Printing of Electrical Functional structures using additive technologies

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Outline

1. Technologies / Materials / Process Flow
   1. Aerosol-Jet-Deposition & Screen Printing
   2. Paste formulation for screen printing and application example
2. Selected R&D topics
3. Further Application examples
4. Further printing capabilities
1. Technologies / Materials / Process Flow

Aerosol-Jet-Printing Deposition Technology for Nanoparticle inks

Equipment @ ENAS

- Customized Optomec AJ300 System
- 300 x 300 mm x-y-Vacuum stage
- Print Speed: max. 200 mm/s

- 2 Atomizer systems:
  - 2 x Pneumatic Atomizer incl. Mixing option
    - [1cP – 1000cP]
  - Ultrasonic Atomizer
    - [1cP – 5cP, from 1ml Fluid]

- 200°C Substrate heater
- Min. line width 10 µm to 20 µm
- Laser-Curing-System included [IR Laser, 700mW, 830nm] and material mixing option
1. Technologies / Materials / Process Flow

**Aerosol-Jet-Printing** General Work Flow

A & B: Producing Aerosol by A: Ultrasonic or B: Pneumatic Atomizer Systeme

C: Focusing Material Beam in printhead and direct maskless deposition on substrate

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Fig 2: General Workflow overview
1. Technologies / Materials / Process Flow

**Aerosol-Jet-Printing General Work Flow**

![Diagram of aerosol-jet-printing process flow]

**Fig 3:** Focused material beam over several millimeters enables deposition on 3D substrates without moving z-axes, diagram shows constant line width between 1mm to 3mm distance between printhead and substrate [Source: Optomec]

**Fig 4:** Examples for Ag deposition on 3D surfaces [deep etched cavities in Si Wafers]
1. Technologies / Materials / Process Flow  

**Screen Printing** General Work Flow

- Screen mask works as stencil
- Mesh made from polymers or metals
- Screen openings represent printable pattern
- Squeegee transfers paste through screen openings onto substrate
1. Technologies / Materials / Process Flow

Screen Printing Equipment

Reprint R29 Spectrum

- Screen frame: 736 x 736 mm (29" x 29") to 736 x 812 mm (29" x 32")
- Camera alignment
- Fully automated vision system
- Registration +/- 10 µm

DEK Horizon 03iX

- Screen frame: 736 x 736mm (29" x 29") standard
- Printable Area (510mm x 508.5mm)
- Modul for Via Filling
- Modul for Dispensing
- Vector Guard stencil printing
- Machine Alignment >2 Cpk @ +/- 12.5µm, 6 Sigma
- Process Alignment >2 Cpk @ +/- 25µm, 6 Sigma

Morphology: Lateral 50 µm - 150 mm; Vertical 10 µm - 1 mm
1. Technologies / Materials / Process Flow

Metal Nanoparticle Inks Overview Sintering Process

Nanoparticle Inks – Post-treatment and sintering

- Suspensions of metal particles in solvents
- Pretreatment for dense layer and electrical conductivity:
  - Drying out solvents, burning out organic shells, sintering

Sintering without pressure

- Particle necking due to diffusion effects

Experimental Setup

- Sintering of Ag Nanoparticles and SEM investigation at different temperature steps

Fig 3: Nanoparticle filled Ink, Drying out solvents, burning out organic shells, sintering

Fig 4: 2 Particle Model [J. I. Frenkel (1945)]

Fig 5: SEM Investigation - Sintering of Ag Nanoparticles and grain size at 60°C, 100°C, 200°C, 250°C, 300°C
1. Technologies / Materials / Process Flow

Paste formulation for Screenprinting

Paste Particle characterization

Paste manufacturing and characterization

Application test magnetic pastes
1. Technologies / Materials / Process Flow

Paste formulation for Screen printing

Using magnetic paste for screen printing a MEMS speaker (electromagnetic actuation) was demonstrated.

Deposition → Curing 120 °C, 30 min → Magnetization → Integrated permanent magnet

Magnetic paste

SEM image of NdFeB particles

MEMS Speaker

Metallic glass membrane

Ø 1 mm
100...150 μmT
3. R&D Focus

1. Printed RDLs for polymer substrates

**Concept**

Printing conductive fine pitch multilayers for a variety of substrates materials enable smart systems

**Needed:**

- Fine pitch, 3D ready deposition process for conductive materials
- Conformal dielectric coating technology for 3D substrates
- Process for via fabrication to enable multilayers

Low temperature processes < 150°C to enable the usage of sensitive / polymer / low cost substrates
Motivation for Parylene:

- Deposition at ambient temperatures (no thermal stresses)
- Pinhole-free at d > 0.2µm
- Uniform layer thickness, in particular at edges, excellent gap penetration
- No solvent or catalyst required
- Yield of 100% monomer above 550°C in vacuum (using [2,2]p-cyclophane)
- No by-products
- Batch process for high throughput
- Bio compatible - medicine products

Gorham Process

- 3 step deposition
- Polymerization @ Roomtemperature (condensation)
3. R&D Focus

1. Printed RDLs for polymer substrates

Parylene Properties

- Conformal coating on Waferlevel < 10% thickness variation developed
- Conformal coating for high aspect ratio patterns
- Highly transparent
- Ar plasma pretreatment enables printing process
- Good moisture barrier

<table>
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<th>Properties of Parylene C</th>
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<tr>
<td>Melting point</td>
<td>290°C</td>
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<tr>
<td>Temperature stability</td>
<td>125°C</td>
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<tr>
<td>Peak Temperature</td>
<td>200°C</td>
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<tr>
<td>Water absorption in 24h</td>
<td>0.06%</td>
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3. R&D Focus

1. Printed RDLs for polymer substrates

Laser-Workstation with two laser sources

*Picosecond Laser* with four wavelengths
→ for micro-structuring

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<th>Wavelength</th>
<th>Power</th>
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<td>266nm</td>
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<tr>
<td>532 nm</td>
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*Thulium-Fiber-Laser (CW)*
→ for welding

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<td>1908 nm</td>
<td>20W</td>
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→ Structuring of almost any material for various applications
3. R&D Focus

1. Printed RDLs for polymer substrates

1. Substrate cleaning

2. 1st layer Parylene deposition (optional)

3. Pretreatment to enable printability on Parylene + 1st layer Ag deposition and sintering

4. 2nd layer Parylene deposition

5. Laser ablation / via drilling for interconnects

6. Pretreatment to enable printability on Parylene + 2nd layer Ag deposition
3. R&D Focus

1. Printed RDLs for polymer substrates

Laser Ablation of Parylene on top of printed Ag

FIB Cross Section

FIB Cross Section Investigation

- Conformal Parylene Coating
- No Ag ablation visible
- Sidewall effects of laser ablation visible

→ Parylene thickness increasing
→ Some defects near Parylene sidewall visible
3. R&D Focus

1. Printed RDLs for polymer substrates

Via Results

2nd layer Ag printing to fill vias, sintering

- Electrical Testing

- Via resistance $[50\mu m \times 200\mu m] < 10 \, \Omega$ after fabrication
- Thermal cycling (-55/125°C, 30min) performed

→ After >300 cycles resistance is stable with around $5 \, \Omega$ / Interconnect due to additional sintering
3. R&D Focus

1. Low temperature Wafer level Bonding using metal nanoparticles

Process Flow

- Adhesion promoter deposition (PVD) Au or Cu [1]
- AJ Printing of Ag Nanoparticles[2]
  - Goal: Bondframes with less than 100µm in width
- Wafer level Bonding [3]

Si Wafer with Au adhesion promoter and printed Ag Bondframes

schematic process flow
3. R&D Focus

1. Low temperature Wafer level Bonding using metal nanoparticles

**Conclusion for all bonds** (for all temperatures 350°C to 200°C and Au / Cu adhesion layer) today → hermetic sealing using Ag Nanoparticle intermediate layer not possible but mechanical bond is successful

**Reasons:** porous interface and inhomogeneous thickness of Bondframe due to printing process at start and endpoint of printed microstructures

**FIB&SEM investigations at the Interface Au-Ag-Au, 250°C:** Ag layer is fully wetting the Au adhesion promoter, porous interface

**FIB&SEM investigations at the Interface Au-Ag-Au, 200°C:** Ag layer is fully wetting the Au adhesion promoter, pore size increasing, diffusion Au – Ag visible using EDX
3. R&D Focus

1. Low temperature Wafer level Bonding using metal nanoparticles

Analogue process was developed for screen printing technology using Au Nanoparticles:

- Applied bond pressure 6.5kN
- Bonding Temperature 200°C
  → High densification within the Bondframe
  → 100% yield after dicing
  → Hermeticity evaluations ongoing
4. Further Application Scenarios
using 3D suitable deposition technology for Nanoparticle Inks

- Printed Sensors (Au Nanoparticles) on low cost substrates
- High density 3D MID Substrates by additive manufacturing
- Printed Interconnects for stacked components
- Flexible Electronics
- Joining (WLB and CLP) using Nanoparticle intermediate layers – low sintering temperature enables Bonding < 250°C
4. Further printing capabilities
upscaling and R2R manufacturing (i.e. printed RFID Antennas)
4. Further printing capabilities
institute for print and media technologies TUC

...this is what we do: Printing beyond color – printed functionalities

Printed antennas – planar and 3D
Printed batteries
Printed sensors
Printed transistors
Printed SAMs
Printed photonics
Printed microsieves
Printed pillars

Thank you for the kind attention

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We would be pleased to cooperate with you in European or German national projects as well as direct cooperation and technology transfer

Service offers:

- Paste/Ink formulation screen printing and Aerosol-Jet
- Testing of inks/pastes (printability, electricaly, reliability, adhesion,...)
- Design and feasibility studies
- Workshops and training to enable technology transfer