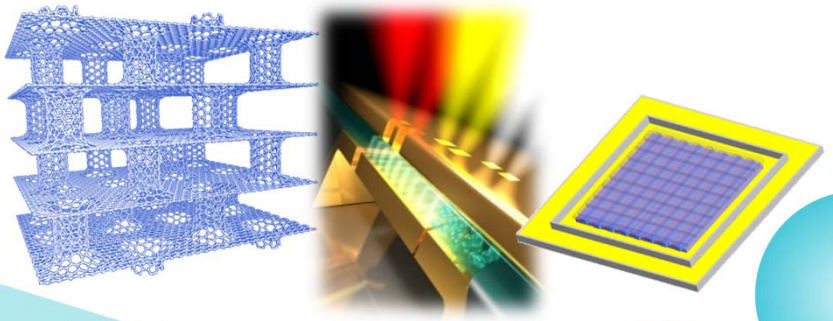


Plasmonic Metal Nanopatterning and Its Applications in Optoelectronics

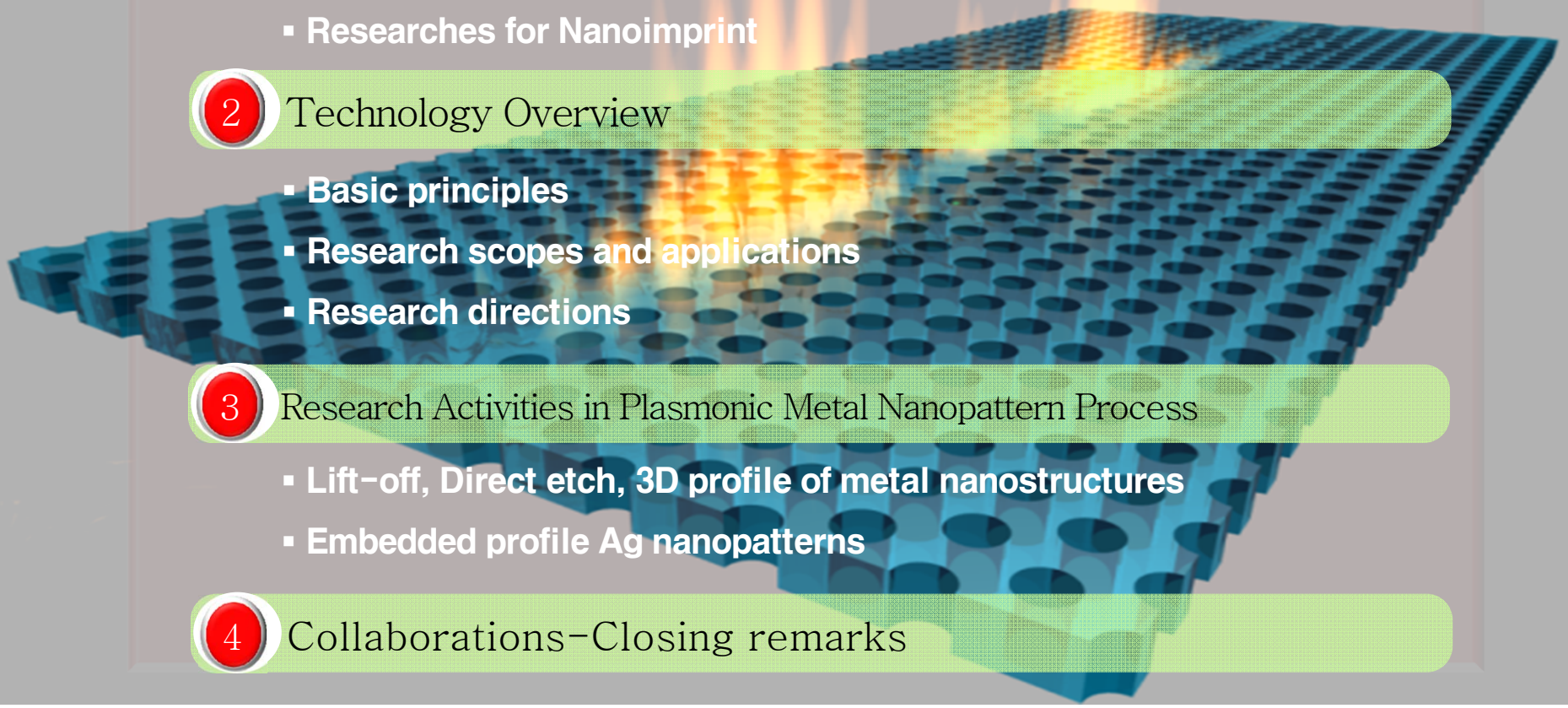
Lee, Eung-Sug

2013. 10. 15

Korea Institute of Machinery & Materials

KIMM 한국기계연구원 KOREA INSTITUTE OF MACHINERY & MATERIALS

Outlines



1. Laboratory Introduction
   - Members / Facility
   - Researches for Nanoimprint
2. Technology Overview
   - Basic principles
   - Research scopes and applications
   - Research directions
3. Research Activities in Plasmonic Metal Nanopattern Process
   - Lift-off, Direct etch, 3D profile of metal nanostructures
   - Embedded profile Ag nanopatterns
4. Collaborations-Closing remarks

Members

- Nanoimprint
  - Process, Tools, Functional mater.
  - Appl.: R-RAM, Sensors, (O)LED
- 3D Multiscale Architecturing
  - Nanowire structuring
  - Nanomaterials self-assembly
- Plasmonic sensors, Light emitting
  - Metal nanostructuring
  - Metal NP. Self-growth

Staffs

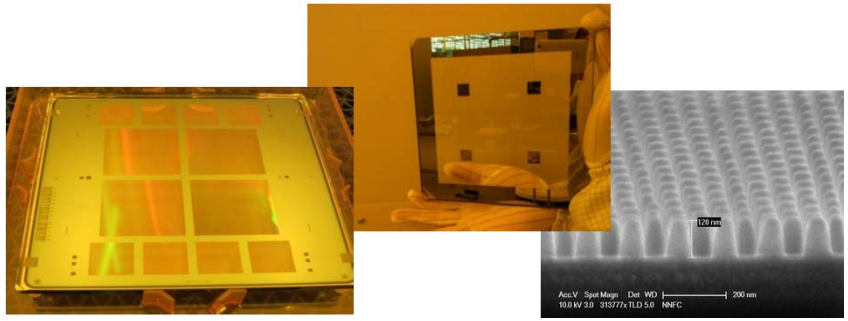
- Lee, Eung-sug: Ultrafind fabrication, Nanomechatronics
- Jeong, Jun-ho: Nanolithography, Nanoimprint
- Choi, Jun-hyuk: Metal nanopattering, Direct/Roll Imprint
- Choi, Dae-geun: Nanoimprint mater. Process chemistry
- Lee, Ji-hye: Nanowire, mask fabrication, biosensors
- Jeong, Joo-yeon: Electronics, Plasmonic optics

Facilities/Infra.

For Nanoimprint at wafer scale

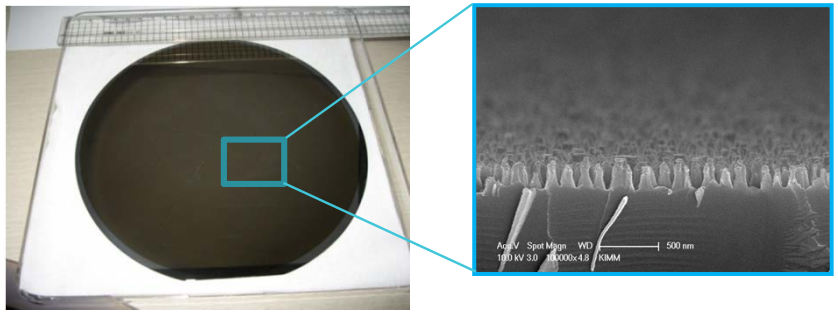
For Nanoimprint in Large area

Master/Molds

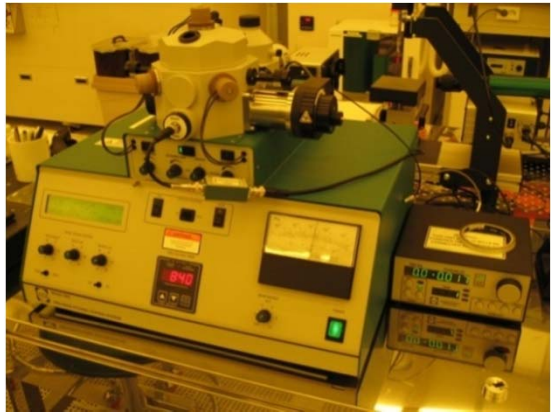


Large area Mold fabrication

Etched master at 8″ wafer

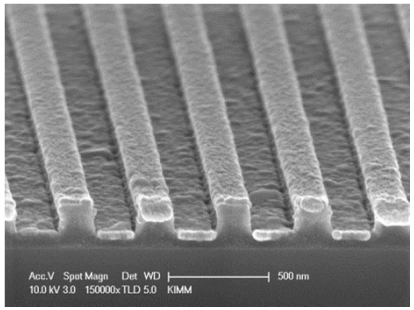


Metal patterning infrastructures

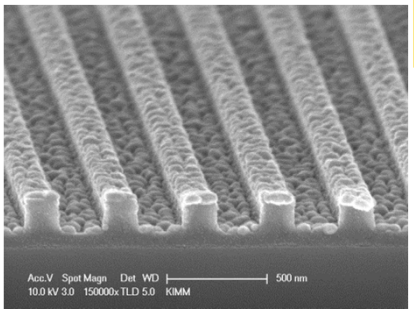


증착속도에 따른 박막 Quality 비교

Ag deposited
By E-beam

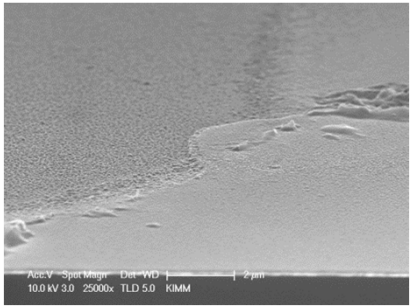


v.s.

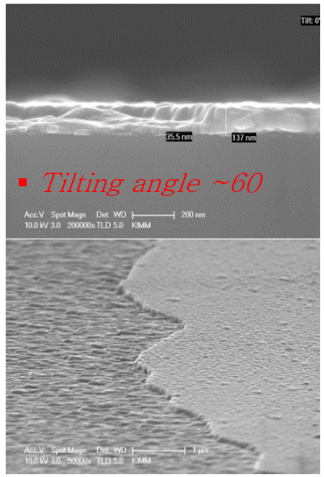


5.0 Å/S *0.5Å/S*

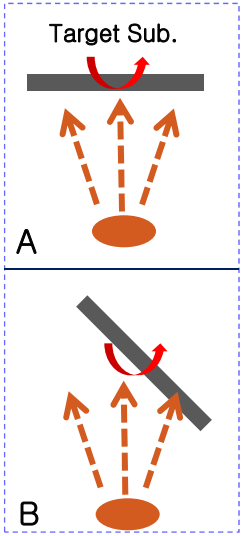
Siliver Milling Test
w.r.t. the variables of current, time, and tilting angle



- *Tilting angle ~0*
- *Current 300 μA*
- *Time 1min*

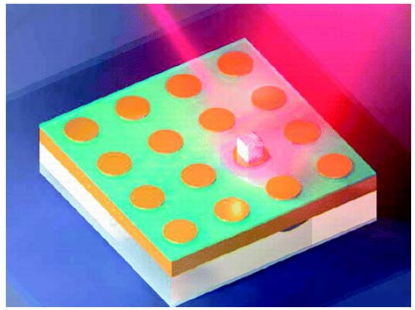


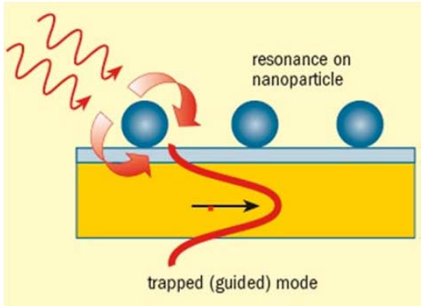
- *Tilting angle ~60*



Technology Overview

Basic Principles



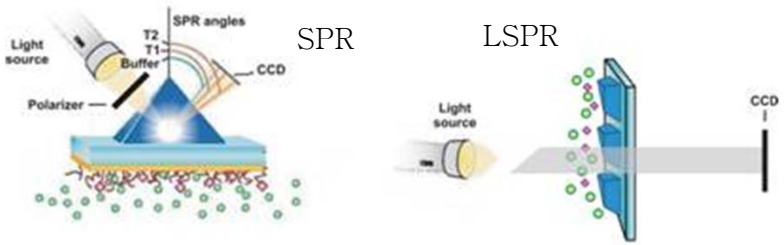


When illuminated outside

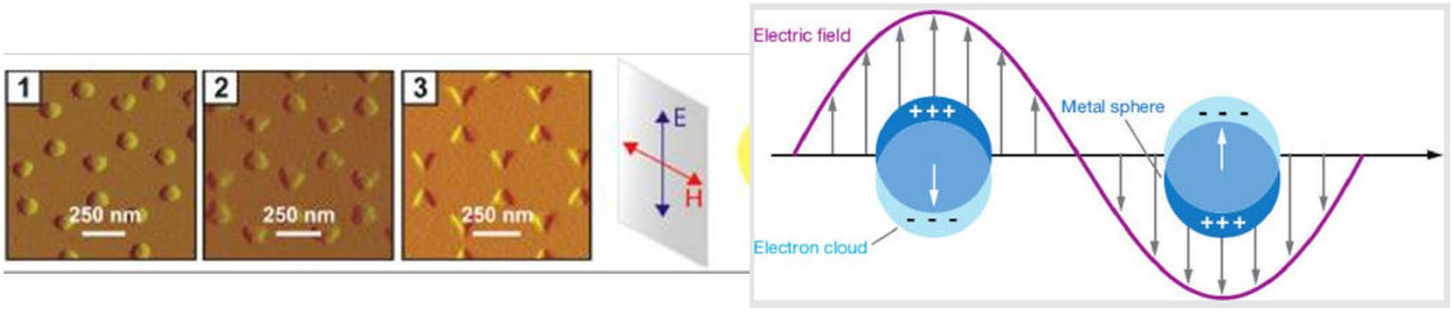
When illuminated inside

Surface plasmon resonace

- Photon-electron coupled phenomenon at resonant condition when illuminated on metal surface
- Collective oscillation of electrons propagating on the surface with positive dielectric constant
- Evanescent wave out of plane
- Locally amplified field formation

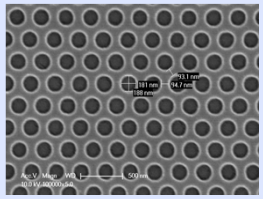


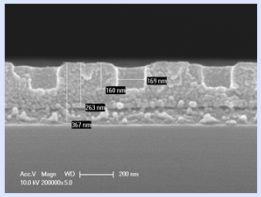
Localized surface plasmon resonance

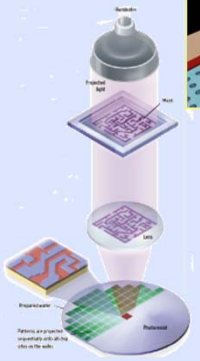


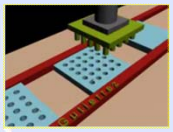
Research area

<Nanopatterning, Lithography>









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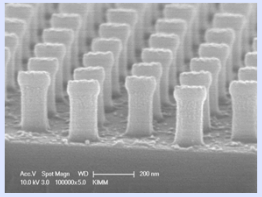
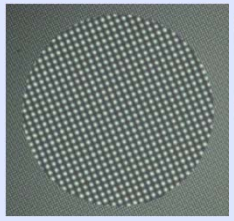
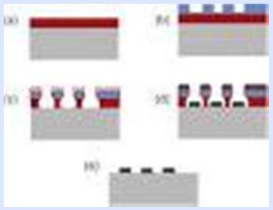
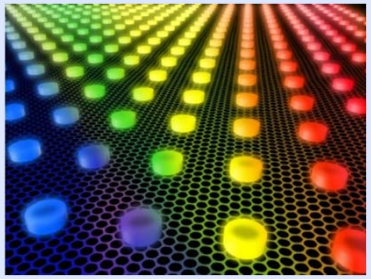


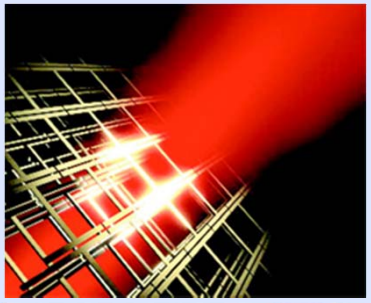
<Metal pattern, Lift-off>

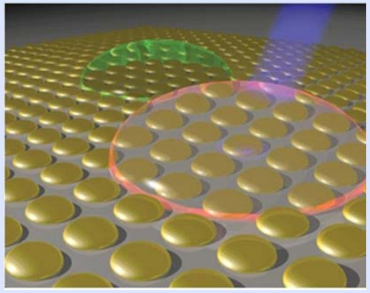




<Metal nanopattern array>

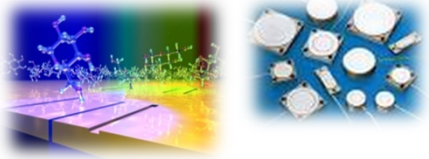




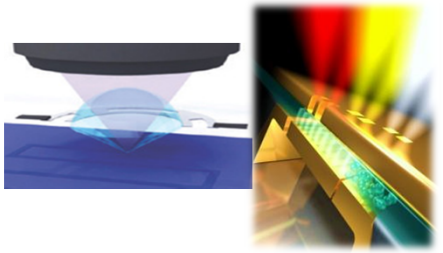


<Optoelectronic Applications>

<Optics-based Sensors>



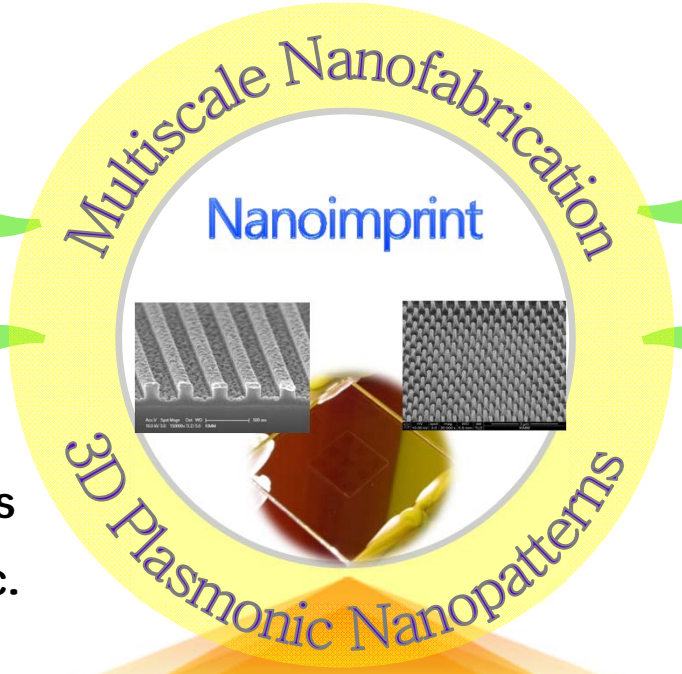
<Plasmonic Lithography>



Research directions

- Multilayer, Enlarged
- Solar cells

- Planarized Struc.
- Plasmonic Litho. Mask



- Plasmonic sensors
- Undercut 3D Struc.

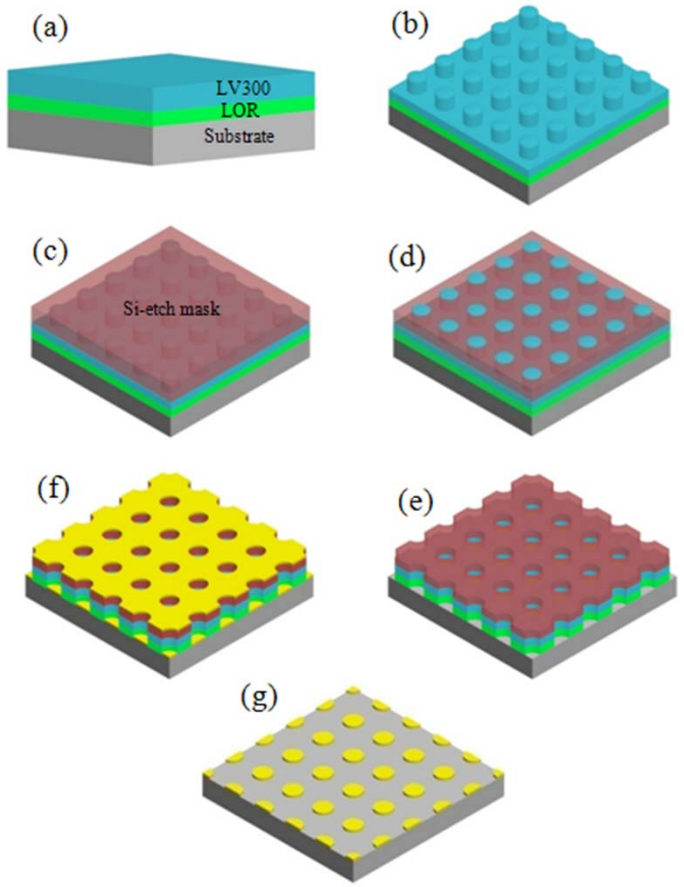
- Optoelectronics
- Embedded structure profile

Infrastructure of metallic nanopatterning

Research Activities

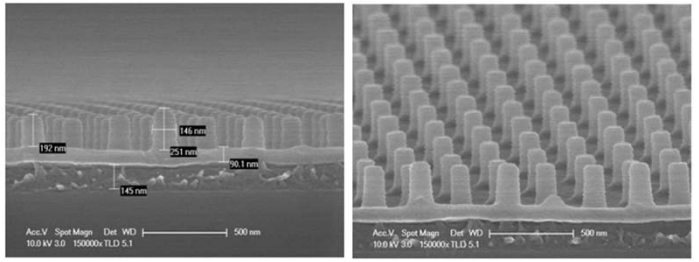
Lift-off for well-round shaped Metal dots

Process Scheme



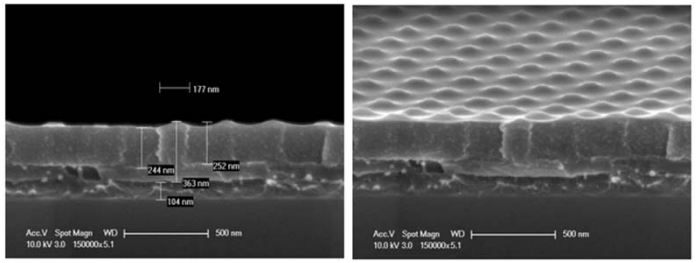
Step 2: Bilayer Imprint

- 150nm, Pillar형, 1:2 A.S.
- LOR 90nm / LV 300nm
- UV Imprint at 2 bar, 90s
- Transferred Height 250nm
- 잔류층 50~60nm



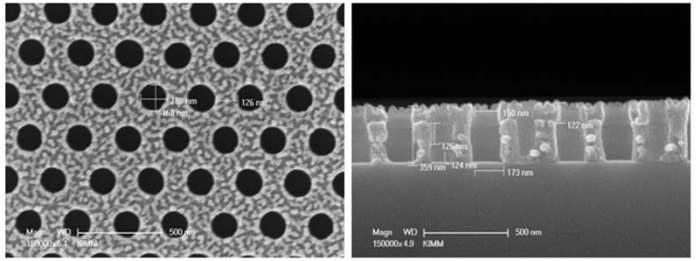
Step 3: Silipin 증착

- 4,000 rpm, 30sec
- 150도에서 3분 어닐링



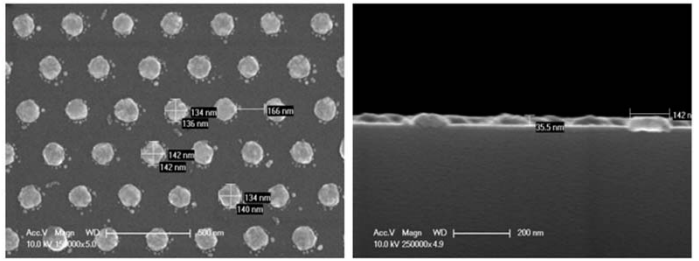
Step 5: Etch-down

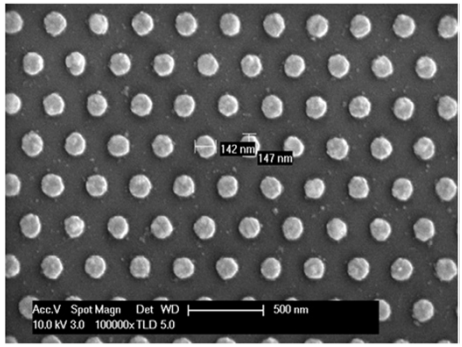
- Silspin Etch 20s, O2+CHF3
- Imprint Resist & LOR Etch
  : 50 sccm of O2, 90s



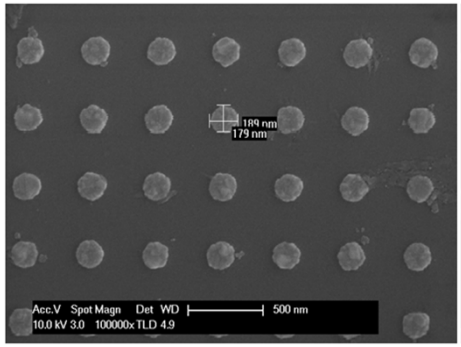
Step 7: Ag 증착-) Lift-off

- Thermal Evap. 30nm
- Developer 400K

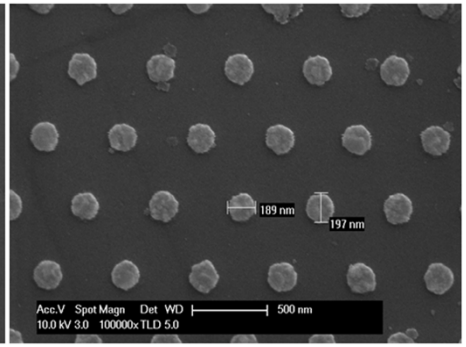




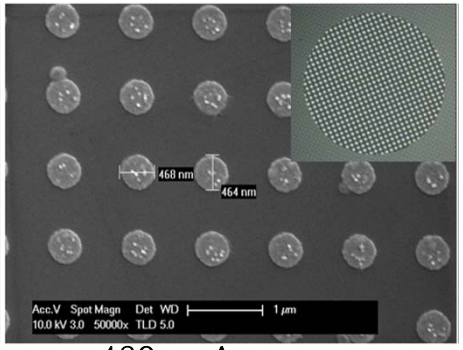
150nm Ag hexa
25nm thick



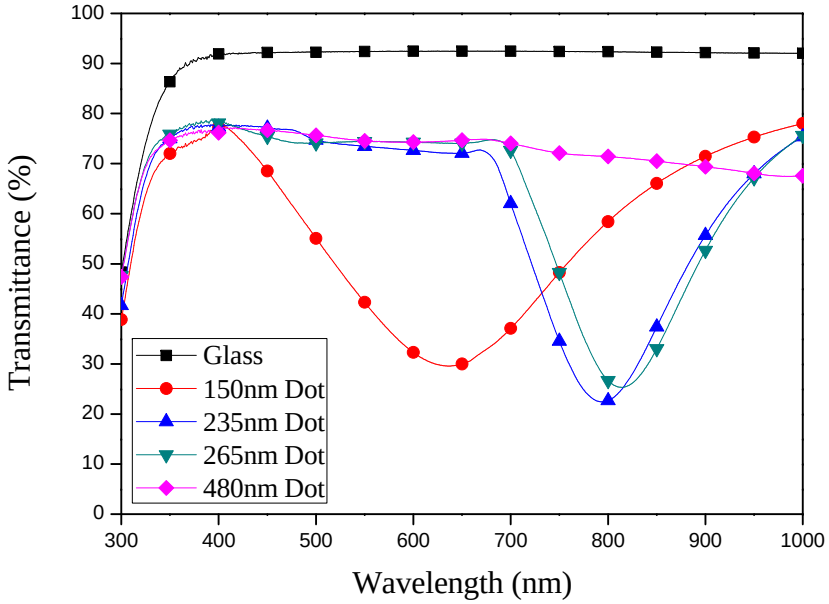
235nm Ag square
25nm thick

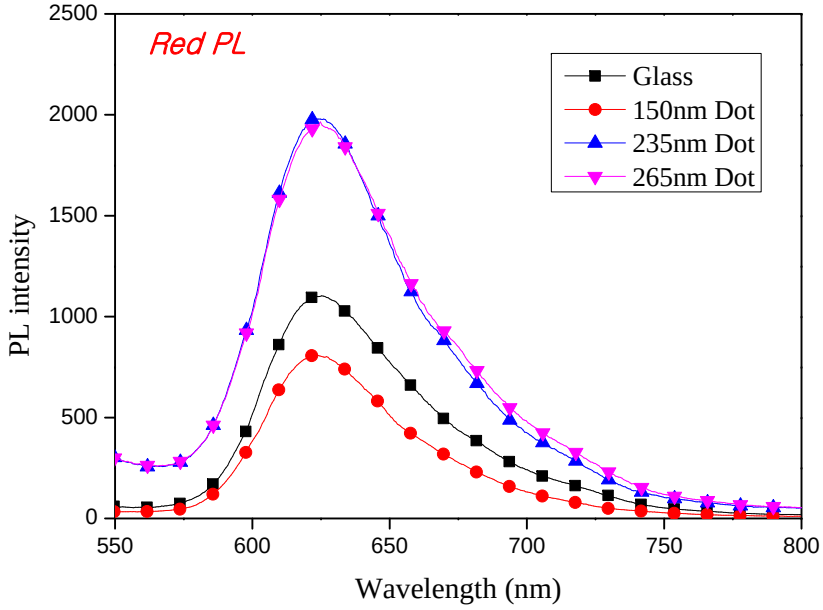


265nm Ag hexa
25nm thick

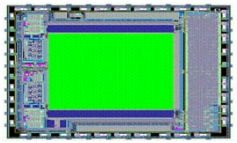


480nm Ag square
25nm thick



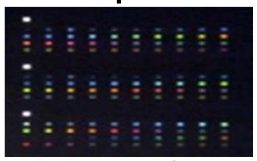


Metal direct etch, Nanoimprint

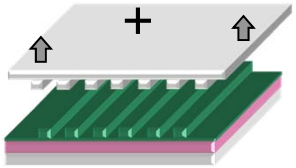


CMOS imaging chip

+

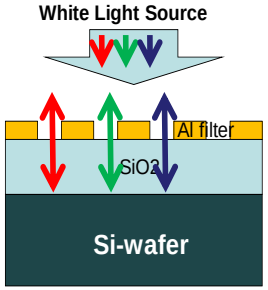


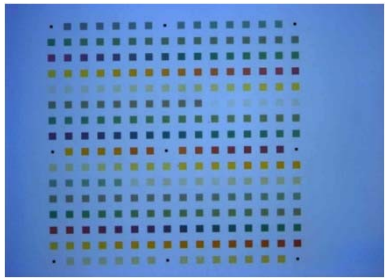
Plasmonic nano filter array

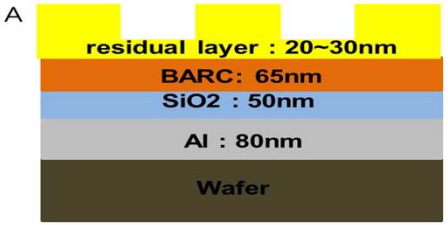


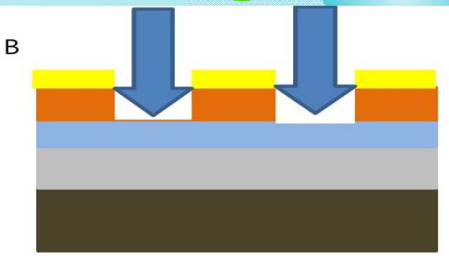
nanoimprint process

❑ Front Illumination &Reflection

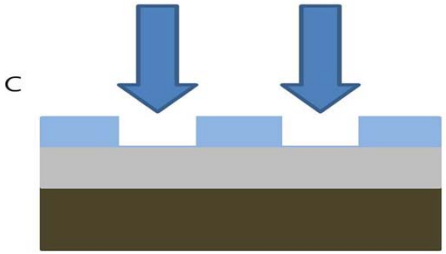




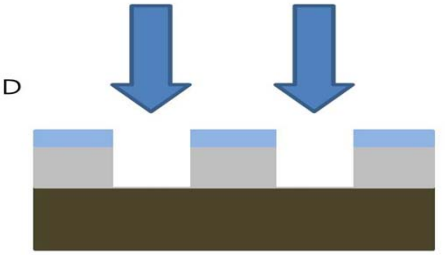




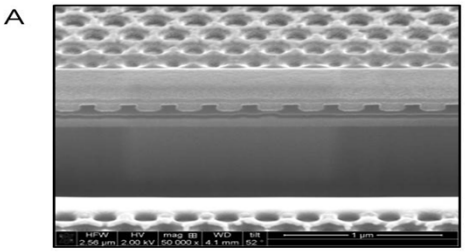
Etching polymer (90nm~100nm)

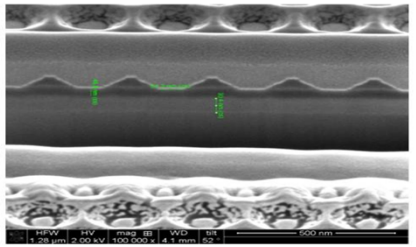


Etching SiO2 (50nm)

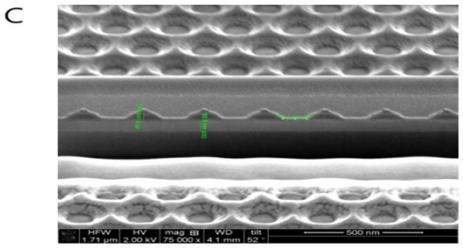


Etching Al (80nm)

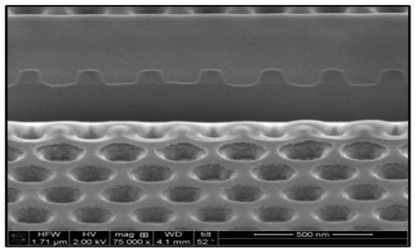




Etching polymer (90nm~100nm)

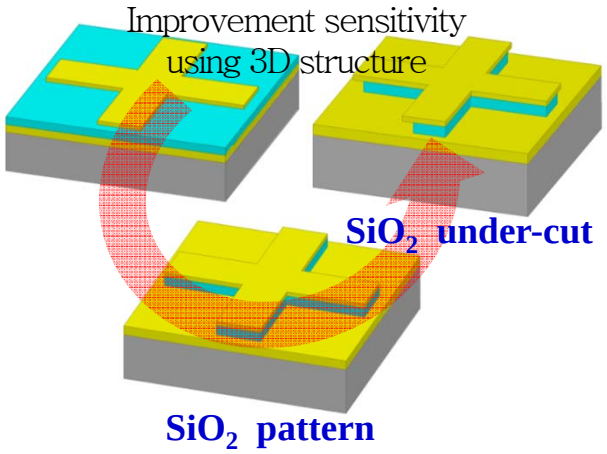


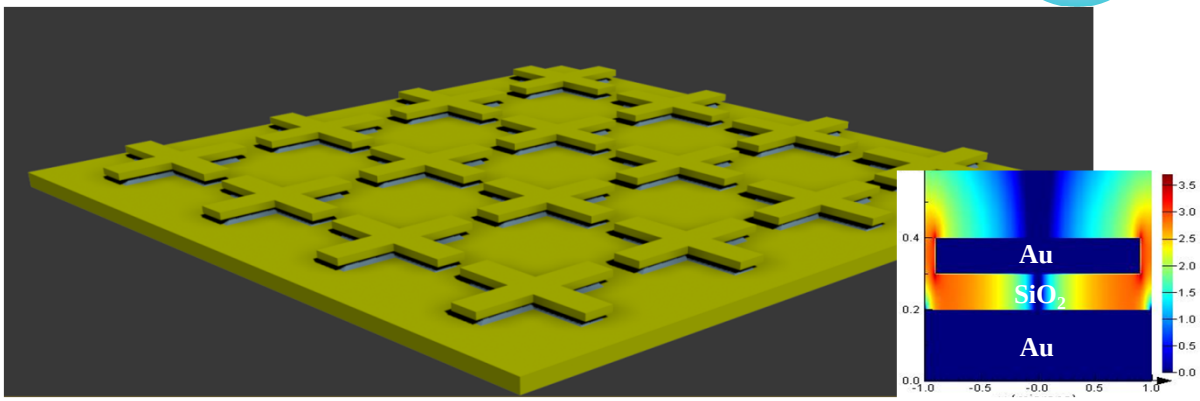
Etching SiO2 (50nm)

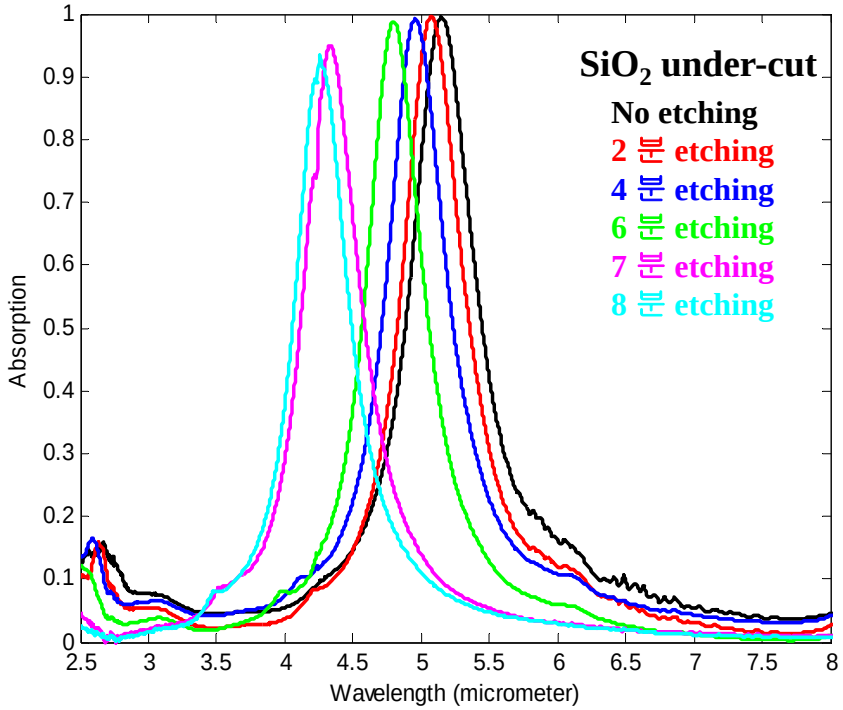


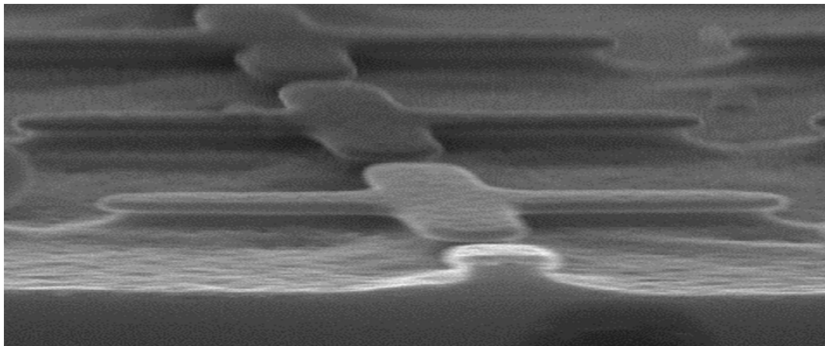
Etching Al (80nm)

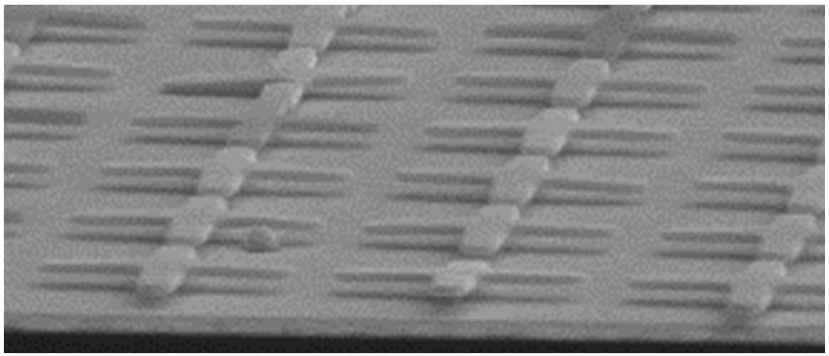
3D Under-cut shape Au nanopattering



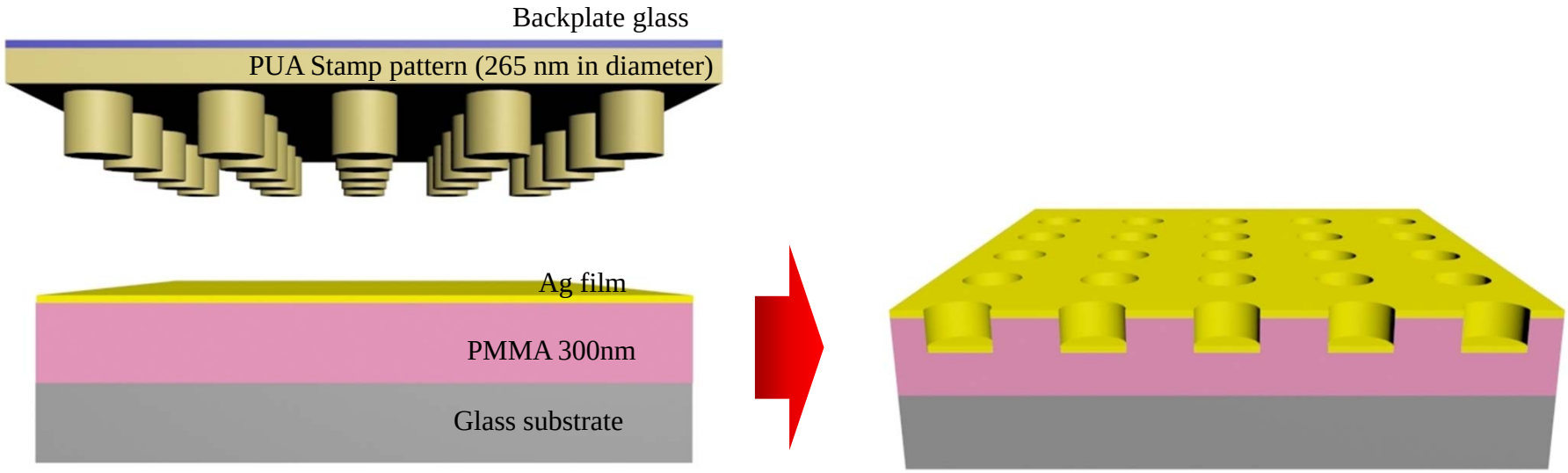




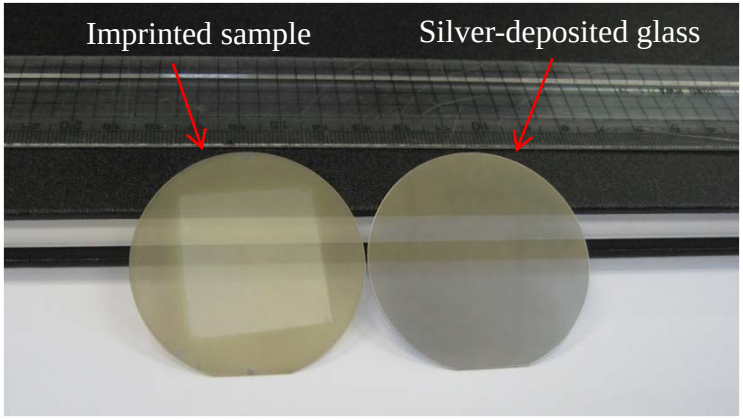


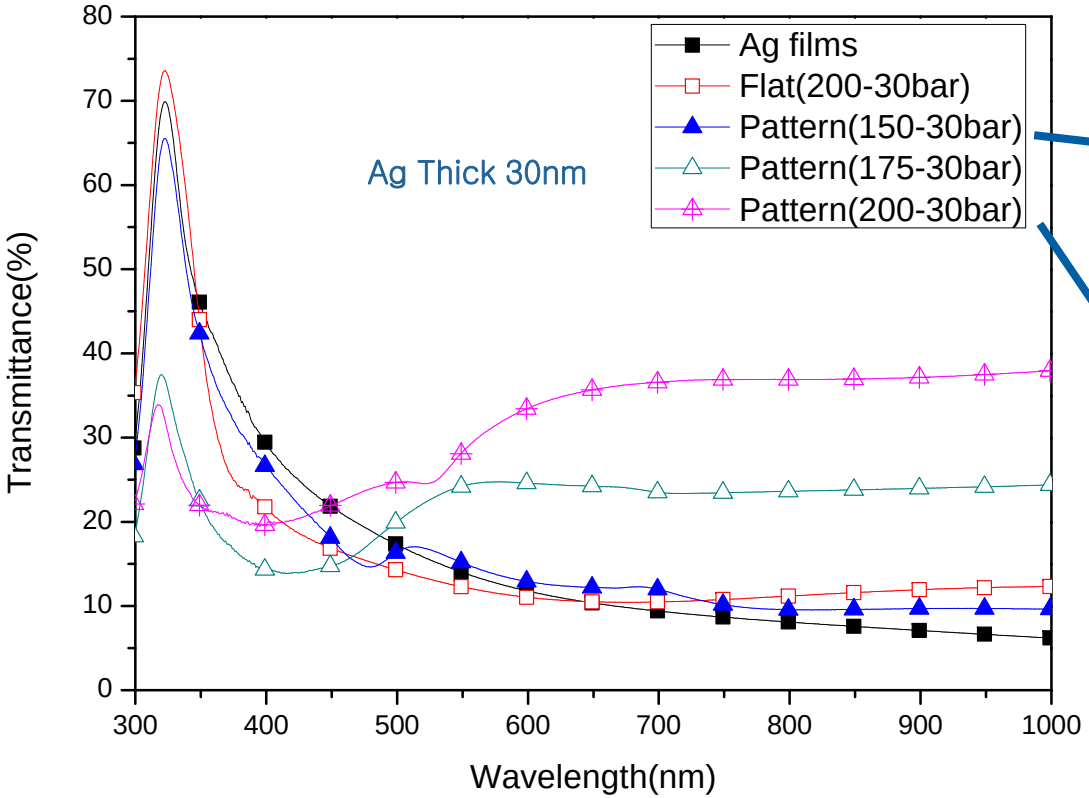


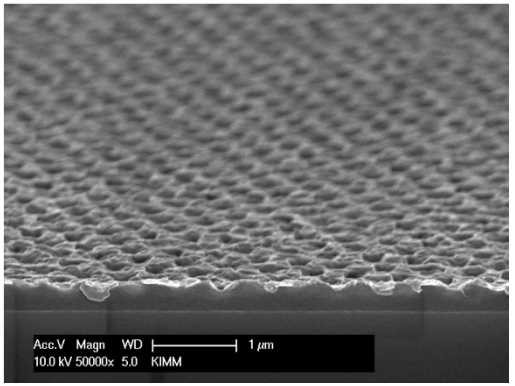
Metal direct nanoimprint (corrugation)

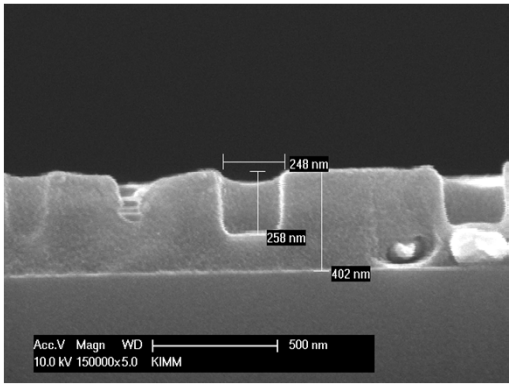


- Implement PMMA layer as a cushioning buffer
- Increased Transmittance
- Configurable for depth, hole shape
- Applicable to UV-resistant tint glass







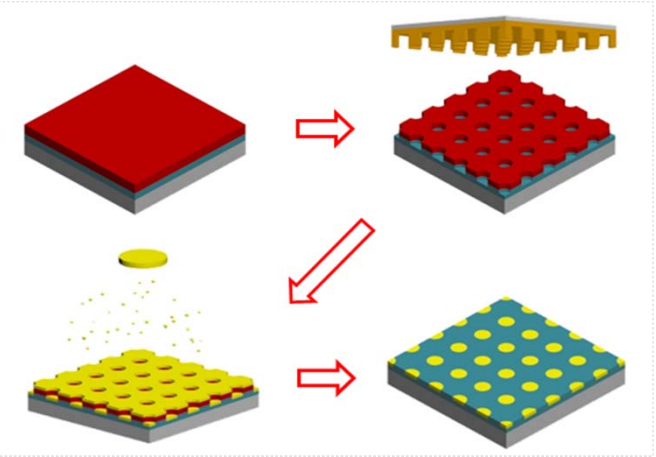


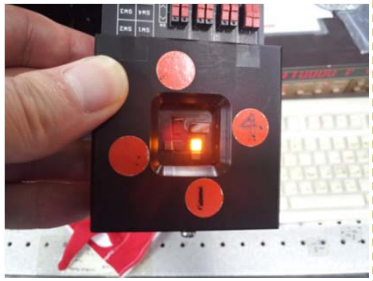
- Temperature dependent
  - Metal diffusion, followed by silver self-aggregation
- Pressure dependent, namely structure dependent
  - Optical modulation through Index-gradient

- Patent registered
- JJAP, 2013

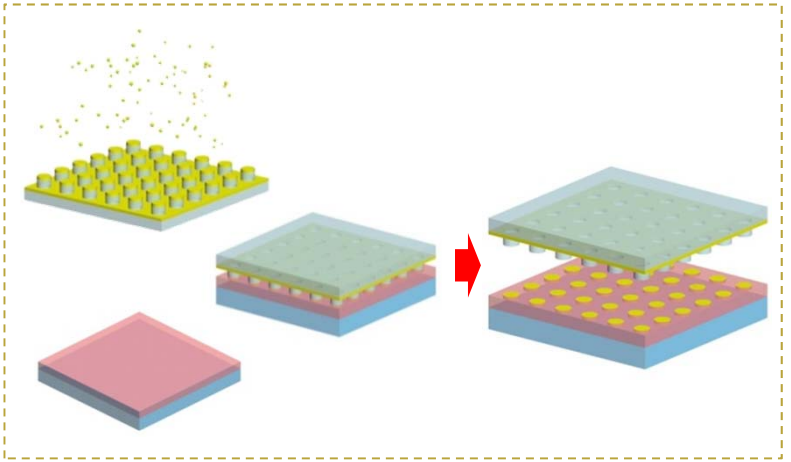
Embedded Ag nanopatterning

1. Bilayer Hybrid NIL –> Lift–off



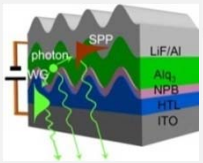


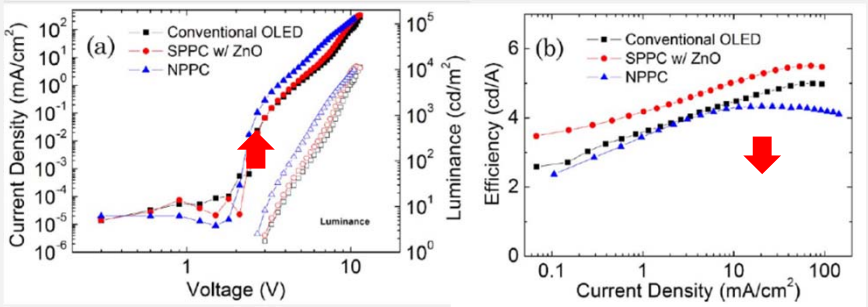
2. Metal Imprint Transfer



Point of the embedded configuration on multilayer optoelectronics

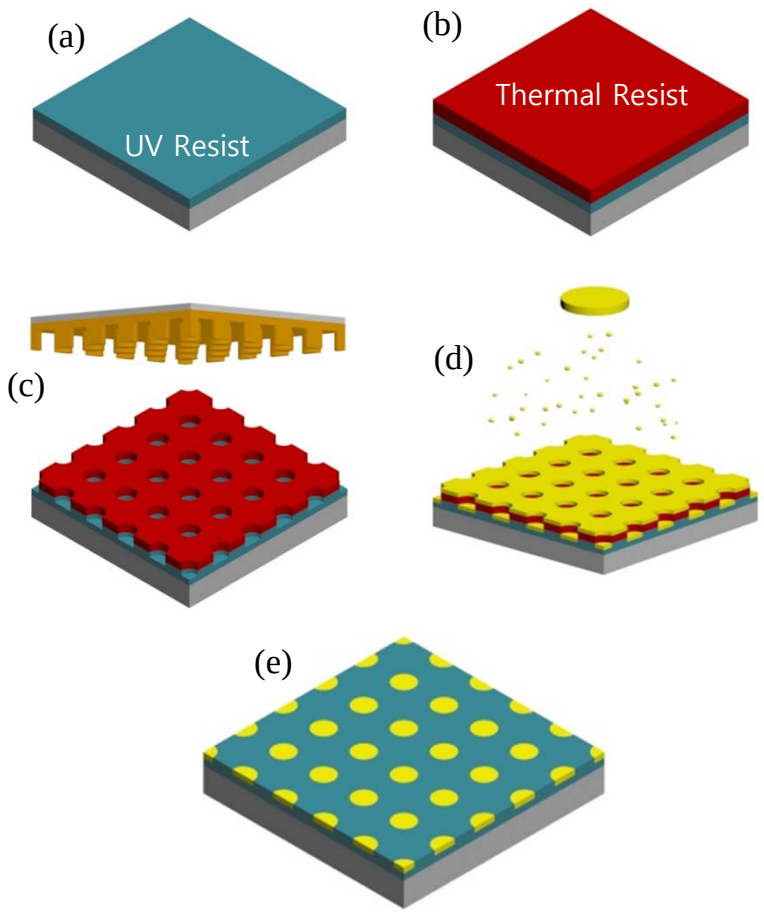
- Non–uniform current flow (Leakage current)
  ⇒ Reduced efficiency
- Electric field/Electron injection enhancement
  ⇒ Electron transport effects
  ⇒ Thermal decay, reduced life–time
- Charge recommbination in solar cells
  ⇒ Thermal decay, reduced efficiency

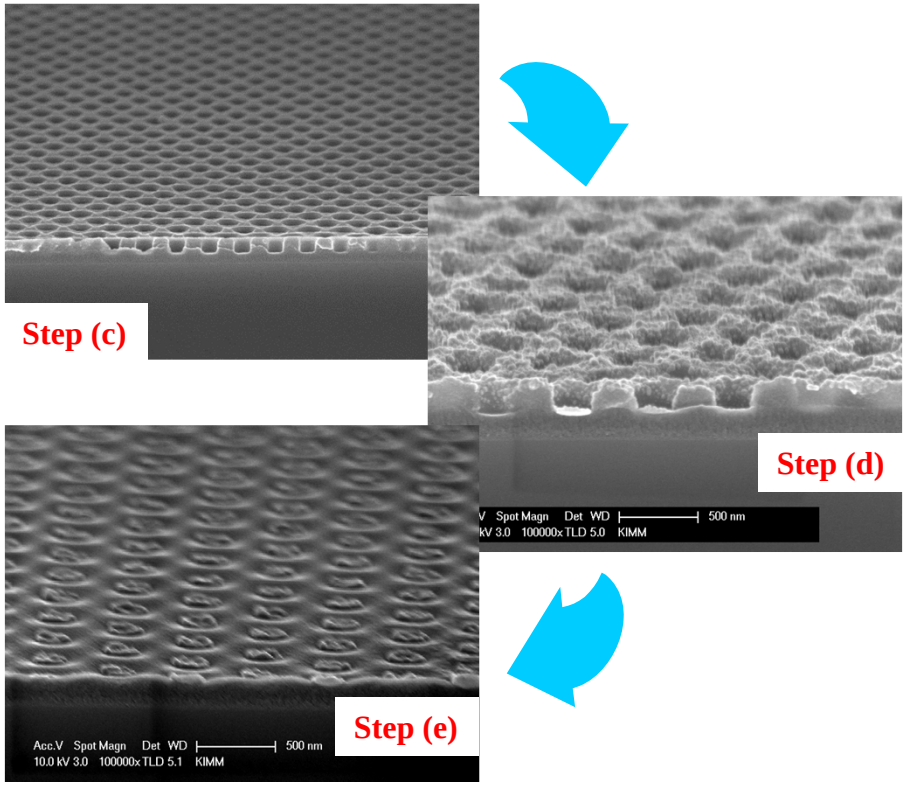




1. Bilayer Hybrid NIL and following Lift-off

Process Scheme



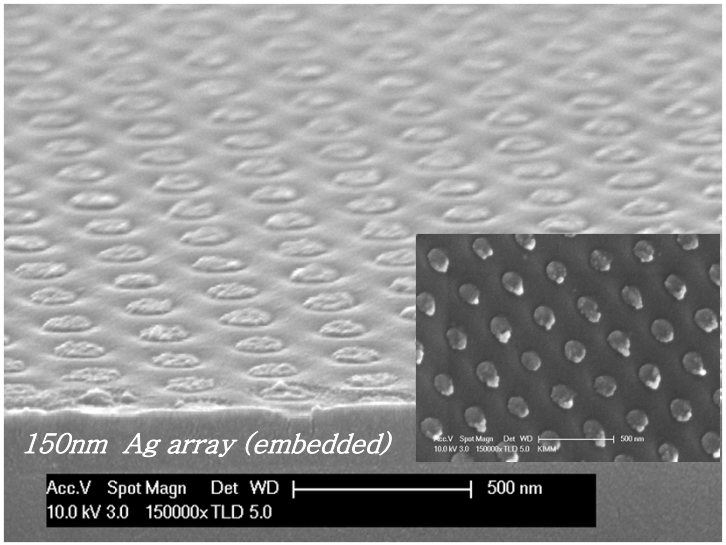


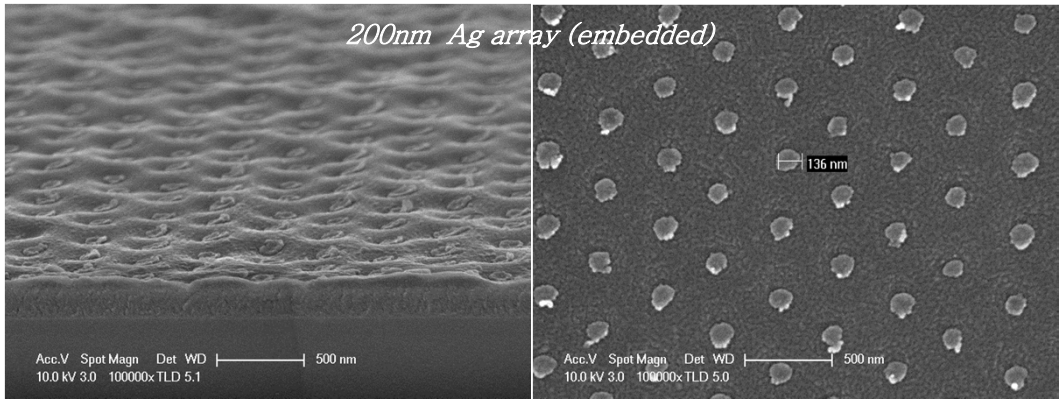
(a) Half pre-cure of the coated UV resist

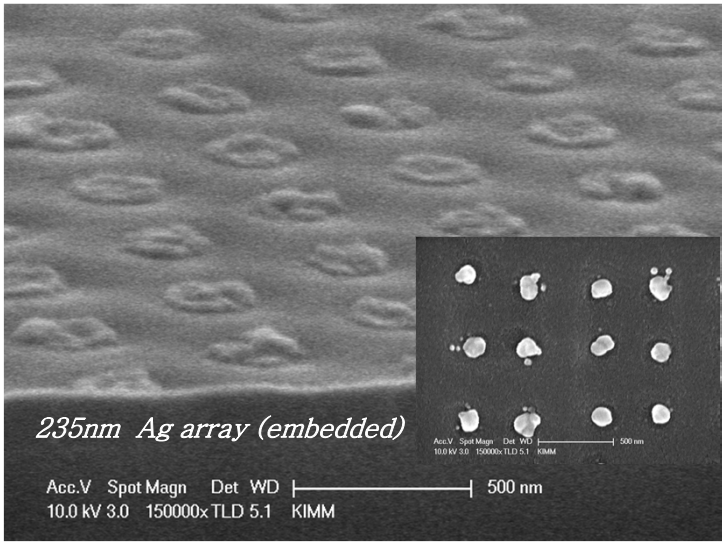
(c) Thermal Imprint, UV exposure while pressed
-> Complete cure of UV resist

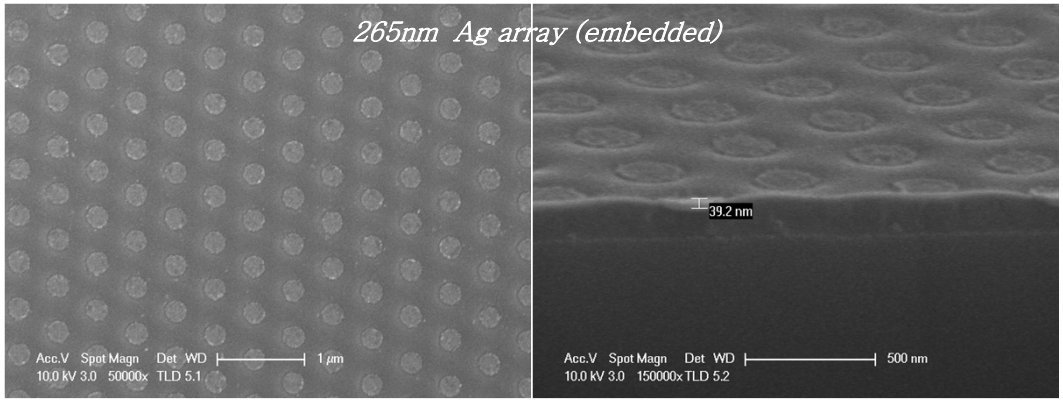
(d) Ag deposition by E-beam evaporation

(e) Lift-off of thermal resist on top layer


150nm Ag array (embedded)
Acc.V Spot Magn Det WD 500 nm
10.0 kV 3.0 150000x TLD 5.0

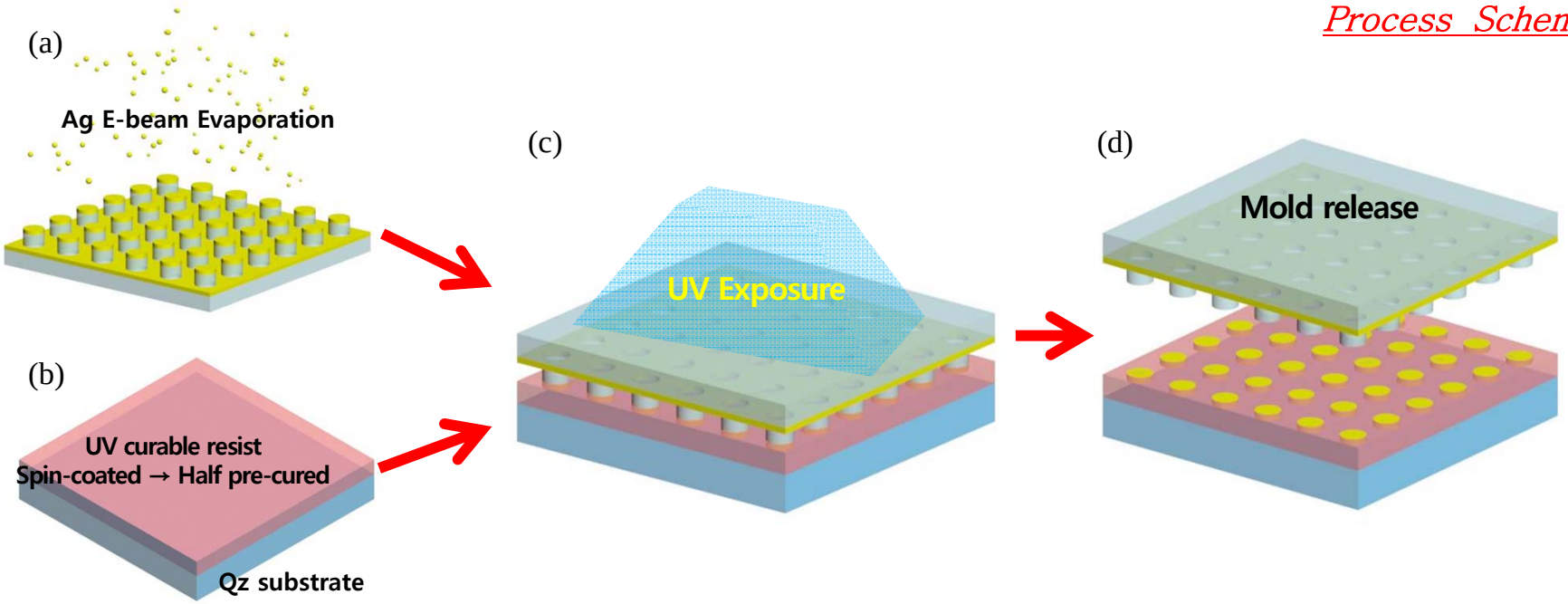

200nm Ag array (embedded)
Acc.V Spot Magn Det WD 500 nm
10.0 kV 3.0 100000x TLD 5.1
136 nm
Acc.V Spot Magn Det WD 500 nm
10.0 kV 3.0 100000x TLD 5.0


235nm Ag array (embedded)
Acc.V Spot Magn Det WD 500 nm
10.0 kV 3.0 150000x TLD 5.1 KIMM


265nm Ag array (embedded)
Acc.V Spot Magn Det WD 1 μm
10.0 kV 3.0 50000x TLD 5.1
39.2 nm
Acc.V Spot Magn Det WD 500 nm
10.0 kV 3.0 150000x TLD 5.2

2. Metal Imprint Transfer

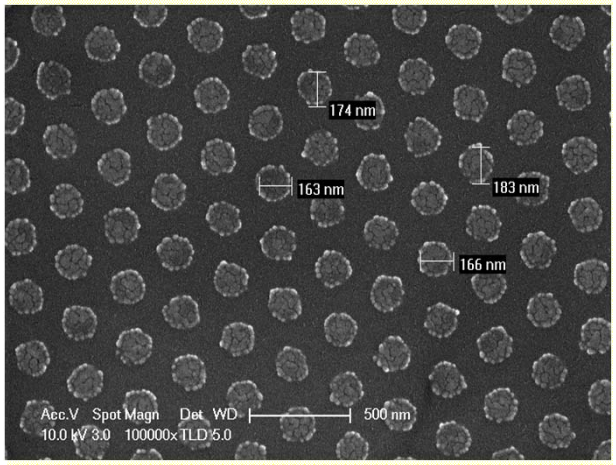
Process Scheme

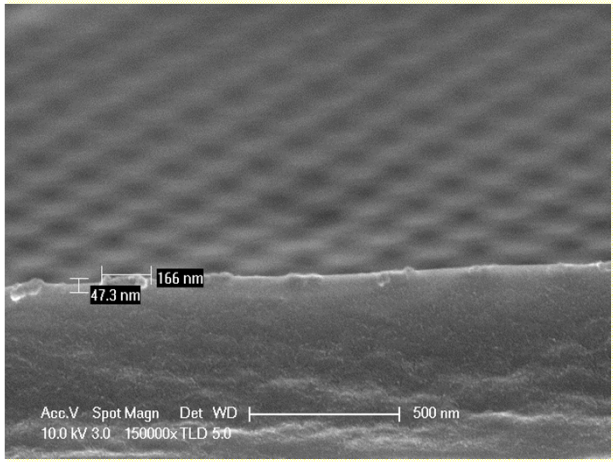


(a) E-beam evaporation of Ag on mold pattern
(b) Half pre-cure of UV curable resist
(c) Only Ag on the top surface of mold in contact with half-cured resist, and UV exposure
(d) Mold release

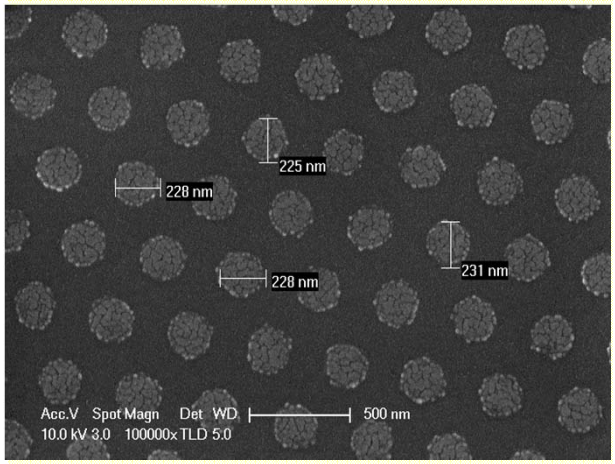
※ Note: *Embedded Dot Arrays*

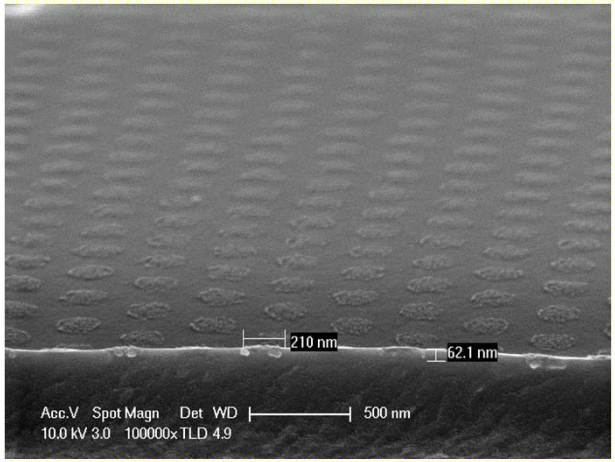
1) Half pre-cured UV-NIL resist
2) Limitedly Imprinted Depth via Pressure Contro
3) Minimized Leakage Current at device depo.



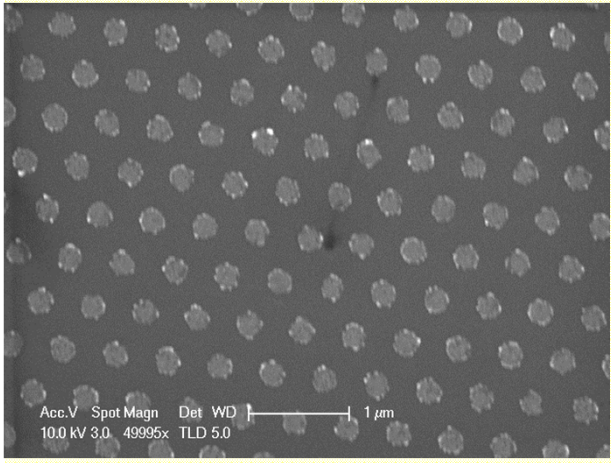


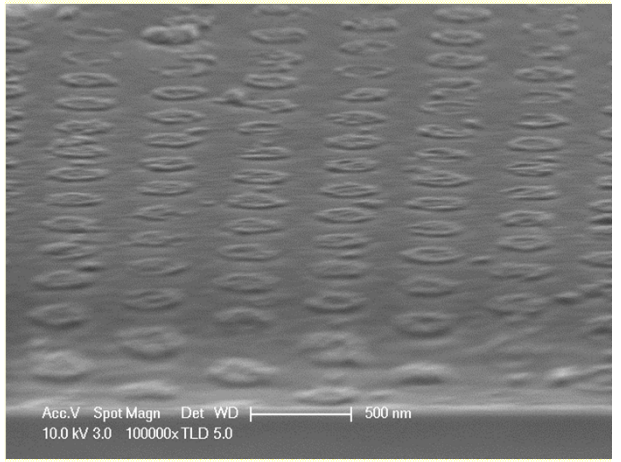
150nm Imprint-Transferred





200nm Imprint-Transferred



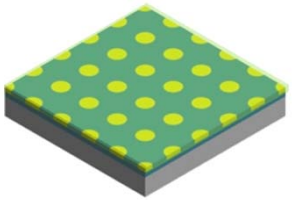


265nm Imprint-Transferred

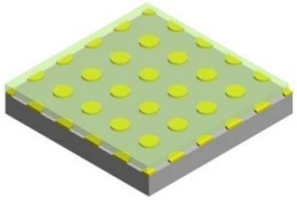
3. PL Enhancements on Green w.r.t. configuration

Comparison of PL enhancement for Green

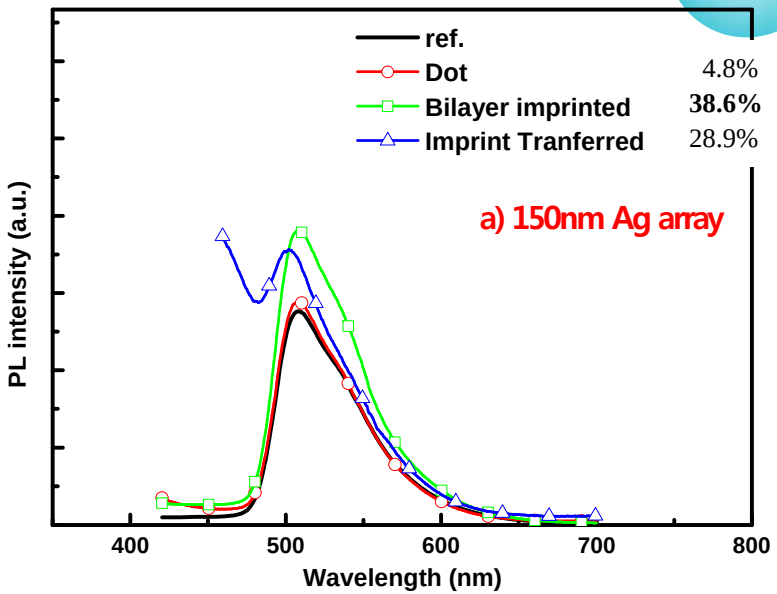
** Ag pattern array / SiO_2 20nm / PL 증착*

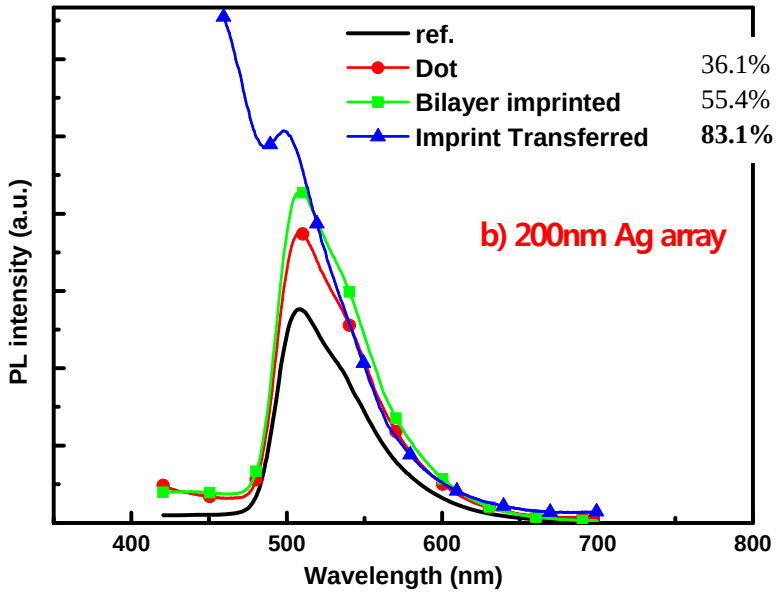


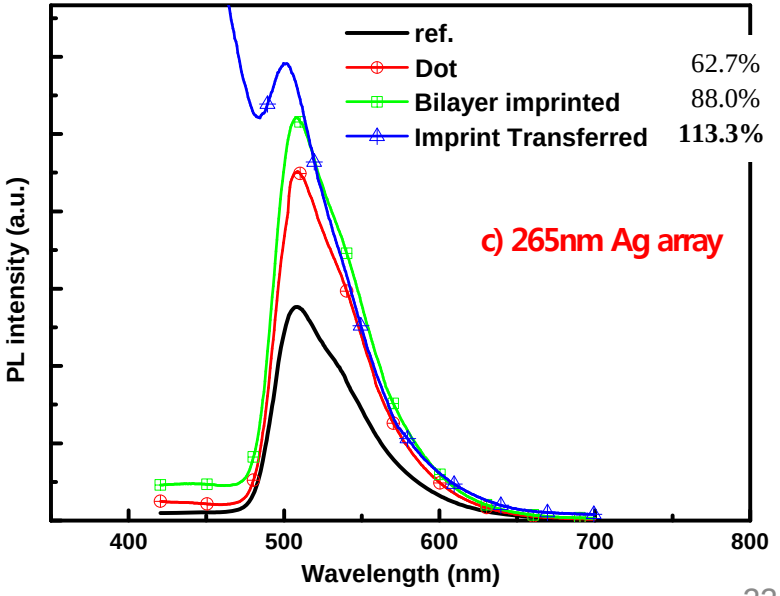
Embedded-config.



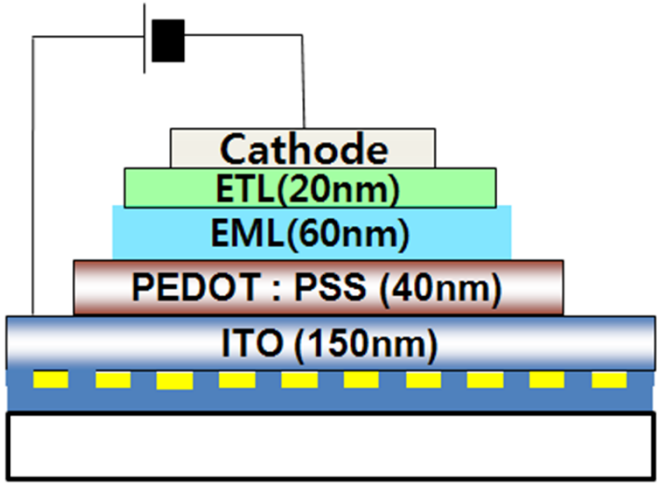
Dot-configuration

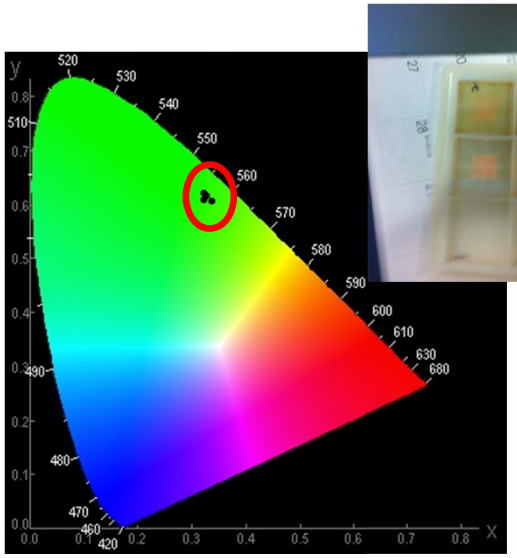


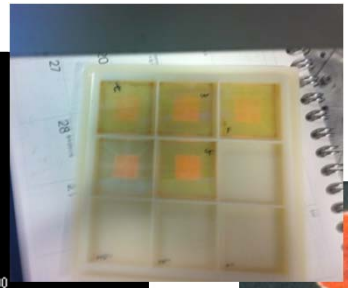


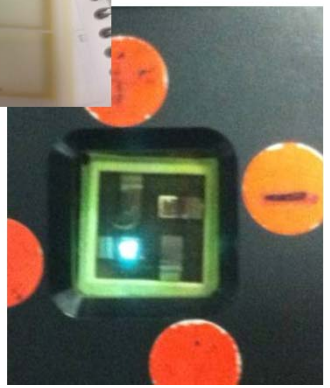


4. EL Enhancements on Green w.r.t. config.









◎ Host – PVK/OXD-7 , TCTA // TPBi

◎ Dopant – Ir(mppy)$_3$ – green emitting material

Device configuration : ITO/PEDOT:PSS/EML/OXD-7/Al.

[b] Turn-on voltage at 1 cd/m^2. [c] Maximum luminance.

[d] Maximum luminance efficiency. [e] The 1993 CIE coordinates at maximum luminance

No.	Turn-On Voltage(V)[b]	L_{max} (cd/m^2)[c]	LE_{max} (cd/A)[d]	QE (%)	CIE Coordinates (X,Y)[e]
Ref.	8.98	1980	16.26	4.71	(0.338,0.604)
150 nm	5.99	2914	17.09	4.61	(0.322,0.618)
200 nm	5.79	2722	13.07	3.94	(0.328,0.614)
265 nm	7.14	2112	26.51	6.44	(0.323,0.607)

➡ EL enhanced by ~ 34% for 265nm

Closing Remarks

- Research Infrastructures for Nanostructures/Patterning
- Nanoimprint-based nanopatterning and its application works
- Several approaches for metallic nanopatterning fabrications introduced in plasmonic fields

- Global Collaborations

UC Berkeley-Micromechanical Analysis and Design (BMAD)

IMRE, Singapore

AMO GmbH Aachen

- Industrial Collaborations

APN Hutem Co. nanoLambda Korea Company

Samsung Electronics-Manufacturing Institute Youngchang Chemical Co. Ltd


KIMM
Thank you for your attentions