



M³D[®] Aerosol-Jet Printing – 5 microns to 5 millimeters

Michael Renn, Ph.D
Director, M³D Applications Laboratory

About Optomec

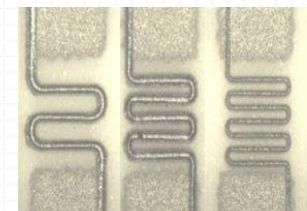
- » Printable Electronics Platform for micron to mm features.
- » >\$25 Million in Technology and Product Development.
 - 13 patents issued, 43+ pending...
- » Targeting \$B markets in Electronics, Energy, Life Science
 - Solar/PV market is the #1 priority.
 - Active Opportunities in Display, Flex, Fuel Cell, Drug Discovery...
- » Sold > 50 Systems in 10 countries.
 - Customers: GE, 3M, Micronics, Samsung, Boeing, MicroCircuit, Fraunhofer ISE & IFAM, HSG, NTN, Sandia, US Army, USAF...
- » Privately Held with HQ in Albuquerque, NM.



Standard Equipment



Solar Cell



Embedded Resistors

\$M = \$ Millions USD / \$B = \$ Billions USD

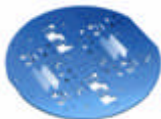
Global Customer Base



BP Solar



MICROCIRCUIT
MICROCIRCUIT SYSTEMS PTE LTD



SCHOTT
solar

For New Technology Network
NTN



UNT
UNIVERSITY OF
NORTH TEXAS
Discover the power of ideas

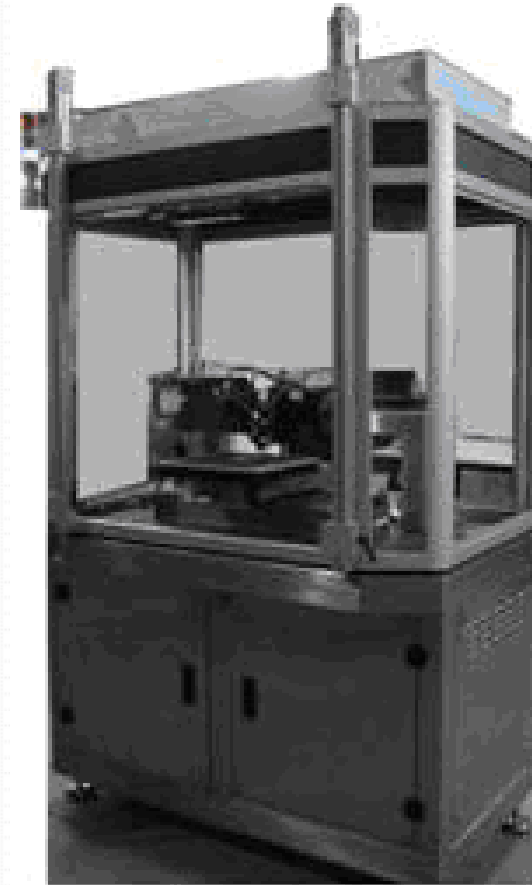
SOUTH DAKOTA
M
SCHOOL OF MINES
& TECHNOLOGY

KRICT
Korea Research Institute of Chemical Technology

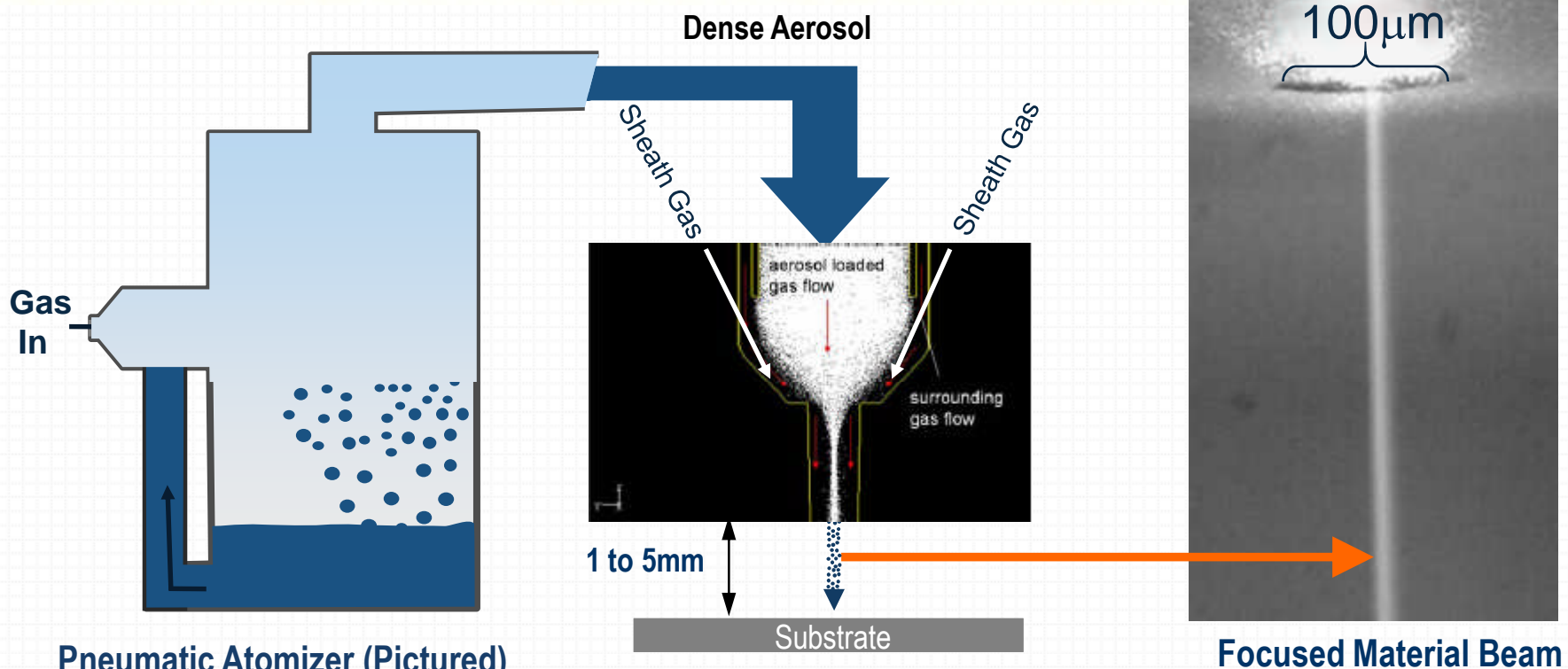
NDSU

M³D Aerosol Jet System Overview

- » Patented Material Deposition Process
 - Supports Many Materials & Substrates
 - Room temperature processing
 - Non-contact w/ wide Standoff range
 - Feature Sizes from 5 μ m to mm's
 - Thin Films from 10nm to μ m's
- » Cost and Functional Advantages
 - Lower Material and Process Costs
 - Improved End-Product Performance
 - Inherently Cleantech



M³D Aerosol Jet Process



Pneumatic Atomizer (Pictured)

➤ 1-2500cP ink handling viscosity

Ultrasonic Atomizer: (Not Pictured)

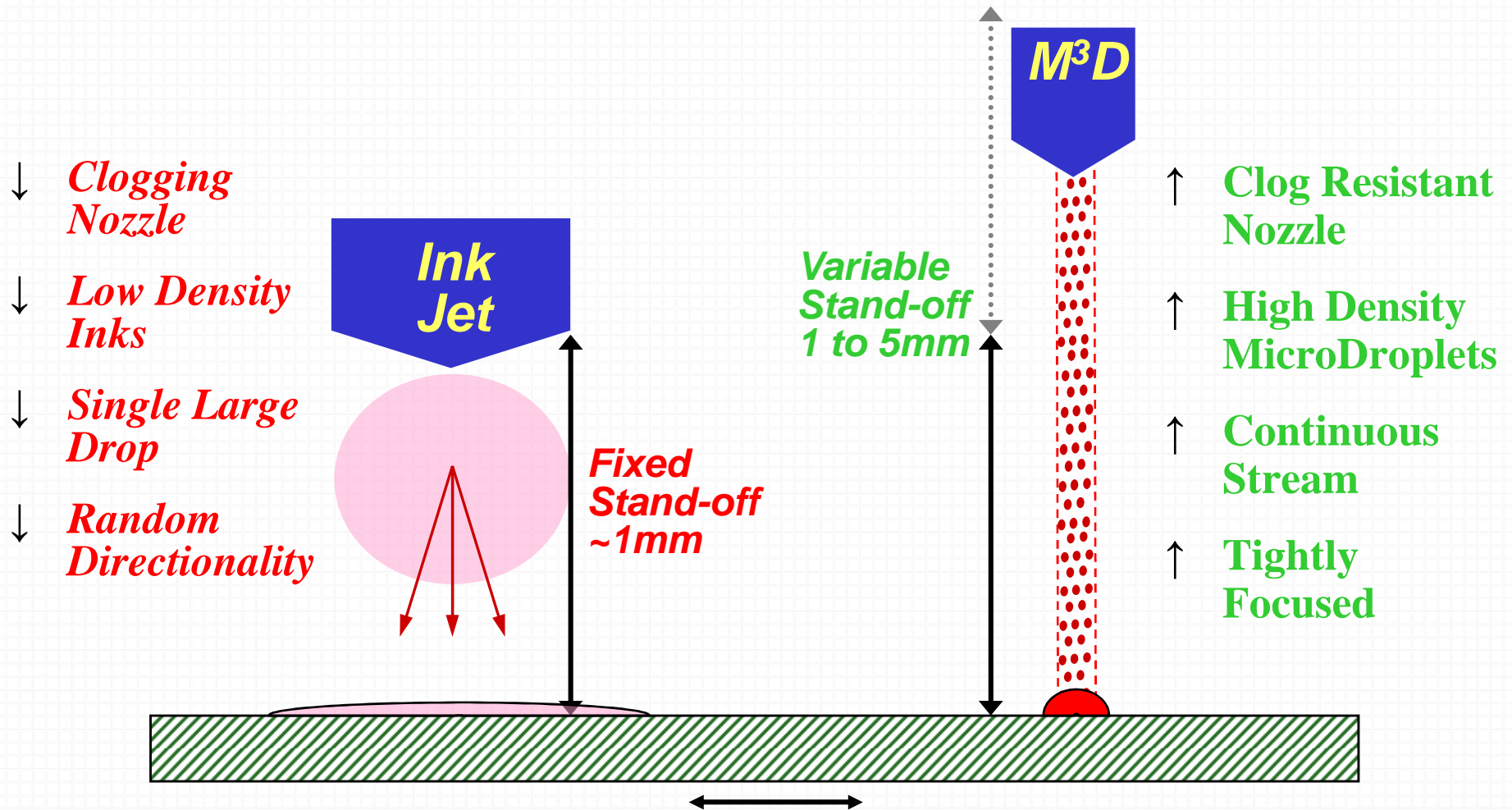
➤ 0.7-30cP ink handling viscosity

Nozzle Output:

➤ Small Aerosol Droplets ~ 1-5um

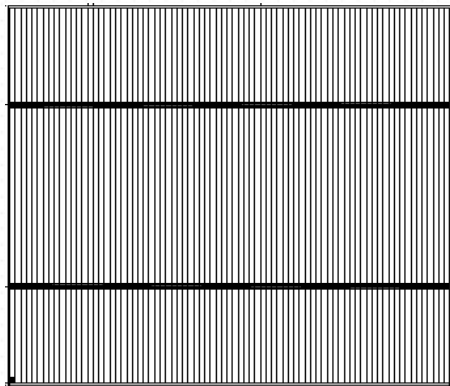
➤ ~2mgs/m to 10mgs/m dispensing speed

M³D Aerosol Jet vs. Ink Jet Illustration



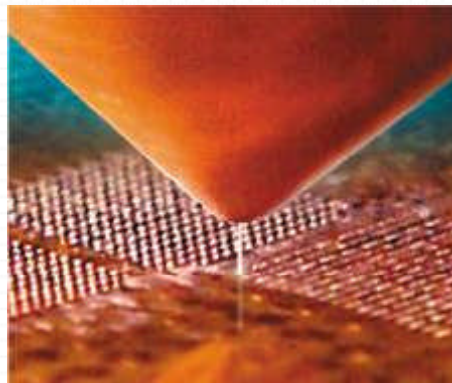
The M³D Aerosol Jet Process

Design



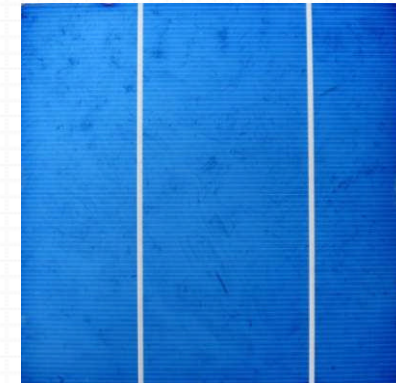
- CAD Model
- Convert to DWG file
- Tool paths generated
Optomec software

Process



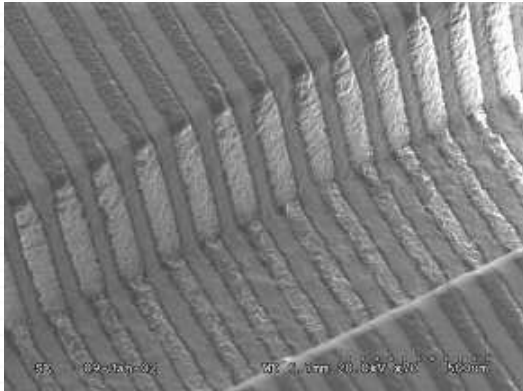
- Liquid raw material
- Create fine (femtoliter) aerosol
- Focus to tight beam (<5 micron)
- Post-process (dry, cure, sinter...)

Part

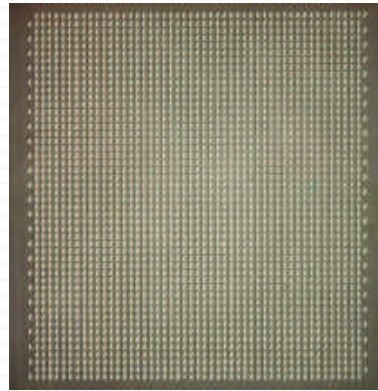


- Fine line traces
- Conformal printing
- Bus Bars
- Embedded passives
- Interconnects
- Coatings
-

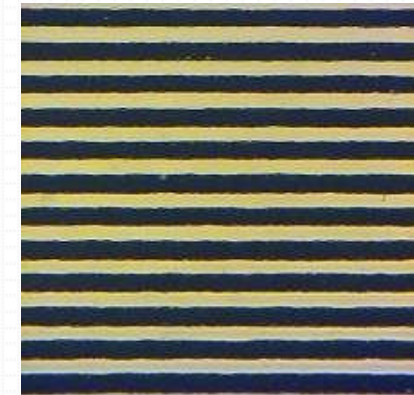
M³D Aerosol Jet Printing Examples



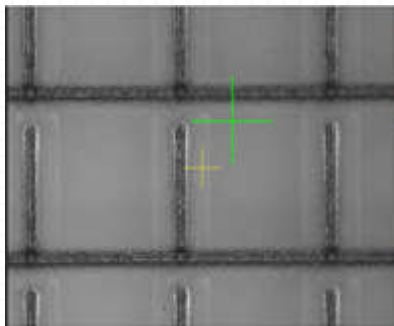
- » Conformal deposition over varying topologies with no change in Z-height
- » 60 micron line width
- » 500 micron trenches



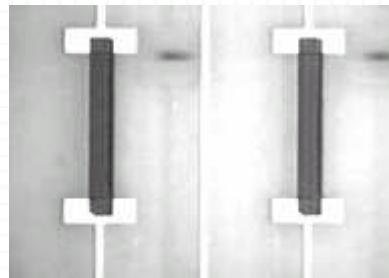
- » 2ms shutter speed
- » Enables clean starts and stops
- » Enables >36,000 spots/hour



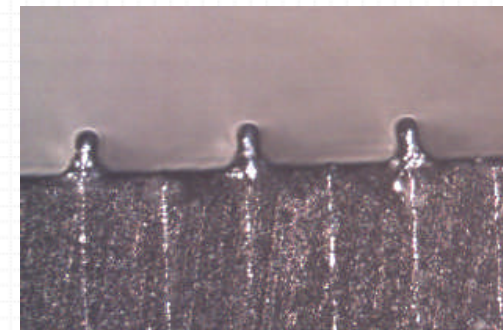
- » 10 micron line width
- » 20 micron pitch



20 µm FPD Gate Lines



Embedded Resistors



High Aspect Interconnects

Sample of M³D Materials and Substrates

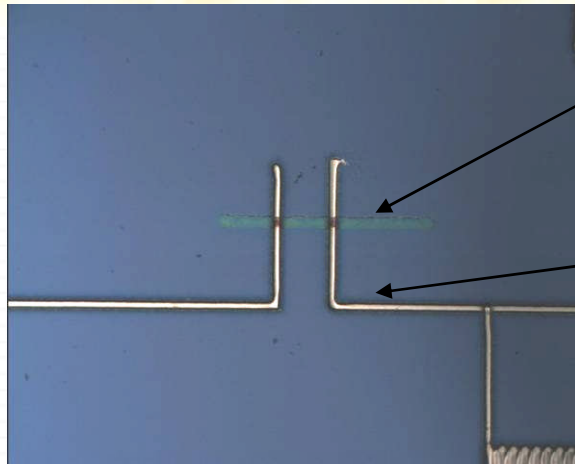
Materials

- Metals
 - Ag and Au Nanoinks
 - Pd, Pt, and Cu R&D Inks
- Resistors
 - Carbon PTF
 - Ruthenium Oxide
- Dielectrics
 - Polyimide, Polyester, PTFE, etc
- Biomaterials
 - R&D Protein and Antibody Solutions
 - Biocompatible Polymers
- Others
 - Semiconducting (PEDOT:PSS, P3HT...)
 - Carbon Nanotubes
 - Insulating UV and Thermal Cure Epoxy

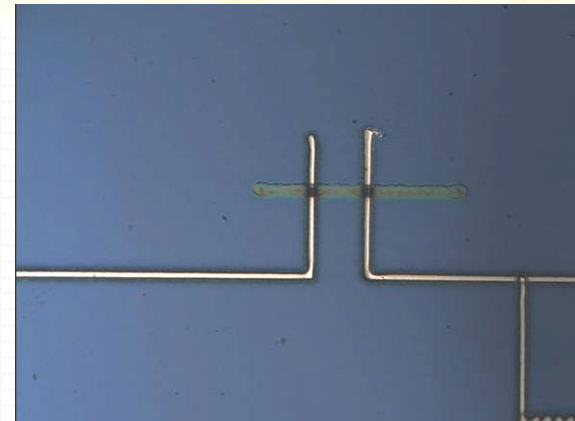
Substrates

- Circuit Board
 - FR4, BT, etc
- FLEX
 - Polyimide (Kapton)
 - PET, PEN
 - Polyethylene (Teslin)
- Composite
- Si Wafer
- Ceramic
- Silica (SiO₂) Coatings

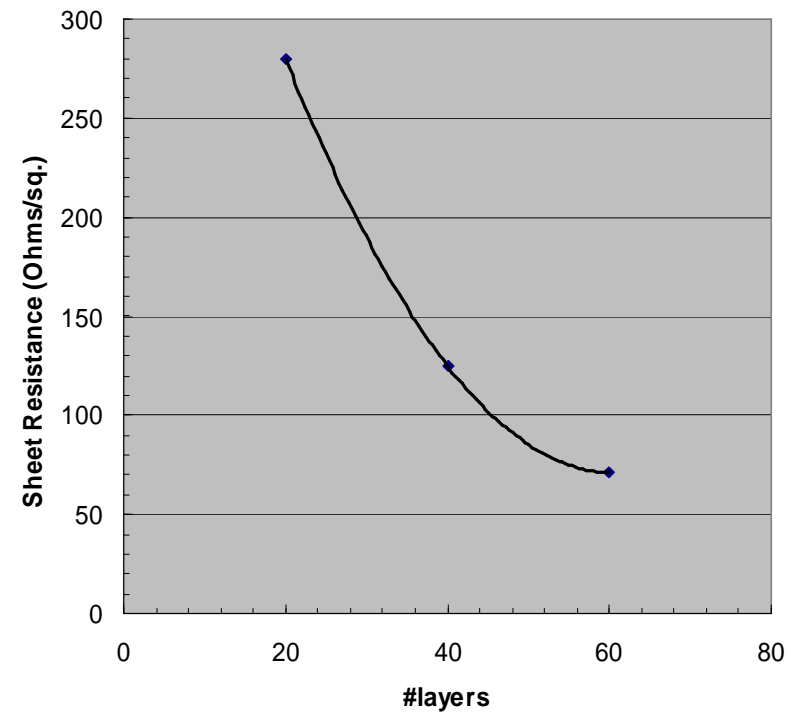
Carbon Nanotube Printing



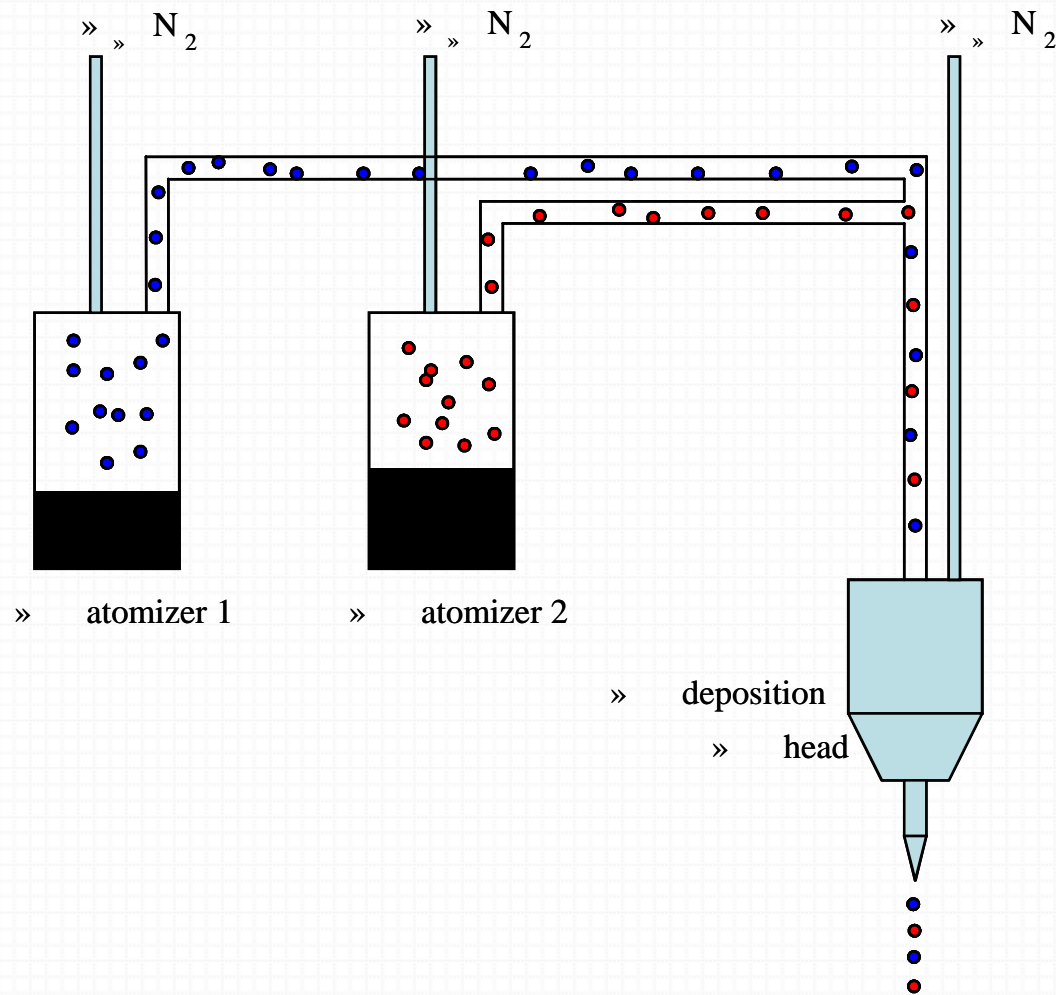
20 layer



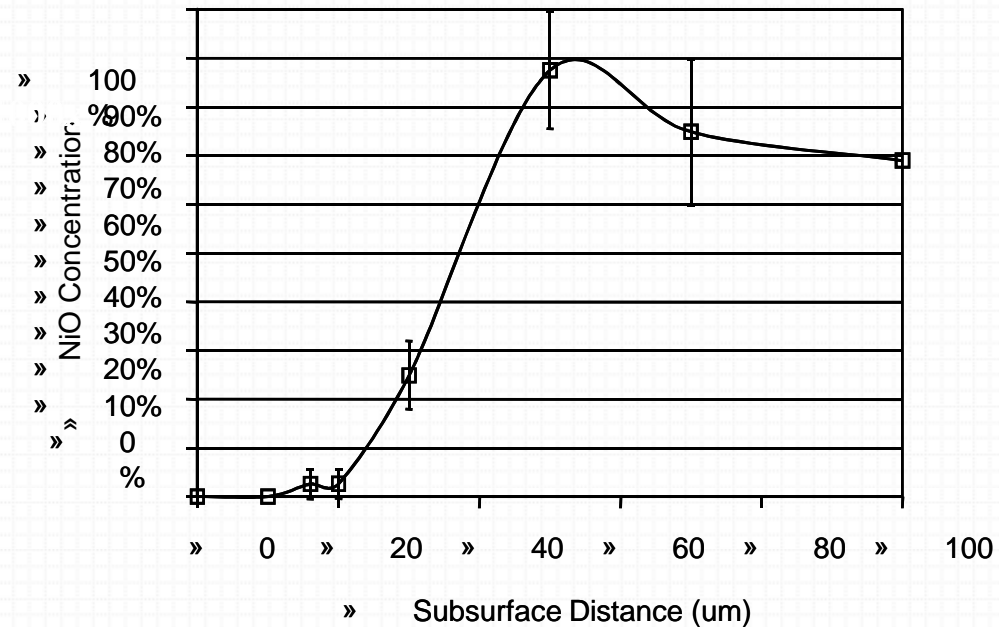
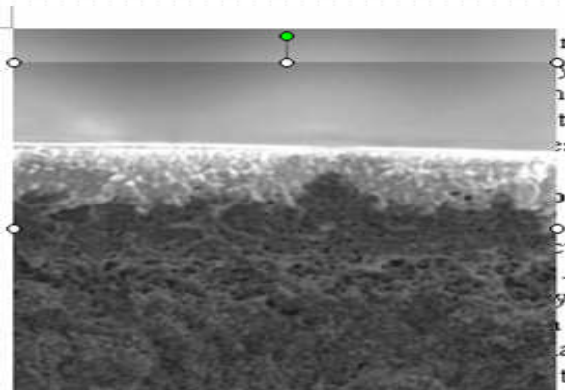
60 layer



Material Mixing for Gradient Fabrication



SOFC Graded Material Interface from YSZ to NiO/YSZ*



Advantages

- Mechanical robustness
- Improved electrochemical efficiency
- Potential for planar microfuel cells

*Collaboration with AFRL, Wright State Univ

SOFC Functional Performance

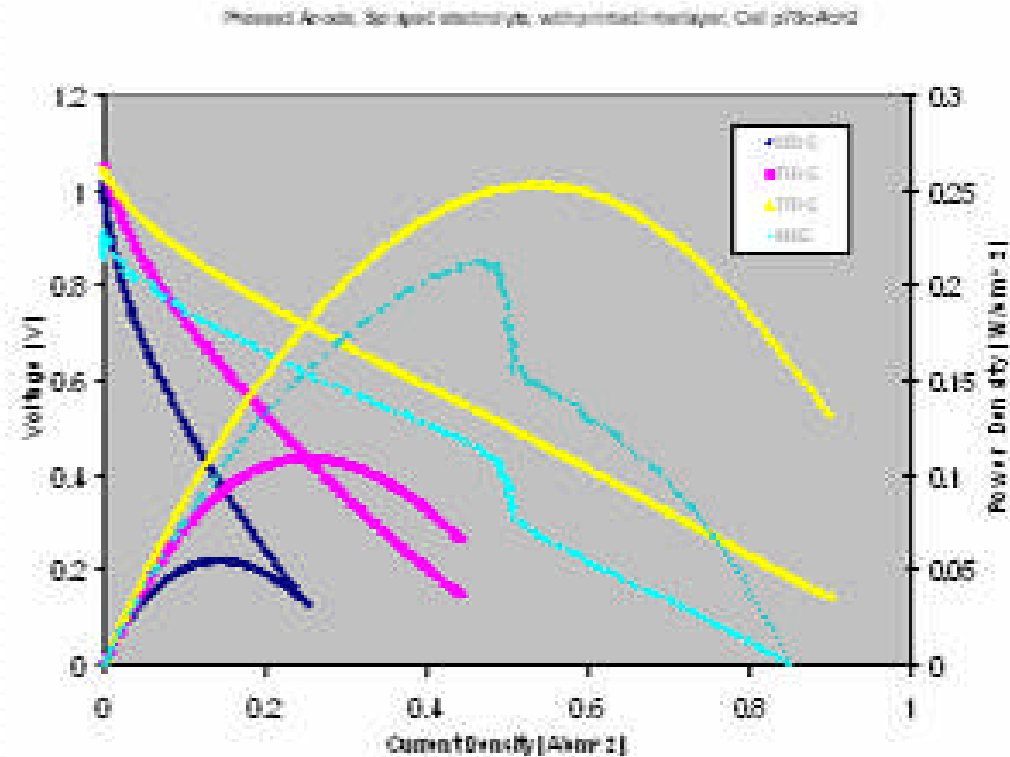
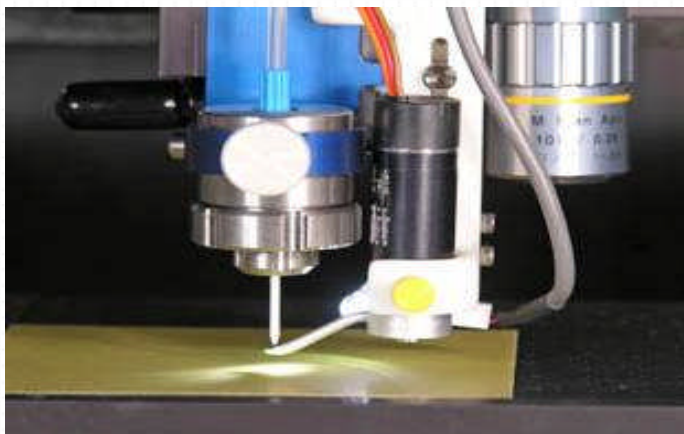
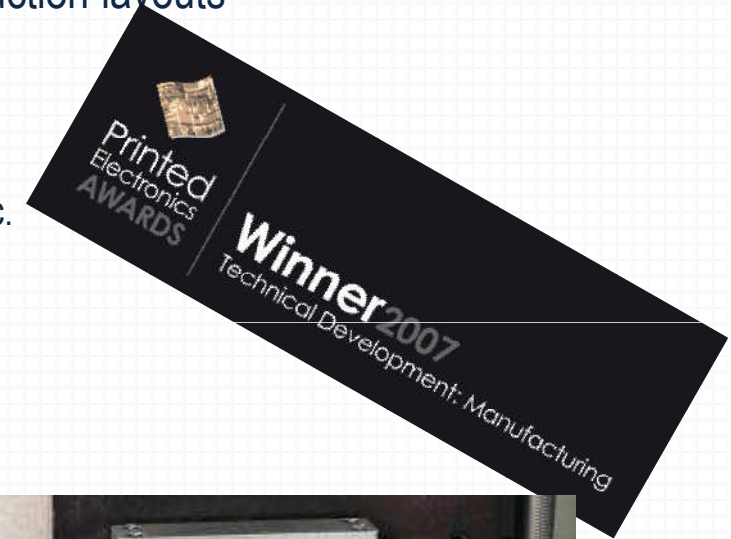


Figure 1: Electrochemical performance of SOFC fabricated by M3D Printing.

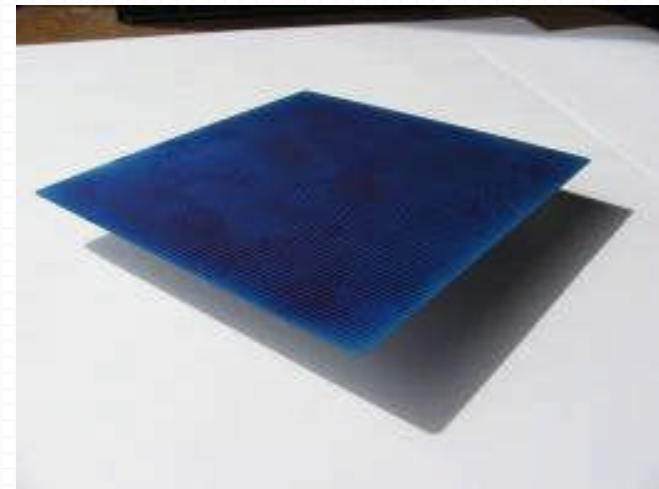
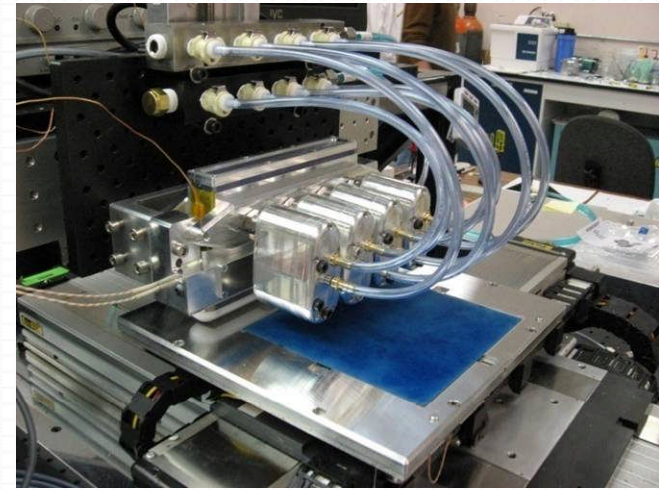
Scaling from Single-nozzle to Multi-nozzle Arrays

- **Increased print speed** to address commercial market opportunities
- **Variable array configurations** adaptable to customer production layouts
- **Capabilities to validate:**
 - Improved material efficiencies
 - Application specific viability
 - Photovoltaics, Life Sciences, Flat Panels, Roll-to-Roll, etc.



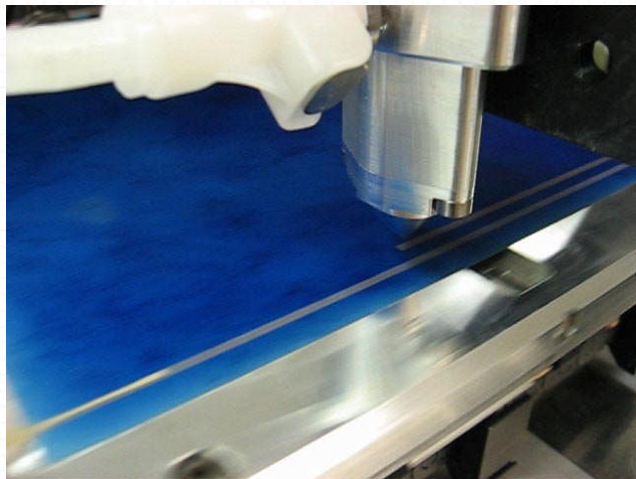
Multi-nozzle Production Solutions

- » Target Applications:
 - Solar Cell – Collector Lines
 - Flat Panel / Flex Display – Bus Lines
 - Fuel Cells – SOFC
- » Easily Configured to Production Layout
 - Nozzle Count – 10, 20, 50, etc. X x Y
 - Nozzle Layout and Pitch
- » Currently completing internal testing (40x head)
- » Customer Beta Release in Q308
- » Production Release Q109



Nozzle Scaling to Large Linewidths

- » Parallel development of PV Bus Bar print heads
 - Scalable from 250um to >3mm
 - Packaging into a common envelop to facilitate quick connect/disconnect, i.e. monolithic atomizer/printhead
- » Availability: Target delivery early Q308
- » Flood coating is a secondary target application resulting from this development effort



3mm wide nozzle for
Spray coat applications

M³D Summary

- Non-contact printing
- Fine features
 - Line widths from 5 micron to 5 mm
 - Film thickness from 10 nm to 10 μ m
- Maskless
 - No screens to replace
 - Computer controlled printing
- Direct Write
 - Greatly reduced material consumption
 - Uninterrupted printing over rough or 3D surfaces
- Production scale printing with multinozzle heads
- Flood coatings with wide nozzle heads



Thank You

<http://www.optomec.com>

