Hydrophobic Lithography for Heterogeneous Organic Arrays for Flexible Electronics

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I. Introduction
- Patterning issues for flexible electronics
- Existing patterning technologies
- Need of a new patterning technique

II. Selective Wettability Inscription
- Wettability control scheme
- Control of wettability by UV: contact angles
- Patterns with high resolution

III. Fabrication of Organic Arrays
1. Array of OTFTs
2. Array of OLED elements
3. 2-D/3-D Heterogeneous Arrays

IV. Conclusion
I. Introduction

Organic Semiconductors: a low-cost alternative to Si

- **Organic thin film transistors (OTFTs)**
  - Driving elements made of an **organic semiconductor** layer: a backplane for active-matrix displays, chemical sensors, and plastic electronics.

- **Organic light emitting diodes (OLEDs)**
  - Electroluminescent devices with an **organic light-emitting** layer: flat-panel displays, light sources.
Patterning Issues for Flexible Electronics

Performance Requirements for Organic Arrays

- For high-performance OTFTs, semiconducting active channels with high-resolution, low leakage current (resistive, capacitive parasitics).

- For high-definition OLEDs, light-emitting elements in high-resolution format over large area, high efficiency, RGB color purity.

→ Most of current patterning techniques: difficulty in solution-processing
# Existing Patterning Technologies

(three main types)

<table>
<thead>
<tr>
<th>Lithography</th>
<th>Optical</th>
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<tbody>
<tr>
<td>simple, cost-effective, R2R applicable</td>
<td>e-beam screen</td>
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<tr>
<td>printing</td>
<td>ink jet micro contact</td>
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<td></td>
<td>laser thermal transfer</td>
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<tr>
<td></td>
<td>shadow masking</td>
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<tr>
<td></td>
<td>embossing / stamping</td>
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<tr>
<td></td>
<td>cold welding</td>
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<tr>
<td>Other</td>
<td>soft lamination</td>
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<td></td>
<td>hot lift-off</td>
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<td></td>
<td>electrical polymerization</td>
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<td>dry transfer</td>
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</table>
General Features of Printing methods

**Screen Printing**

“Printing through Woven Mesh”
D. Bould & T. Claypole
(Welsh Printing and Coating Center)

**Ink Jet Printing**

“Organic TFT Arrays by Additive Printing”
B. Street (PARC)

**μ-Contact Printing**

“Conducting structures produced by μ-contact printing”
M. Decre (Philips)

“Organic thin-film transistors fabricated by μ-contact printing”
M. Leufgen (University of Wurzburg)
## - Merits/Drawbacks

<table>
<thead>
<tr>
<th>Method</th>
<th>Merits</th>
<th>Drawbacks</th>
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<tbody>
<tr>
<td>Screen Printing</td>
<td>• simple &amp; inexpensive</td>
<td>• limited feature size</td>
</tr>
<tr>
<td></td>
<td>• capable of all active elements in OTFTs</td>
<td>(&gt;75 μm)</td>
</tr>
<tr>
<td></td>
<td>• high resolution (≈ 25 μm)</td>
<td>• unable to routine fab.</td>
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<tr>
<td></td>
<td>200 nm with surf. modifi</td>
<td></td>
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<tr>
<td></td>
<td>• outstanding for soluble semiconductors</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• ease of surf. treatment by SAMs</td>
<td>• incompatibility between mat. &amp; sol. in print head</td>
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<tr>
<td></td>
<td>• adjustable to flexible process</td>
<td></td>
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<tr>
<td>Ink Jet Printing</td>
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<tr>
<td>μ-Contact Printing</td>
<td></td>
<td>• errors in multilevel registration over large area</td>
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<tr>
<td></td>
<td></td>
<td>(single layer patterning)</td>
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<tr>
<td></td>
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<td>• deformation of stamp</td>
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</table>
II. Selective Wettability Inscription

Liquid Morphologies on Structured Surfaces
(with hydrophilic and hydrophobic patterns)


Use as a patterning tool???
Framework of Wetting Phenomena

- Control Scheme of Selective Wettability

UV irradiation → Photomask → Substrate → Thermal activation → Photo-thermal disruption

Transmittance (%) vs. Wavelength (nm)

CYTOP™: \[\text{CF}_2\text{CF}_2\text{CF}_2\text{CF}_2\]_n

F8T2: \[\text{R}_1\text{R}_2\text{S}_1\text{S}_2\text{R}_1\text{R}_2\text{S}_1\text{S}_2\]_n

hydrophobic
Control of Wettability by UV

Contact angle of *Commanding* Surface

![Graph showing the relationship between UV intensity and contact angle.](image-url)
Patterns of **Structured Commanding Surface**
(UV ablation of CYTOP layer)

Optical Micrographs (resolution of *a few microns*)
III. Fabrication of Organic Arrays

1. Array of OTFTs: well-defined channels (JJAP, 2005)

$F8T2 \mu = 0.03 \text{ cm}^2/\text{V} \cdot \text{s}$

$I_{on}/I_{off} = 10^5$
Performances of OTFT: 

**Output characteristics**

- $V_G = -10, 0V$
- $-20V$
- $-30V$
- $-40V$

- Low leakage current
2. 2D/3D Combinatorial Arrays (Adv. Mat., 2009)

Concept of Wetting Transition:
2D → 3D (critical thickness)

Precise self-registration of G on R:
vdW driven wetting
Conceptual Diagram

Fabrication of Different Classes of Elements

In each unit process, commanding layer + SWI

Element patterns only in the wetting regions

Pattern-by-pattern by repetition

wettability patterning & polymer coating
hydrophobic layer
polymer pattern

dissolving hydrophobic layer
regenerating hydrophobic layer

hydrophobic polymer
fluorinated solvent

unit process 1

single-component array (A)

unit process 2

multi-component array (A')
Pattern-by-Pattern 2D Arrays
(2 different classes of elements)

Geometrical profiles

Above the critical thickness
Color- OLED array and combinatorial array on curved surface

Dissimilar elements on cylinder
Color *Pattern-by-Pattern* (2D) and *Pattern-on-Pattern* (3D) Arrays
Successive *Pat-on-Pat* Processes for White OLED

(3D Registration of B on G on R)
## IV. Conclusion

<table>
<thead>
<tr>
<th>A new patterning technology based on surface wettability</th>
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<tr>
<td>- <strong>Selective inscription</strong> of surface wettability</td>
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<td>by laser through a photomask.</td>
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<th>Fabrication of organic arrays through simple solution processes</th>
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<tr>
<td>- <strong>High-fidelity</strong> of selective wetting patterns.</td>
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<td>- OTFT and OLED arrays with high resolution over large area</td>
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SWI provides a primary route to *multidimensional integration* of heterogeneous organic elements in solutions into *complex combinatorial arrays* on a variety of substrates for ubiquitous applications: Through simple solution processes, being capable of *large area coverage at low cost,* with *high resolution,* it opens up a totally *new paradigm of developing flexible electronics.*