Printed Electronics and Gravure

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Daetwyler R&D Corporation

- *Daetwyler R&D Corporation* is a precision, multi-discipline, equipment/software manufacturer with an expertise in gravure printing, which resides near Dayton, OH USA for 30+ years.
- Member of the Heliograph Holding
- Our customer and equipment base extends over 50 countries.
- Approached Printed Electronics in 2002
  - Improved precision by a factor of 10:1
  - Feature size < 5 micron
  - Depth control in 200 nanometer range
  - Improved cylinder-to-cylinder registration through machine design
  - Improved cylinder precision through temperature control
Printed Electronics Overview

Wide-spread, low-cost, lower-performance circuits with unconventional use *(at least in theory)*
Reality

+ 

= 

?
## Deposition Techniques

<table>
<thead>
<tr>
<th>Printing / Coating</th>
<th>Semiconductor Deposition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process in which material is applied to a substrate to transfer information or coat</td>
<td>Any process that grows, coats or otherwise transfers a material onto a wafer</td>
</tr>
<tr>
<td>Patterning is Additive</td>
<td>Patterning is Subtractive</td>
</tr>
</tbody>
</table>

- Offset
- Flexo / Letter Press
- Gravure
- Screen
- Inkjet
- Pad
- Slot Die Coating
- ...

- Spin Coating
- Vapor Deposition
- Electrochemical Deposition
- Photolithography
- ...

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PaperCon 2011  Page 5
## Print vs. Silicon

<table>
<thead>
<tr>
<th>Performance Criteria</th>
<th>Printing</th>
<th>Semiconductor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Visual</td>
<td>Functional</td>
</tr>
<tr>
<td>Substrate</td>
<td>Flexible</td>
<td>Rigid</td>
</tr>
<tr>
<td>Factory Cost</td>
<td>$</td>
<td>$$$</td>
</tr>
</tbody>
</table>
Performance Criteria

Printing

VISUAL*
- Limited to Human Eye
- Color
- Registration
- Fade / Wear
- …

Semiconductor Fab

FUNCTIONAL
- Electron Flow performance
  - Conductance
  - Gain
  - Watts
  - Luminescence
  - …

* Coatings are the exception

PE ultimately combines these two functions to drive value
Semiconductor Fab Review

Process

DEPOSITION
- Spin Coating
  • PVD / CVD
  • ECD • MBE
  • ALD

PATTERNING
- Photolithography

DOPING
- Ion Implantation

REMOVAL
- Dry Etch - Wet Etch
  - Chem. Mech
  Planarization

Modern devices cycle through hundreds of process steps
Spin Coating

Method to apply thin uniform films to flat substrates

1. Excess amount of solution placed on substrate
2. Substrate rotation uses centrifugal force to create a thin uniform layer
3. Thickness a function of angular speed and solution / evaporating solvent mixture
4. Photo resist is typically spun to around 1 µm thick
5. Surface roughness often 1% of thickness
6. Ultra thin films are possible
Photolithography

Subtractive Patterning Process
Photolithography

Stepper System Example
1. Align
2. Expose
3. Step
Repeat

This is Patterning or Image Transfer
Self-Aligned Imprint Lithography

Active Matrix Backplanes on Flexible Substrate

1: coated substrate
2: coat with polymer
3: emboss
4: cure with UV
5: release
6: etch

Source: HP FlexTech 2010 Conference
Semiconductor Characteristics

- Small rigid substrates (wafers)
- Ultrafine resolutions (50 nm)
- Very expensive foundries ($1.0B)
- EXTREMELY high cost per area
Screen Printing

Versatile technique for Printed Electronics
Screen Printing

- Uses a woven mesh to support an ink blocking stencil
- Stencil forms open areas of mesh that transfer ink as a sharp edge image onto substrate
- A roller or squeegee is moved across the screen stencil, forcing ink past the threads of the woven mesh in the open areas
Screen Process Steps

1. Substrate is placed underneath screen
2. Ink is added
3. Squeegee pushes ink through open parts of screen
4. Screen is lifted from substrate, revealing printed image
The Screen

Parameters

1. Frame Material
   - Stability for Stretched Mesh
   - Method of Registration

2. Mesh Material

3. Mesh Count (wires per length)

4. Wire Thickness

5. Open Area

6. Tension

7. Weave Pattern
Stencil

Rough Stencil Wall – Poor Edge Definition

Smooth Stencil Wall – Good Edge Definition

Source: Jay Sperry, Clemson University
Print Quality

Print Characteristics Affected by …

1. Frame – Registration
2. Stencil & Mesh – Edge Quality
3. Mesh – Resolution & Ink Thickness
4. Squeegee material, speed & angle
5. Lift – Edge Quality
6. Ink – Uniformity
7. Surface Energy Interactions
8. …
Rotary Screen

- squeegee
- ink
- deposited ink

[Image of a rotary screen machine]

[Image of a large industrial machine]
Screen Printing - Summary

Already playing a significant role in PE

<table>
<thead>
<tr>
<th>Advantage</th>
<th>Ink Thickness (60 µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limitation</td>
<td>Resolution (50 µm)</td>
</tr>
<tr>
<td>Applications</td>
<td>• Conductive runs</td>
</tr>
<tr>
<td></td>
<td>• Photovoltaic's</td>
</tr>
<tr>
<td></td>
<td>• Batteries</td>
</tr>
</tbody>
</table>
Inkjet Printing

Desktop Prototyping for Printed Electronics and more …
Inkjet Characteristics

- Non-contact printing for Rigid & Flexible substrates
- Advanced systems can deliver ink referenced to fiducials
- Each print can be customized
- Deceptive simplicity
- Ink volume is very low – Multi-pass may be required
- R2R systems are available
Inkjet Printing - Summary

Already playing a significant role in PE

<table>
<thead>
<tr>
<th>Advantage</th>
<th>Limitation</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Rapid Prototyping</td>
<td>• Limited Single Pass Thickness</td>
<td>• Any and everything on a prototype basis</td>
</tr>
<tr>
<td>• Each copy can be customized</td>
<td>• Speed &amp; Cost-Per-Volume</td>
<td></td>
</tr>
</tbody>
</table>
Gravure Printing

Inherent Potential for Printed Electronics
Gravure Review

Think of small cups for holding ink

- A copper cylinder holds the image.
- The image is etched or engraved into the copper.
Gravure Printing

Direct Gravure

Offset Gravure
Gravure Cell Shapes

100 %  50 %  5 %

Direct Laser

Diamond or Etch Diamond cut Sphere
Direct Ink Transfer

Nip – Compression point where ink transfer occurs. Substrate is sandwiched between Impression Roller and Gravure Cylinder or Plate.

Source: Jay Sperry, Clemson University
Gravure Review

Gravure’s Strengths

- Variety of substrate types
- High resolution / accuracy
- Life of printing roll
- Variable ink film thickness
  - 3D Printing
Gravure Insight – 3D Printing

Dry Ink Thickness to 50+ µm

X & Y Axis - Screening

150 dpi

750 dpi

1000 dpi

Traditional Gravure

Z Axis - Depth

120°

Unique Shapes

90°

Stylus

tranScribe Gravure
# Gravure Printing

## Printed Electronics – Gravure

<table>
<thead>
<tr>
<th>Advantage</th>
<th>Offers all:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Fine resolution</td>
</tr>
<tr>
<td></td>
<td>• High ink transfer volume</td>
</tr>
<tr>
<td></td>
<td>• High speed</td>
</tr>
</tbody>
</table>

| Limitation         | • Perceived to use only for HUGE production volumes |
|--------------------|• Daetwyler R&D offers single cylinder making and Lab/limited production press |

| Applications       | • OLED’s |
|--------------------|• High Density Transistors, Circuits |
|                    | • Interconnect |
|                    | • Photovoltaic, Battery, RFID |
Print Comparison

Compare Printing Methods

Resolution

Ink Film Thickness

Courtesy WMU CAPE November 20, 2009  * In-process, DR&D testing
## Comparison of Traditional and Electronic Printing

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Traditional</th>
<th>Electronics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution</td>
<td>15µm – 100 µm</td>
<td>&lt;&lt; 20 µm</td>
</tr>
<tr>
<td>Registration</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Edge Sharpness</td>
<td>High</td>
<td>Very High</td>
</tr>
<tr>
<td>Uniformity of Layers</td>
<td>Not Really Important</td>
<td>Very Important</td>
</tr>
<tr>
<td>Adhesion of Layers to Substrate</td>
<td>Important</td>
<td>Important</td>
</tr>
<tr>
<td>Adhesion of Layers to Other Layers</td>
<td>Less Important</td>
<td>Very Important</td>
</tr>
<tr>
<td>Solvents in Ink</td>
<td>Cost Issues</td>
<td>Functional Issues</td>
</tr>
<tr>
<td>Purity of Solution</td>
<td>Not Really Important</td>
<td>Very Important</td>
</tr>
<tr>
<td>Visual Properties</td>
<td>Very Important</td>
<td>Not Important</td>
</tr>
<tr>
<td>Electrical Properties</td>
<td>Not Important</td>
<td>Very Important</td>
</tr>
</tbody>
</table>
## Comparison of Conventional and Printed Electronics

<table>
<thead>
<tr>
<th></th>
<th>Solid State (Conventional)</th>
<th>Organic and Printed Electronics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Process</strong></td>
<td>Batch</td>
<td>Continuous</td>
</tr>
<tr>
<td><strong>Production Speed</strong></td>
<td>Slow</td>
<td>Potentially Fast</td>
</tr>
<tr>
<td><strong>Capital Cost</strong></td>
<td>Extremely High</td>
<td>Low to Moderate</td>
</tr>
<tr>
<td><strong>Materials</strong></td>
<td>Well Defined</td>
<td>Developmental</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>Moderate in High Volume</td>
<td>Low to Moderate</td>
</tr>
<tr>
<td><strong>Substrates</strong></td>
<td>Rigid Silicon</td>
<td>Rigid and Flexible</td>
</tr>
<tr>
<td><strong>Environmental</strong></td>
<td>Acceptable</td>
<td>Friendly</td>
</tr>
<tr>
<td><strong>Economic Run Length</strong></td>
<td>Large</td>
<td>Small to Very Large</td>
</tr>
</tbody>
</table>
## Comparison between Paper and Polymer Substrates

<table>
<thead>
<tr>
<th>Property</th>
<th>Paper</th>
<th>Polymer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stiffness</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Shrinkage</td>
<td>Low</td>
<td>Typically high but can be improved</td>
</tr>
<tr>
<td>Surface Modifications</td>
<td>Possible using coatings</td>
<td>Possible but can be costly</td>
</tr>
<tr>
<td>Absorbency</td>
<td>High</td>
<td>Very low</td>
</tr>
<tr>
<td>Biodegradable</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Chemical stability</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Mechanical strength</td>
<td>Low to Moderate</td>
<td>High due to strong cross linking</td>
</tr>
<tr>
<td>Surface smoothness</td>
<td>Typically Low but can be improved</td>
<td>Very high surface smoothness</td>
</tr>
</tbody>
</table>
Markets and Application Areas

Source: http://www.frost.com/prod/servlet/cio/108885719

Printed Electronics Market: Revenue Forecasts, 2006 to 2025 (World)

- ThinFilm's total addressable market
  - $4.5 billion in 2013
  - $16 billion in 2017
  - $125 billion in 2027

Notes: All figures are rounded. Source: Frost & Sullivan

Source: http://www.frost.com/prod/servlet/cio/108885719
**Functional Inks**

Typically Inks used for graphic printing consist of:

- Pigments
- Resins
- Solvents
- Additives

In functional inks, Pigments are replaced by functional materials such as Conductive, Semiconductive or Dielectric materials that give functional attributes to the ink.

<table>
<thead>
<tr>
<th>Functional Ink Type</th>
<th>Examples of the Materials that can be Used</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Conductive Inks</strong></td>
<td>Silver, Gold, Copper, Nickel, Carbon, ITO particles, ATO particles…….</td>
</tr>
<tr>
<td><strong>Semiconductive Inks</strong></td>
<td>C60, Fullerenes, Pentacene, poly(3 – hexylthiophene) (P3HT), poly(9,9’ – dioctyl – fluorine - co – bithiophene) (F8T2)….</td>
</tr>
<tr>
<td><strong>Dielectric Inks</strong></td>
<td>poly (methylmethacrylate) (PMMA), poly (4-vinyl phenol) (PVP), polystyrene (PS), polyimide (PI)…..</td>
</tr>
</tbody>
</table>
# Ink Comparison Relative to Printed Electronics

<table>
<thead>
<tr>
<th>Printing Method</th>
<th>Print Speed</th>
<th>Drying Needs</th>
<th>Viscosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screen</td>
<td>Slow 1-10 fpm</td>
<td>High 100-150° C</td>
<td>5000-40,000 centipoise</td>
</tr>
<tr>
<td>Flexography</td>
<td>Medium 25-1000 fpm</td>
<td>Medium 50-150° C</td>
<td>2000-5000 centipoise</td>
</tr>
<tr>
<td>Gravure</td>
<td>Fast 100-3000 fpm</td>
<td>Low 50-100° C</td>
<td>500-2000 centipoise</td>
</tr>
</tbody>
</table>
Good and Bad Printed Samples

Images of Solvent Based Silver Flake Inks Printed on PET
Left image is a good image with an even ink lay and no pinholes whereas the image on the right shows pinholes and is probably due improper viscosity adjustments and thus improper transfer form the gravure cells to the substrate. (Images taken on ImageXpert)

Cross-sectional View of Dried Ink Film on Substrate using SEM (Scanning Electron Microscope)
Functional vs. Visual

Opens, Shorts, Partial Transfer

Courtesy B. Bazuin of WMU CAPE
Print Samples on Different Substrates

Examples of Samples Printed on Paper (Left) and Paper Board (Right)

Print Sample on PET using Nano-Silver Ink
Examples of Proper and Improper Blade Wiping on the Cylinder

Examples of Proper wiping on the Cylinder (Left) and Improper Wiping on the Cylinder (Right)
Ballantine’s PE Example

Integrated Graphic Equalizer
Gravure Printed Product Sample

ADD-VISION, INC.

Printed, Flexible, Polymer OLED Displays

www.add-vision.com
Heliograph Holding - Products for Gravure Printing

Equipment for Gravure Printing

Engraving Technology

Laser Technology

Full Automation

Cranes

Plating Technology

Cylinder Handling

Finishing Technology
# Daetwyler R&D - Products for Printed Electronics

<table>
<thead>
<tr>
<th><strong>μStar</strong> MicroEngraving System</th>
<th><strong>High-Precision Diamond Cutting Tool</strong></th>
<th><strong>Unique 3-D shapes</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Engraves features &lt; 5 µm Control &lt; 200 nm depth Up to 12,000 features/s</td>
<td>• High Density Printed Electronics • Dry Ink Thickness to 50+ µm • Micron Lens for Optical Film • Coating, Embossing, Security Work, • Medical Strips, Lenticular Lenses, • and more....</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>AccuPress® MicroGravure Printing System</strong></th>
<th><strong>Lab / Limited Production</strong></th>
<th><strong>Layer-to-Layer Registration</strong></th>
<th><strong>Allows Hybrid Printing</strong></th>
<th><strong>Custom Enhancements</strong></th>
<th><strong>Levels of Automation</strong></th>
<th><strong>Level 1</strong></th>
<th><strong>Level 3</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>5 µm features</td>
<td>Single Layer</td>
<td>High Precision Air Bearings</td>
<td>Machine Accuracy &lt; 20 µm and more</td>
<td>Multi Layer</td>
<td>High Precision Air Bearings</td>
<td>Machine Accuracy &lt; 5 µm and more</td>
<td></td>
</tr>
</tbody>
</table>
MicroGravure Cycle Solutions

Completing the Micro Printing Process Cycle

Micro-Gravure Printing

AccuPress MicroGravure Printing System

Printed Electronics

μStar MicroEngraving System

Partners, Products
MicroGravure Workflow

INPUT
- Image or Pattern

Cylinder Layout
- CollageMicro
- Custom Patterns

ENGRAVE
- μStar MicroEngraving System

PROOF
- On-screen

PRINT
- AccuPress MicroGravure Printing
μStar MicroEngraving™ System

• Advanced Data Processing capability with *Collage-Micro* Layout System

• Unique 3-D Shapes
  - Ink Transfer Optimization
  - Micron Lens Design
  - Features < 5 μm

• High Productivity with Ultra Fast Tool
Ultra Diamond Cutting Tool

MicroEngraving Tool
• High-Precision
  - Control < 200 nm in depth
• Up to 12,000 features per second
  - < 50 µs rise-time !!
• Feedback controlled
• Cartridge tool design
• Diamond tools
μStar Applications – Printed Circuits

High Resolution Examples

5 microns
Precision Gravure Printer

- Lab / Limited Production
- Layer-to-Layer Registration
- Allows Hybrid Printing
- Custom Enhancements
- Levels of Automation
- μStar Cylinders
Precision Gravure Printer

LEVEL 1
• High precision bearings
• Accuracy to 20 µm
• Option:
  - Electrostatic Assist
Precision Gravure Printer

Printed Electronics Sheet-fed Press

- Single or Multi-Layer Printing
- Ink Transfer Testing
- Gravure Direct Printing

Production machine AccuPress Type 1/CE with fume hood and safety mat
Precision Gravure Printer

LEVEL 3

• High precision
• Air bearings
• Temperature control
• Accuracy to 5 µm
Precision Gravure Printer

Printed Electronics Sheet-Fed Press
• Single or Multi-layer printing
• Gravure offset printing

Production machine Gravure Offset to Glass Sheet
4 m x 4 m sheet size
Engineered Cylinders

- MicroGravure
  - Optimized Ink Transfer
- MicroLens for Optical Film
- Precision High Accuracy Gravure
- Photovoltaic
- High Density Printed Electronics
- Coating, Embossing, Security Work

... and more
## MicroGravure Printing - Summary

### Gravure/MicroGravure for Printed Electronics

<table>
<thead>
<tr>
<th>Advantage</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fine resolution</td>
</tr>
<tr>
<td></td>
<td>High ink transfer volume</td>
</tr>
<tr>
<td></td>
<td>Uniform laydown</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scalability</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>AccuPress</strong> for prototyping</td>
</tr>
<tr>
<td></td>
<td>Scalable &amp; consistent for R2R</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Applications</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PLED’s</td>
</tr>
<tr>
<td></td>
<td>Fine Resolution Conductive Lines</td>
</tr>
<tr>
<td></td>
<td>High Density Transistors</td>
</tr>
<tr>
<td></td>
<td>Backplanes</td>
</tr>
<tr>
<td></td>
<td>Photovoltaic, Battery</td>
</tr>
</tbody>
</table>

Playing increasing role as benefits embraced & equipment is available
For more information

www.daetwyler-rd.com

- Always up-to-date
- All products and services
- Contact information
- Sign up for our RSS news feed
Questions