Inkjet Printing For Making Fine Conductors and Multi-Layer Electronics

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Outline

1. VTT overview
2. Inkjet technology
3. Inkjet for making printed electronics
4. Inkjet printing conductors
5. Inkjet printing multi-layer electronics
6. Summary
VTT - Technical Research Centre of Finland

- Impartial and multidisciplinary expert organisation
- 2,900 employees
- Turnover 220 million €, 5000 customers
- Confidential research projects, joint venture projects and strategic, self-financed research

STRATEGIC RESEARCH

BUSINESS SOLUTIONS

VENTURES

EXPERT SERVICES

Research and development

New enabling technologies
VTT-wide sales and marketing
IPR, spin-offs
Productive consulting services

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PUBLICATION:
- Quality Potential of Digital Photo Printing
- Innovative Development of Ink Jet (NI)
- Integrating Printed and Electronic Media
- PRINT INTERACT
- Business from Functional Printing

MANUFACTURING:
- Functional Inks in Inkjet Printing
- Surface Proximity Assay
- Printable Quality Indicator
- Manufacturing Technologies Based on Inkjet

PACKAGING:
- On Demand Package Printing
- Communication in Consumer Packages
- Sustainpack (EU IP)

State-of-the-art, industrial, piezo electric inkjet printheads → research results upscalable for production

Water-, oil- and solvent-based inks
UV-curable inks
Hot melt inks and waxes
Conductive and dielectric inks
Biochemical and diagnostic fluids
Indicator fluids
Printing methods

Conventional printing
- Offset
- Flexography
- Gravure
- Screen printing

Digital printing
- Electrophotography
  - Dry toner
  - Liquid toner
- Inkjet
  - Continuous
  - Drop-on-demand
    - Binary deflection
    - Multiple deflection
  - Thermal
    - Piezo-electric
      - Binary
      - Greyscale
Inkjet printing compared to other printing technologies

**Inkjet**
- Customisation, small series
- Printing speed increasing (currently around 1 m/s)
- Substrate independent
- Ink development challenging
- Easy to integrate with existing production lines

**Conventional printing methods**
- No variable data, large volumes
- Mass manufacturing with high speed (around 20 m/s)
- Not all substrates suitable
- Ink development not so challenging
- Integration requires space and changes in existing production lines
Inkjet printing technology

- Digital non-impact printing method, additive
- Substrate independent
- Accurate, high resolution, high speed
- Possibility for mass customisation
- Low material consumption
- Inks for all kinds of applications
Benefits of inkjet printing in printed electronics

- Direct write of electronic components and circuits
  - less manufacturing steps
  - less material waste
  - cost savings
  - shorter turnaround times → small series and customisation

**Inkjet printing:**
substrate → printing → material

**Photolithography:**
spin-coating e.g.
resist → mask + expose → etching → cleaning

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Application areas for inkjet printed electronics

- Not meant to replace traditional manufacturing methods
- Low-cost devices
- Low performance, single-use, disposable devices
- New application areas
- New features to printed products
- Hybrid printing → inkjet for customisation
- Multiple material deposition with several printheads
- Layering of materials → 3D structures

Diagram:
- Printhead
- Heat
- UV
- IR
- Curing
- Conductive ink
- Dielectric ink
- Resistor ink
- Conductive ink
- Semi-conductive ink
- Protective layer
- Curing etc.
Nano-particle inks for making conductors

- Small particle size and ink stability crucial in inkjet printing
- Nano-particles provide:
  - high metal loading with low viscosity
  - ink stability
  - jetting reliability
  - low curing temperature
- Metal nano-particle inks provide printed conductors with low resistance values
  - even in the range of $\mu\Omega$
Inkjet printing fine conductors

- Lines as fine as possible and continuous
- Drop size and spreading define line width
- Print resolution defines line continuity
- Substrate pre-treatment or pre-patternning
Inkjet printing multi-layer electronics

- Transistors, displays, passive components

- Multi-colour printing
  - at least one printhead for each ink
  - color registration

- Interactions between different materials
  - printing on substrate vs. printing on ink layer
  - colour bleed

- Ink availability
UV-curable dielectric ink for inkjet printing

- Printing in elevated printhead temperature
- Drying with absorption and UV light
- Good wear resistance
- High gloss
- Smooth ink layer without pin holes

Example of capacitor

Dielectric inkjet printed between electrodes

1st silver electrode

2nd silver electrode
Experimental

- UV-curable polymer based dielectric ink (yellow)
  - Curing with 120 W/cm² bulb UV light source for 20 seconds
  - 1 or 2 ink layers

- Silver nano-particle ink (black)
  - Curing in 120 °C for 15-30 minutes
  - 1 or 2 ink layers

- Paper and plastic substrate

- Piezo-electric inkjet, 80 pl drop size, 630 dpi resolution
Height profile of UV-cured dielectric ink layers on plastic substrate

- 10 ink layers, UV-curing 30 s
  - Peak over scale: $\sim 13 \mu m$

- 5 ink layers, UV-curing 30 s
  - Height profile:
    - ~45 $\mu m$

- 1 ink layer, UV-curing 10 s
  - Height profile:
    - ~13 $\mu m$

- 1 ink layer, UV-curing 30 s
  - Height profile:
    - ~20 $\mu m$
Performance of multi-layer electronics

- 600 mΩ/□ - 220 Ω/□
- ~1 - 200 Ω/□
- > 1 MΩ/□
- 60-190 mΩ/□

1 layer dielectric and 1 layer silver on paper 190 mΩ/□

→ pin holes?

• On paper increase in amount of dielectric layers increases resistance on top of it.
Summary

- Inkjet printing suitable method for manufacturing electronics
- Fine inkjet printed conductors possible even without substrate pre-treatment
- Metal nano-particle inks produce conductive structures with low resistance
- Inkjet printing suitable method for making multi-layer structures
- UV-curable dielectric ink produces smooth and thick ink layers
Thank you for your attention!

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Functional Printing

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