Advances in Roll-to-Roll Imprint Lithography for Display Applications Using Self Aligned Imprint Lithography

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Outline

Introduction
Roll to Roll Challenges and Benefits
HP Labs Roll to Roll SAIL process overview
Current toolset and methods
Initial R2R demonstrators
Transitioning to Manufacturing
  • Internal work
  • Still needed
Call for Standards
Summary
HP Labs has developed a process for TFT flexible display backplanes.
TFT film stack deposition done by PowerFilm Solar in Ames IA.
All patterning, etch and testing done in HP Labs.
Process routinely yields workable devices.

Strong desire by both HP and PowerFilm to move from Lab Project to Manufacturing.
## Challenges & Benefits of R2R Electronics Fabrication

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Challenges</th>
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<tbody>
<tr>
<td>Lower substrate cost</td>
<td>Lower process temperature</td>
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<tr>
<td>Steady state processing: high-throughput, high yield</td>
<td>Defect repair</td>
</tr>
<tr>
<td>Lower cleanroom requirements</td>
<td>patterning</td>
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<tr>
<td>Cheaper equipment - better scaling?</td>
<td>Limited equipment available – no previous generation</td>
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R2R SAIL Process Flow

1. Vacuum deposition of metals, dielectrics, & semiconductors
2. Multiple mask levels imprinted as single 3D structure
3. Patterning completed w/ wet & dry processes
SAIL process: Imprinting

- Imprinting roller with elastomeric stamp
- Imprinted web
  - 40 nm line width
- High aspect ratio & multiple step heights
  - Sub-micron features with 4 levels and 5:1 aspect ratio

- Coating Station
- Imprinting Station
- Supply
- Take-Up

House-built R2R coating & imprinting machine
(throughput rate = 0.5~5 m/min)
# Imprint Lithography is the Best Choice for R2R Patterning

<table>
<thead>
<tr>
<th></th>
<th>Photolithography</th>
<th>Imprint Lithography</th>
<th>Inkjet</th>
<th>Physical mask</th>
<th>Laser ablation</th>
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<tbody>
<tr>
<td><strong>Throughput</strong></td>
<td>Moderate: limited by step &amp; repeat / stitching</td>
<td><strong>High:</strong> &gt; 5 meters/min</td>
<td>Low</td>
<td>Limited only by deposition</td>
<td>Low</td>
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<tr>
<td><strong>Resolution</strong></td>
<td>Limited by substrate flatness ~10µ</td>
<td>100nm demonstrated</td>
<td>&gt;10µ</td>
<td>10µ -100µ</td>
<td>~10µ</td>
</tr>
<tr>
<td><strong>Alignment</strong></td>
<td>Limited by substrate flatness ~10µ</td>
<td>Self alignment possible</td>
<td>External sensor required</td>
<td>poor</td>
<td>~10µ</td>
</tr>
<tr>
<td><strong>Issues</strong></td>
<td>Scaling to large areas costly</td>
<td>New technology</td>
<td>Materials must be jettable</td>
<td>Cleaning, particles</td>
<td>Thermal effects, selectivity</td>
</tr>
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PDMS Copies of Master Wafer

Liquid PDMS on patterned wafer.

Trimmed PDMS stamp.
Imprint Roller Fabrication

Full-size shim for roller cover.

Finished imprint rollers.
1/3m Coater/Imprinter in Operation
1/3 m R2R Coater/Imprinter
• 1/3m wide web; 6” core
• Up to 3 inline etch zones (1 currently)
• Chlorine compatible system
• Currently fluorine based chemistries: CHF$_3$, CF$_4$, SF$_6$, Ar, N$_2$, O$_2$ for polymer and Si etching
• Web grounded to temp controlled electrode
• Vision system for microscopy or endpoint control
Current R2R Tool Summary

- 330mm wide web; 6” core
- Either vacuum or class 100 enclosures

<table>
<thead>
<tr>
<th>Process</th>
<th>Description</th>
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| Metal     | • 13” sputter or evaporation  
             • multiple inline targets  
             • simultaneous front/back coating  
             • no sliding contact           |
| PECVD     | • 13” production solar cell or 13” drum coater (no sliding contact  
              • optimized for TFT materials |
| Imprint   | • 13” gravure coater  
             • cure through stamp and quartz roller  
             • large format masters (A4)         |
| Wet Etch  | • 13” enclosed, clean system  
             • front side protection  
             • acid based processes for Cr and Al with inspection |
| RIE       | • 13” system                                                               |
| Cleaning  | • integrated tacky roller system cleaning in imprinter                      |
Initial display demonstrators

SAIL Backplane on flexible substrate

World’s first active matrix display made exclusively with R2R processes (including E Ink Front Plane)
Transition from lab to Manufacturing

Internal activities

• Instituted tracking of all web processing
  – Implemented a MES system
• Testing TFT stack webs from PowerFilm for conformance to spec
• Developed a web marking methodology using 2D Data matrix codes written on the edge of the web for real time process tracking through tools
Transition from lab to Manufacturing

Stamp (roller) lifetime – transition from PDMS
• Amorphous fluorocarbons have demonstrated good durability

Goal: 1 KM imprint/roller
Still needed

Higher quality substrates
  • Lower particulates, clean from manufacturer
  • Better control of center to edge finish
    – Master roll ~ 1 meter wide, slit into 1/3 meter widths

Inspection tools for both patterned and unpatterned webs
  • CAMM working on unpatterned measurements
  • HP has done some initial work with Rudolph Technology on patterned inspection
Still needed

Etched quartz imprint rollers

• Polymer approach is great for prototyping or short runs
• High volume long runs will need a more durable master
• Existing mask making tools can be adapted for this application - High NRE costs

Test equipment and methods compatible with R2R manufacturing
Standards

Standards would allow unified specification to both material suppliers and equipment suppliers. Would allow for faster development of products and processes, higher yields and ultimately lower cost.

Approach – work on common items

Materials
- Width, roll lengths, identification marks, particles

Inspection

Lithography - Imprint and projection
Summary

R2R manufacturing of electronics on flexible substrates is feasible and will be cost effective.
Basic materials, processes, and architectures have been demonstrated, but more work remains to be done to improve yield and scaling.
Complete toolset for R2R processing capable of pilot production.
Standards for web materials and tool sets will open up more choices as we move to high volume manufacturing.
Sail Backplane Demo