemission of triangular gold optical antennas.



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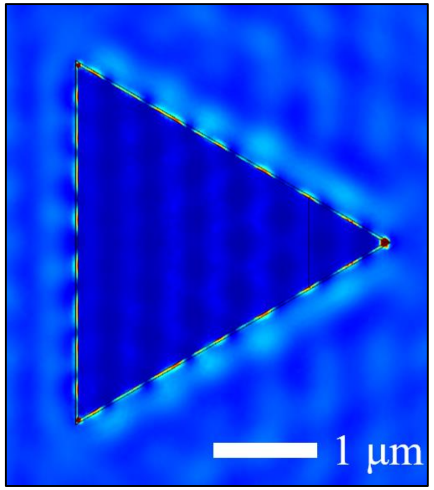

(Reference 1)

Acknowledgements

- Theodore Stenmark (PSU)

Portland State Physics

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1. Scheffler, Christopher M., “Localized Photoemission in Triangular Gold Antennas” (2019). *Dissertations and Theses.* Paper 4866.

2. C. M. Scheffler, R. C. Word, and R. Könenkamp, “Controlling Localized Photoemission of Triangular Gold Antennas Through Polarization, *Conference Proceedings of the 13th Nanotechnology Materials and Devices Conference (NMDC)*, 2018.

3. Carl Zeiss, 2017, “Orion NanoFab,” www.zeiss.com, accessed 3/3/2017, <https://www.zeiss.com/microscopy/us/products/multiple-ion-beam/orion-nanofab-for-materials.html>.

4. By 彭嘉傑 - Own work, CC BY 2.5, <https://commons.wikimedia.org/w/index.php?curid=60733412>.

5. R. C. Word and R. Könenkamp, “Photonic and plasmonic surface field distributions characterized with normal- and oblique-incidence multi-photon PEEM,” *Ultramicroscopy*, vol. 183, pp. 1339–1351, 2017.

Thank you for attending.

Q&A