In the name of Allah, the merciful, the compassionate

Fabrication of Large Area Plasmonic Grating using Laser Interference

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The IAS Winter School and Workshop
HKUST, Hong Kong
January 2016

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Content

- Introduction
- Photolithography
  - Lithography
  - Interferometry
  - Liftoff Technique
  - Device Characterization
- Plasmonic cavity
  - Theory
  - Application
  - Cavity structure
  - Results
- Conclusion

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Introduction

The surface plasmon polariton (SPP)

A quantum of a charge- density wave of free electrons on a metal/dielectric interface.

No excitation of SPP at the flat metal/dielectric interface

According to the dispersion relation at the metal/dielectric

$$\beta = k_0 \sqrt{\frac{\varepsilon_1 \varepsilon_2}{\varepsilon_1 + \varepsilon_2}} \qquad \beta > k_{dielectric}$$

The array of apertures at the metal/dielectric interface

It serves to couple incident light with SPPs at the interface

Stefan A. Maier, "PLASMONICS: FUNDAMENTALS AND APPLICATIONS", Springer 2007

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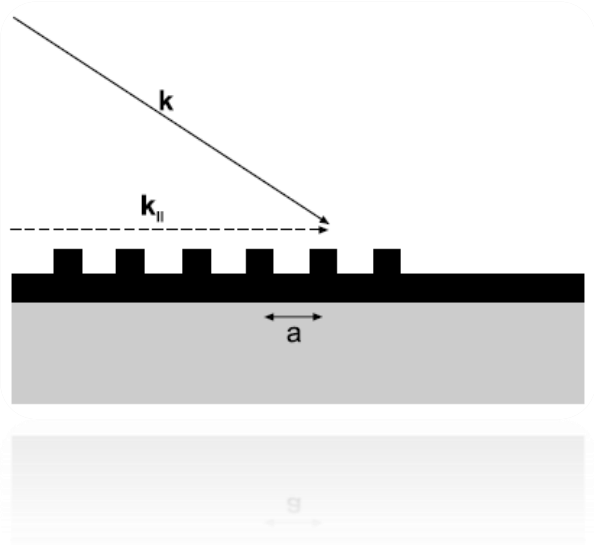
Introduction

Effective parameters on coupling strength



- ✓The hole size
- ✓ Lattice spacing
- ✓Metal film thickness
- ✓Angular dispersion
- ✓The metal type
- ✓ The symmetry role in the dielectric/metal/dielectric layer stack
- ✓The lattice finite-size
- ✓ The hole shape

F.J. Garcia-Vidal, L. Martin-Moreno, T.W. Ebbesen, L. Kuipers, Reveiws of Modern Physics, 82, 729, (2010).

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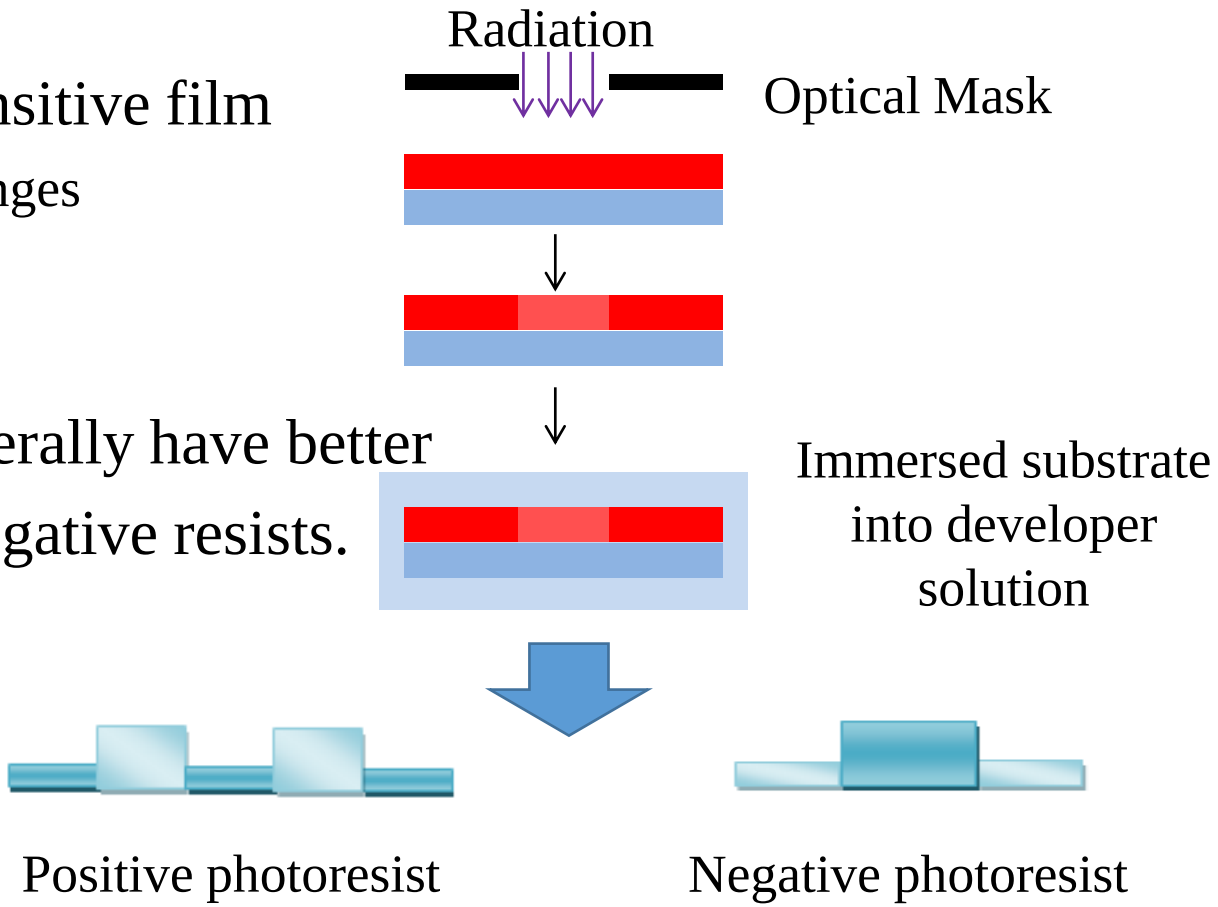
Photolithography

Lithography

- Recording photosensitive film
  structure properties changes
  under light exposure.

- Positive resists generally have better resolution than do negative resists.



Nicolas F. Borrelli,"Microoptics Technology", CRC Press 2004.

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Photolithography

Michelson Interferometer

Using Optical Mask

- Two equal laser beams
- Equal optical length for each interferometer arm
- Constructive interference
- Destructive interference
- Pitch size relation of grating

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\delta$$

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2}$$

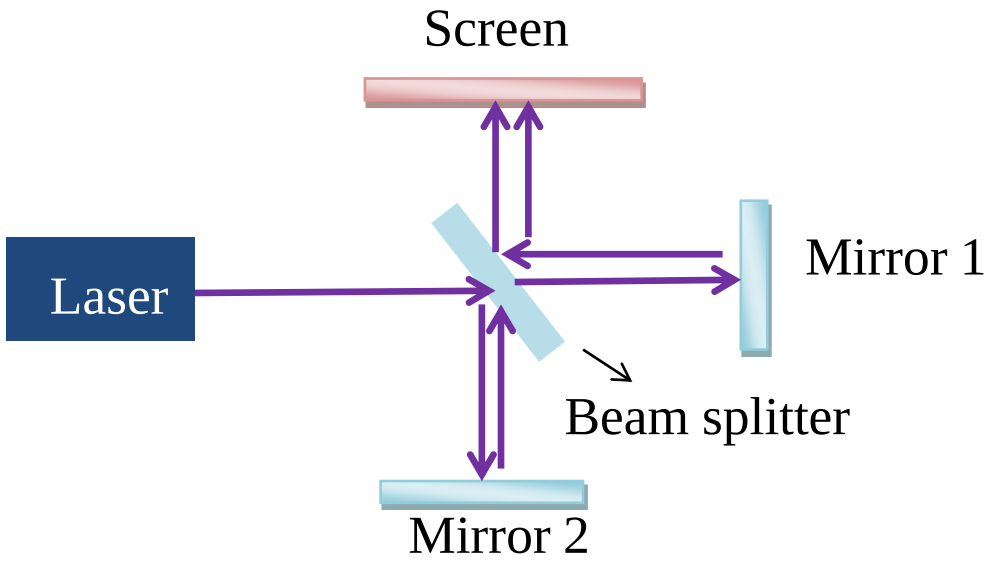
$$I = I_1 + I_2 - 2\sqrt{I_1 I_2}$$

$$\Lambda = \lambda / 2n\sin\theta$$

He-Cd laser with 442 nm

Illumination Area: 10 x 10 mm^2

Tuning of pitch size by two beams interference angle



Eugene Hecht, "Optics" 4th ed., Addison Wesley, (2002).

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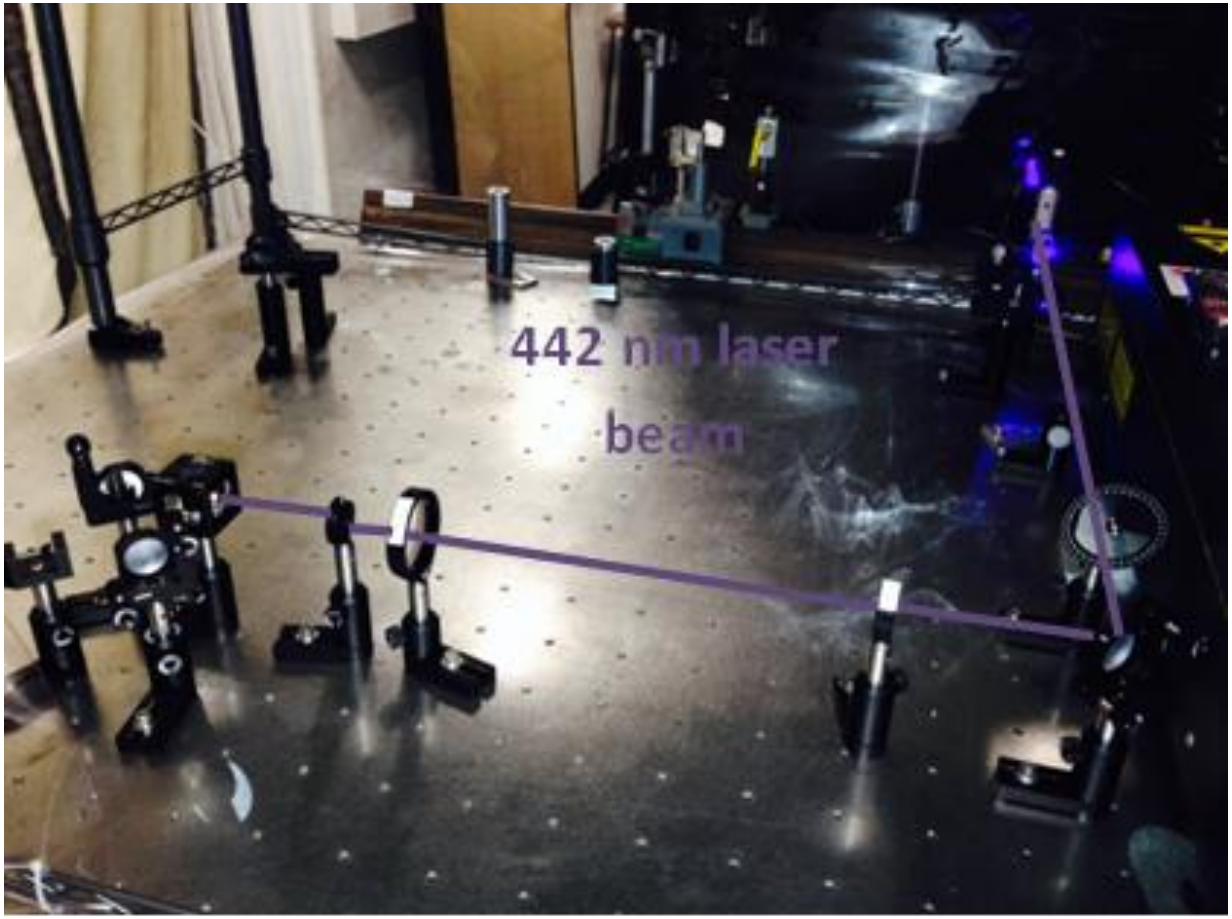
Photolithography



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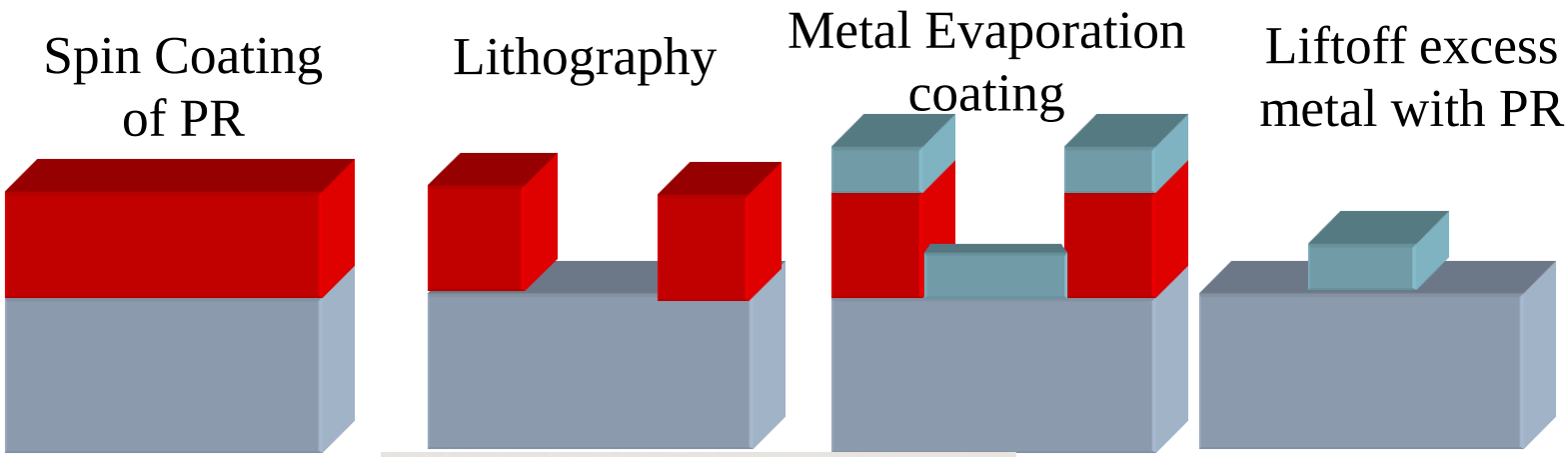
Photolithography

Liftoff Technique





Nicolas F. Borrelli,"Microoptics Technology", CRC Press 2004.

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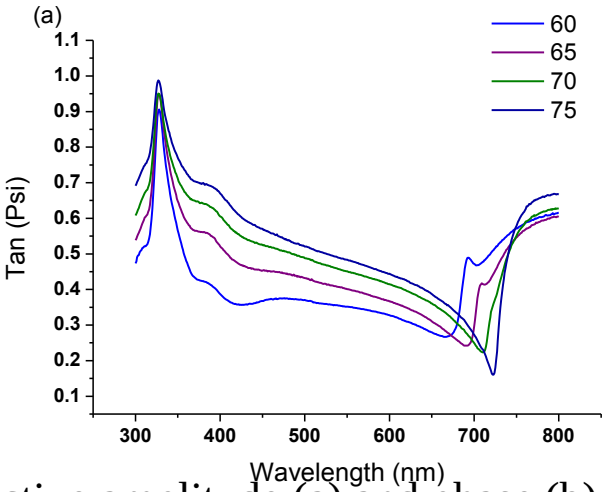
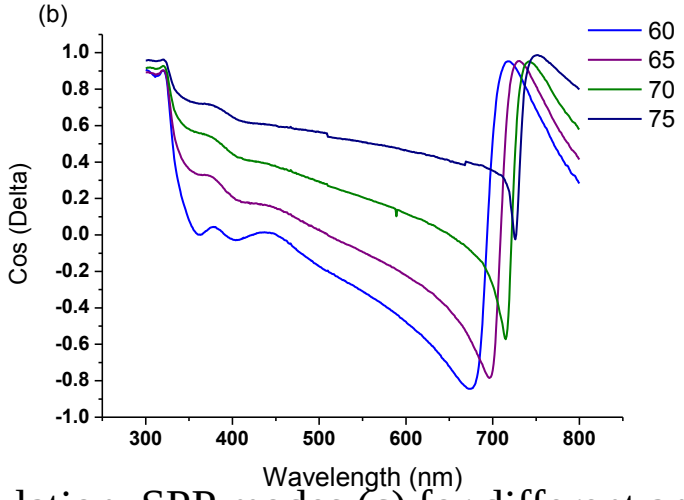
Photolithography

Device Characterization

- Ellipsometric measurement and calculation

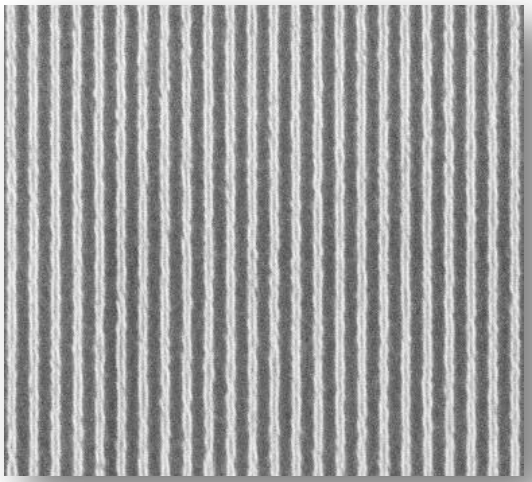




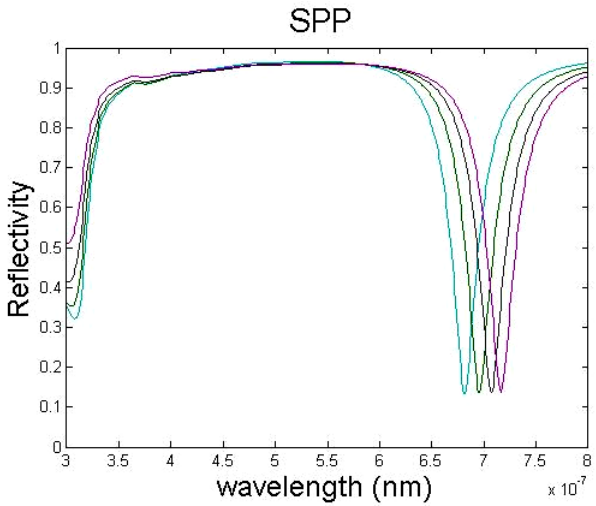
- Reflective amplitude (a) and phase (b) variation, calculation SPP modes (c) for different angle

- SEM image.

Λ~360nm



(c)



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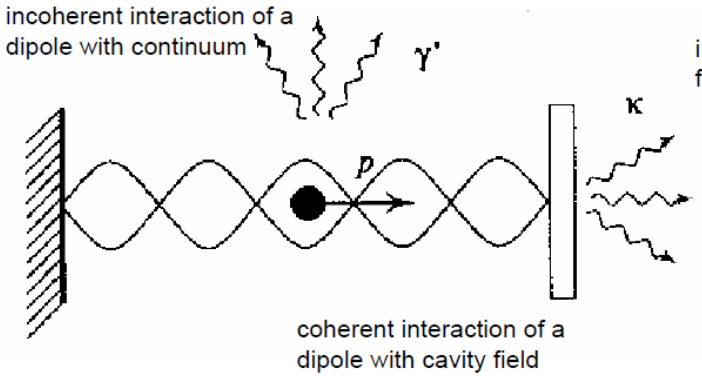
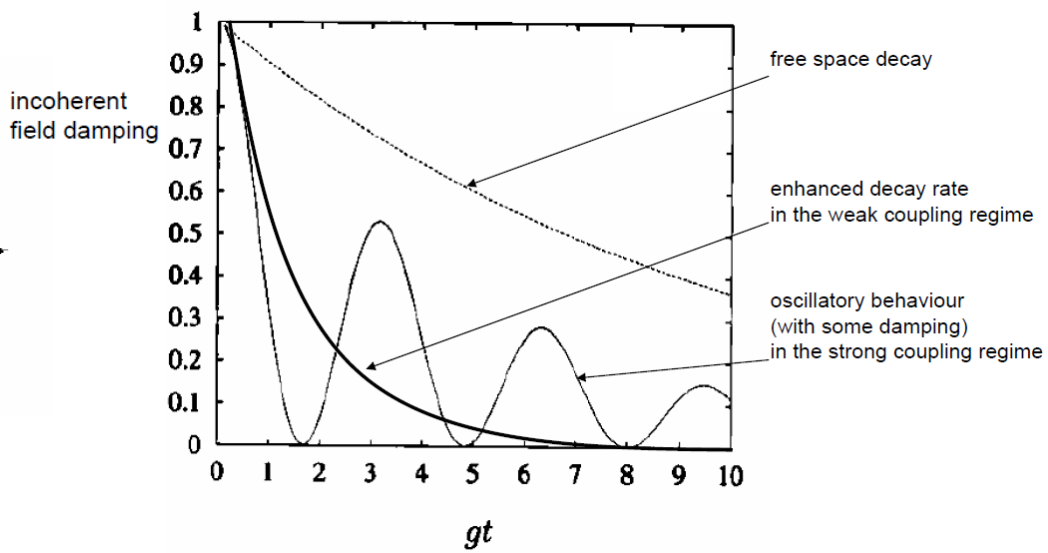
Plasmonic cavity

Theory

- When electromagnetic field interacts with a matter like a single emitter, the following intractions can be found:





- Two different regimes:

i. Strong coupling regime: This is dominated by coupling constant of interaction.

ii. Weak coupling regime: the damping rates are dominated.

Aspect of Nano-quantum Optics, Ch. 9, Nano optics.

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Plasmonic cavity

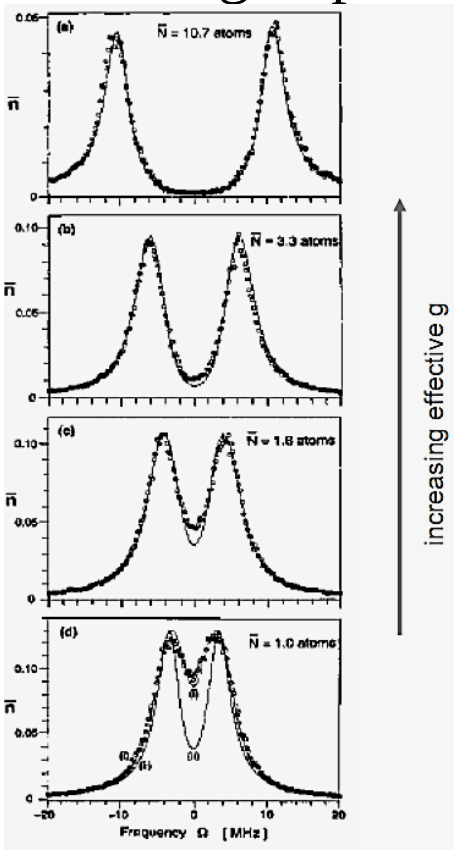
Theory

Strong Plasmon-Cavity coupling

➢Rabi-like splitting

Supposing the surface plasmon as two level system using dipole moment approximation with single mode cavity.

$$H = \begin{pmatrix} E_N & g \\ g & E_{LP} \end{pmatrix} \qquad H\Psi = \begin{pmatrix} E_N & g \\ g & E_{LP} \end{pmatrix} \begin{pmatrix} \psi_N \\ \psi_{LP} \end{pmatrix} = E \begin{pmatrix} \psi_N \\ \psi_{LP} \end{pmatrix}$$



➢ According to phase matching, no surface modes exist for TE polarization so there is just TM mode SPP coupling at the surface

Ralf Ameling,Harald Giessen,” Microcavity plasmonics: strong coupling of photonic cavities and plasmons” Laser Photonics Rev., 1–29 ,2012.

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Plasmonic cavity

Application

- Reducing the pumping threshold of polariton lasing
- Controlling the energy redistribution pathways in molecules and tailoring the resonance energy of excitons in semiconductor materials
- The coupled photonic–plasmonic systems
- The organic–plasmonic hybrid system
- THz metamaterials
- Controlling the energy distribution channels in a hybrid plasmonic nanocavity

Shumei Chen, Guixin Li, Kok Wai Cheah, "Efficient energy exchange between plasmon and cavitymodes via Rabi-analogue splitting in a hybrid plasmonic nanocavity" Nanoscale, 2013, 5, 9129.

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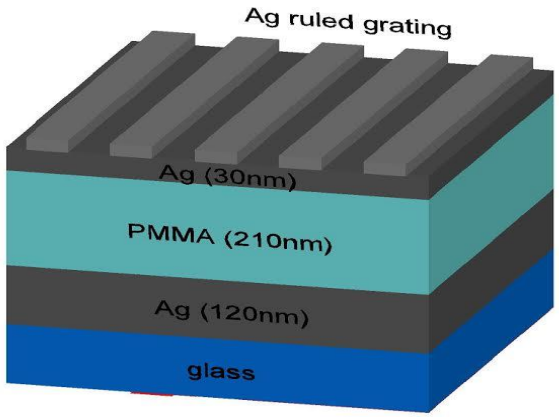
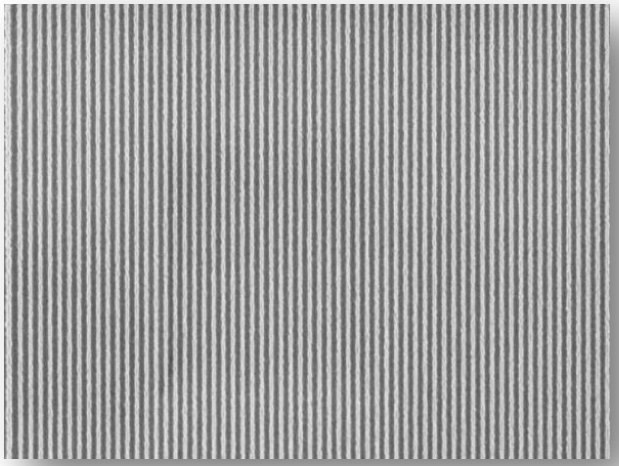
Plasmonic cavity

Device structure





- Thermal evaporation silver
- Spin coating PMMA and Photoresist
- Making grating on photoresist by photolithography
- Grating height ~ 15nm with pitch size ~ 370nm
- Cavity dimension: 10 x 10 mm^2

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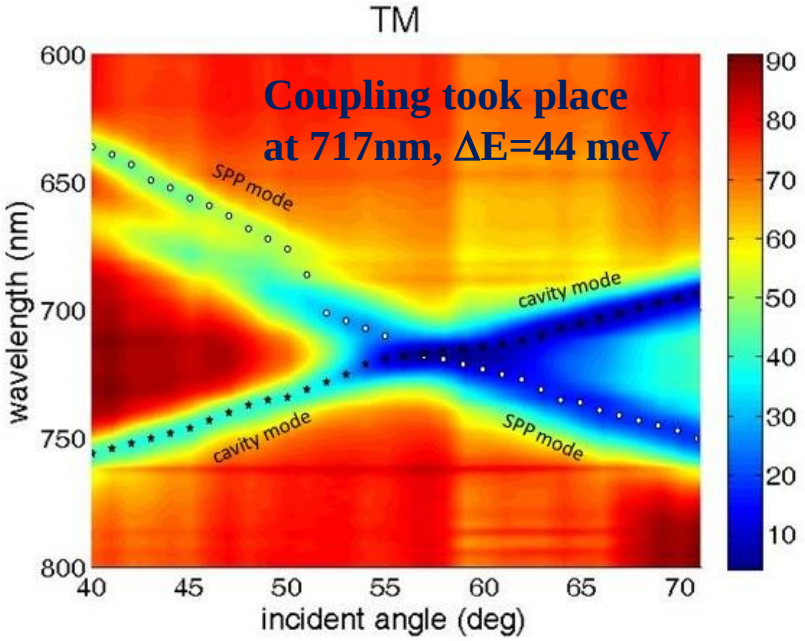
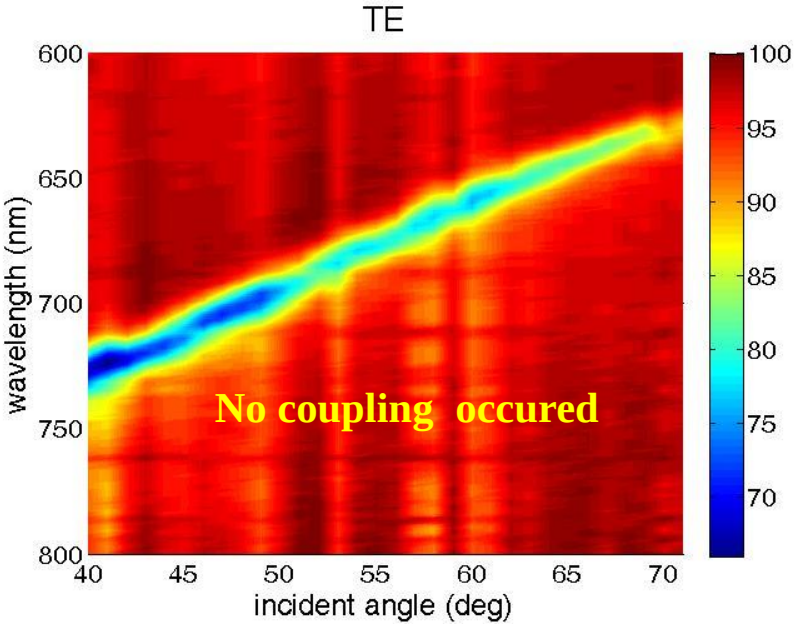
Plasmonic cavity

Experimental Results





Cavity length ≈ 210 nm

Pitch size ≈ 370 nm

Anti-crossing degree ≈ 52

Anti-crossing wavelength ≈ 717 nm

Linewidth of splitting ≈ 17.5 nm ~ 44mev

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Conclusion

- The ruled grating was fabricated with high surface quality and uniformity in large area.
- The grating performance was examined with SPPs excitation at the metal/dielectric interface for different angles by reflectivity measurement.
- The calculated first mode of SPPs excitation for different angles were quite matched with experimental results.
- The plasmonic cavity with ruled metal grating was fabricated in large area.
- Anti-crossing was obviously observed due to the coupling of SPPs and Fabry-Perot cavity mode in the fabricated plasmonic structure.

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Acknowledgment

I would like to express my sincere gratitude to my supervisor Prof. Cheah for his generous support and insightful comments.



This project is supported by Hong Kong Research Grant: AoE/P-02/12.