Printed electronics
Digital fabrication
Workshop | 4th Mar '13

System design for smart systems employing Digital Fabrication methods

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CATAPULT High Value Manufacturing

cpi ...the future inspired

Printed Electronics Limited

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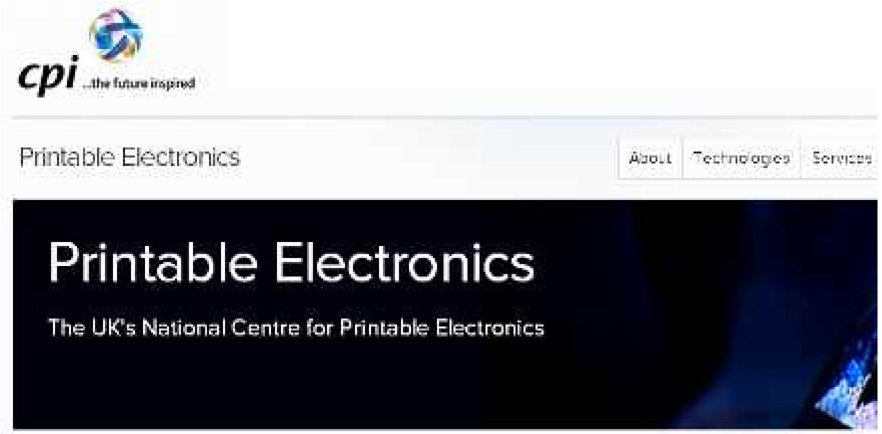
http://www.printedelectronics.com/

Centre for Process Innovation Limited, National Printed Electronics Centre



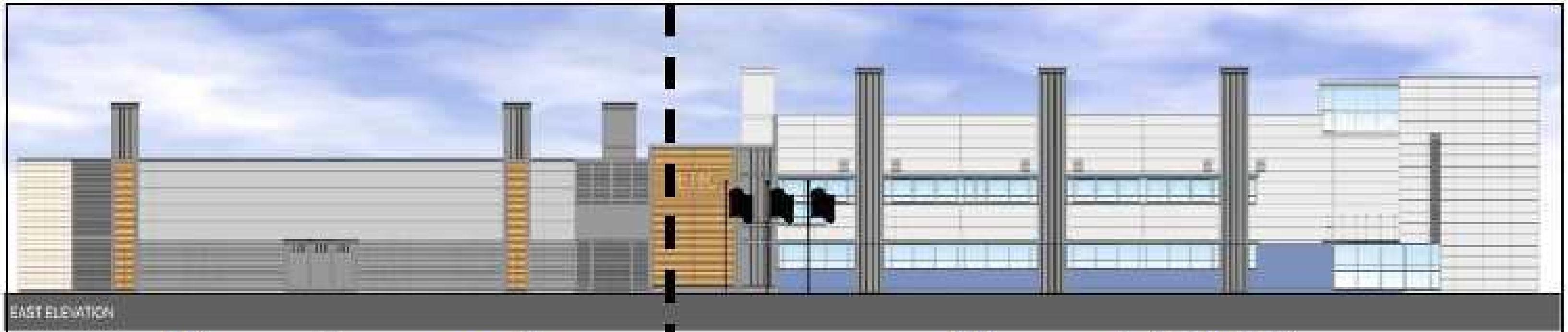
http://www.uk-cpi.com/

CPI Printable Electronics Centre introduction

- UK national facility for printed and plastic electronics (established in 2008)
- Managed by parent company - Centre for Process Innovation (CPI)
- Purpose - scale up from R&D to pilot processing
- Substrates from 4” square to Gen 2
- 1500 m^2 of clean room facilities

Gen2 means 370mm X 470 mm substrate

CPI National Printable Electronics Centre



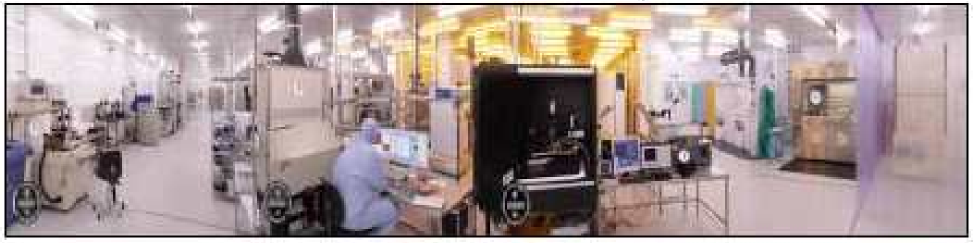
Phase 2 expansion
Pilot facility (2011)

Phase 1 (2009)
Focus on Prototyping

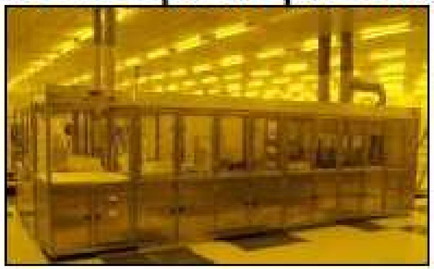
SSL OLED pilot line

OLED tile demo

Prototyping for OTFT, OLED, OPV, barrier film, etc



Gen2 backplane pilot line



OTFT array on 10μm thick substrate

R2R source-drain metal on PET

OTFT EPD

AC-EL

Comparing an analogue smart system and a digital smart-print system

Analogue

- Uses Tooling – plate lead-times need to be considered, tooling cost is not high
- Each part is fixed in its design, iterations of designs can be needed
- Mostly additive – excess material is needed in print sumps and for plate coating

- An **established industry** with long know-how in graphics printing
- Electronic materials are understood
- **Transition to routine printing of electronic materials is underway** - builds on experience in e.g. screen printing of silver
- **Very high speed**
- **Accurate and precise** – but cannot compensate for in process distortion
- Multilayer is challenging

Digital

- **Tool-less**– benefits quick-turn production and rapid prototyping
- **Adaptive** – **every part can be different**. Batch identifiers, **security markers** *etc* can all be added to the part *during print*
- **Additive** – only the material *intended to be sold* is printed onto the substrate . Losses in print systems can be minimal
- An established industry with long know-how in graphics printing
- Electronics materials less well understood
- Digital is not yet transitioned to routine printing of electronic materials: relies on e.g. nano-material supply chain
- **Can be fast** – speeds for inkjet based graphics systems are approaching analogue
- **Accurate and precise** – can compensate for distortion
- **Multilayer** printing is possible
- **Cost Effective**

System Considerations
- for successful printed electronics

Inkjet

- Inkjet is probably the natural choice for R2R printed electronics
- For printed electronics - every dot should be in the correct place. For a smart system that may need to drive 100,000 nozzles at up to 20kHz this is not straightforward.
- Dropped nozzles *are* going to occur so the system needs redundancy built-in
- Inkjet system inevitably deposit (lots of) low viscosity liquid onto a fast moving substrate. Surface interaction is perhaps *the most important* consideration.

100um to mm features

Nozzle Deposition

- Vector (line drawn) systems are able to deposit thicker and more viscous materials – so material choice is perhaps easier and surface interaction is less of a concern
- Not applicable to R2R production
- Few nozzles means that the system is likely to be very slow
- More suited to precise part printing and 3D forming
- E.g. Nordsson Picodot, Optomec and Nscrypt etc

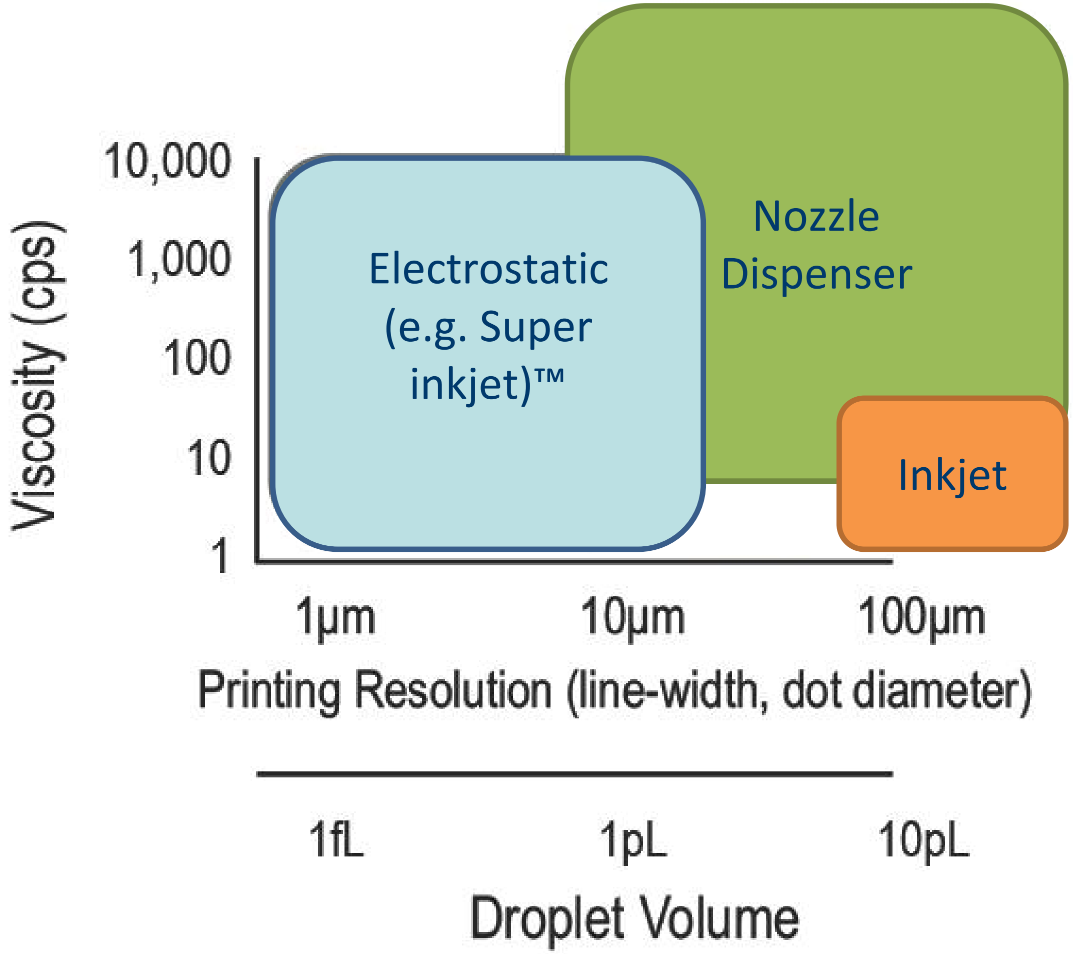
100um to mm features

Electrostatic (femto) deposition

- For extremely fine features it may be necessary to consider femto-litre and electrostatic systems that can deposit structures at 1um line-width
  - Chip attach
  - Wire bond
  - Etc
- Such systems are *part of the story* but are incompatible with fast printing and cannot be integrated into R2R
- E.g. Super Inkjet (Japan) etc

1um to 50um featrues

Comparison

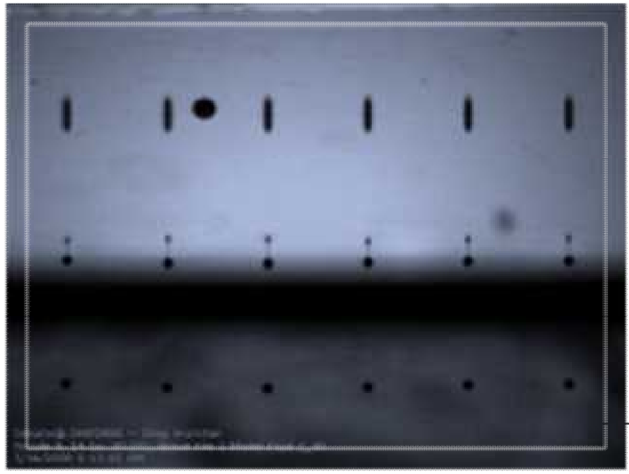


- Material control is more challenging for inkjet than either of the other techniques
- Inkjet is the only multi-nozzle technique with sufficient speed to consider for R2R processes

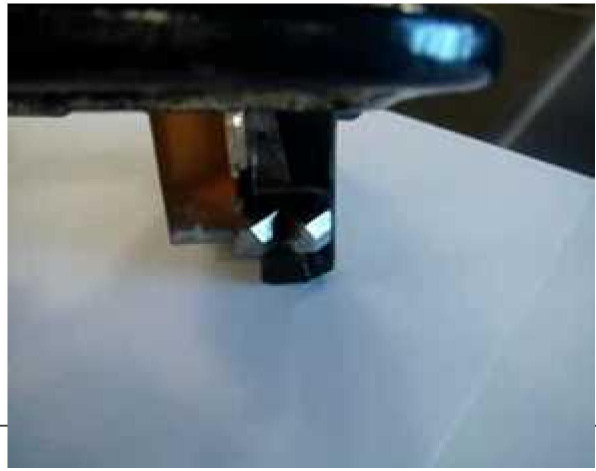
Inkjet Printed Circuits

- Direct Printing using inkjet is already proven for circuits on paper, plastic and other flexible surface e.g. PEL
- A R2R compatible system is essential for high volume printed electronic systems e.g CIT process
- CPI digital roadmap includes the combination of R2R ISS (Integrated Smart System) and Printing tools.

Inkjet precision process



Fast circuit printing



CIT R2R

Multi Material Inkjet Printing

- Array head designed to allow simultaneous printing of different inks.

Potential applications / aims:

- Mixing graphics with electronics
  - print colour graphics to hide electronic circuits or other features
- Print multiple electronic elements in a linear pass
  - Conductors, resistors etc
- Print chemically reactive species to form chemical reactions on a substrate
- Print biological agents
  - Simultaneously print a range of biologically active material
  - can change the printed area and concentration of functional materials

Previous efforts on Digital Fabrication from mass production companies

Mainly driven for cost saving purposes!!!

Examples from Display Industry

Productivity and cost effectiveness are critical in display industries

Inkjet printing of *color filter* in LCD display

Inkjet printing of *spacer* in LCD display

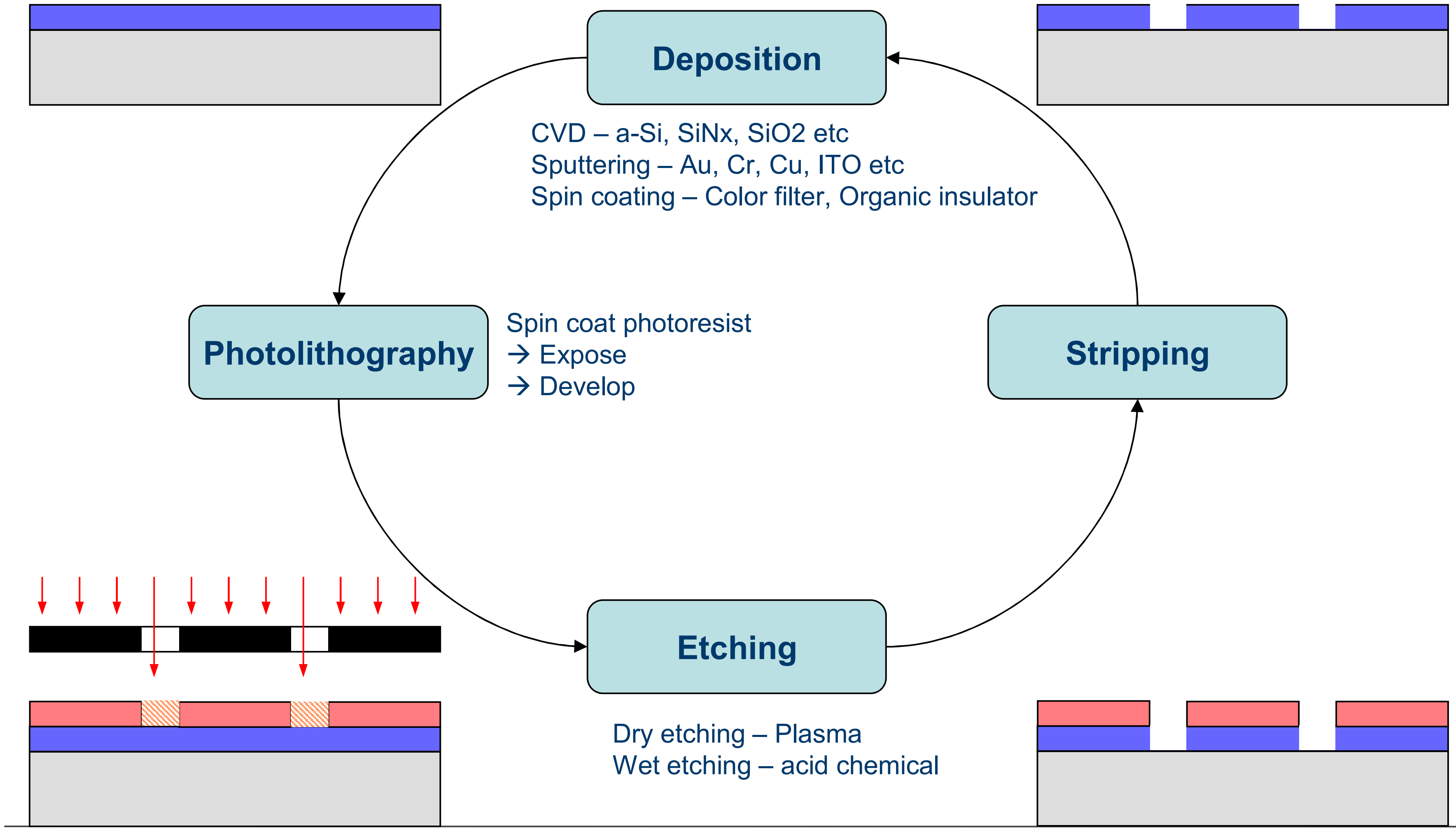
Inkjet printing of *alignment layer* in LCD

Inkjet printing of *light emitting polymer* in OLED

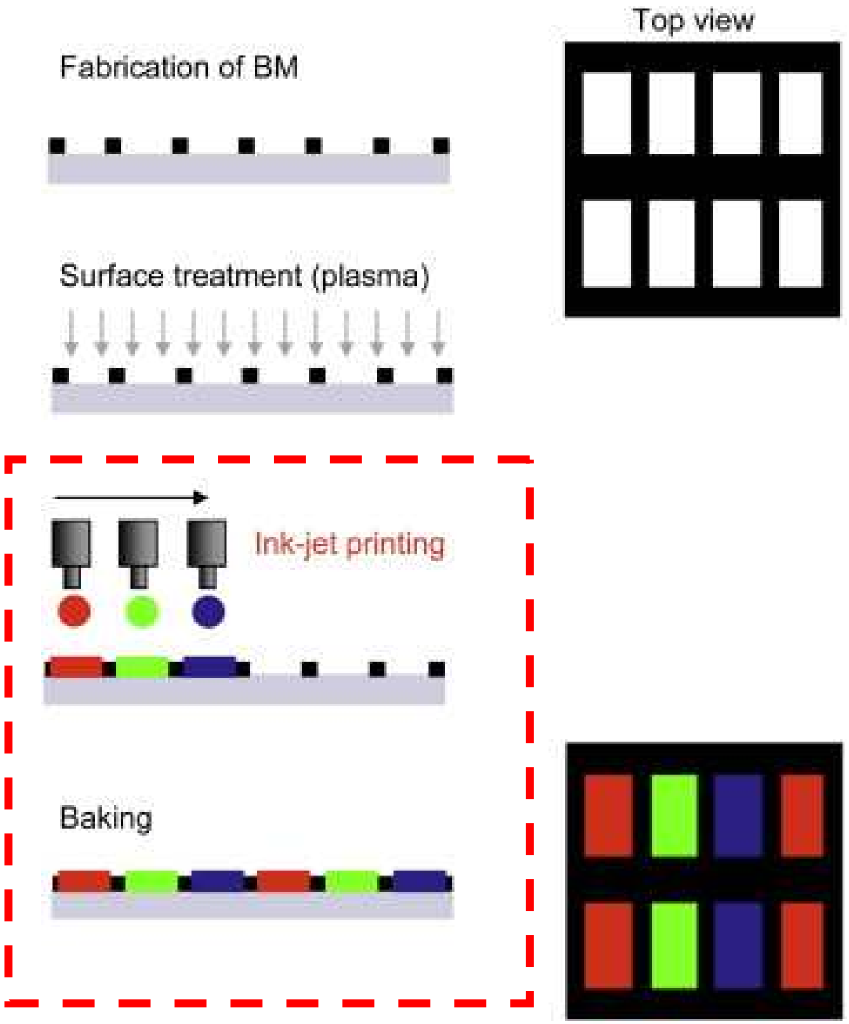
Nozzle printing of *light emitting polymer* in OLED

Digital Lithographic tool

Conventional Thin Film Patterning Cycle



Inkjet Printed Color Filter for LCD



http://www.rnd.lgchem.com/hf_out/d2009016.asp

Are these already in use now?

Essential for cost saving in manufacturing
(e.g. Polymer/Soluble OLED)

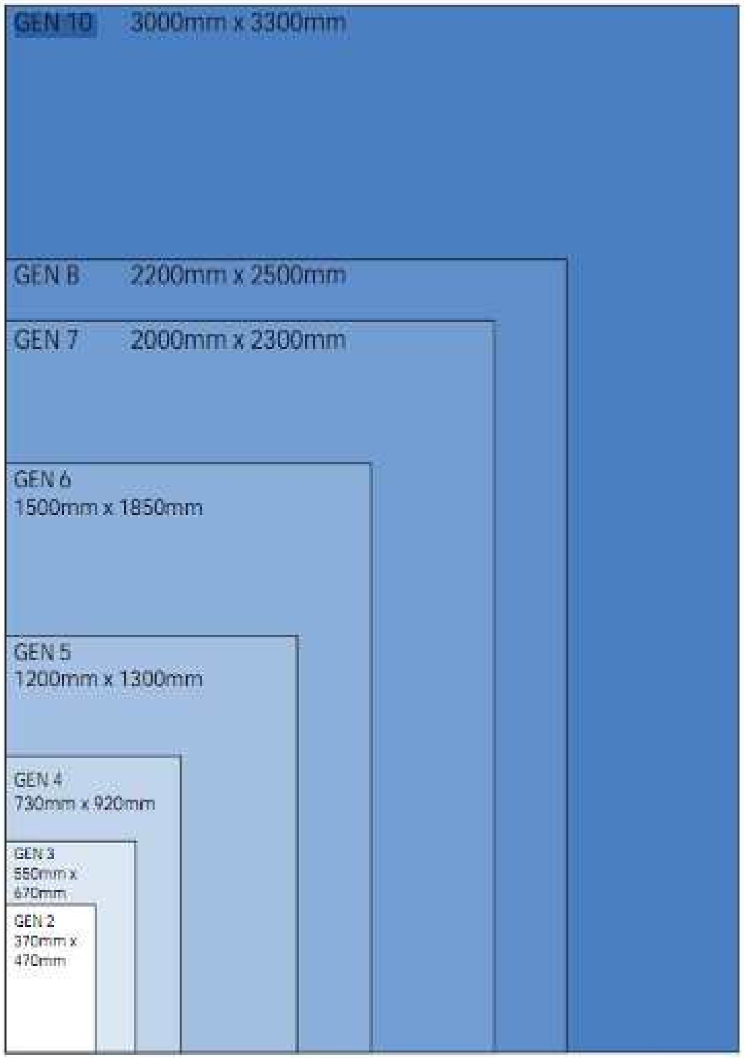
But still many issues
Reliability issue (24/7 operation is challenging)
Maintenance issue (one clogged nozzle → line defect)
Uniformity issue: <5% uniformity required

$$\text{Min-Max Uniformity} = \frac{\text{Max} - \text{Min}}{\text{Max} + \text{Min}} \times 100$$

1440 X 900 X 3 (RGB) = 3.888 million pixels
(WXGA+)

Another approach for digital fabrication – Digital Lithography

Digital Lithography



cf) LCD glass generation

Mother glass size is becoming bigger and bigger for higher productivity

A large size photomask for 8th generation color filters

http://electronics.toppan.co.jp/english/pm/01.html

Digital Lithography

A lot of masks needed.
- BM (Black Matrix) mask
- RGB Color filter mask
- TFT masks (~5 ea)

Mask errors in development

Mask delivery time

Mask life time

800M USD for photomasks cost in LCD industries in 2008 (Source: Display Bank Report 2008)

Gen7 mask: 300k USD, Gen7 Half tone mask: 800k USD

Digital Lithography

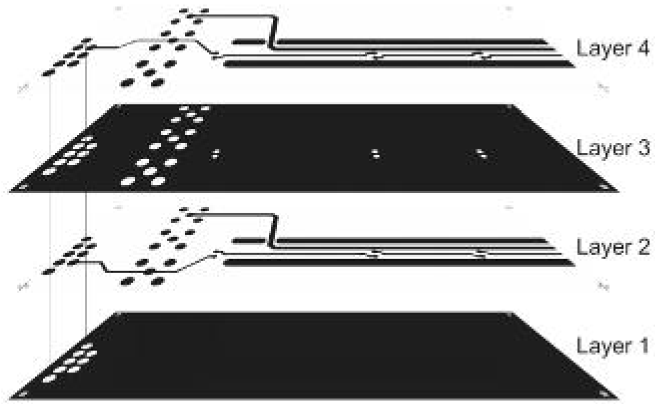
No mask cost (especially beneficial for large generation display fabrication)
No mask fabrication / delivery time needed: shortening the development time
No mask contamination / disposal issue
No errors due to mask alignment
Easy for design change (e.g R&D product)
Small scale production
Easy for R2R fabrication
In-situ pattern correction: Distortion compensation function is essential.
(including non-uniform/non-linear distortion)

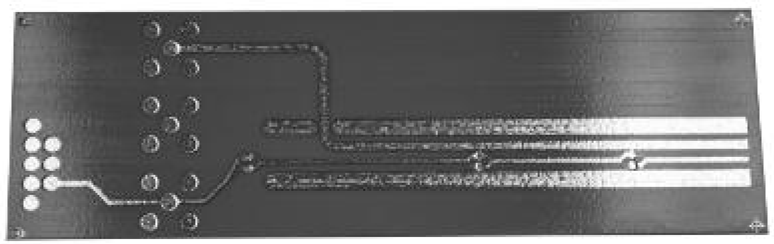
Printed Electronic Component
Smart System Component

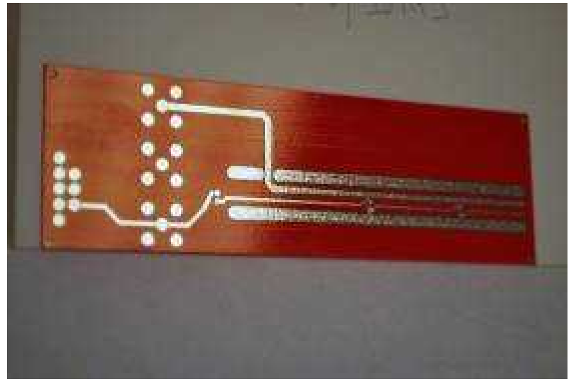
Multilayer Structures

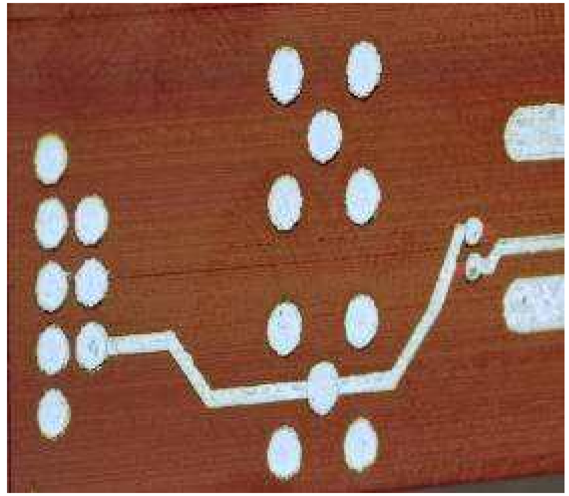
- Conductive & Dielectric layers are printed to form multilayer PCB-like structures
  - Thickness - few μm
  - Flexible

- A multilayer "PCB" by inkjet

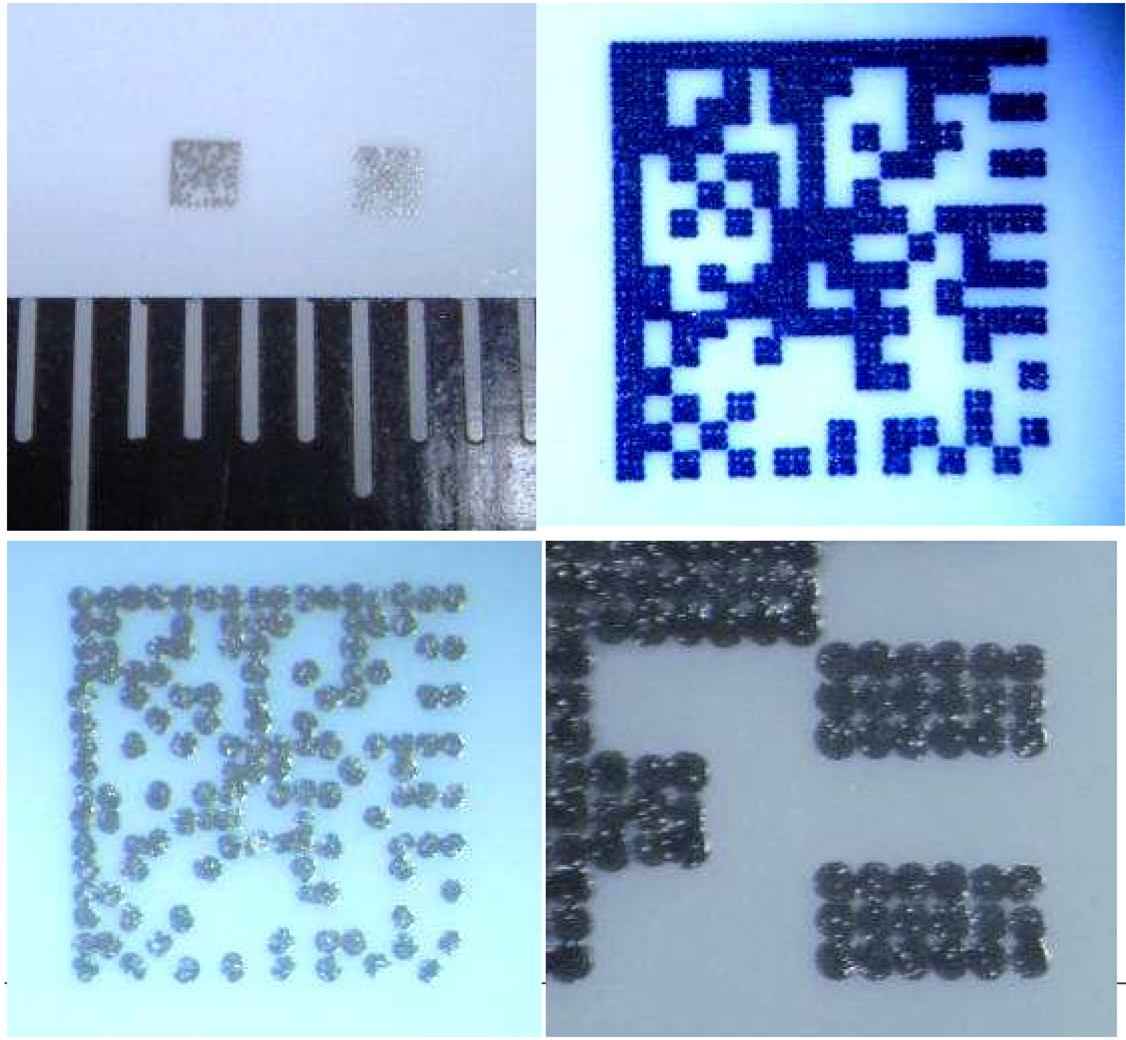








DIGITAL - Adding batch idents or security to each part



PEL - Machine-readable "single pixel" 2D barcode - Hidden Marking application

- Inkjet's precise drop volume: each droplet can be placed with a precision of a few μm to each other
- Print Functional materials
- Print Invisible tracer/marker materials
- Application – identity protection, covert and overt security.

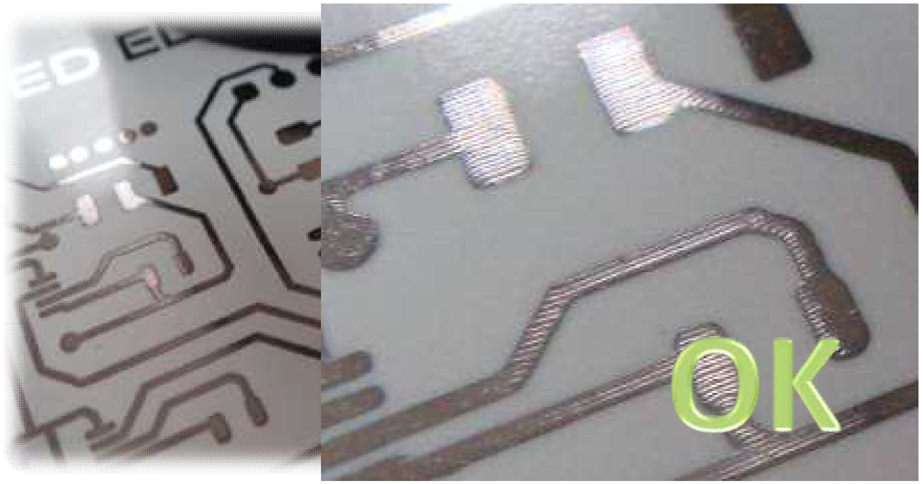
But…

There are technical Challenges…

Nothing comes easy.

Printing vs. Deposition

- Printing means making something that the eye sees as a “perfect representation”
- Digital deposition requires excellent drop placement
- Missing drops = open circuit



Issues in Inkjet Printing

Positioning

- Optimized nozzle to substrate distance
- No vibration
- Optimized firing conditions

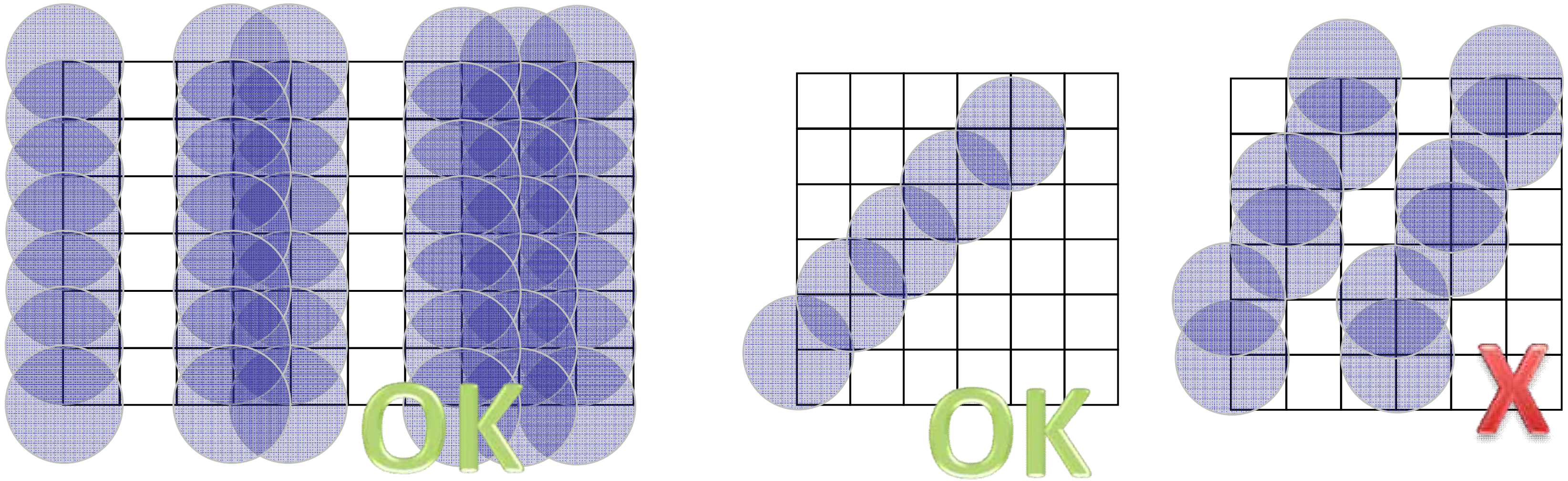
Coffee Stain

- Predefined layer structure for OLED/LCD
- Ink formulation
- Printing environment

Surface Treatment

- Affects printing pattern size, quality
- Inevitable in high precision printing
- Unharmful condition for underlying layers

Inkjet = fixed (low) resolution printing

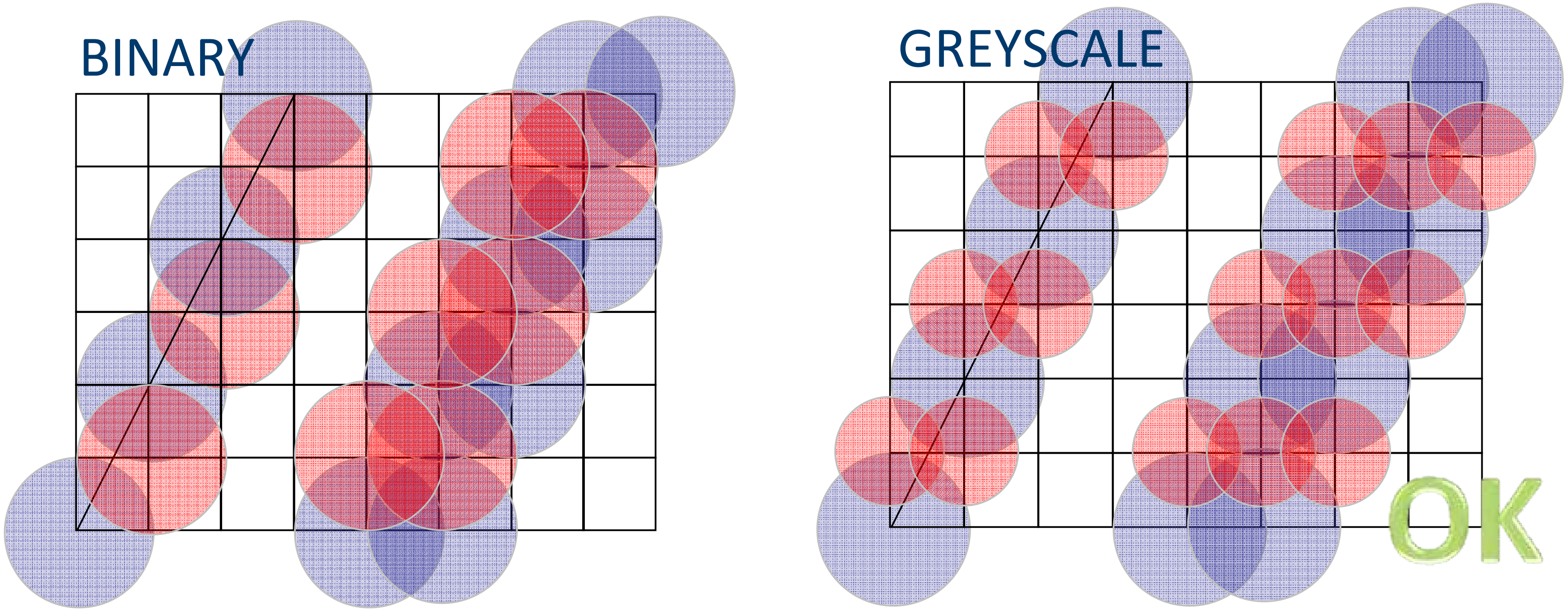


Inkjet has it roots firmly in graphic arts

Many of the drop formations that are acceptable in graphic arts have no place in printed electronics

Conventional electronics (e.g. PCB) uses print resolutions of >9000 dpi, inkjet might use 1000 dpi so feature pixilation is significantly different.

Greyscale printing may be required

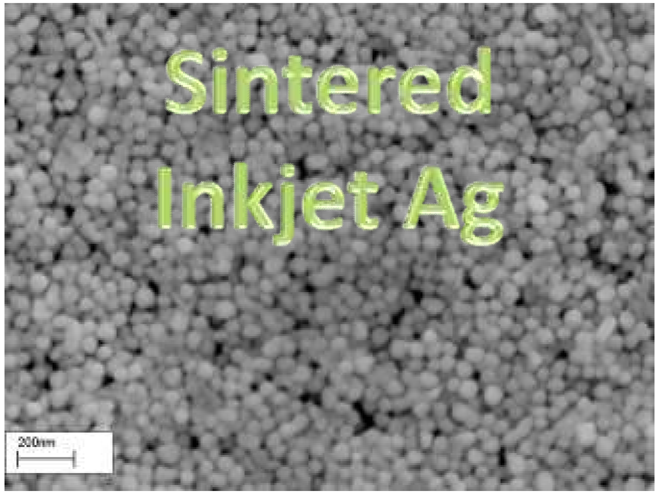


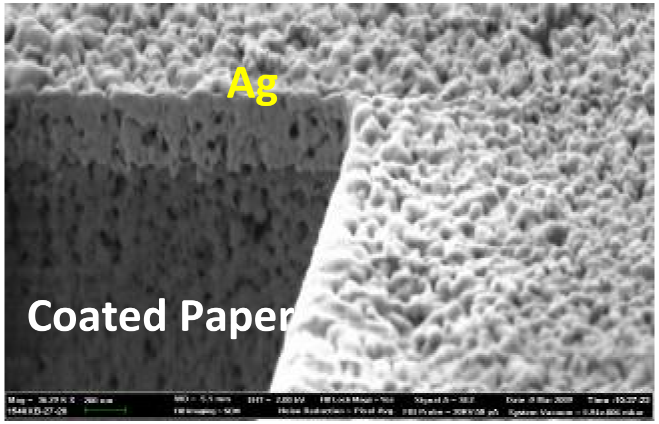
Additional drops (shown in red) are required to <u>connect</u> the line
Larger drop size 35um, Smaller drop = 25um

In electronics, gaps are just as important as tracks

Printing alone does not mean conducting

- Printed patterns need to be cured to make them conductive
  - Thermal
  - Photonic
- *Shrinkage will occur*
  - Compensation will be needed for multilayer printing

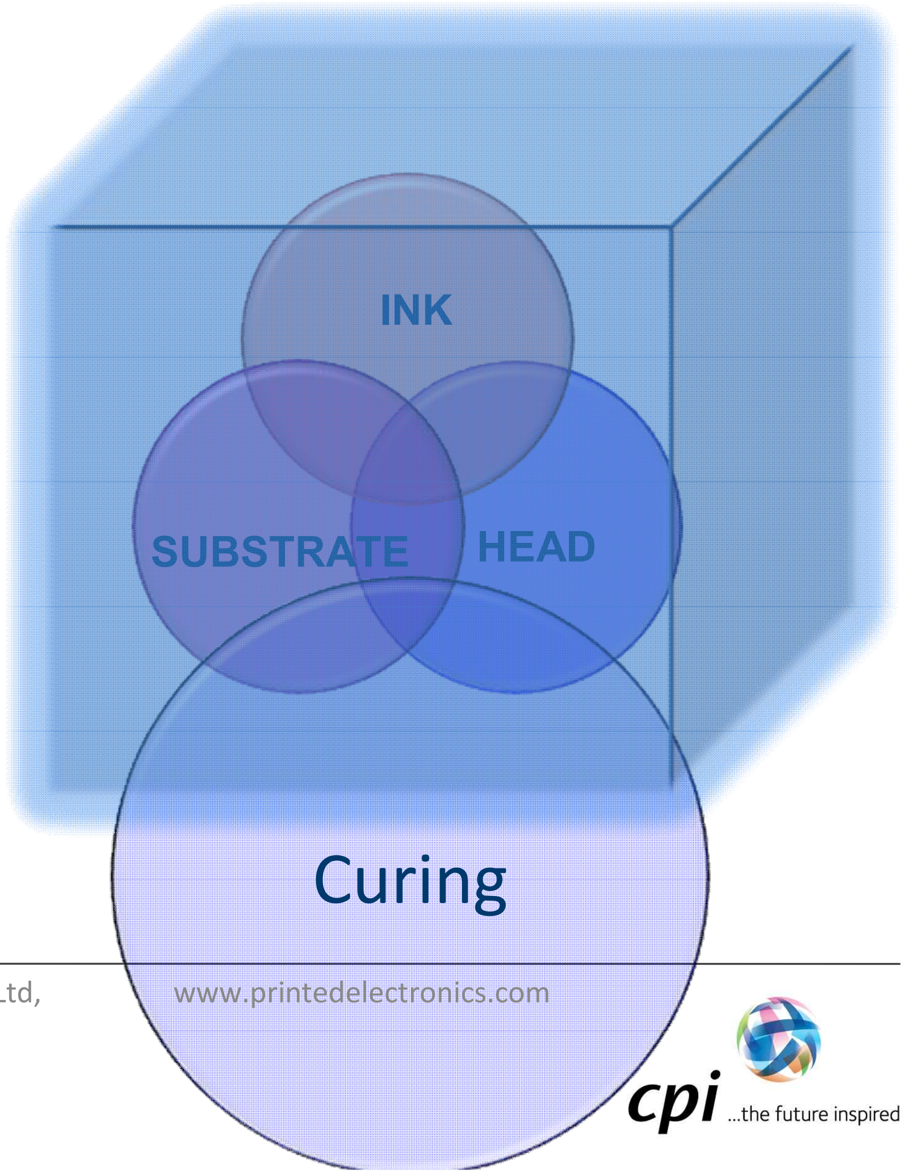




Material Deposition by Inkjet

Inkjet deposition of materials involves 5 basic elements.

- •The Ink(s)
- •Head(s)
- •Substrate(s)
- •Curing
- •Print platform (system)



Key decisions

- What (ink) are you going to jet?
  – Influences the heads and ink systems that you should choose
- What is your substrate?
  – Influences the ink rheology that you will need (wetting)
- What is your feature size?
  – Influences the head type and print speed that you can achieve
- What throughput do you need?
  – Influences the choice of scanning or single pass system

CPI examples

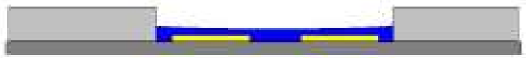
FlexOS™

Inkjet Printed Organic TFT devices - CPI results

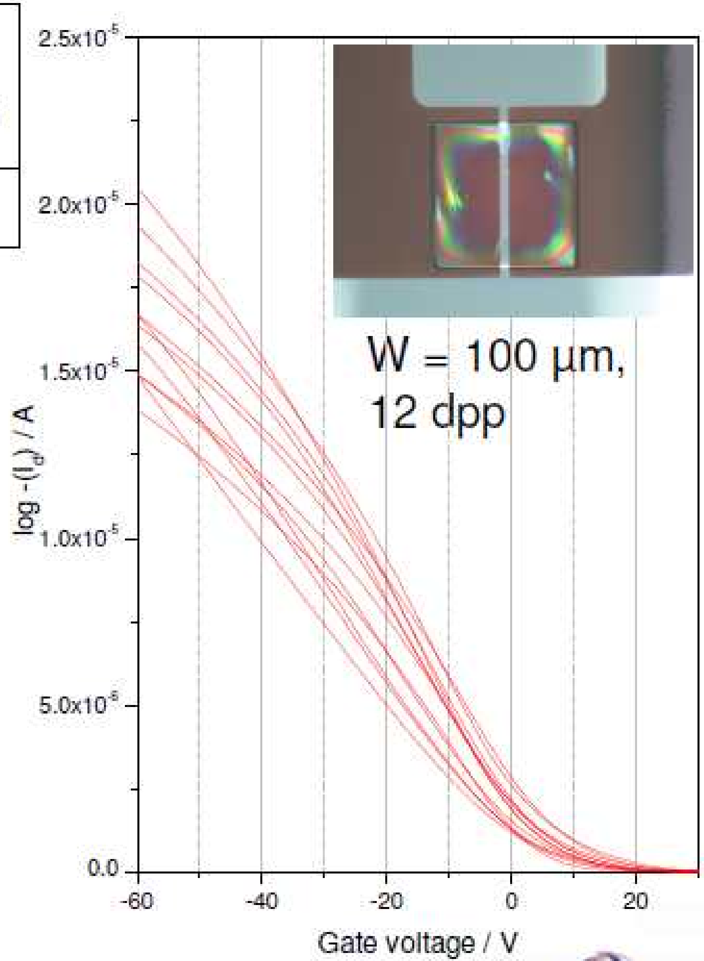
Channel Length / µm	Linear Mobility / cm^2/Vs	Max-min / %	s.d. / %	No. of transistors
7	**2.9**	16.3	12.2	12

Prepare SD electrodes and bank structures by photolithography

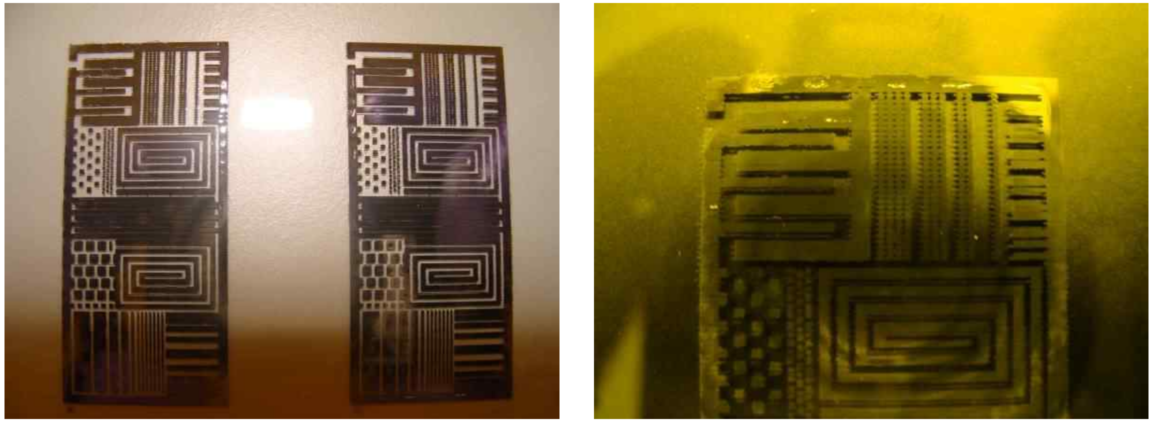
IJ print OSC layer and dry in air (using Dimatix DMP2800)



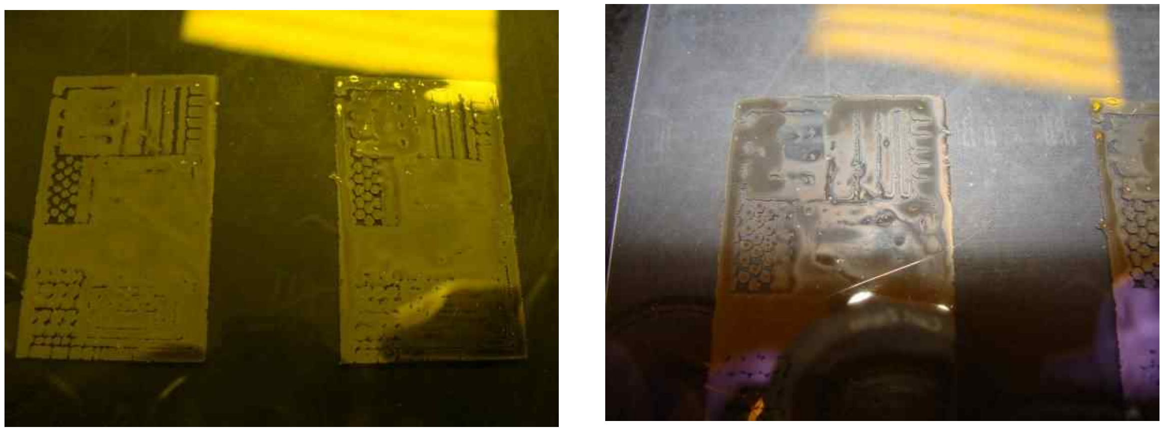
Hotplate bake



Substrate Effect



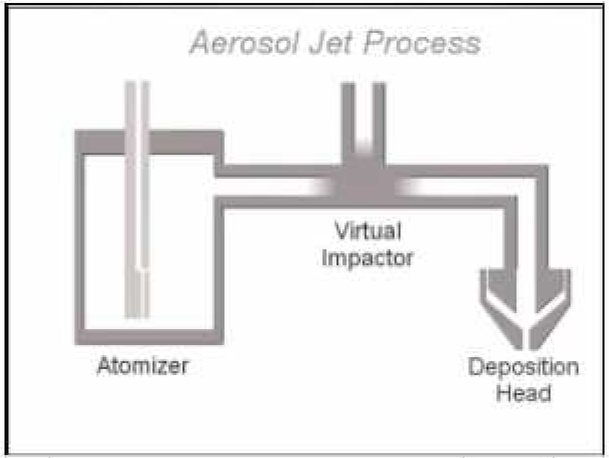
Silver ink printed on glass substrate



Silver ink printed on PET-adhesion coated substrate

Aerosol Jet Printing (Alternative Print Platform)

Aerosol jet printing - Optomec



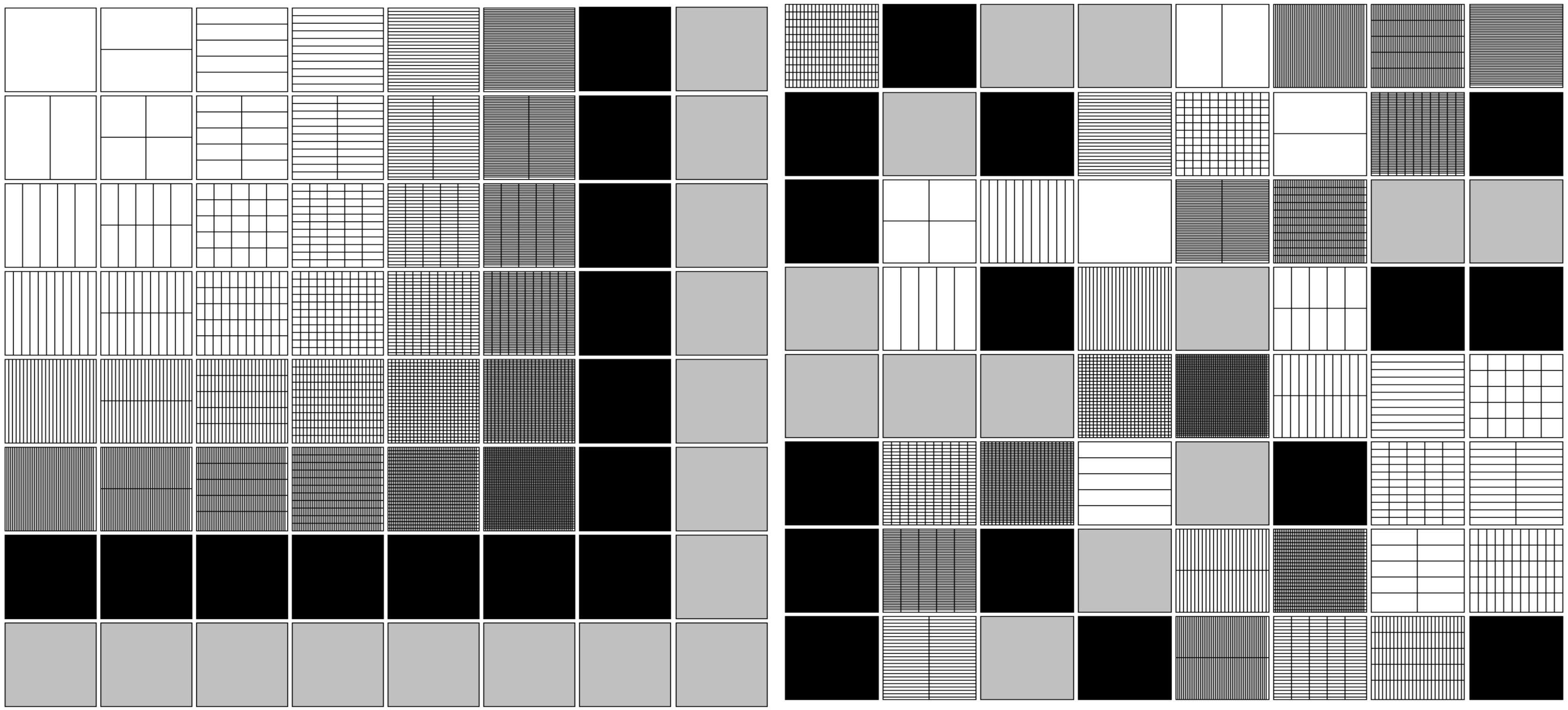
Sometimes very good alternative to inkjet printing – less dependant on ink properties (viscosity, density etc)

- Optomec M3D
- Mesoscale direct write printer
- Capable of printing **10μm width lines**
- Capable of using a variety of different inks and pastes
  - **Conductor inks** including Ag, Pt, Pd, and Cu have been developed with cure temperatures down to 150 C°
  - diluted thick film pastes, thermosetting polymers such as UV-curable epoxies, and solvent-based polymers
  - Bio-materials including proteins and DNA have also been printed.

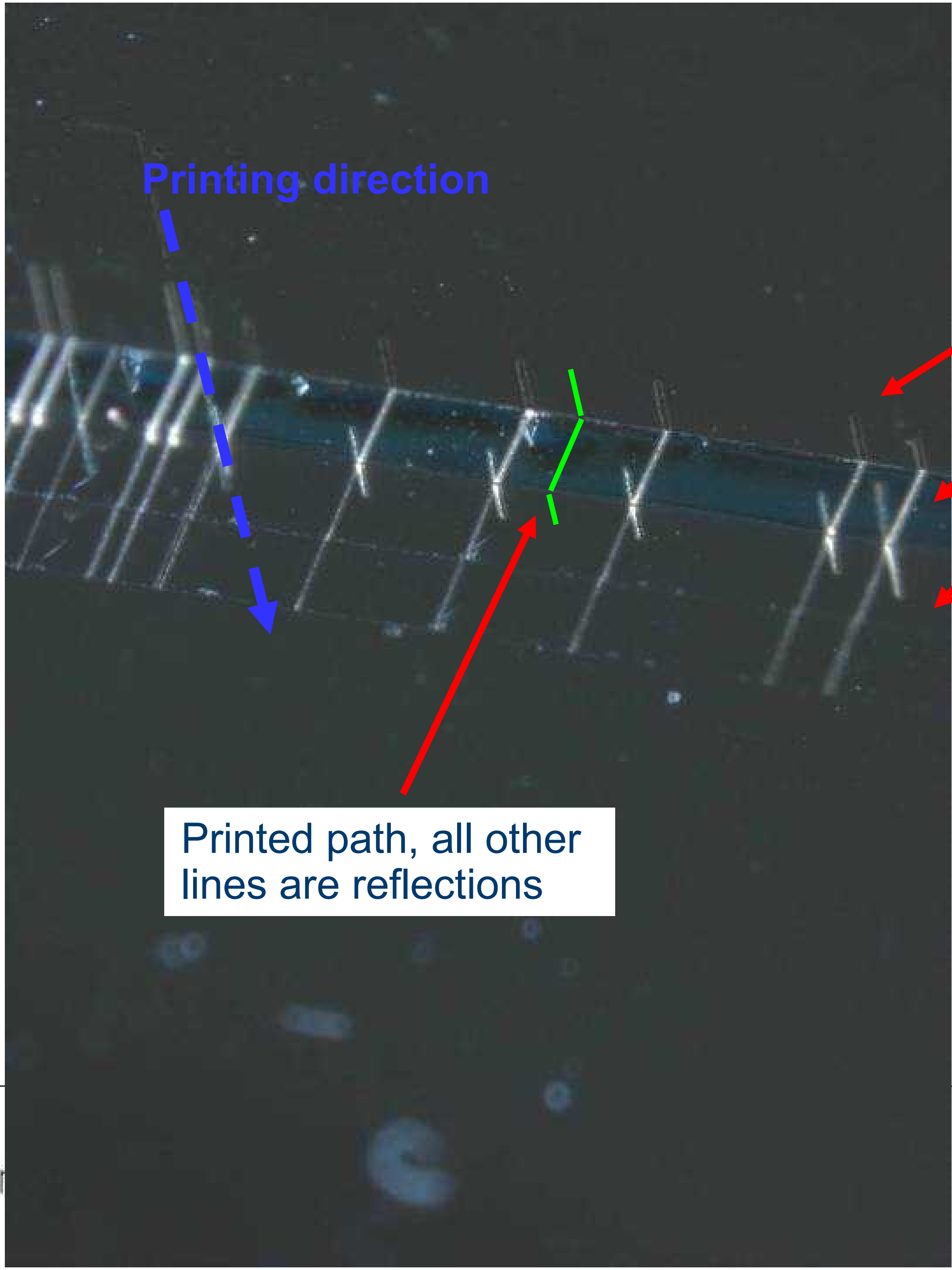
Already adopted by industry
e.g. Repair of bus line defect in PDP (Plasma Display Panel)

Grid test pattern for SSL and PV application

Quite versatile for developing grid electrode patterns
- Auxiliary electrode in SSL (solid state lighting) and Current collector in PV (photovoltaic)



Step edge

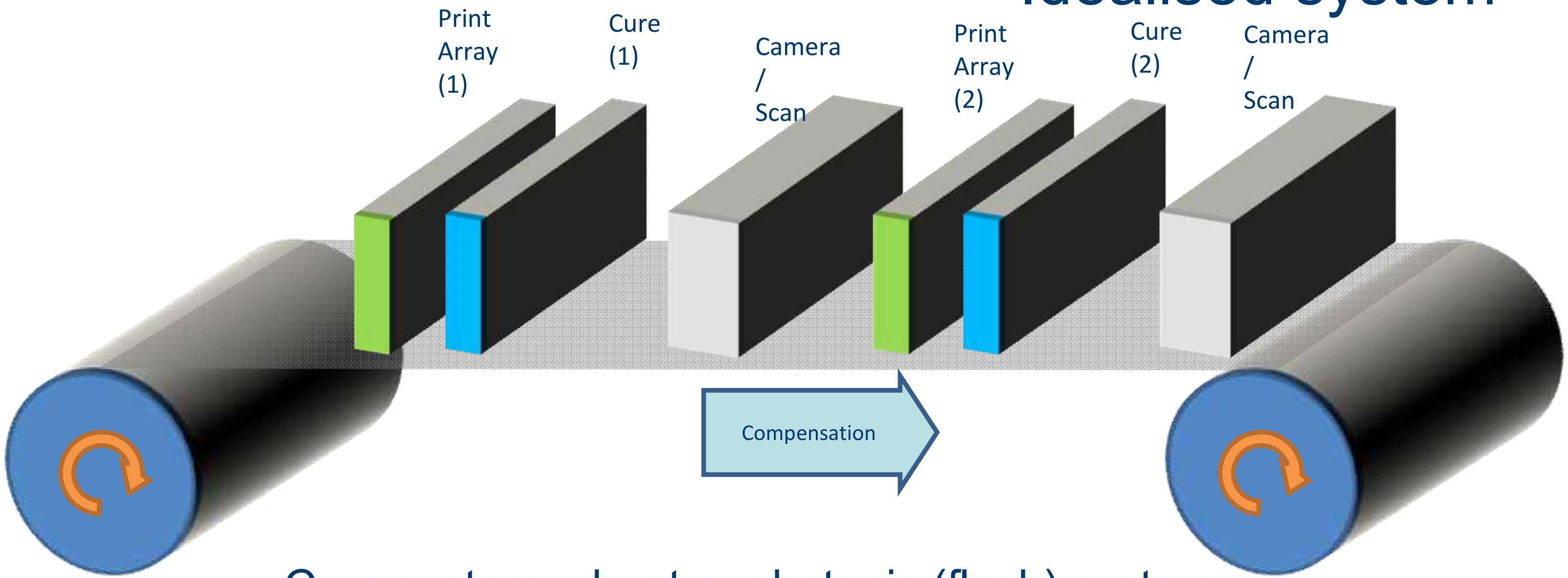


- Top glass surface
- Edge of top glass sheet
- Surface of lower glass sheet

CPI examples

Digital Printing System Design
- Potential for R2R Fabrication

Idealised system



- Cure system = heat or photonic (flash) system
  - Will cause distortion of substrate
- Camera should check for missing lines and measure distortion
- Compensation to 2nd print head for
  - Missing nozzles
  - Substrate distortion

Digital Smart System

- Key considerations
  - Choose right process (for R2R needs)
  - Decide what materials are to print
  - High precision inkjet head array
  - In-line cure system
  - Camera / Line-scan system for in-line image checking
  - In-line distortion and image compensation
  - Requires very powerful software system for print and image control

Thanks for your kind attention!

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