Surface Plasmon Polaritons on Metal-Dielectric Nanocomposite Films

Zhimin Shi[1], Giovanni Piredda[1,2], Andreas C. Liapis[1], Mark A. Nelson[3], Lukas Novotny[1] and Robert W. Boyd[1]

[1] The Institute of Optics, University of Rochester Rochester, NY 14627 USA
[2] now with Dept. Chemie und Biochemie, Ludwig-Maximilians-Universität München, 81377 München, Germany
[3] Los Alamos National Laboratory, Los Alamos, NM 87545 USA

***CLEO/IQEC 2009*, Baltimore MD**
Paper IThG
4:00 pm, Jun. 4th, 2009

Outline

- Background and motivation
- Experimental results
- Numerical modeling and analysis
- Summary

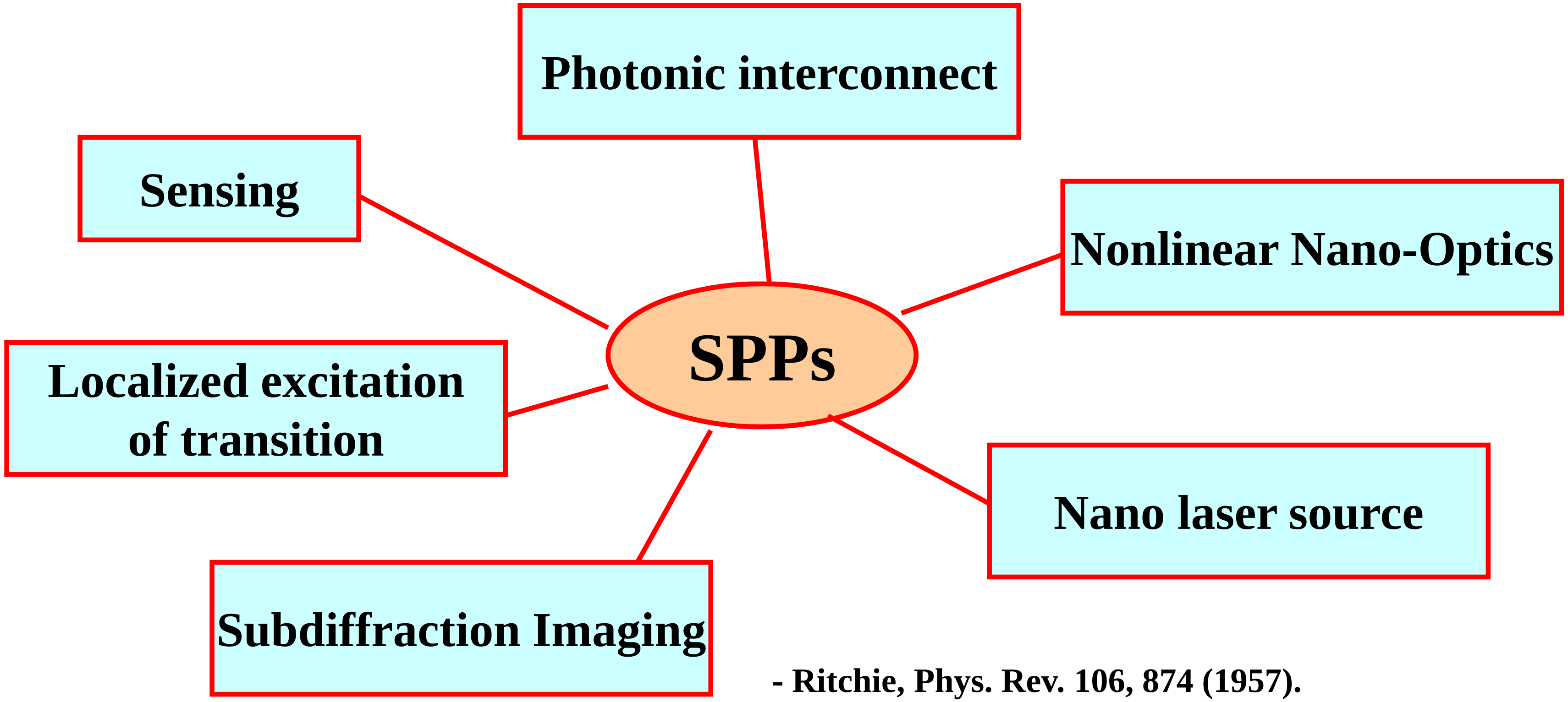
Background

- **Surface Plasmon Polaritons (SPPs) are important for sensing, localized excitations of transition, miniaturized photonic interconnection, nonlinear optics, etc.**

- **To design or control the properties of SPPs, e.g., its propagation (mode index), dispersion (group index), spatial profile, etc., for better performances.**

- Ritchie, Phys. Rev. 106, 874 (1957).
- Stern and Ferrell, Phys. Rev. 120, 130 (1960).
- Homola, et al., Sens. Actuat. B: Chem. 54, 3 (1999).
- Moskovits, Rev. Mod. Phys. 57, 783 (1985).
- Barnes, et al., Nature424, 824 (2003).
- Danckwerts and Novotny, PRL. 98, 026104 (2007).
- Palomba and Novotny, PRL 101, 056802 (2008).
- Pendry, el al., Science 305, 847 (2004).

Background of Surface Plamson Polaritons (SPPs)



- Ritchie, Phys. Rev. 106, 874 (1957).
- Stern and Ferrell, Phys. Rev. 120, 130 (1960).
- Homola, et al., Sens. Actuat. B: Chem. 54, 3 (1999).
- Moskovits, Rev. Mod. Phys. 57, 783 (1985).
- Barnes, et al., Nature 424, 824 (2003).
- Danckwerts and Novotny, PRL 98, 026104 (2007).
- Palomba and Novotny, PRL 101, 056802 (2008).
- Pendry, el al., Science 305, 847 (2004).
- …

Motivation

- **Free conduction current can support SPPs on a metal-dielectric surface.**
- **Q: Can displacement current support SPPs?**
- **Further Q: To what extent can we tailoring the properties of SPPs via changing the volume fraction of metal in a random metal-dielectric nanocomposite?**

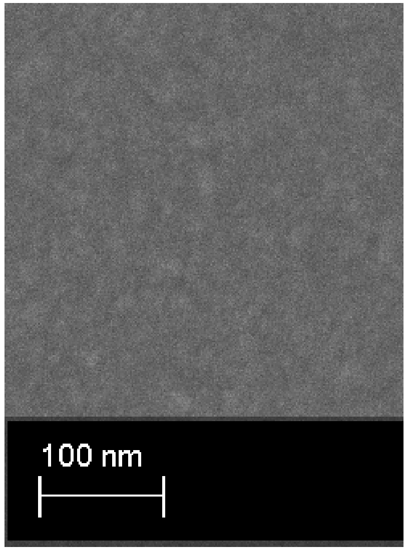
Experiment: samples

- **Samples: a collection of 30-nm-thick gold-air nano-composite film with gold fill fraction ranging from 1 to 0.35.**

continuous → **semi-continuous** → **isolated**

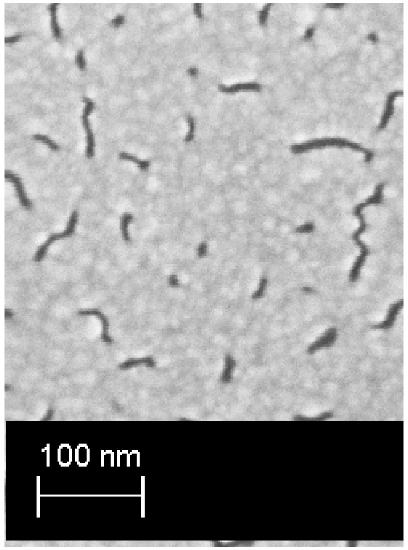
SEM image

f **= 1**



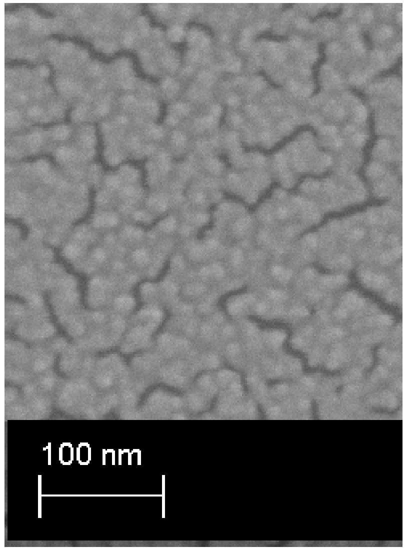
SEM image

f **= 0.95**



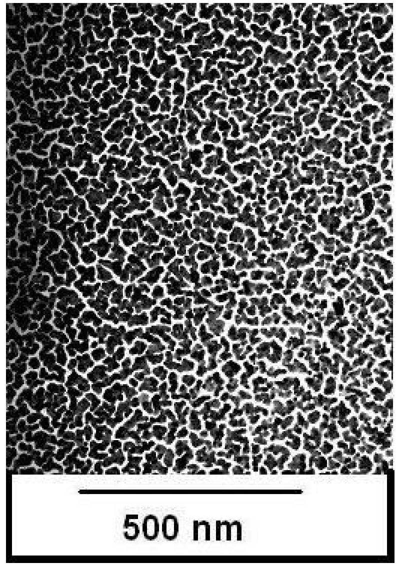
SEM image

f **= 0.85**



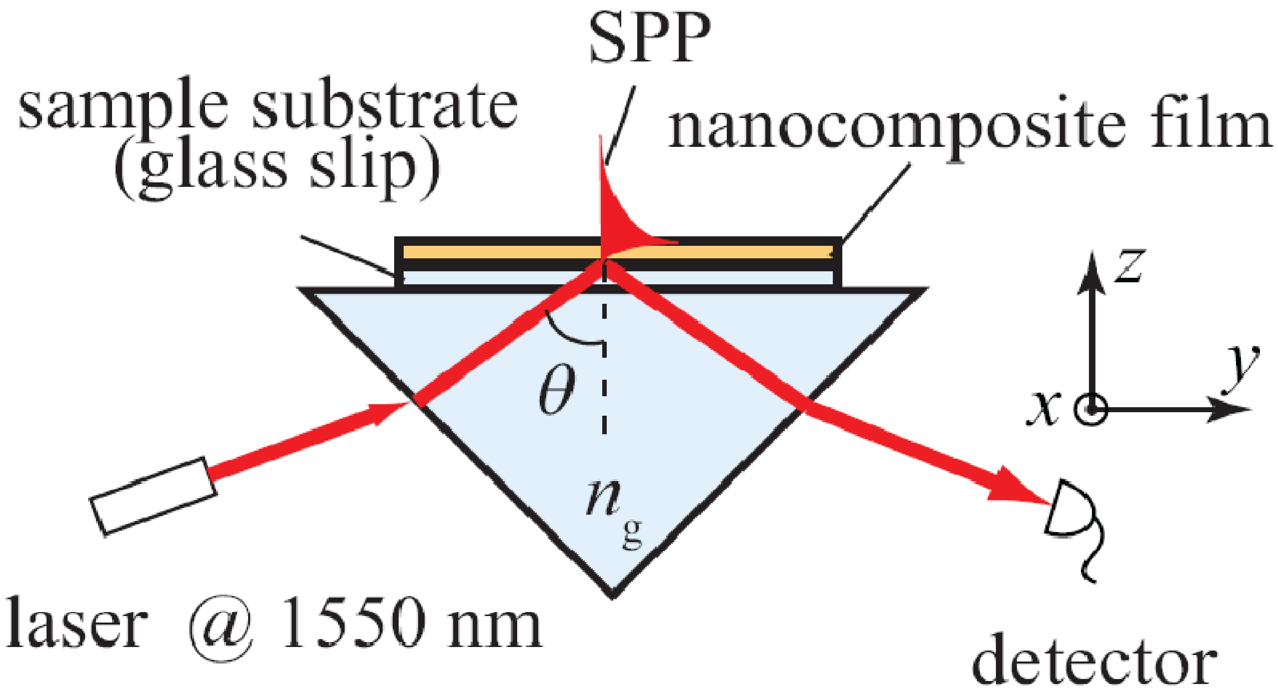
TEM image

f **= 0.65**



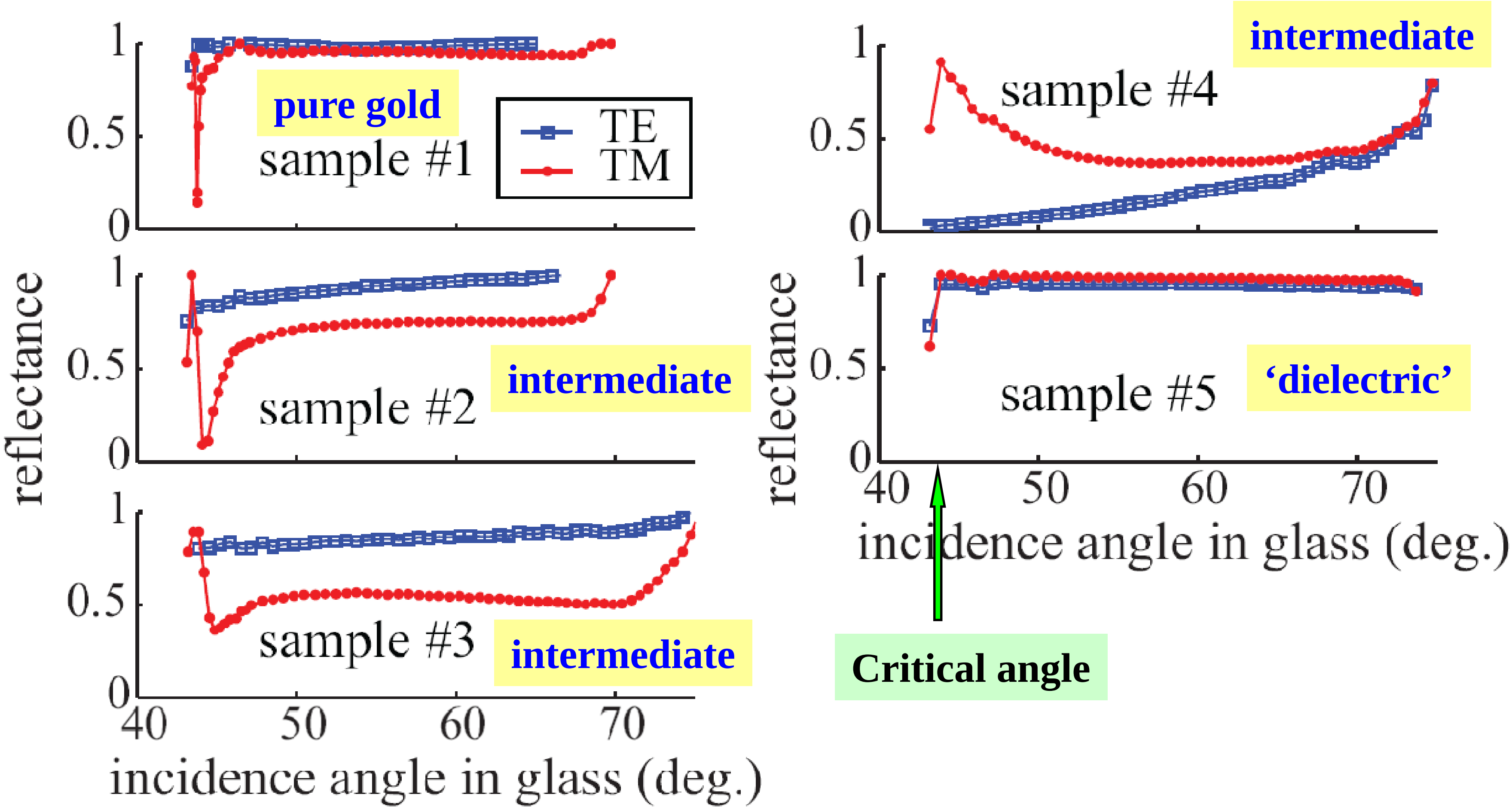
Experiment: setup

- **Reflectance in Kretschmann configuration**
  - **Wavelength: 1550 nm**
    (far away from localized SP resonance wavelength)



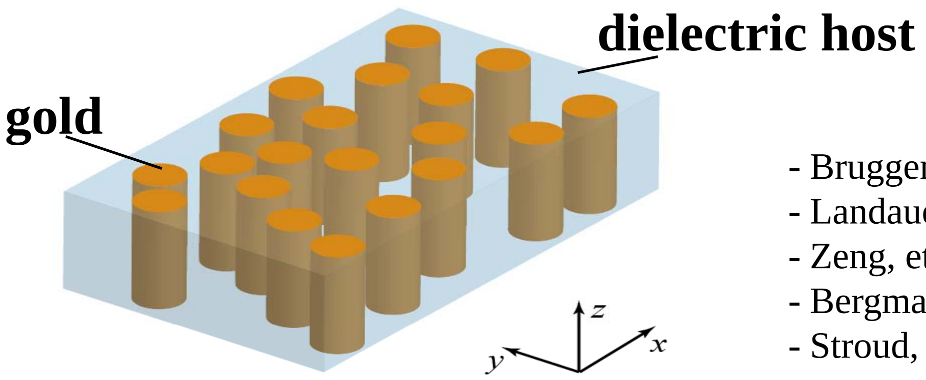
Experiment: results

➢ **Gold fill fraction decreases from sample #1 to #5.**

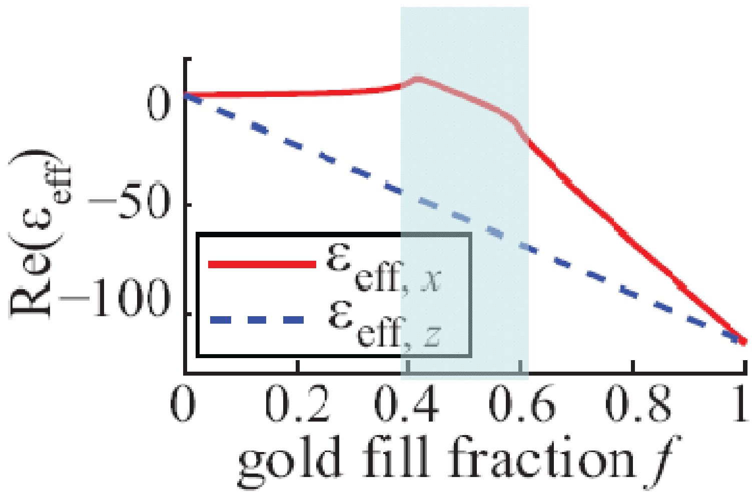


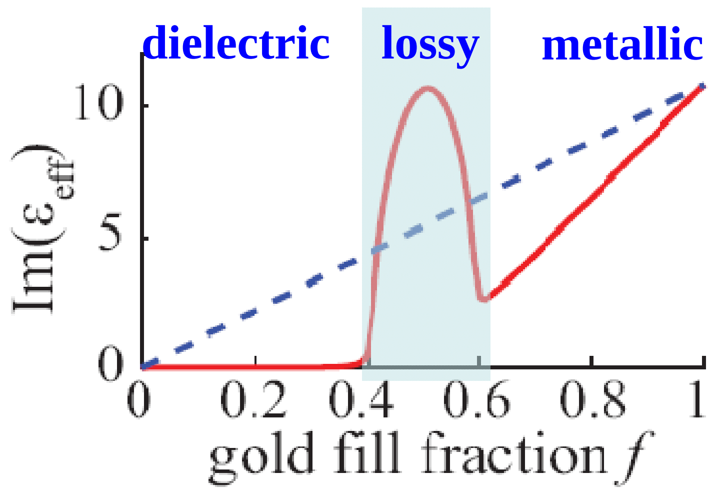
Modeling the optical property of nanocomposite films

- **Anisotropic effective medium approximation (EMA)**
  - **Nano-structural variation in *x*-*y* plane only**

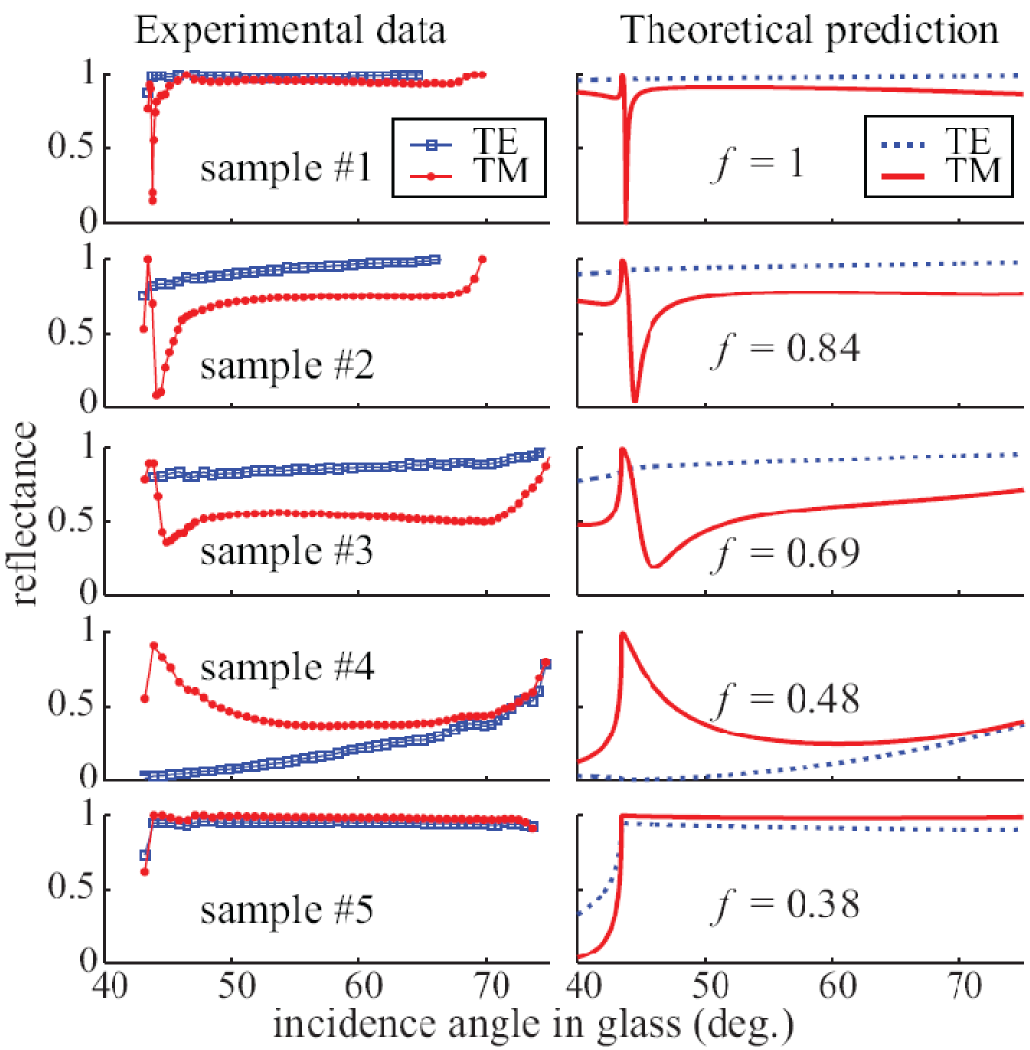


- Bruggeman, Ann. Phys. (Leipzig) 24, 636 (1935).
- Landauer, J. of Appl. Phys. 23, 779 (1952).
- Zeng, et al., Phys. Rev. B 38, 10970 (1988).
- Bergman and Stroud, Solid State Physics 46, 147 (1992).
- Stroud, Superlattices and Microstructures 23, 567 (1998).





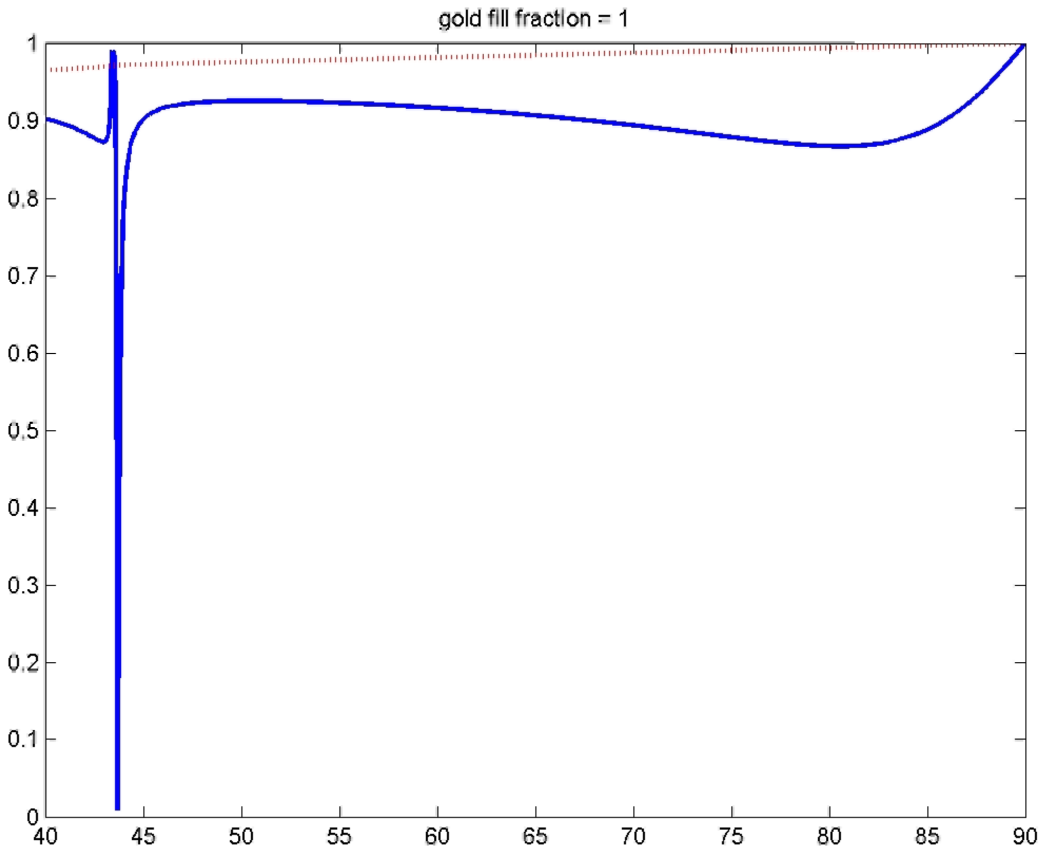
Comparison between experimental and numerical results



EMA can describe qualitatively the optical properties of the nanocomposite.

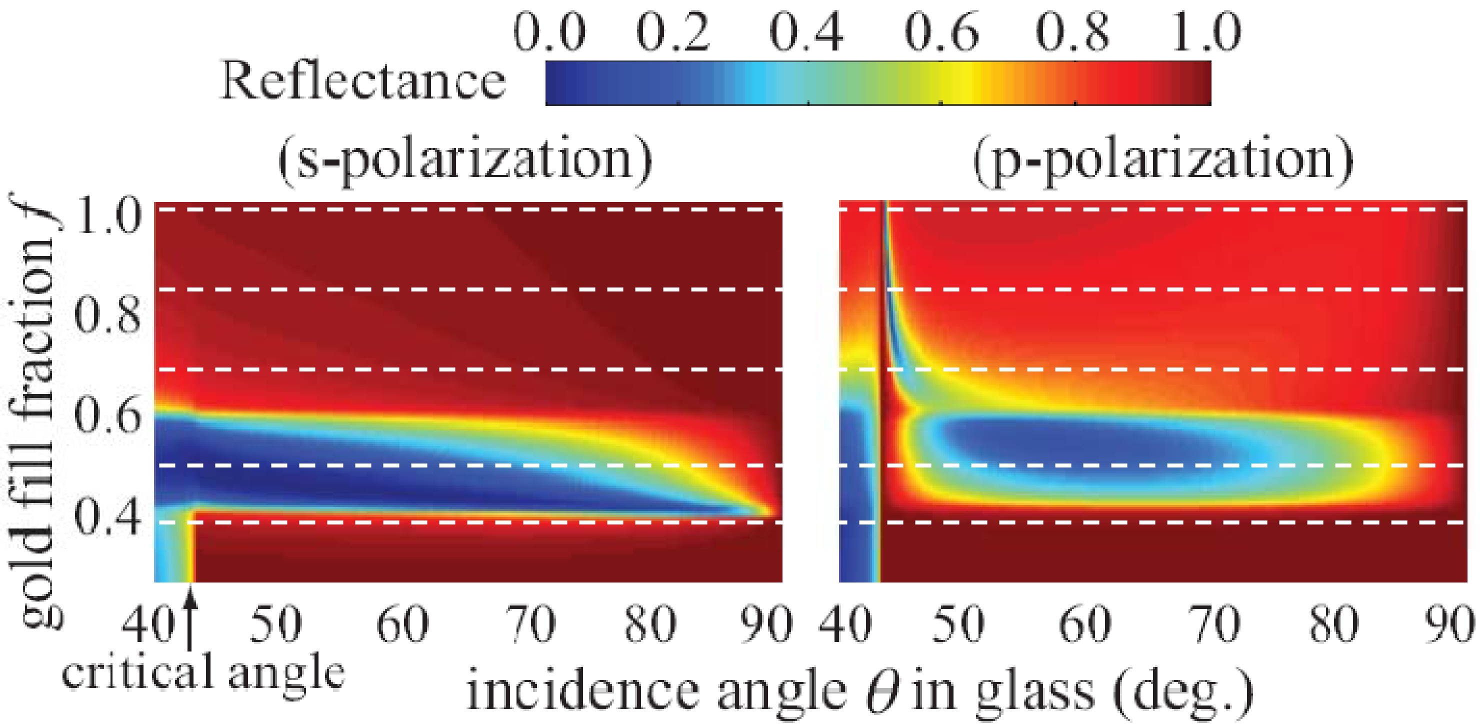
Evolution of reflectance curve

- **Continuously change the gold fill fraction**



Evolution of reflectance curve

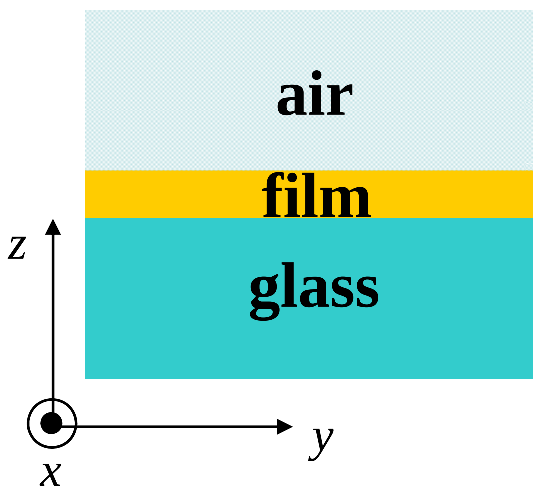
- **Continuously change the gold fill fraction**

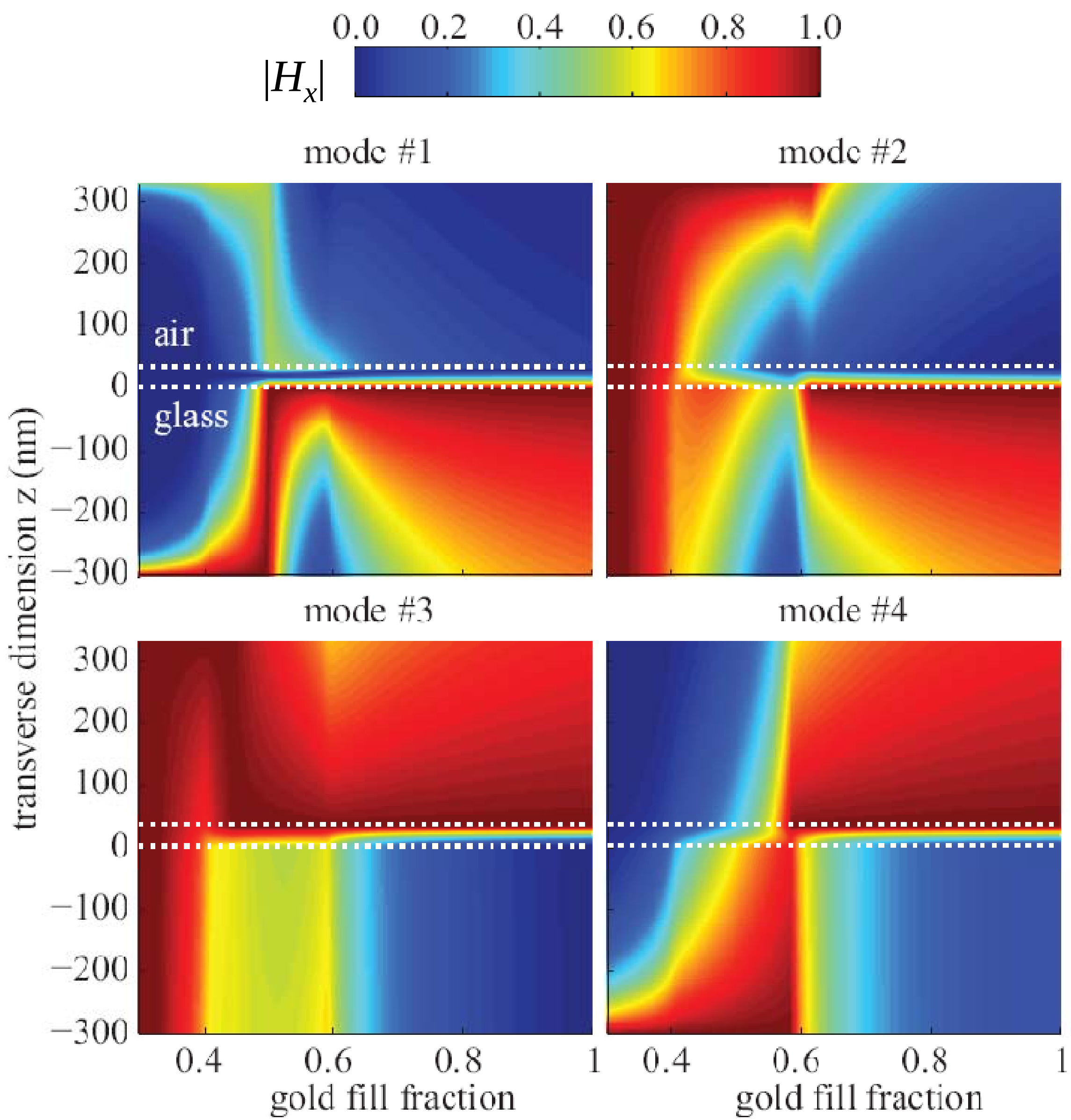


- **For 1 > *f* > 0.6, the conventional SPP dip transits smoothly**
- **What happens for 0.4 < *f* < 0.6 ?**

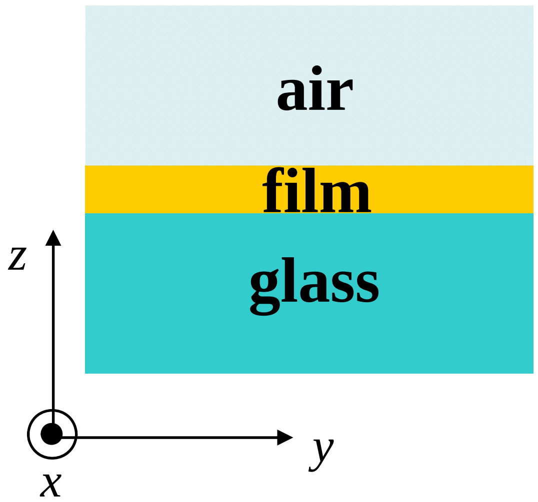
Spatial profiles of the four supported modes

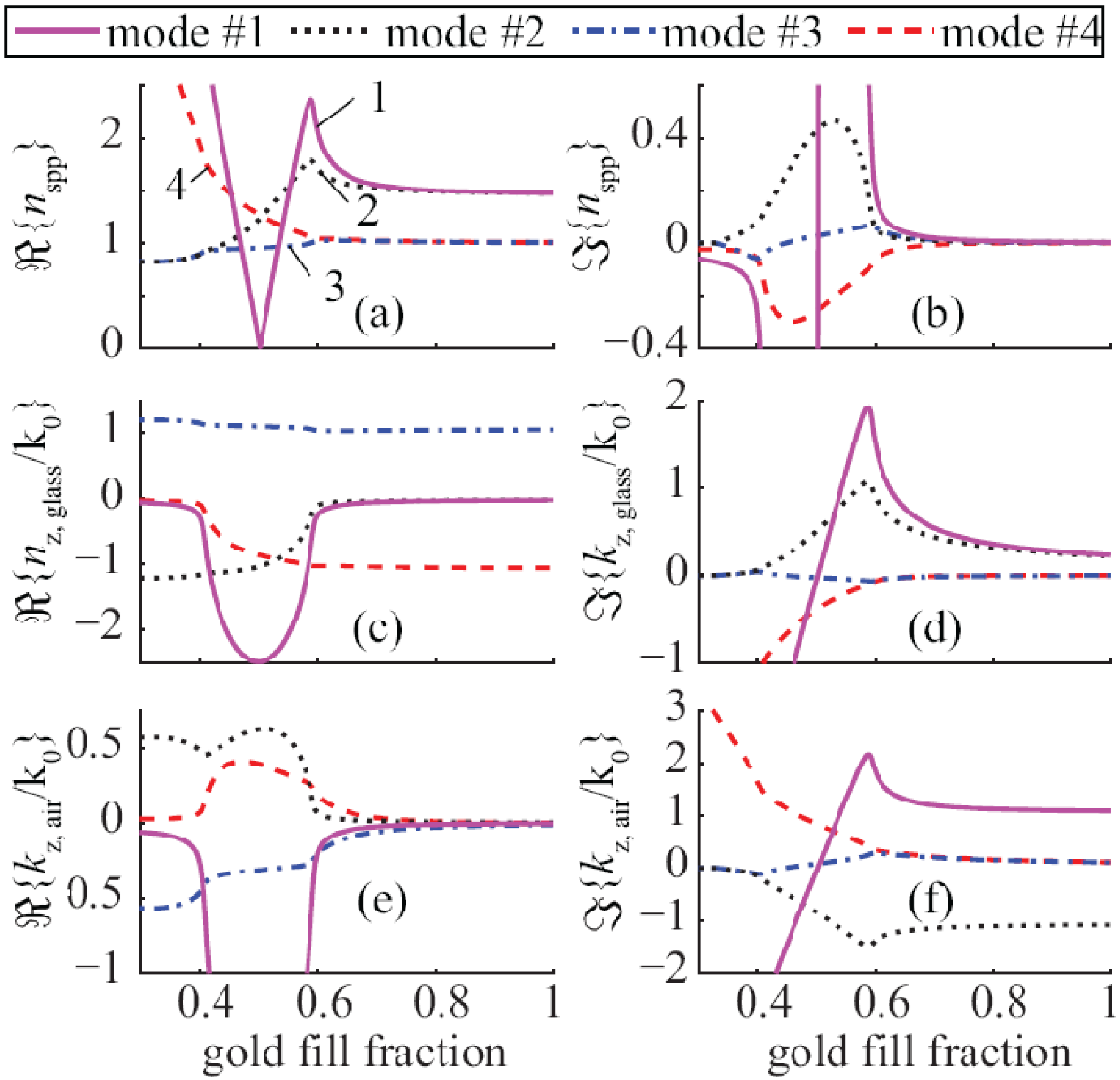
Color indicates $|H_x|$ amplitude





Longitudinal and transverse mode properties

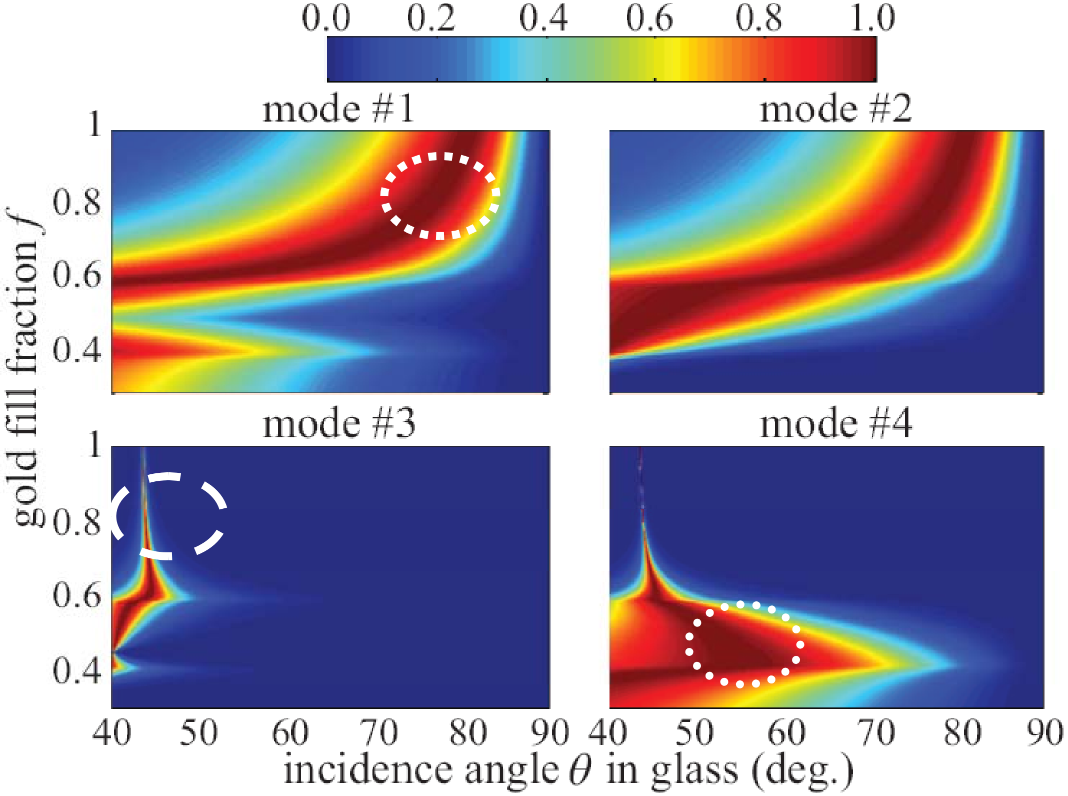




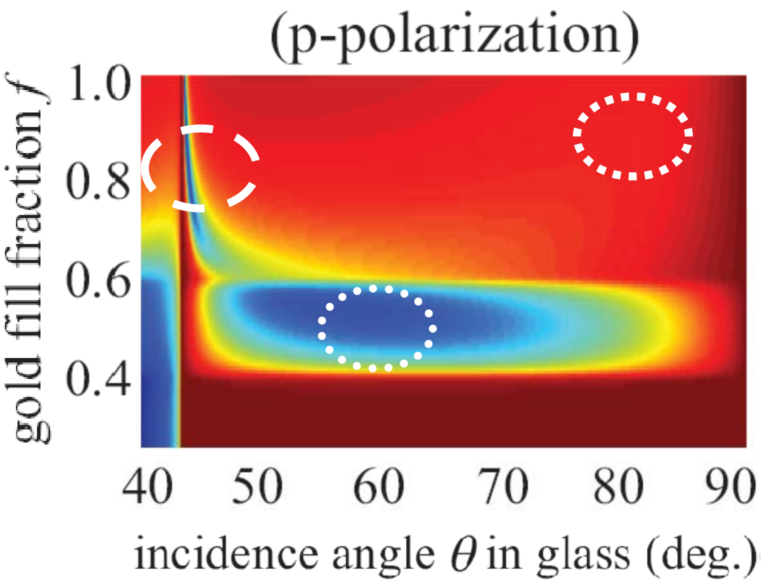
Coupling strength of each mode with incident plane wave

$$|F(\theta)|^2 = \frac{\cos^2\theta}{(\Re\{n_{\rm spp}\} - n_{\rm g}\sin\theta)^2 + (\Im\{n_{\rm spp}\})^2}$$

Normalized Coupling strength



TM reflectance



- Burke, et al., Phys. Rev. B 33, 5186 (1986)

Summary

- **We have experimentally excited SPPs on a collection of gold-air nanocomposite films with various values of gold fill fraction.**

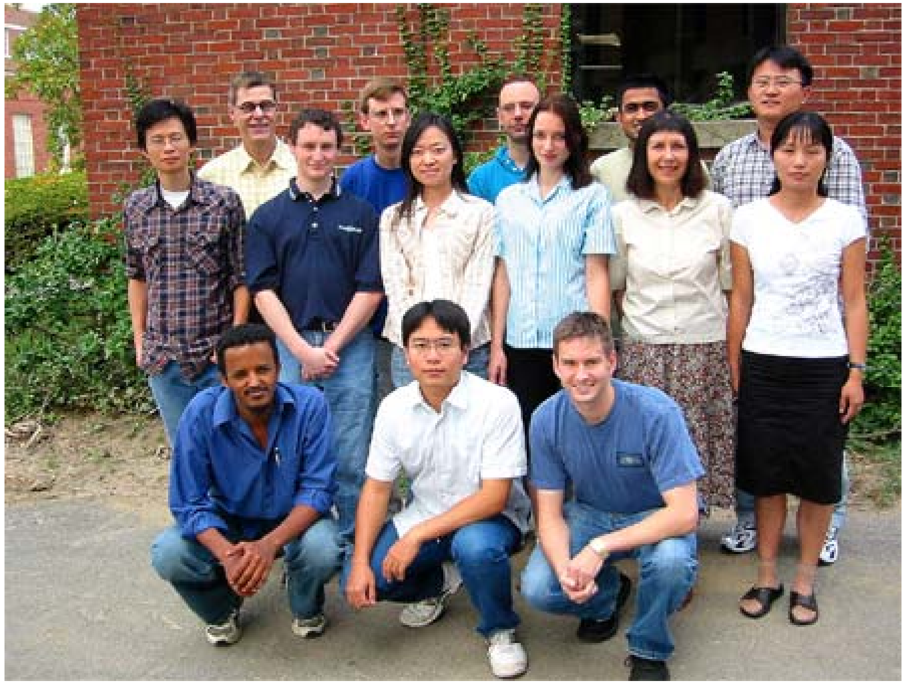
- **The reflectance as func. of θ_{inc} shows very different characteristics, which falls into one of three distinct regimes.**

- **The air-nanocomposite-glass geometry supports four mathematical modes, and different modes may be responsible for the reflectance shapes for films with different values of the gold fill fraction.**

Acknowledgements

- **Research group of nonlinear optics at Univ. of Rochester**

Website: www.optics.rochester.edu/~boyd



- **Brian McIntyre and Brad Deutsch at Univ. of Rochester**
- **Dr. Z. Charles Ying at NMSU (now at NSF)**

Thank you for your attention !

Dispersion relations