Low Temperature Fabricated Conductive Lines on Flexible Substrate by Inkjet Printing

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**Nanomaterials and circuits**

**2D conductive lines and low MP metallic nanopowders**


**3D structures for interconnections**


\[ \text{Au} \approx 1064°C \text{ (bulk)} \]

\[ \text{Au} \approx 327°C \text{ (2 nm)} \]

“NANOLAWNS”
Advantages of Inkjet Printing

Conventional method (Lithography based)

Direct Writing (Inkjet printing)

DOD (drop on demand) Inkjet Printing Technique

jetlab® 4 (custom)

PZT

Ink

Pressure Chamber

Nozzle

Positive Voltage

trise ~ tdwell

PZT

Contracted

Liquid Chamber

Expanded

Orifice

Ink

Supply

Printhead

L

PZT

Liquid Chamber

Orifice

Negative Pressure

[Diagram showing the working principle of the printhead with voltage and time graph]

Voltage (V)

Time (μs)

V1

V2

0 20 40 60 80

0 50

PUMP

LED

flash light

CCD camera

Control system (PC)

observation camera

substrate plate

support equipment drawer

x stage

y stage

z stage

print head

support equipment drawer

systate
Industrial Application

- Microelectronic and optoelectronic packaging
- Organic thin film transistor
- Solar cell
- LCD and large polyLED displays
- MEMS

Inkjet Printing Technique

**Ink: molten solder**
- lead-free Sn-Ag-Cu

**Ink: nano-suspension**

**Ink Materials:**
- Suspensions,
- Metal-organic Solution,
- molten solder

**Substrates:**
- Si, Glass (Hard)
- Metal Foil, Polymer (Flexible)
Inks for Inkjet Printing

Materials for Inkjet Printing

Printing materials

• Metals (surfactants)
  - Au NPs (octanethiol)
  - Cu NPs (octanethiol)
  - Ag NPs (PVP, Thiosalicylic acid, 2-Mercaptopropanionic acid, octanethiol)
  - Metals (surfactants)

• Semiconductors
  - ZnO
  - TiO₂

• Metal salt (or with extra surfactants)
  - AgNO₃
  - CuCl₂
  - HAuCl₄

• Metalorganic (MO) complex
  - Ag(hfa)COD
  - Cu(hfa)·VTM

• Liquid solders
  - SnAgCu lead free solders

• NPs suspension

Inks for Inkjet Printing
Inks for Inkjet Printing

Ink Materials:
- Suspensions – nano Ag suspension
- Metal-organic Solution – AgNO₃

![Image of particle size distribution](image.png)

Average: 3.39 ± 1.21 nm

<table>
<thead>
<tr>
<th>Liquid (unit)</th>
<th>Viscosity (mPa·s)</th>
<th>Surface tension (mN·m⁻¹)</th>
<th>Specific gravity (g·cm⁻³)</th>
<th>Contact angle (°, with Kapton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AgNO₃</td>
<td>2.12</td>
<td>49.58</td>
<td>1.518</td>
<td>37.49</td>
</tr>
<tr>
<td>Nano Ag Suspension</td>
<td>2.95</td>
<td>61.68</td>
<td>1.324</td>
<td>37.61</td>
</tr>
</tbody>
</table>
Reduction of Inkjet Printed Circuit

Reduction of nano Ag suspension

Sintering temperature: 300 °C
Heat rate: 5 °C/min
Time: 1 hr

Gas: H₂ and O₂

TGA analysis

Sample: silver
Size: 6.3410 mg
Method: Ag1

File: D:...\3C-heat6hr-1
Operator: st
Run Date: 10-Jul-07 15:33

Universal V2.5H TA Instruments

Reduction of AgNO₃

AgNO₃

Glass dish

Ethylene glycol vapor

vapor reaction

Silver lines

Kapton® or PET

ethylene glycol vapor reduction
Results and Discussion

Droplet generation

The conditions of droplet formation and injection for AgNO₃ with (a) ±18V (b) ±21V (c) ±24V

The conditions of droplet formation and injection for nano silver suspension with (a) ±15V (b) ±18V (c) ±21V

The relation of droplet size (triangle) and velocity (square) versus pulse voltage for (a) nano silver suspension and (b) AgNO₃.

Under proper driving pulse control and liquid properties stable droplets can be generated.
Results and Discussion

Line Printing

Droplet overlap = \( \frac{L}{D} \times 100 \, (\%) \)

A schematic diagram of overlapped neighboring droplets to form a line.

Variation of line width with droplet overlap (a) AgNO₃ (b) nano suspension
Results and Discussion

Optical microscopic images of inkjet printed AgNO₃ silver lines on Kapton substrate at room temperature as a function of interspacing distance between dots and driving pulse voltage.

Optical microscopic images of inkjet printed nano silver suspension silver lines on Kapton substrate at room temperature as a function of interspacing distance between dots and driving pulse voltage.
Pure Ag conductive microstructures were prepared on the untreated PI substrates at room temperature. The printed pattern can be easily reduced in one-step low-temperature (below 300 °C) thermal process. The resistivity of line patterns was about 7.78 μΩ · cm.
Thank you for your attention!