Printed Electronics and Gravure

Eric Serenius

Vice-President
Daetwyler R&D Corporation
eserenius@daetwyler-rd.com

May 1-4
PaperCon 2011
Northern Kentucky Convention Center

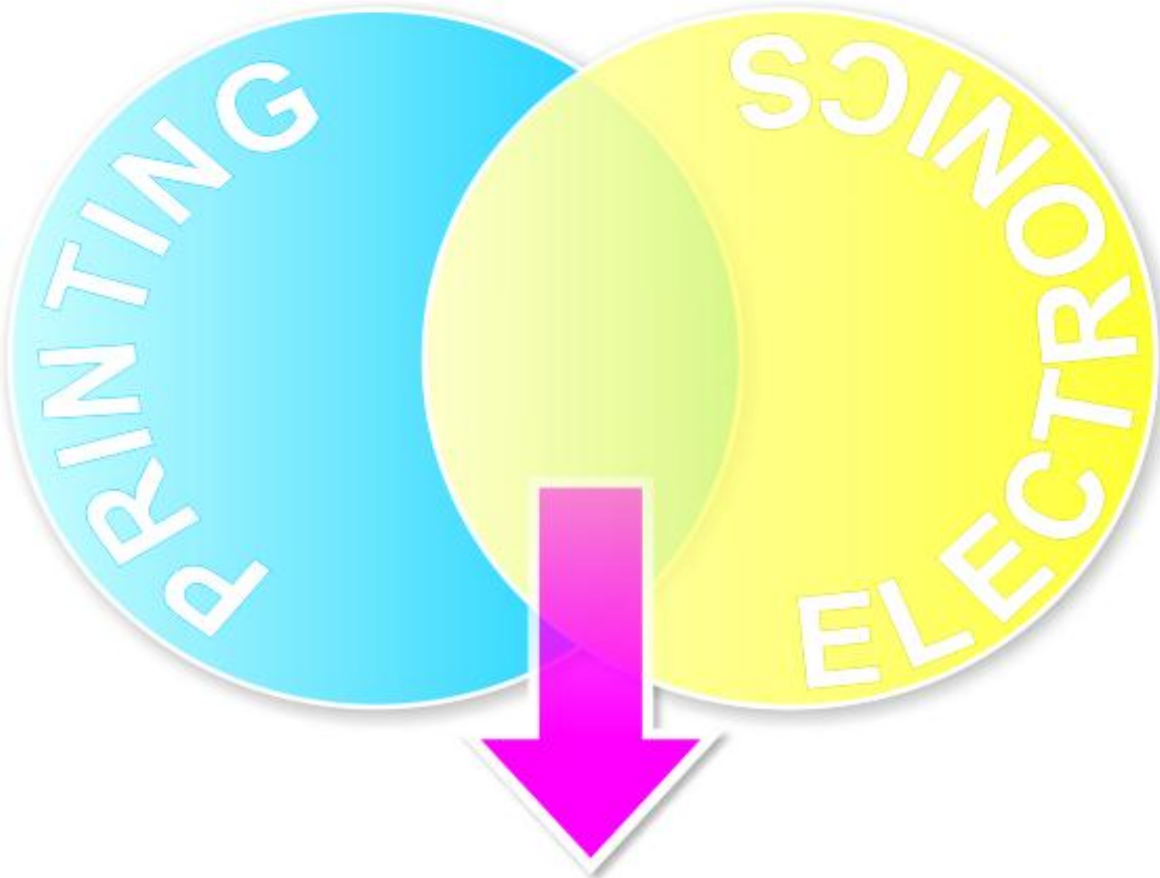
RETHINK PAPER:
Lean and Green

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

Printing / Coating	Semiconductor Deposition
Process in which material is applied to a substrate to transfer information or coat	Any process that grows, coats or otherwise transfers a material onto a wafer
Patterning is Additive	Patterning is Subtractive

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

- Spin Coating
- Vapor Deposition
- Electrochemical Deposition
- Photolithography
- …

Print vs. Silicon

	Printing	Semiconductor
Performance Criteria	Visual	Functional
Substrate	Flexible	Rigid
Factory Cost	$	$$$

Performance Criteria

Printing

VISUAL*

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

* Coatings are the exception

Semiconductor Fab

FUNCTIONAL

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

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

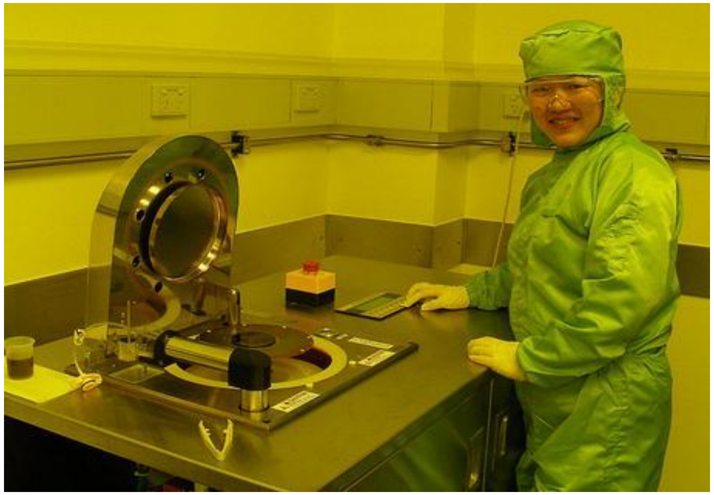
REMOVAL
- Dry Etch -Wet Etch
- Chem. Mech Planarization

Modern devices cycle through hundreds of process steps

Spin Coating

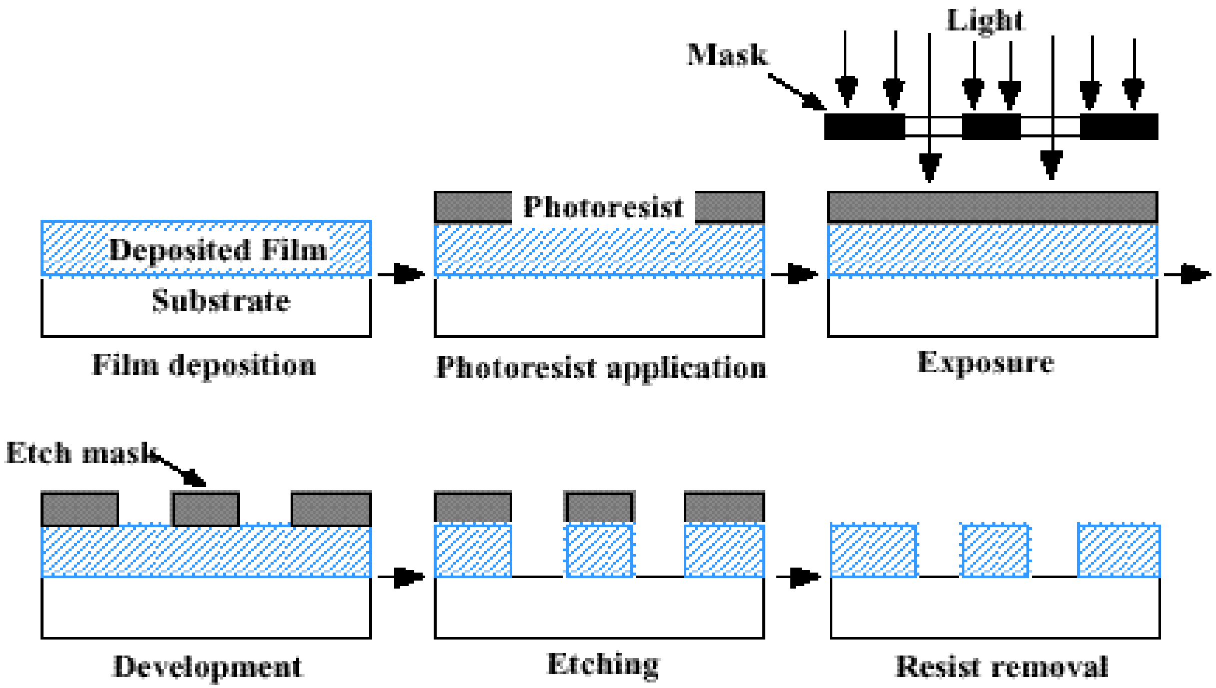
Method to apply thin uniform films to flat substrates

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

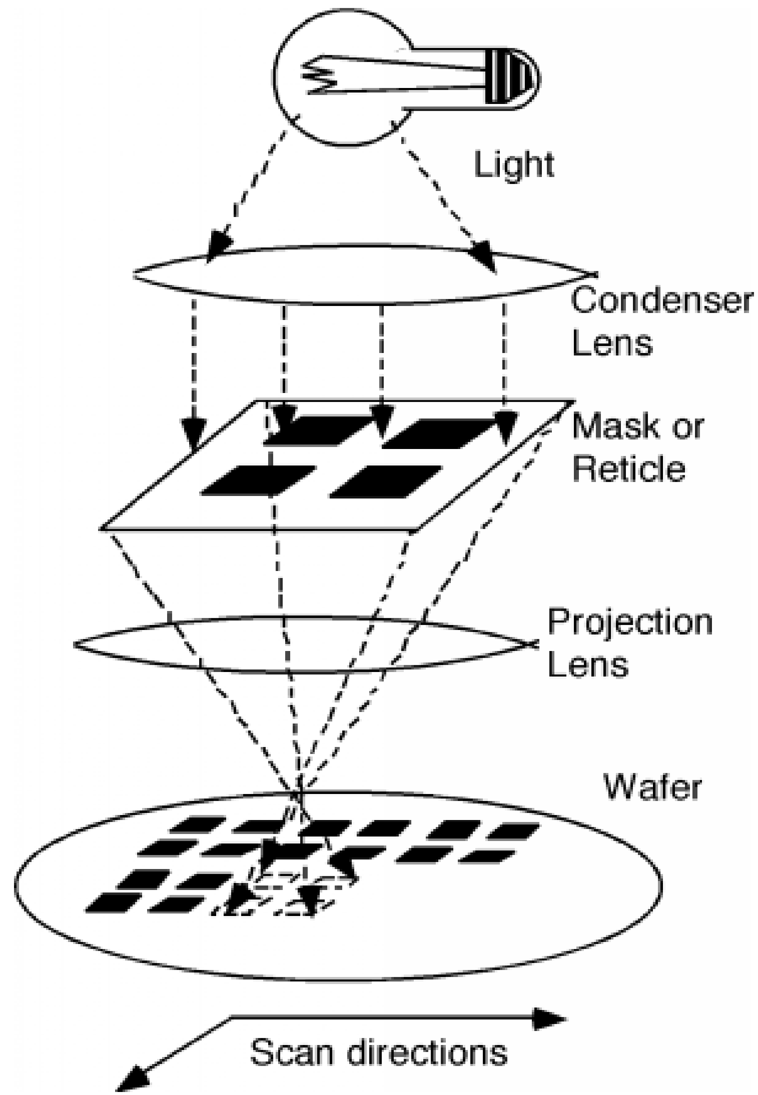


Photolithography

Stepper System Example

1. Align
2. Expose
3. Step

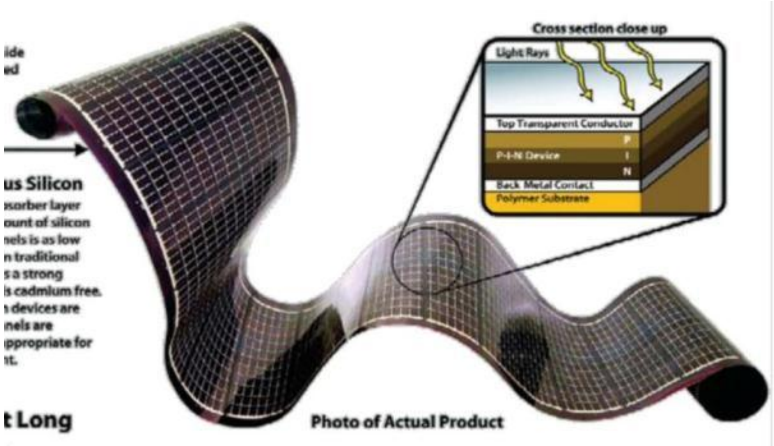
Repeat



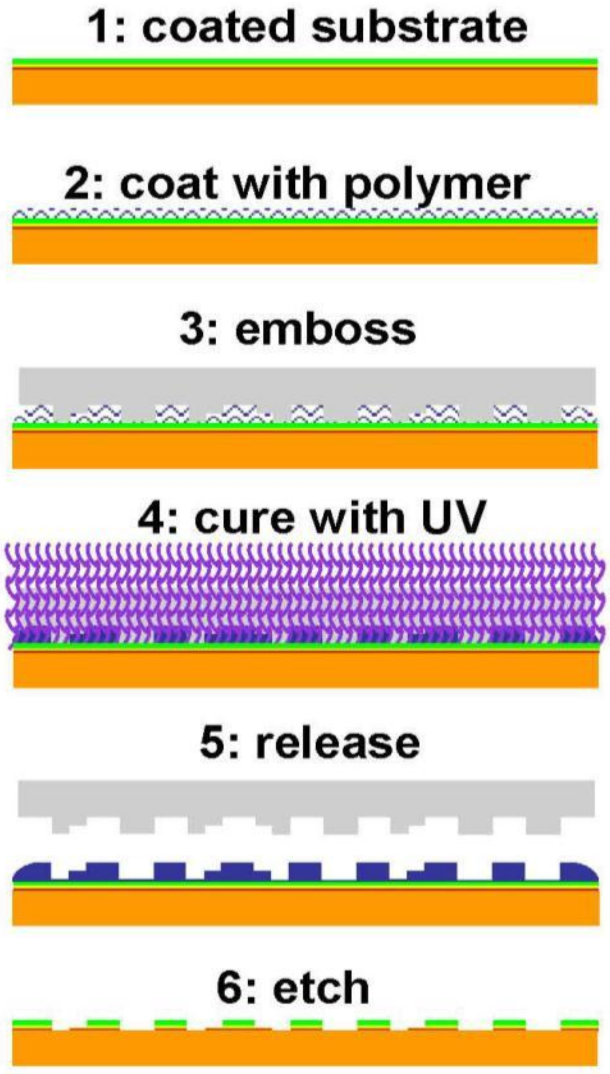
This is Patterning
or Image Transfer

Self-Aligned Imprint Lithography

Active Matrix Backplanes
on Flexible Substrate

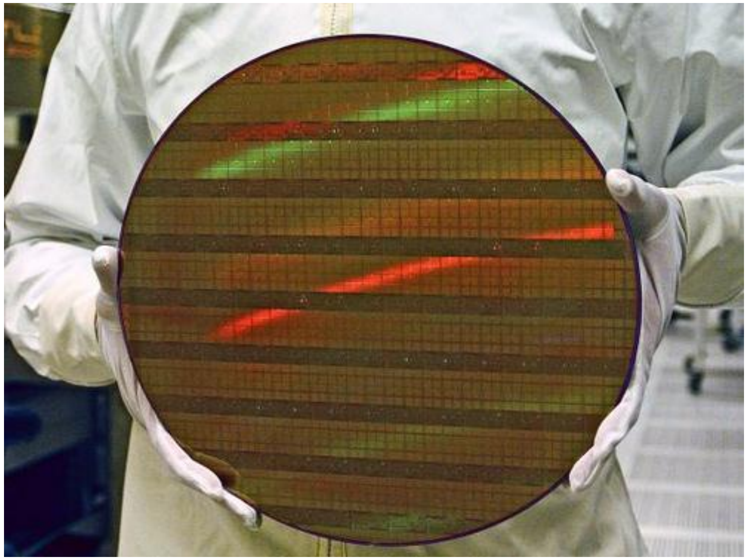


Source: HP FlexTech 2010 Conference



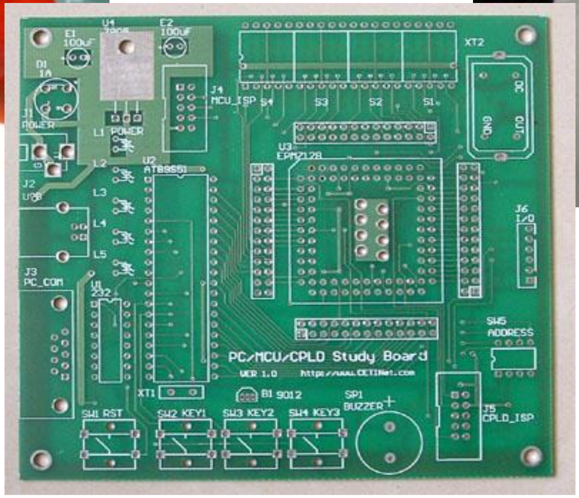
Semiconductor Characteristics

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



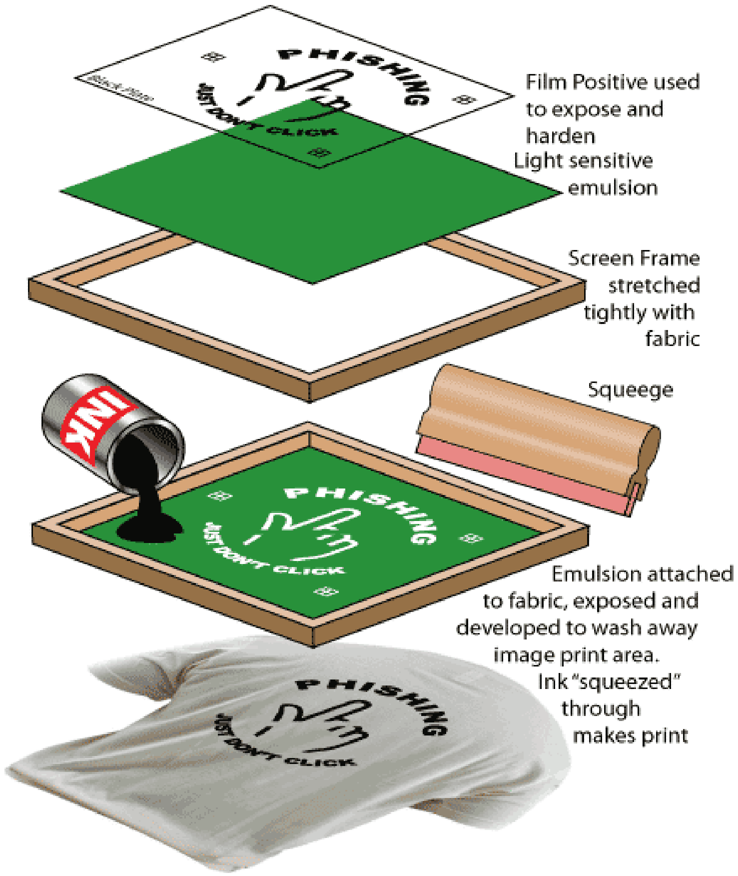
Screen Printing

Versatile technique for Printed Electronics

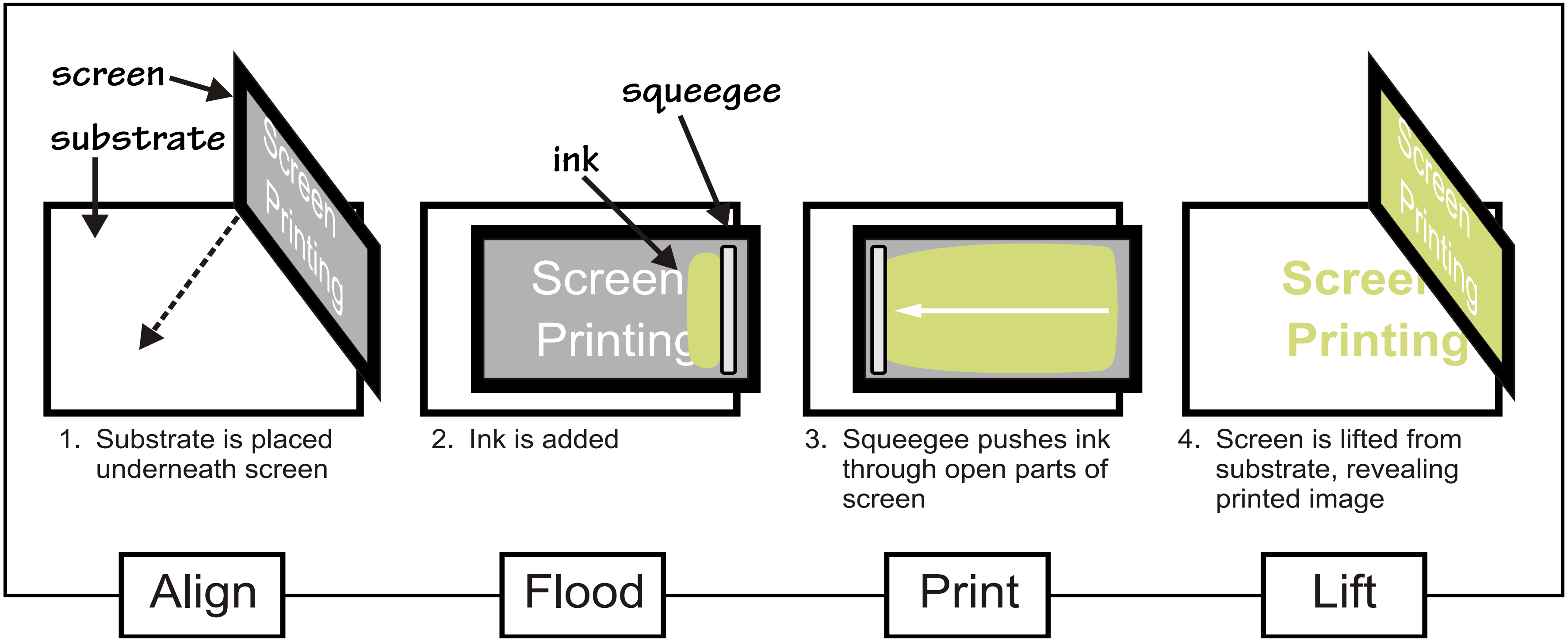


Screen Printing

- 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

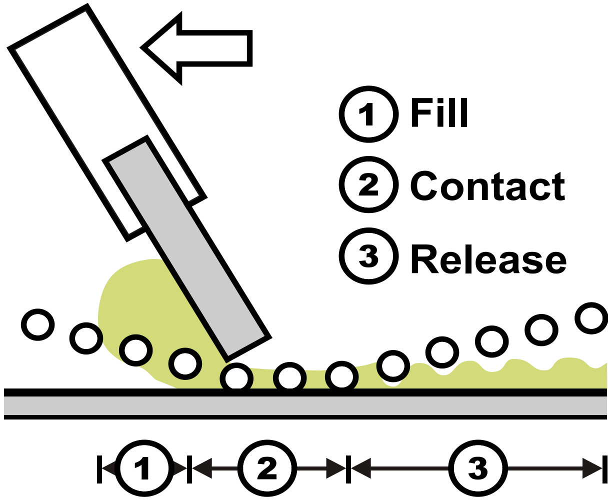


Screen Process Steps



IDTechEx Masterclass Dresden 2010

Print Dynamic

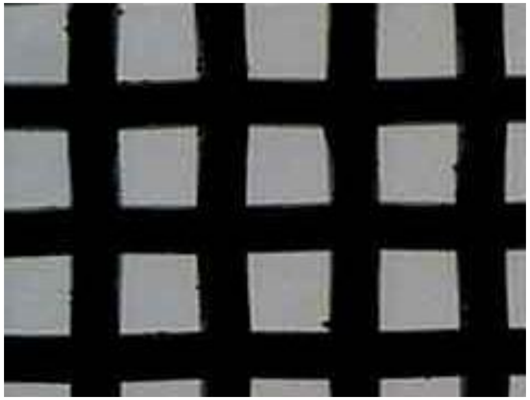


IDTechEx Masterclass Dresden 2010

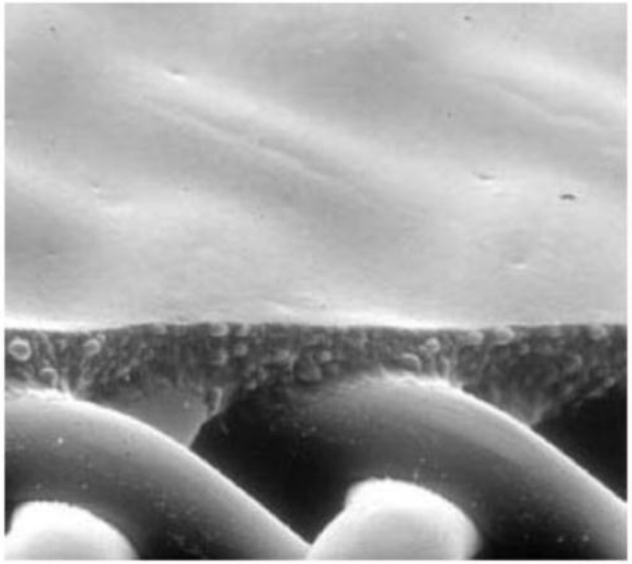
The Screen

Parameters

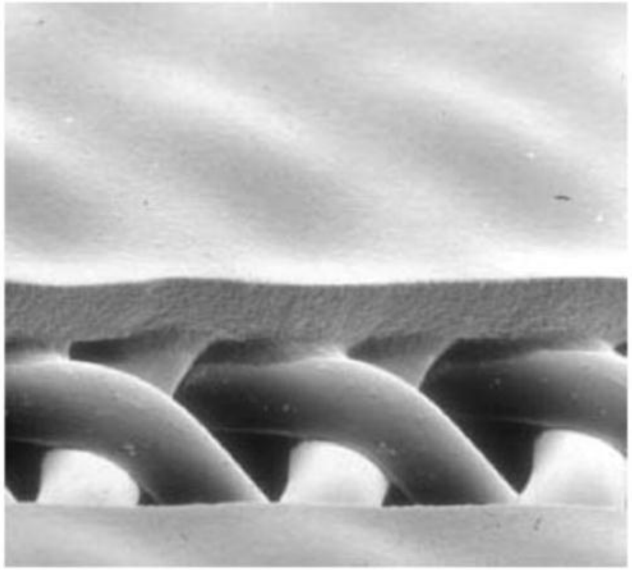
1. Frame Material
    - Stability for Stretched Mesh
    - Method of Registration
2. Mesh Material
3. Mesh Count (wires per length)
4. Wire Thickness
5. Open Area
6. Tension
7. Weave Pattern



Stencil



Rough Stencil Wall –
Poor Edge Definition



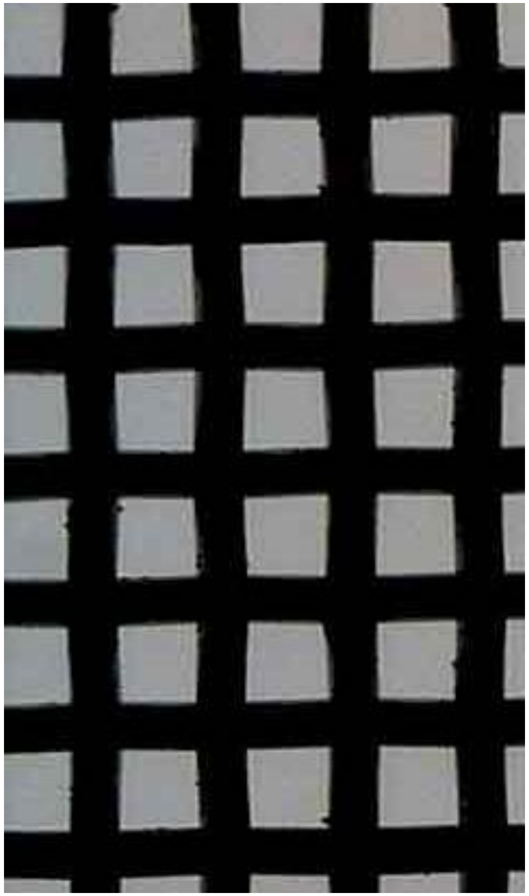
Smooth Stencil Wall –
Good Edge Definition

Source: Jay Sperry, Clemson University

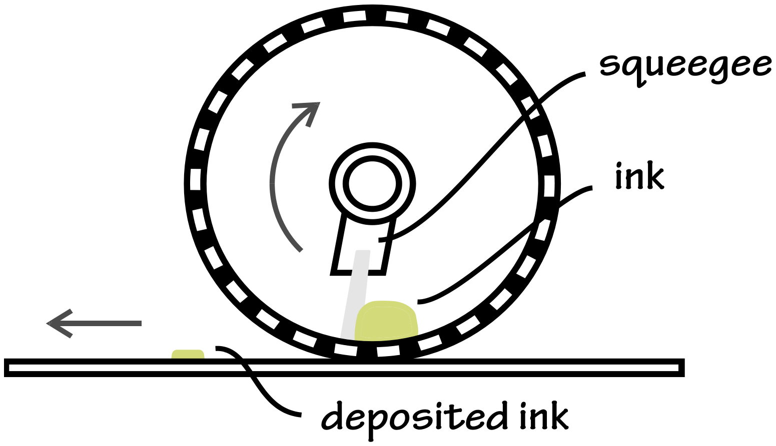
Print Quality

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



Screen Printing - Summary

Already playing a significant role in PE

Printed Electronics – Screen Summary	
Advantage	Ink Thickness (60 µm)
Limitation	Resolution (50 µm)
Applications	• Conductive runs • Photovoltaic's • Batteries

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

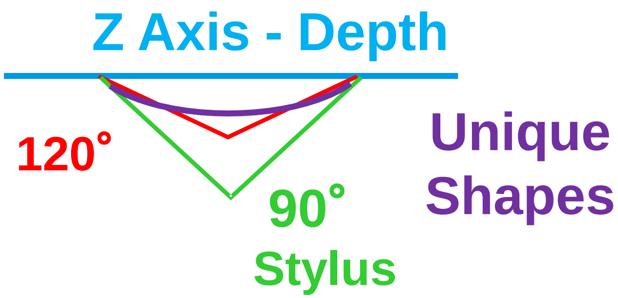
Inkjet Printing - Summary

Already playing a significant role in PE

Printed Electronics – Inkjet Summary	
Advantage	• Rapid Prototyping • Each copy can be customized
Limitation	• Limited Single Pass Thickness • Speed & Cost-Per-Volume
Applications	• Any and everything on a prototype basis

Gravure Printing

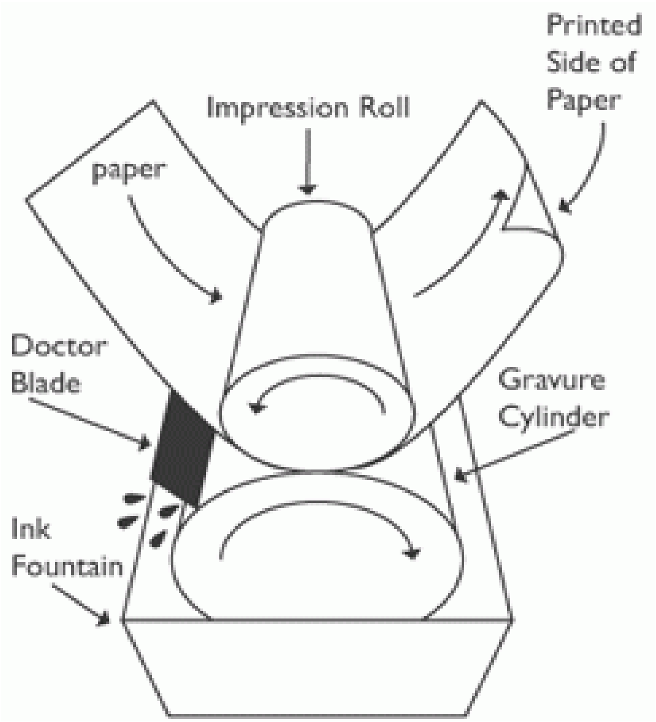
Inherent Potential for Printed Electronics

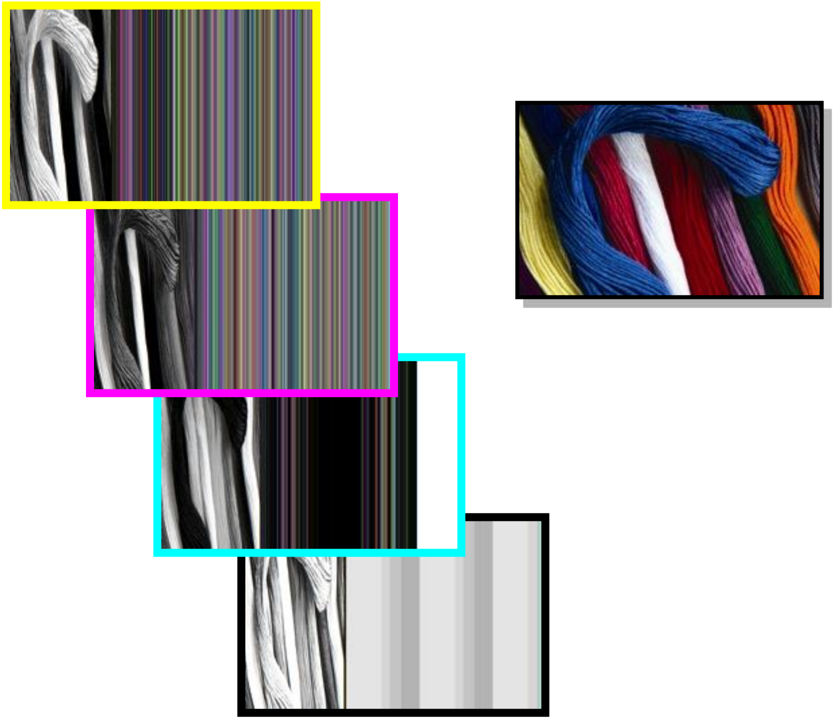


Gravure Review

Think of small cups for holding ink

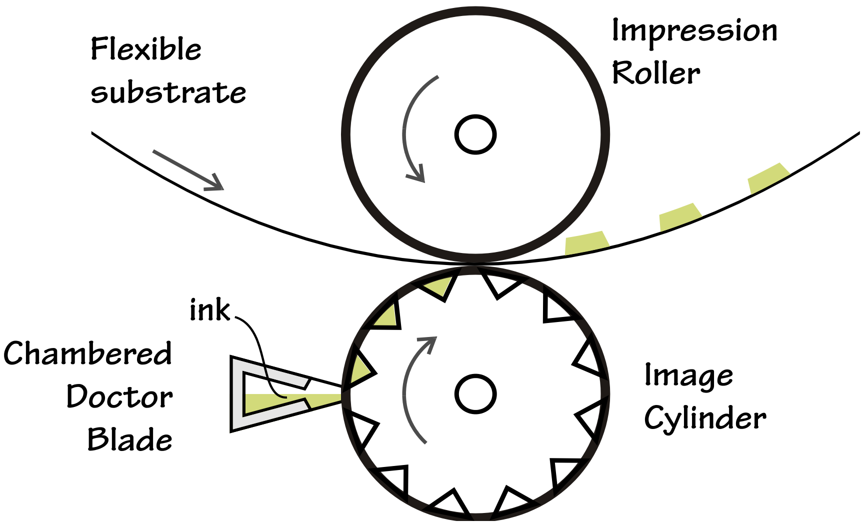
- A copper cylinder holds the image.
- The image is etched or engraved into the copper.



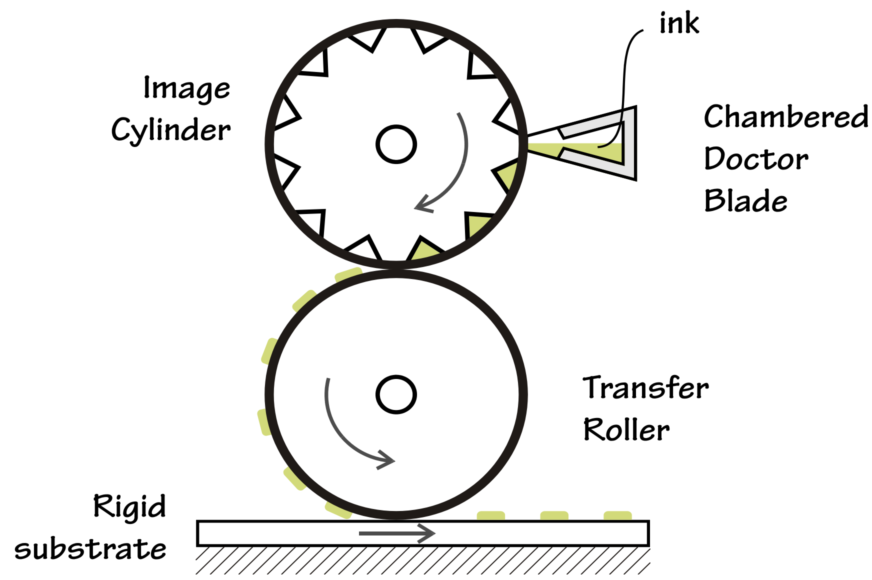


Gravure Printing

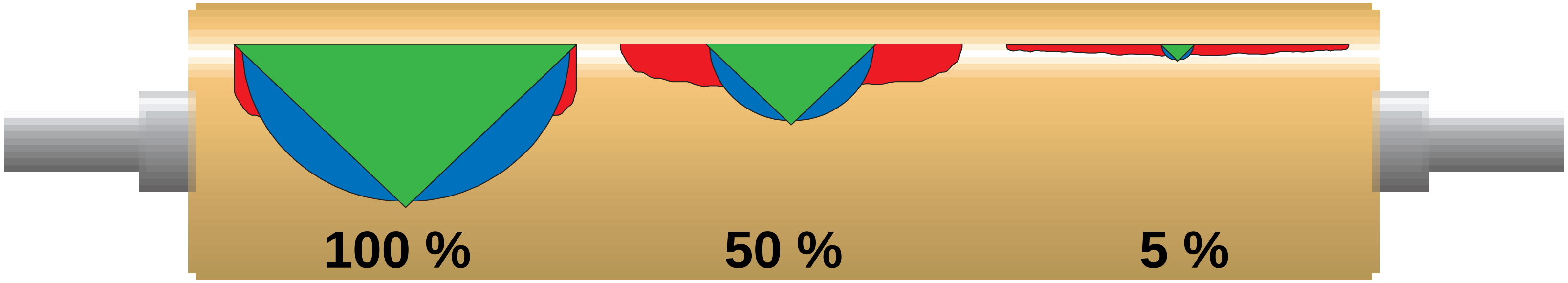
Direct Gravure



Offset Gravure



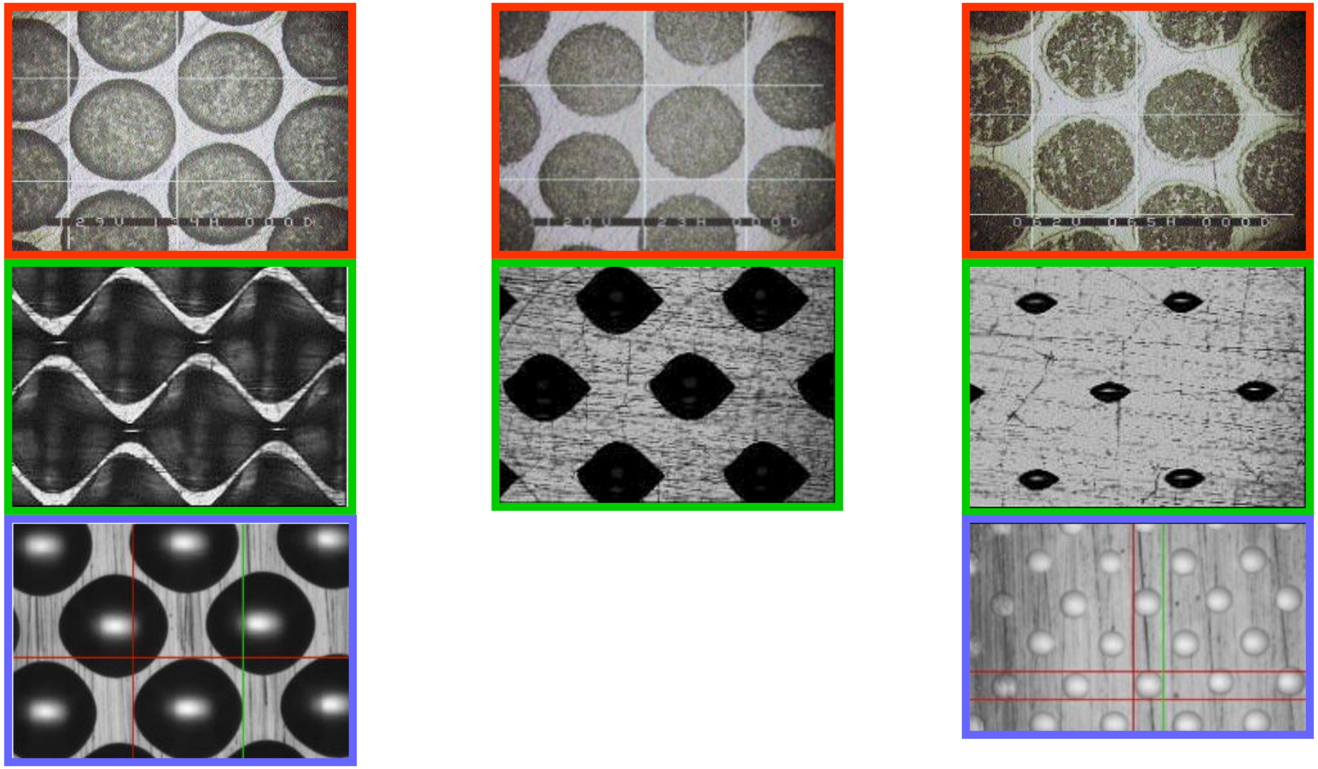
Gravure Cell Shapes



Direct Laser

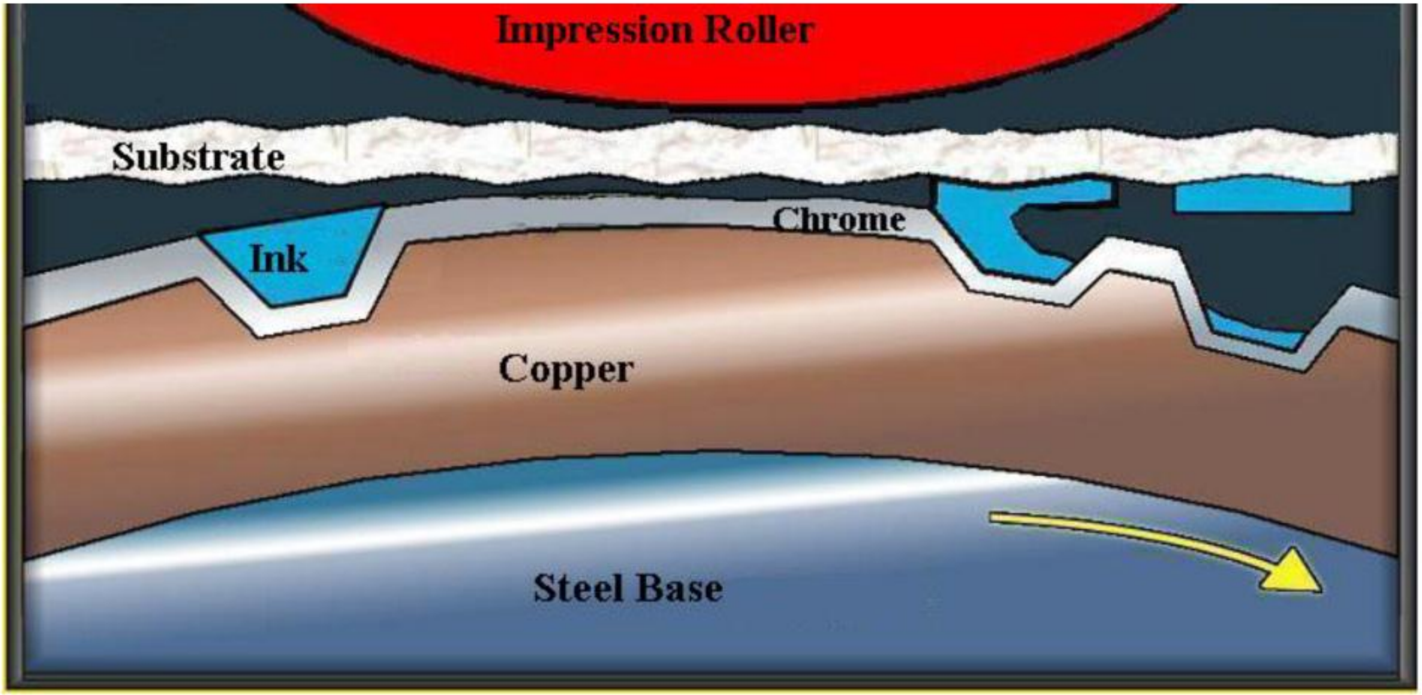
Diamond or Etch

Diamond cut Sphere



Direct Ink Transfer

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

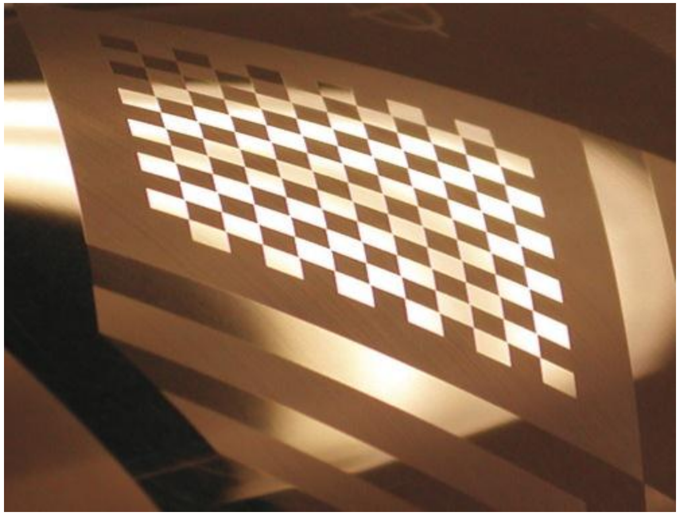


Source: Jay Sperry, Clemson University

Gravure Review

Gravure's Strengths

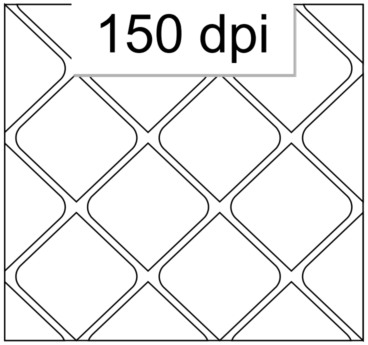
- Variety of substrate types
- High resolution / accuracy
- Life of printing roll
- Variable ink film thickness
  - 3D Printing

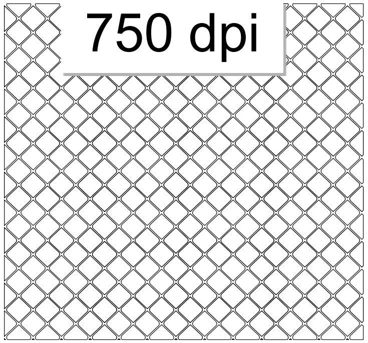


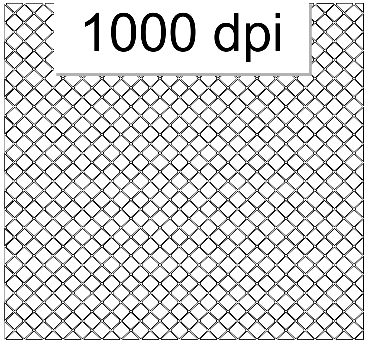
Gravure Insight – 3D Printing

Dry Ink Thickness to 50+ μm

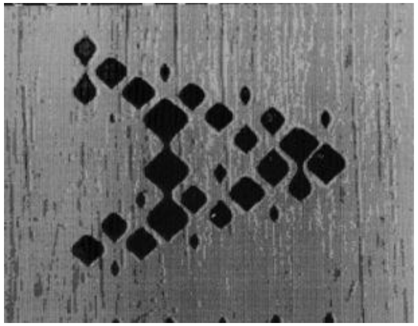
X & Y Axis - Screening

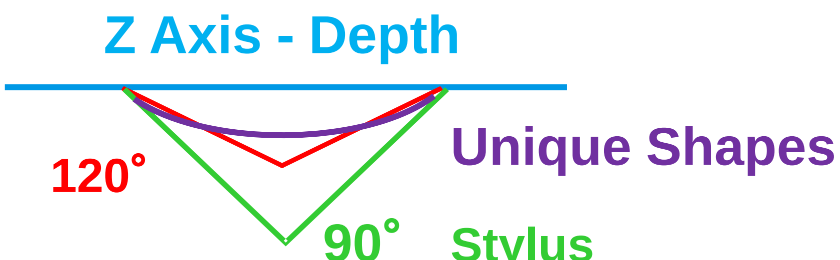




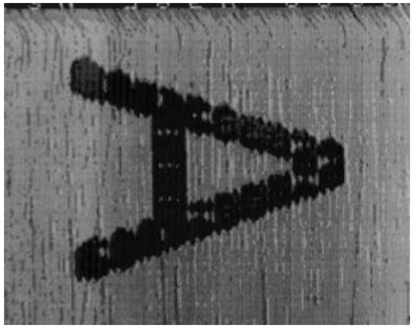


Traditional Gravure





tranScribe Gravure



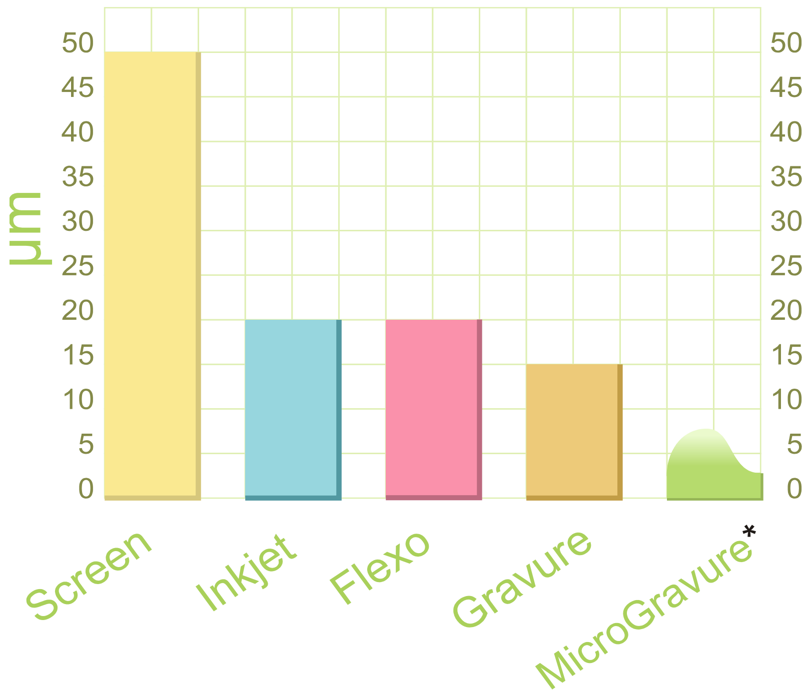
Gravure Printing

Printed Electronics – Gravure	
Advantage	Offers all: • Fine resolution • High ink transfer volume • High speed
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

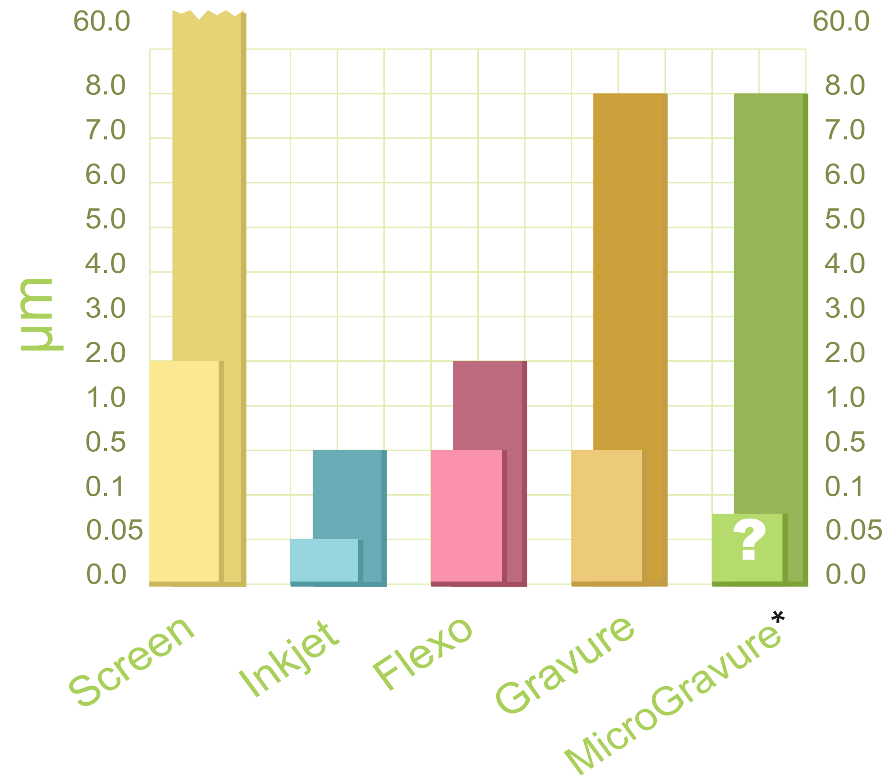
Print Comparison

Compare Printing Methods

Resolution



Ink Film Thickness



Courtesy WMU CAPE November 20, 2009 * In-process, DR&D testing

Comparison of Traditional and Electronic Printing

Requirements	Traditional	Electronics
Resolution	15µm – 100 µm	<< 20 µm
Registration	Low	High
Edge Sharpness	High	Very High
Uniformity of Layers	Not Really Important	Very Important
Adhesion of Layers to Substrate	Important	Important
Adhesion of Layers to Other Layers	Less Important	Very Important
Solvents in Ink	Cost Issues	Functional Issues
Purity of Solution	Not Really Important	Very Important
Visual Properties	Very Important	Not Important
Electrical Properties	Not Important	Very Important

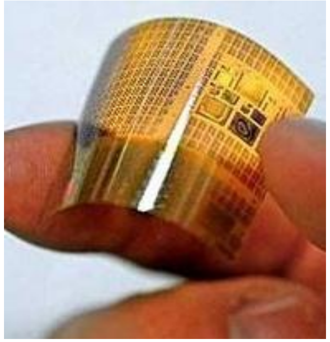
Comparison of Conventional and Printed Electronics

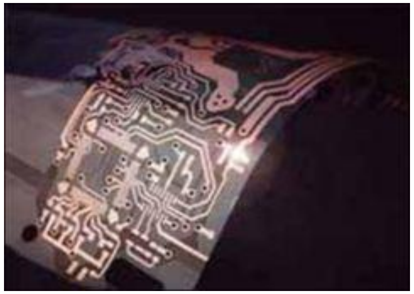
	Solid State (Conventional)	Organic and Printed Electronics
Process	Batch	Continuous
Production Speed	Slow	Potentially Fast
Capital Cost	Extremely High	Low to Moderate
Materials	Well Defined	Developmental
Cost	Moderate in High Volume	Low to Moderate
Substrates	Rigid Silicon	Rigid and Flexible
Environmental	Acceptable	Friendly
Economic Run Length	Large	Small to Very Large

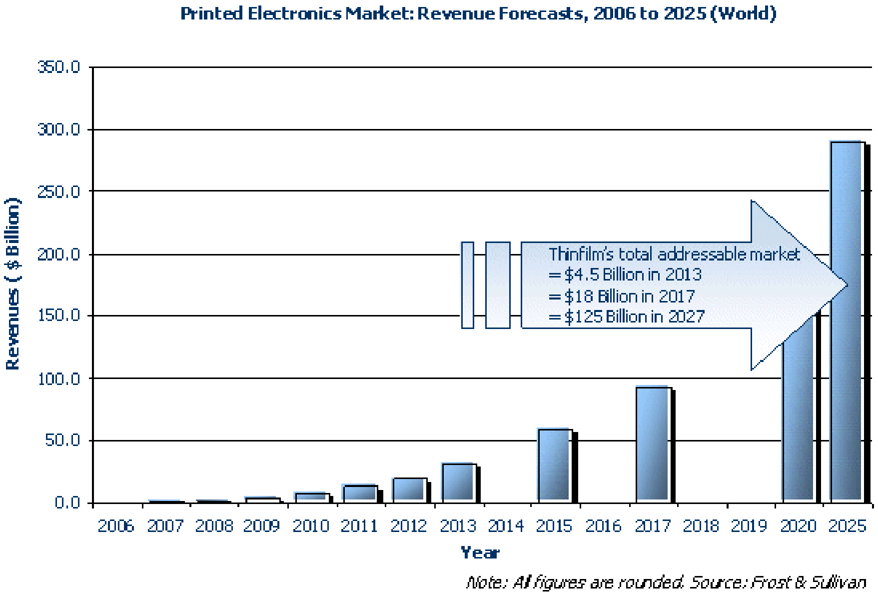
Comparison between Paper and Polymer Substrates

Property	Paper	Polymer
Stiffness	High	Low
Shrinkage	Low	Typically high but can be improved
Surface Modifications	Possible using coatings	Possible but can be costly
Absorbency	High	Very low
Biodegradable	Yes	No
Chemical stability	Low	High
Mechanical strength	Low to Moderate	High due to strong cross linking
Surface smoothness	Typically Low but can be improved	Very high surface smoothness

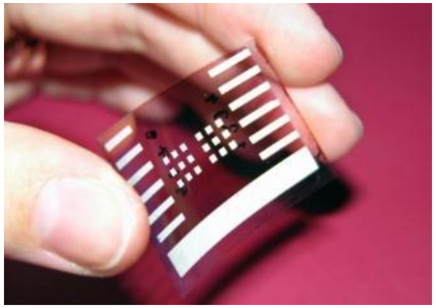
Markets and Application Areas







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



Functional Inks

Typically Inks used for graphic printing consist of:

Pigments – Resins – Solvents – Additives

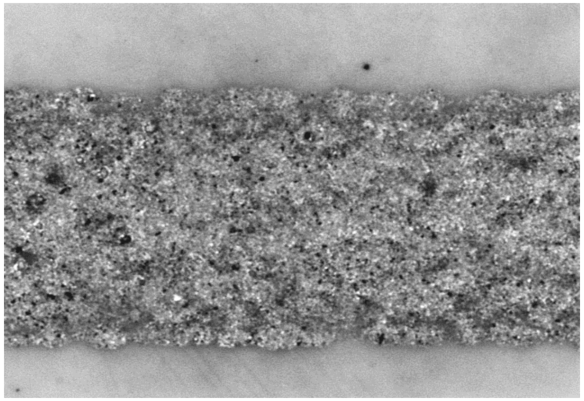
In functional inks, Pigments are replaced by functional materials such as Conductive, Semiconductive or Dielectric materials that give functional attributes to the ink.

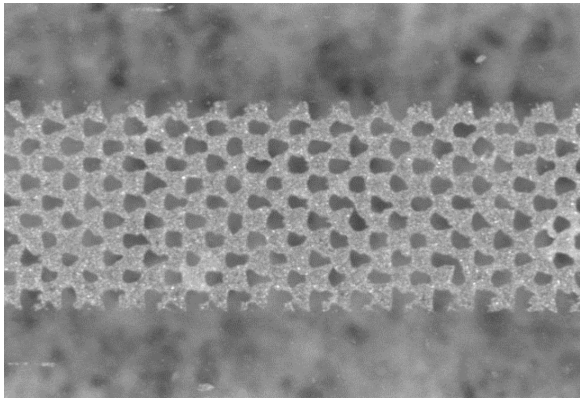
Functional Ink Type	Examples of the Materials that can be Used
Conductive Inks	Silver, Gold, Copper, Nickel, Carbon, ITO particles, ATO particles……
Semiconductive Inks	C60, Fullerenes, Pentacene, poly(3 – hexylthiophene) (P3HT), poly(9,9’ – dioctyl – fluorine - co – bithiophene) (F8T2)….
Dielectric Inks	poly (methylmethacrylate) (PMMA), poly (4-vinyl phenol) (PVP), polystyrene (PS), polyimide (PI)…..

Ink Comparison Relative to Printed Electronics

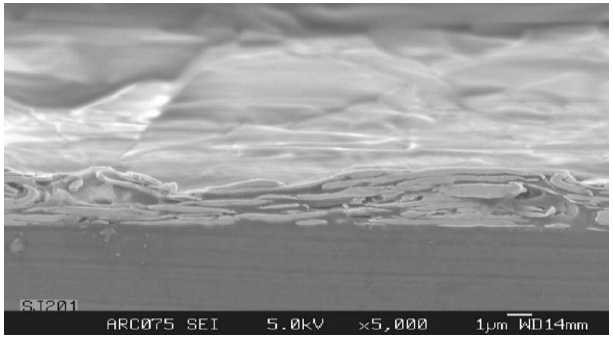
Printing Method	Print Speed	Drying Needs	Viscosity
Screen	Slow 1-10 fpm	High 100-150° C	5000-40,000 centipoise
Flexography	Medium 25-1000 fpm	Medium 50-150° C	2000-5000 centipoise
Gravure	Fast 100-3000 fpm	Low 50-100° C	500-2000 centipoise

Good and Bad Printed Samples





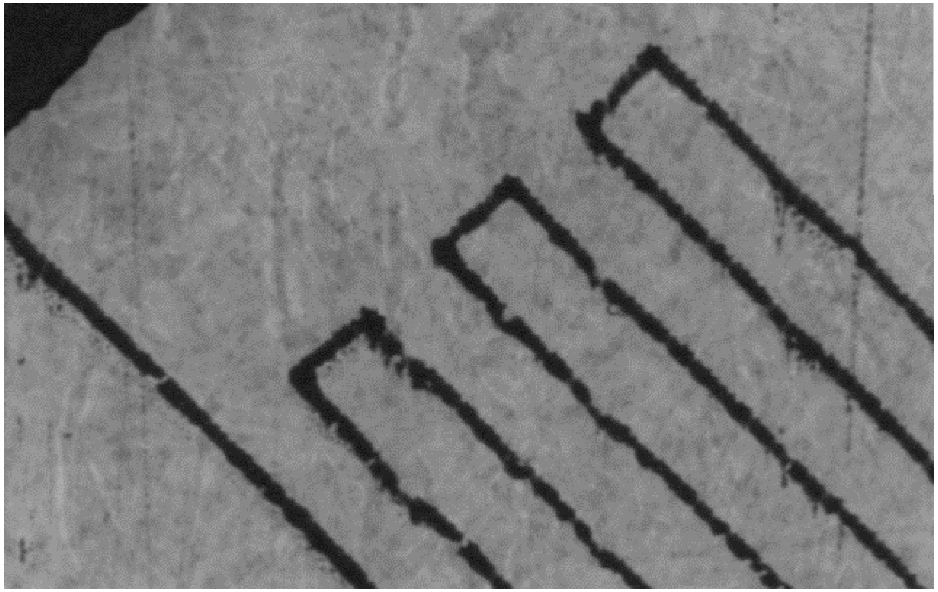
Images of Solvent Based Silver Flake Inks Printed on PET
Left image is a good image with an even ink lay and no pinholes whereas the image on the right shows pinholes and is probably due improper viscosity adjustments and thus improper transfer form the gravure cells to the substrate.(Images taken on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

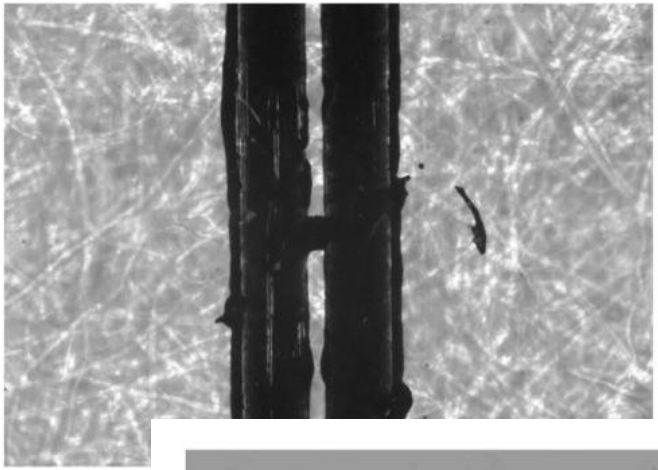


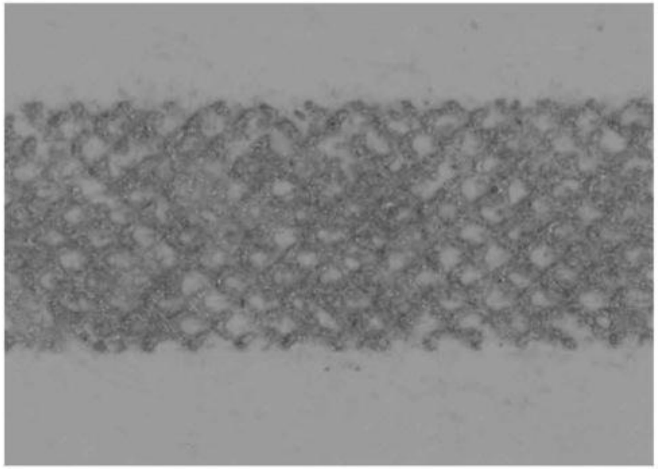
Cross-sectional View of Dried Ink Film on Substrate using SEM (Scanning Electron Microscope)

Functional vs. Visual

Opens, Shorts, Partial Transfer

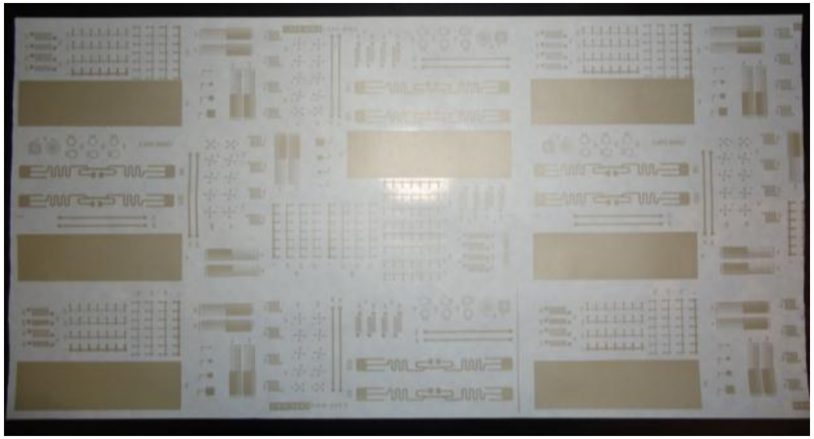


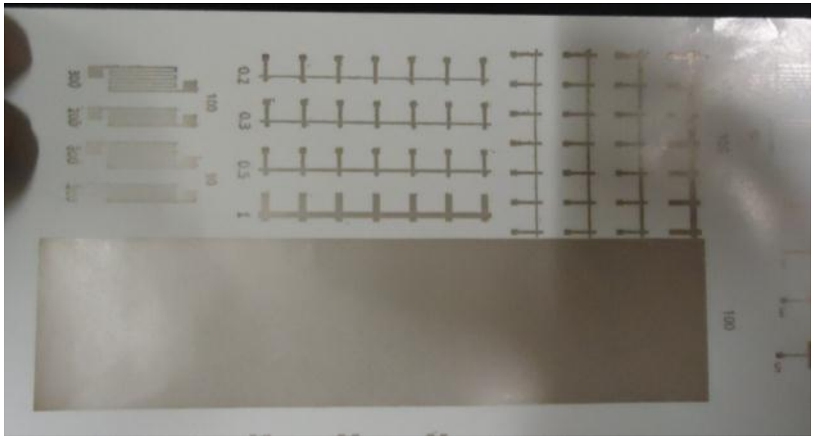




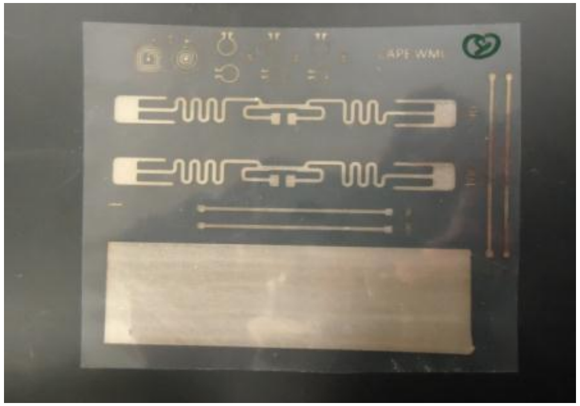
Courtesy B. Bazuin of WMU CAPE

Print Samples on Different Substrates



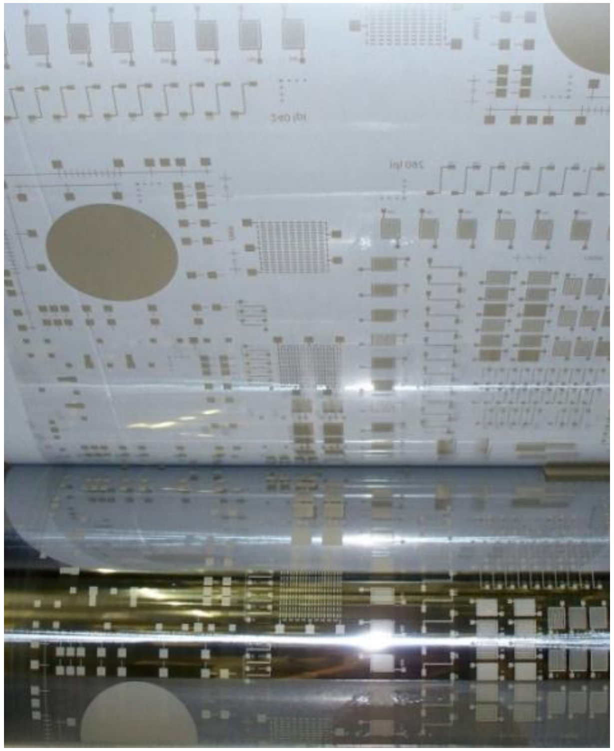


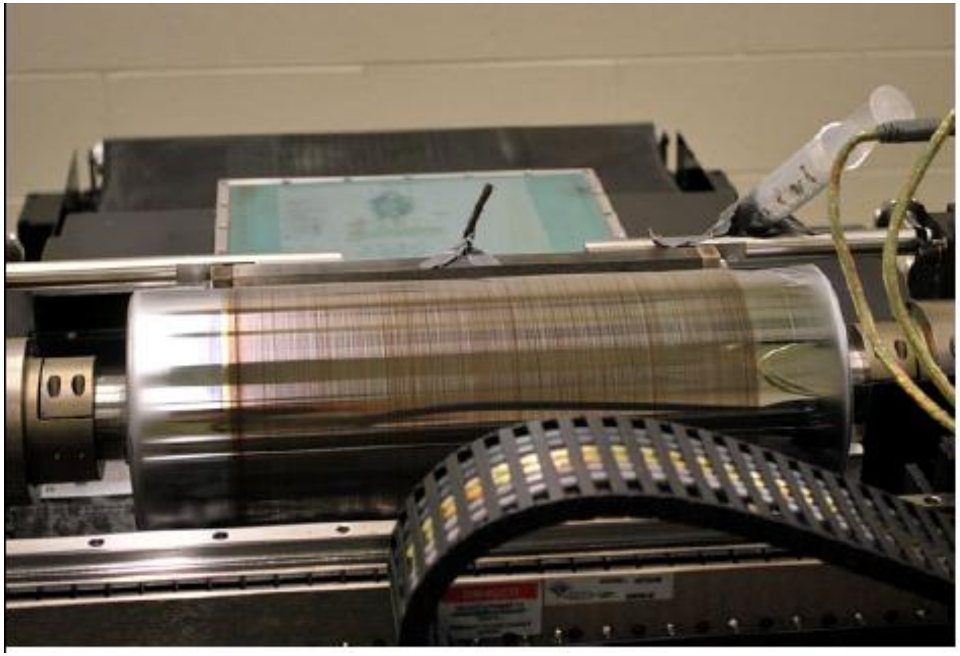
Examples of Samples Printed on Paper (Left) and Paper Board (Right)



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

Heliograph Holding - Products for Gravure Printing

Equipment for Gravure Printing

Engraving Technology

Laser Technology

Full Automation

Cranes

Cylinder Handling

Finishing Technology

Plating Technology

Daetwyler R&D - Products for Printed Electronics

μStar
MicroEngraving System

High-Precision Diamond Cutting Tool

Engraves features < 5 μm
Control < 200 nm depth
Up to 12,000 features/s

Unique 3-D shapes

- 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….

5 μm features

optical lenses

AccuPress®
MicroGravure Printing System

- Lab / Limited Production
- Layer-to-Layer Registration
- Allows Hybrid Printing
- Custom Enhancements
- Levels of Automation

Level 1
Single Layer
High Precision Bearings
Machine Accuracy < 20 μm and more

Level 3
Multi layer
High Precision Air Bearings
Machine Accuracy < 5 μm and more

AccuPress™
MicroGravure Printing System

MicroGravure Cycle Solutions

Completing the Micro Printing Process Cycle

Micro-Gravure Printing

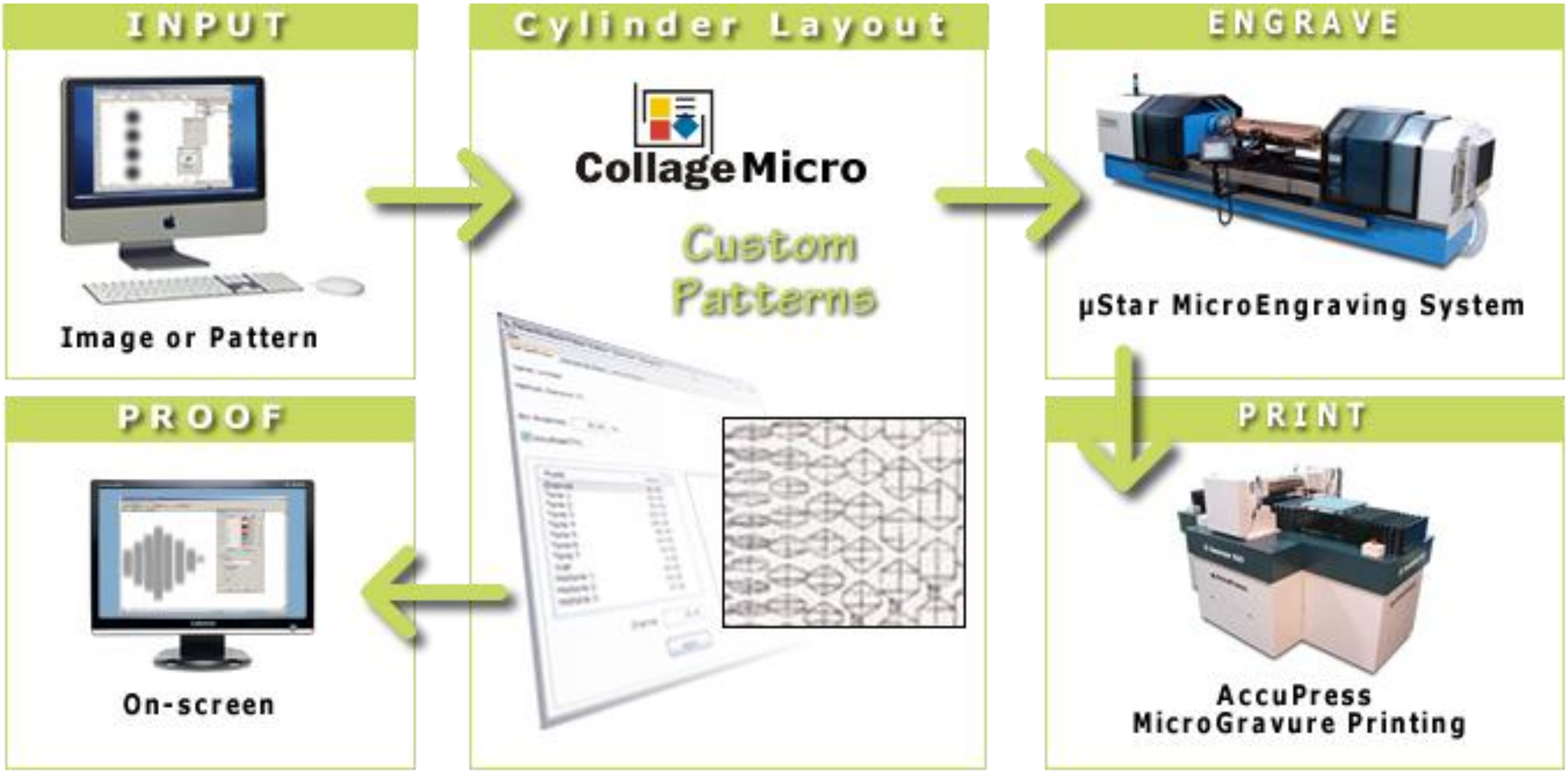
AccuPress MicroGravure Printing System

Printed Electronics

µStar MicroEngraving System

Partners, Products

MicroGravure Workflow



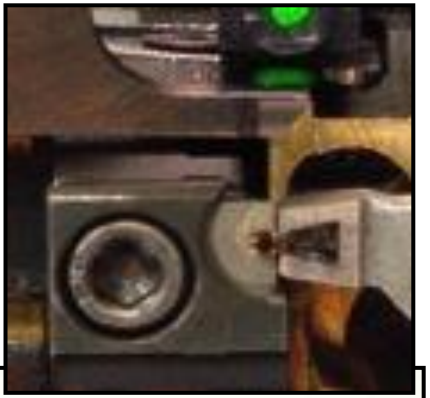
μStar MicroEngraving™ System

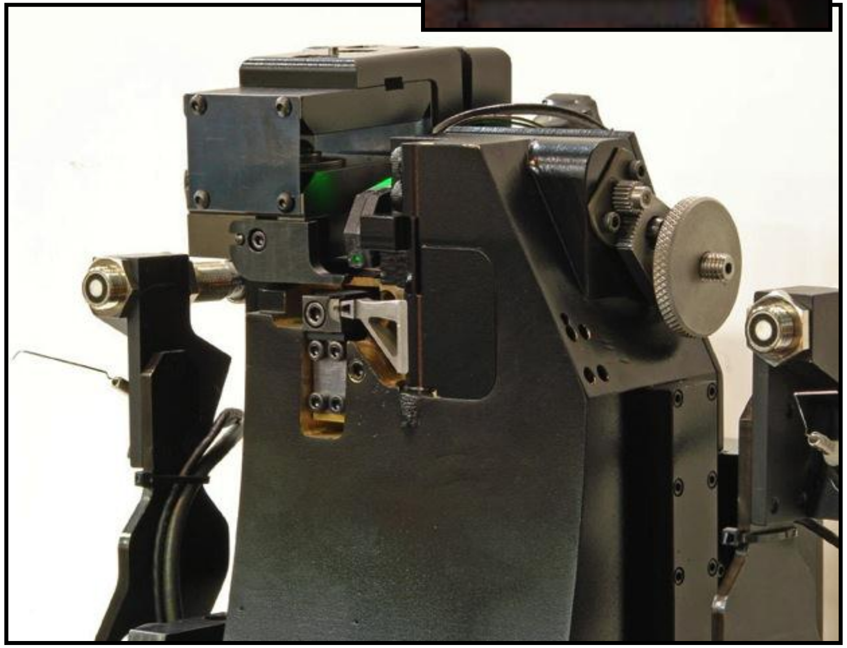
- Advanced Data Processing capability with *Collage-Micro* Layout System
- Unique 3-D Shapes
  - Ink Transfer Optimization
  - Micron Lens Design
  - Features < 5 μm
- High Productivity with Ultra Fast Tool

Ultra Diamond Cutting Tool

MicroEngraving Tool

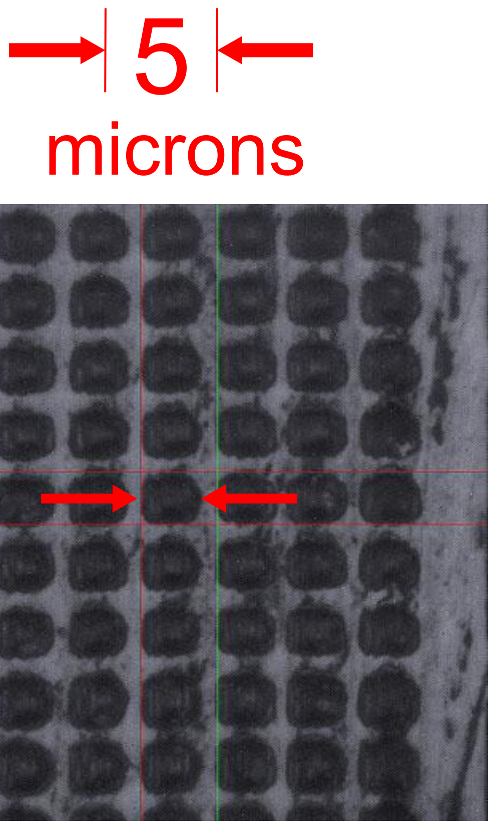
- High-Precision
  - Control < 200 nm in depth
- Up to 12,000 features per second
  - < 50 µs rise-time !!
- Feedback controlled
- Cartridge tool design
- Diamond tools

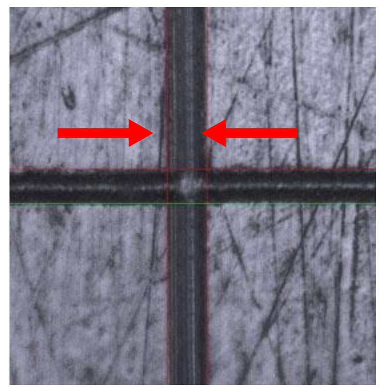


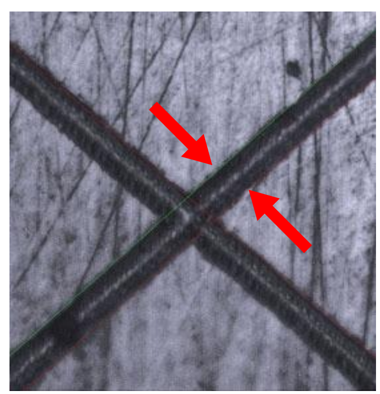


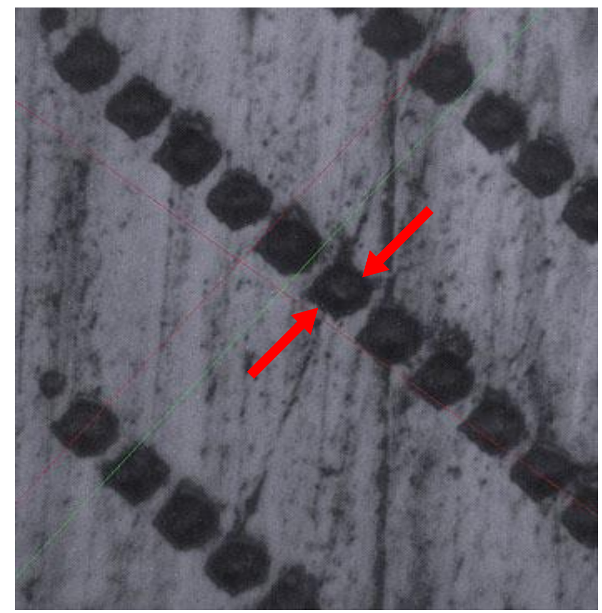
µStar Applications – Printed Circuits

High Resolution Examples









Precision Gravure Printer

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

AccuPress®
MicroGravure Printing System

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	
Advantage	• Fine resolution • High ink transfer volume • Uniform laydown
Scalability	• *AccuPress* for prototyping • Scalable & consistent for R2R
Applications	• PLED's • Fine Resolution Conductive Lines • High Density Transistors • Backplanes • Photovoltaic, Battery

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