Hybrid AM With Functional Printing

Denis Cormier
Rochester Institute of Technology
Department of Industrial and Systems Engineering
Outline

• Introduction to functional printing
• Digital functional printing technologies
• Pulsed photonic curing
• Summary
Printing As A Manufacturing Process

- Color printing
  - Pixel color determined by ratio of CMYK ink or toner deposited at that point
- Print functional materials rather than color inks/toners to produce devices rather than documents
  - Local control of material composition
  - Digital materials will change the way a lot of things are made in the future

Energy harvesting device requiring assembly
Digital Printing of Functional Materials

• Ink jet
  – Multi-material
  – Limited (primarily) to planar deposition and very low viscosity inks (<20 cP)

• nScrypt Microdispensing
  – Pneumatically extrudes viscous inks/pastes
  – Printed traces from ~70-200 μm wide/thick easily achievable

Optomec Aerosol Jet
Atomizes inks up to 1000 cP
Typical printed traces on the order of 20 μm wide x 1-2 μm thick
Injet Printing of Nanoinks

- Fuji Dimatix DMP-2831; Pixdro IP410; Roland LEF-20
- Dimatix DMP-2831
  - Fillable and disposable ink cartridges
  - Full control over head firing voltages/waveforms/temp
  - Drop watcher camera
Optomec’s Aerosol Jet Process

- Atomized nanoinks
- Ceramic nozzle with 150-300 μm nozzle ID (user selectable)
- Aerodynamic focusing

Image courtesy of Optomec
AJ Printed Copper Nanoink Circuit

20 μm line width

Flip-chip pattern on 40 μm thick flexible zirconia substrate
Aerosol Jet Printed Pillars

5mm standoff distance

10mm standoff distance

Student: Niranjan Damle
Microdispensing (nScrypt)

• Ink/Paste is dispensed through a needle valve
  – Up to 1M cP

• Controllable Parameters
  – Pressure
  – Translation speed
  – Valve position
  – Dispensing height
  – Nozzle diameter

• Multi-material dispensing?
Microextruded Fuel Cell Electrodes

Student: Prasanna Khatri-Chhetri
Freeform Fiber Alignment Via Microextrusion

- Mix a UV curable epoxy with chopped carbon fibers
  - Zoltek Panex 150 μm
- Pneumatically extrude the paste through a needle
  - 22 gauge (~410 μm ID)
- Fibers align as they flow through the nozzle
- If proper feed and standoff are used, fibers maintain alignment as they exit the nozzle.

Student: Chaitanya Mahajan
Toolpath Planning

- Fibers will align with the direction of nozzle travel
  - Conventional raster filling patterns.
  - Spiral patterns
Image Processing To Measure Fiber Alignment

Student: Chaitanya Mahajan
Printed MEMS Drug Delivery Micropump

Figure 4: (a) Photograph of nScrypt direct write tool depositing sacrificial material (blue) on a microfluidic device chip. (b) Photograph of Optomec direct write tool depositing silver onto a microfluidic device chip.

Figure 5: Photograph of thermo-pneumatic actuators, anemometer, and contacts drawn directly on top of microfluidic device with the Optomec.

Figure 6: Photograph of layer of UV curable resin defining thermo-pneumatic actuation plenums (one plenum outlined in yellow.)
Pulsed Photonic Curing

- Rapid curing/sintering of high temperature printed materials (e.g. metal or ceramic) on low temperature surfaces (e.g. paper or plastic).

- **Novacentrix pulsed photonic curing/sintering**
  - High power Xenon strobe lamps
  - Peak Power: 100 kW/cm²
  - Sustained Power: 5 MW/pulse
  - Pulse Length: Down to 25 μsec
  - Pulse Rate: Up to 1 kHz

Novacentrix Pulseforge 3300
Simplest Processing Condition: One Pulse

- High temperature processing removes excess solvent and enhances sintering.
- Substrate is undamaged.

**Numerical Simulation**

- Peak surface temp >1000 C
- Substrate < 150 C @ 8 ms
- Thermal equilibrium @ 35 ms (90C)

**Conditions:**
- Pulse length: 300 µs
- Radiant exposure: 1 J/cm²
- Stack: 1 µm Ag on 150 µm PET

Novacentrix: Used with permission
Micropulsing

- To convert the copper oxide to copper, certain elevated temperature must be reached and sustained long enough for the reaction to complete.
- The exact required temperature and time are not known \textit{a priori} for a given system: too low or too high will yield poor results.

Pulse Configurations

- Shaped Pulse (top)
- Basic Pulse (bottom)

Resulting Thermal Simulation

(Generated using \textit{SimPulse})

This Basic Pulse creates temperature too hot and too short.

Shaped Pulse creates optimal temperature for optimal time.

Novacentrix: Used with permission
Pulsed Photonic Curing of Copper On Paper

Copper oxide nanoink on paper

Photonically cured copper nanoink
Photonic Curing of High Temperature Materials

- Yttria-Stabilized Zirconia
- Processing conditions
  - 460V pulse for 250μs x 10 pulses at 2 Hz
- 10+ hrs in high temp furnace versus <1 sec in Pulseforge

As-printed sample 1000X magnification

Photonically sintered sample 1000X magnification
What About Photonic Curing With AM Processes?

- Broad spectrum Xenon flash lamps
- Interactions with polymer AM materials due to unwanted absorption?
Photonic Curing With Black ABS
Summary

• A variety of nano-ink printing processes are being used to produce micron-scale devices such as fuel cells, micropumps, and sensors

• Pulsed photonic curing is a promising approach for high speed curing/sintering of high temperature printed materials on low temperature substrates
  – Opens up potential for printed electronics embedded on or within 3D printed geometries
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