Plasmonic Metal Nanopatterning and Its Applications in Optoelectronics

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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**
  - 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 nanopatterning, 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

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

- Tilting angle ~0
- Current 300 μA
- Time 1min
Technology Overview
Surface plasmon resonance

- 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>

<Metal pattern, Lift-off>

<Etching>

<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, Pillar: 1:3 A.S.
- LOR 90nm / LV 300nm
- UV Imprint at 2 bar, 90s
- Transferred Height 250nm
- 전류층 50~60nm

**Step 3: Spin**
- 4,000 rpm, 30sec
- 15도에서 3분 이상

**Step 5: Etch-down**
- Silspin Etch 20s, O2+CHF3
- Imprint Resist & LOR Etch
  - 50 sec of O2, 90s

**Step 7: Ag (+-) Lift-off**
- Thermal Evap. 30nm
- Developer 400K
Metal direct etch, Nanoimprint

CMOS imaging chip

Plasmonic nano filter array

Nanoimprint process

- Front Illumination & Reflection
- White Light Source
- Etching SiO2 (50nm)
- Etching Al (80nm)
- Etching polymer (90nm-100nm)
3D Under-cut shape Au nanopatterning

Improvement sensitivity using 3D structure

SiO₂ under-cut

SiO₂ pattern

SiO₂ under-cut

No etching
2 分 etching
4 分 etching
6 分 etching
7 分 etching
8 分 etching

Absorption

Wavelength (micrometer)
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
(b) Thermal Imprint, UV exposure while pressed
   → Complete cure of UV resist
(c) Ag deposition by E-beam evaporation
(d) Lift-off of thermal resist on top layer
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 Control
3) Minimized Leakage Current at device depo.
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

PL intensity (a.u.)
Wavelength (nm)
ref.
Dot
Bilayer imprinted
Imprint Transferred

a) 150nm Ag array

b) 200nm Ag array

c) 265nm Ag array

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

PL intensity (a.u.)
Wavelength (nm)
ref.
Dot
Bilayer imprinted
Imprint Transferred
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.

- Turn-on voltage at 1 cd/m$^2$.
- Maximum luminance.
- Maximum luminance efficiency.
- The 1993 CIE coordinates at maximum luminance

<table>
<thead>
<tr>
<th>No.</th>
<th>Turn-On Voltage (V)$^b$</th>
<th>$\text{L}_{\text{max}}$ (cd/m$^2$)$^c$</th>
<th>$\text{LE}_{\text{max}}$ (cd/A)$^d$</th>
<th>QE (%)</th>
<th>CIE Coordinates (X,Y)$^e$</th>
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<tr>
<td>Ref.</td>
<td>8.98</td>
<td>1980</td>
<td>16.26</td>
<td>4.71</td>
<td>(0.338,0.604)</td>
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<tr>
<td>150 nm</td>
<td>5.99</td>
<td>2914</td>
<td>17.09</td>
<td>4.61</td>
<td>(0.322,0.618)</td>
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<tr>
<td>200 nm</td>
<td>5.79</td>
<td>2722</td>
<td>13.07</td>
<td>3.94</td>
<td>(0.328,0.614)</td>
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<tr>
<td>265 nm</td>
<td>7.14</td>
<td>2112</td>
<td>26.51</td>
<td>6.44</td>
<td>(0.323,0.607)</td>
</tr>
</tbody>
</table>

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
Thank you for your attentions