Center for Nanoscale
Chemical-Electrical-Mechanical
Manufacturing Systems

E-Jet: A Printing-based Approach for Nano-manufacturing

Andrew Alleyne

an NSF-sponsored center for nanoscale science and engineering

Outline

NanoCEMMS Overview

E-jet Challenges and Solutions

Demonstrated Accomplishments

Vision for Nano-CEMMS

Vision: Manufacturing at the nanoscale:

- Is routine and practical,
- Resides on well-developed scientific knowledge
- Supported by a diverse, educated workforce

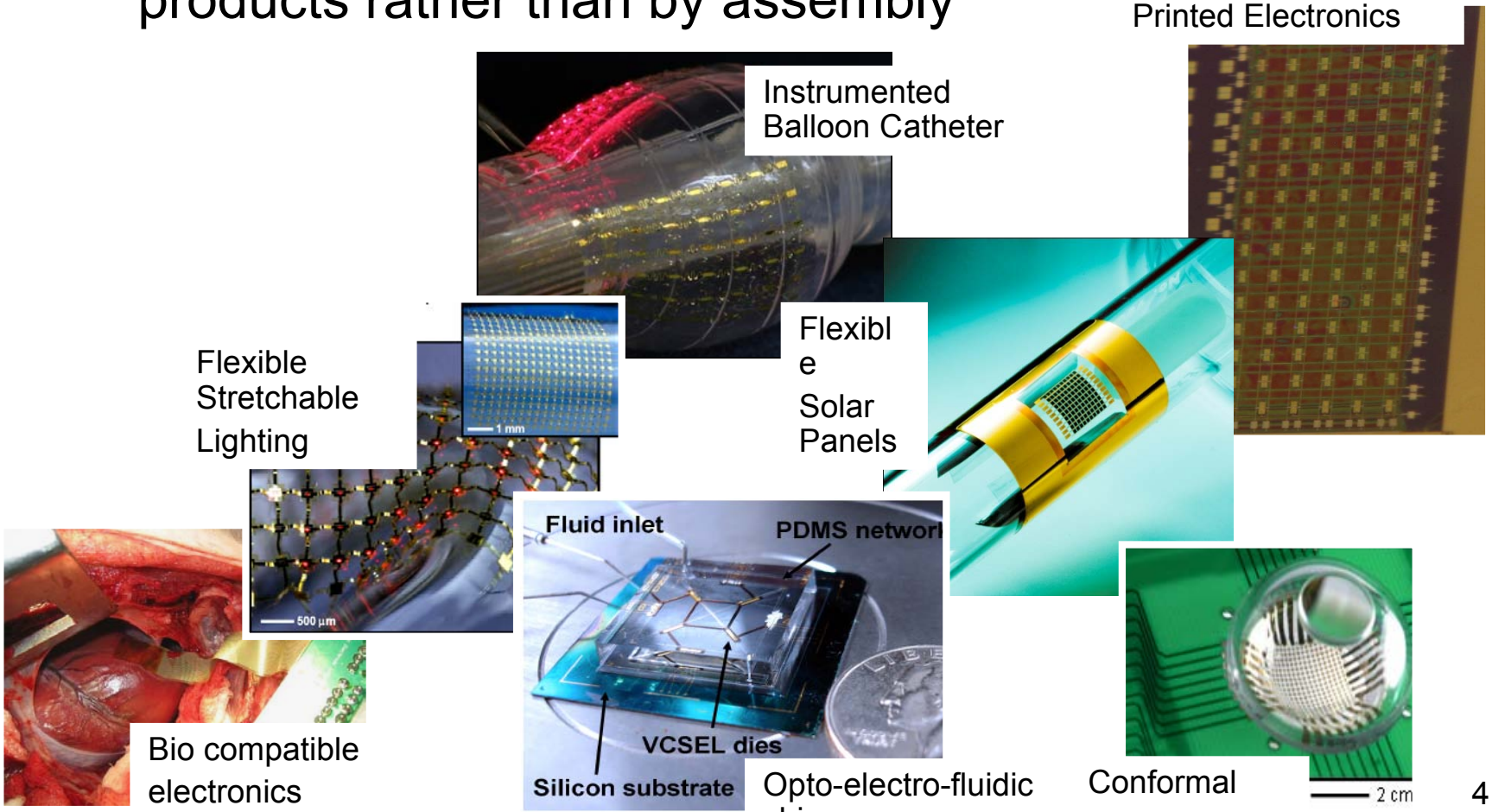
Core Activities of Center Research:

- Nanofluidic and ionic transport
- Practical and efficient 'fluidic-based' nanomanufacturing
- Miniaturization and heterogeneous integration

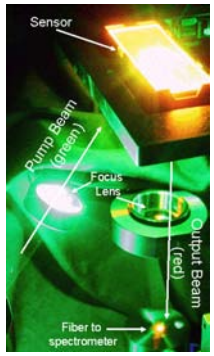
Research Motivation

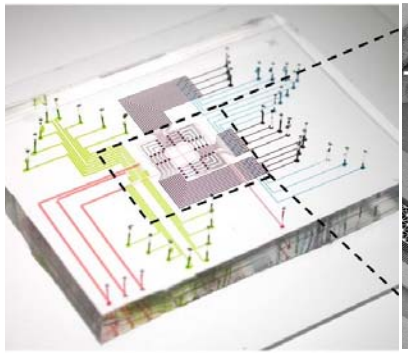
Emerging Paradigm in New Product Development

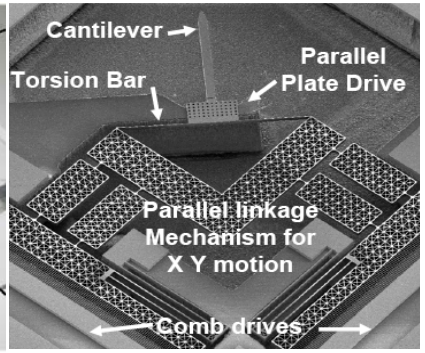
- Direct, heterogeneous integration of functions into products rather than by assembly



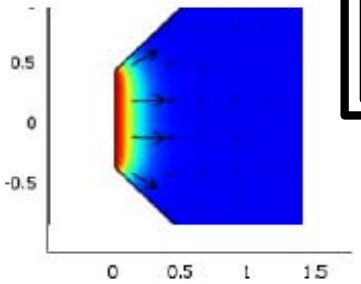
Research Integration

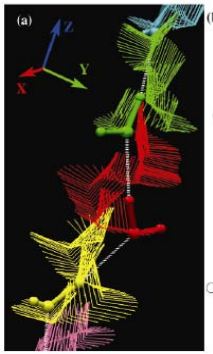


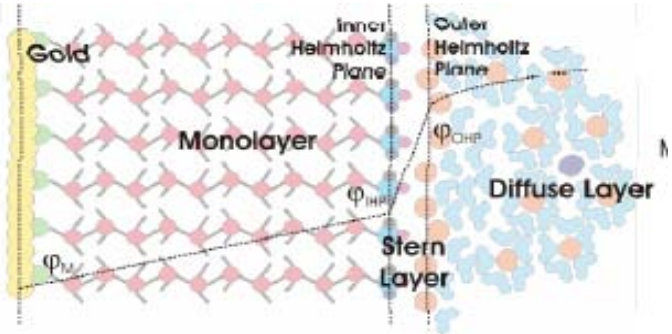




Nanoscale Sensing, Fabrication & Positioning

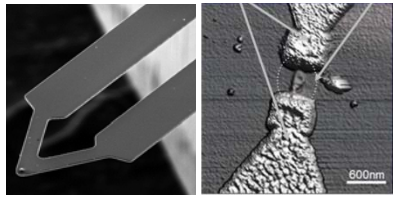




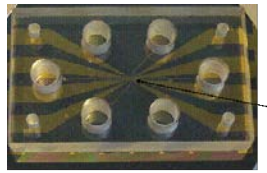


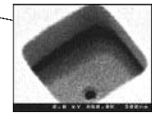
Fundamentals Micro-Nano Fluidic & Ionic Transport

Tip-based Processes

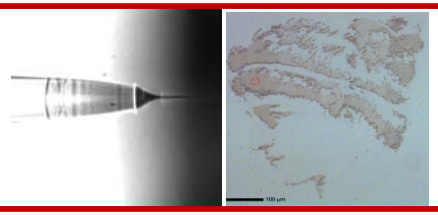


Molecular Gate Toolbit

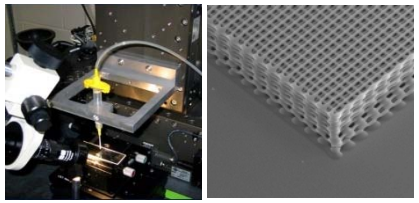




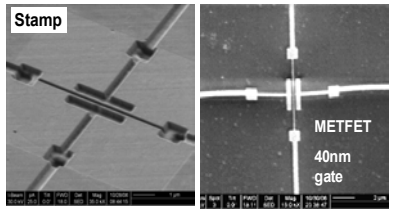
Electro-jet Writing



Direct Ink Writing



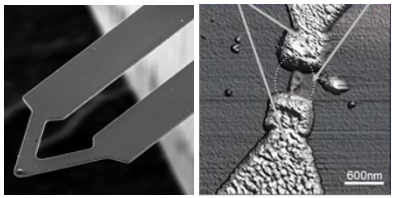
Electro-Chem Processes



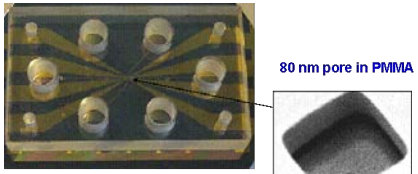
Basic Research and Enabling Technologies → Nanostructure Creation

Pathway to Nano-enabled Systemrs

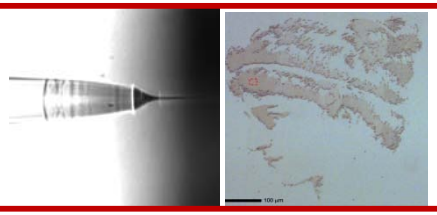
Tip-based Processes



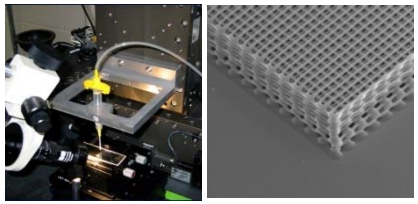
Molecular Gate Toolbit



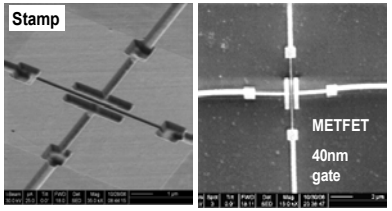
Electro-jet Writing



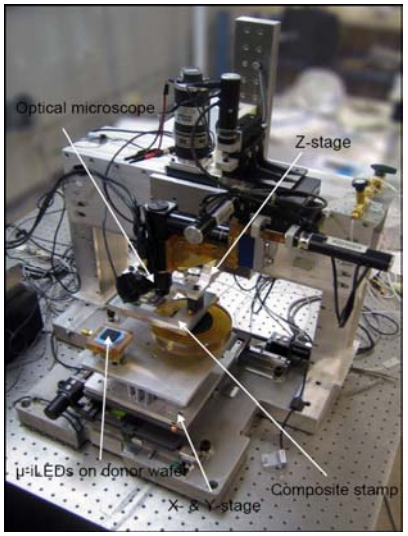
Direct Ink Writing



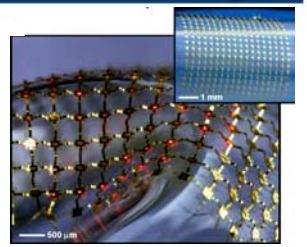
Electro-Chem Processes



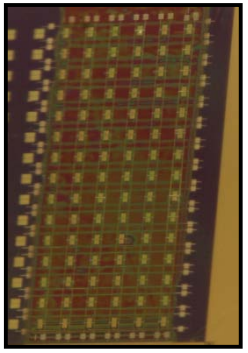
OTHER PROCESSES



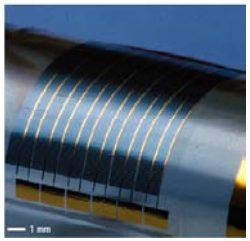
Micro Transfer Printing



Flexible Solid-State Lighting & Displays



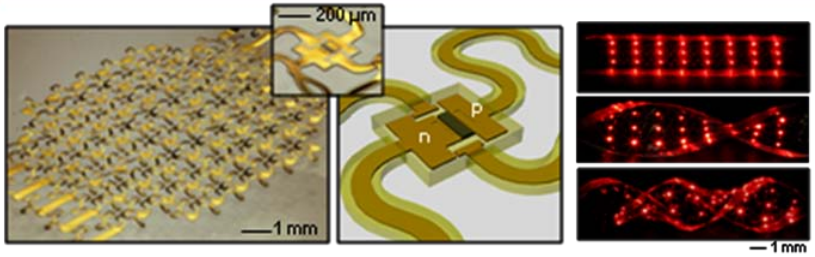
High Performance Printed Electronics



Photovoltaics

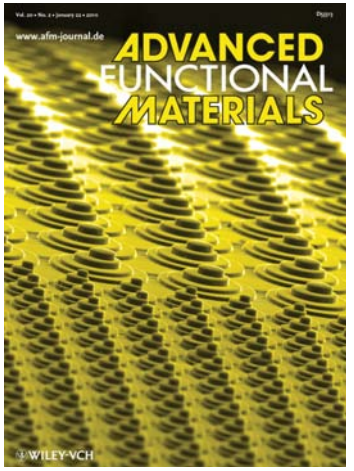
Nanostructure Creation → Integration → Products

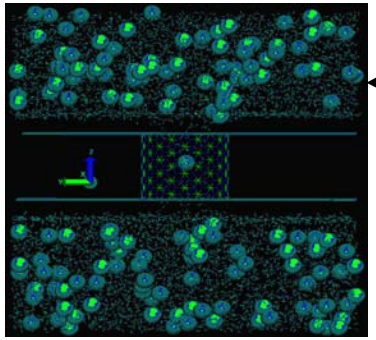
Research Accomplishments for Last Year



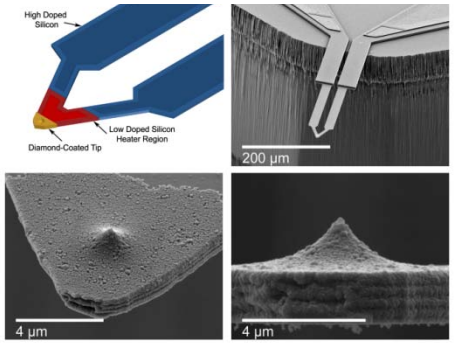
Flexible Lighting Systems

Thermal Transfer Printing Process

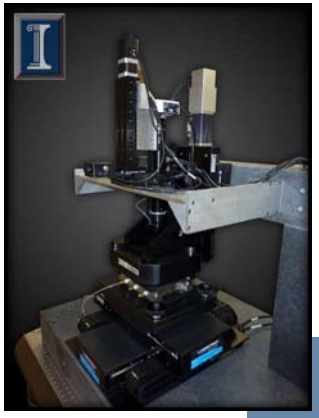




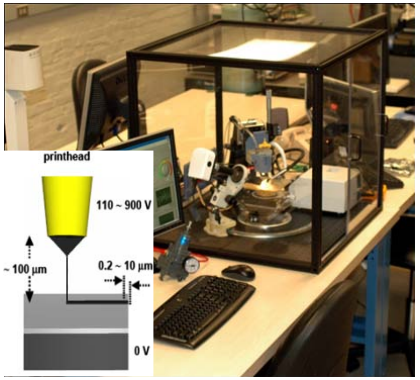
Transport in Boron Nitride Nanotubes



Ultrananocrystalline Diamond Cantilever Tips

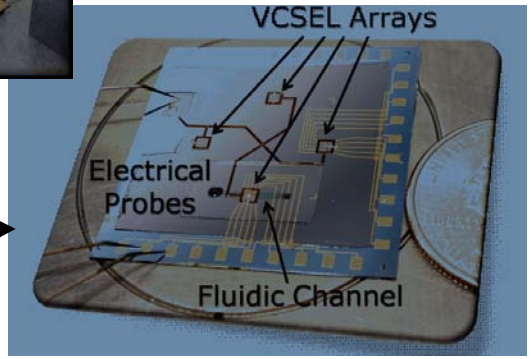


Large Area Transfer Printer



Affordable E-jet Printer with x10^3 Speed Increase

Optofluidic Microchips

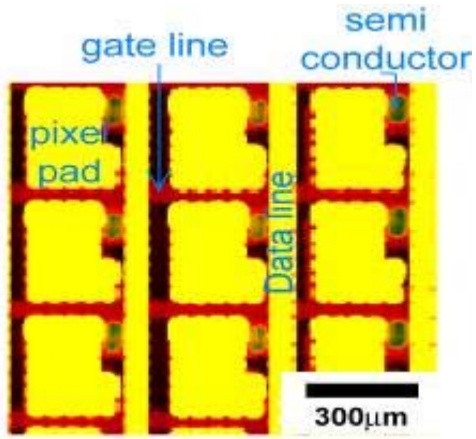


Research Outcome for Last Year

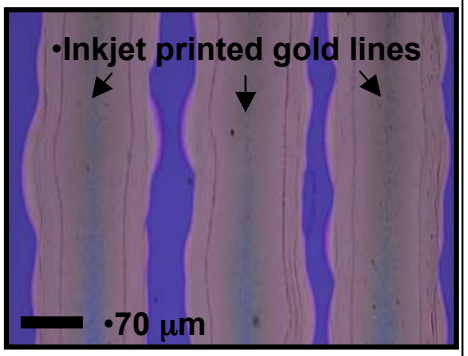
- By the numbers……
  - Publications
    - 128 Journal papers
    - 38 Conference papers
    - 63 with multiple NSEC authors
  - Patents
    - 5 Invention disclosures
    - 13 Patent applications
    - 3 Patents allowed
    - 5 License
  - Graduate Students
    - 7 PhD graduates
    - 5 MS graduates

Conventional Inkjet Technology

•*For Printed Electronics*



•transistors



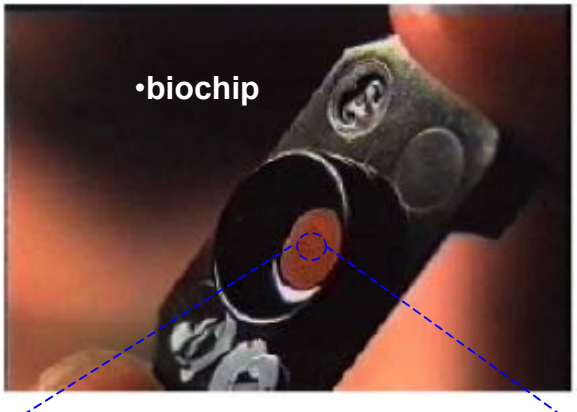
•electrodes

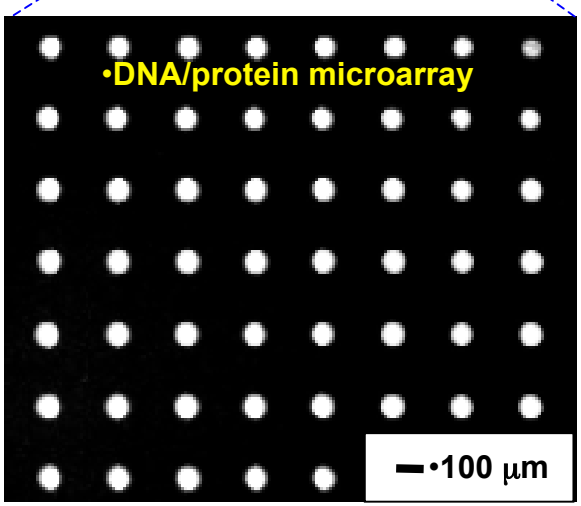
•Color filters for 8G large LCD

•(Sharp, 2006)

•Science, 290, 2123 (2000), *APL,* 85, 3304 (2004)

•*For Biotechnology*



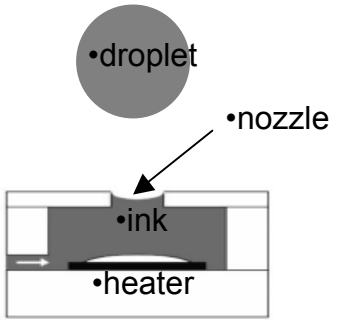


•***Nature Biotech.*, 18, 438 (2000)**

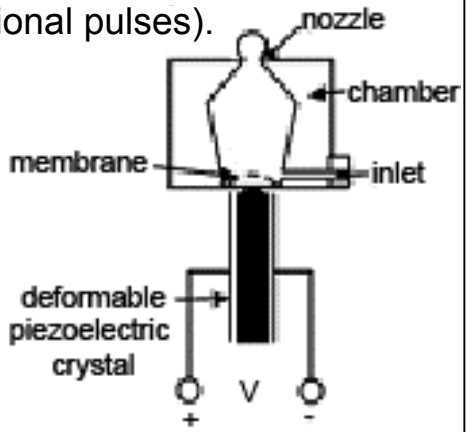
Limits on Conventional Inkjet Technology

•Current inkjet techniques: thermal or piezoelectric types

•: to push an ink through the nozzle by ΔP (ΔP is generated by thermal or vibrational pulses).



•thermal inkjet



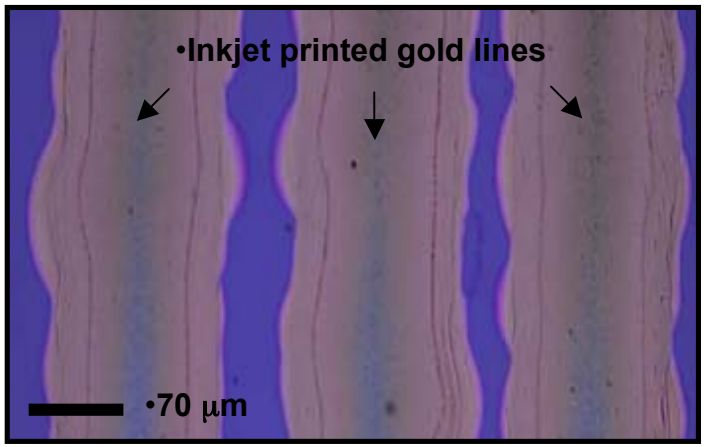
•piezoelectric inkjet

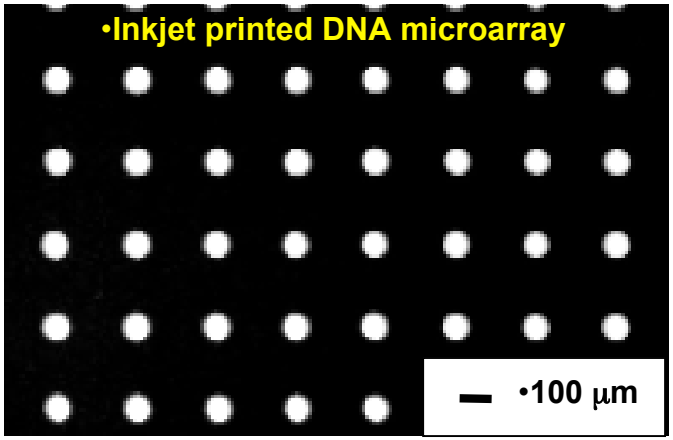
•: Limitation to reduce nozzle sizes (min.: ~ 3 μm)

•: Droplet diameters bigger than the nozzle sizes

•: Droplet placement errors caused by statistical deviation of jet trajectory

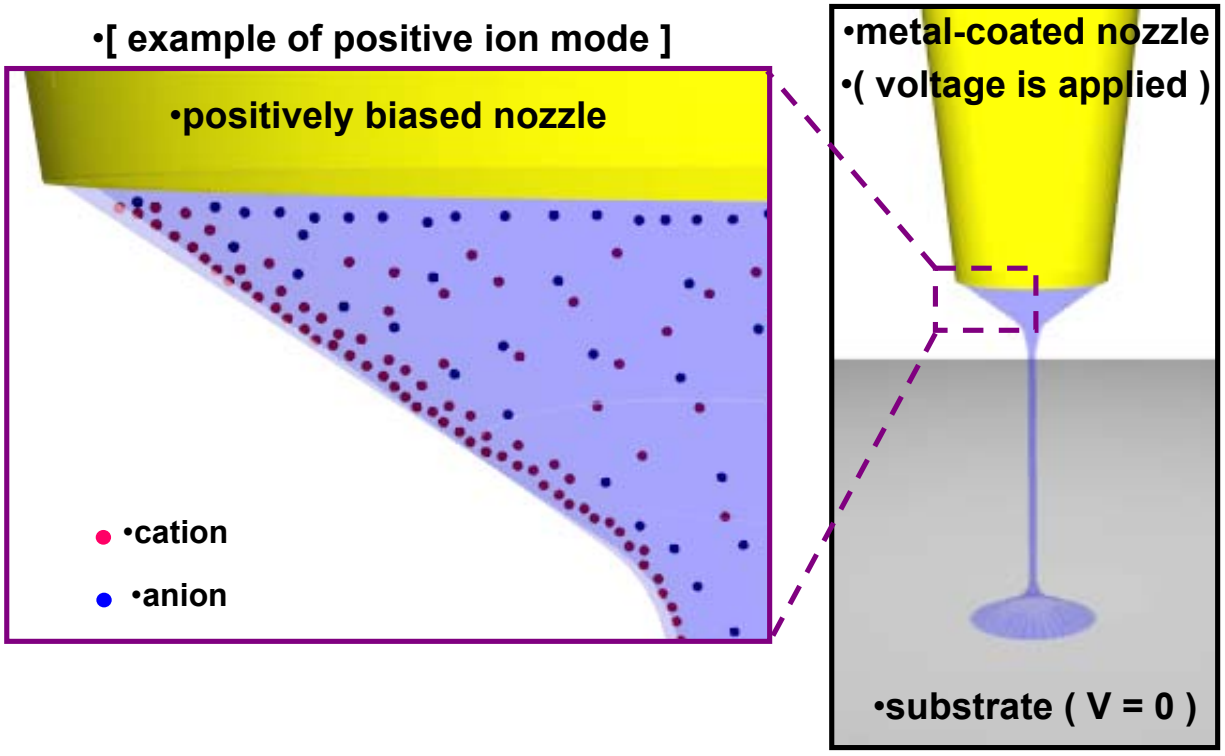
•⇒ **Coarse printing resolution : ~1 pL in droplet volume (dot diameter: ~ 10 μm)**

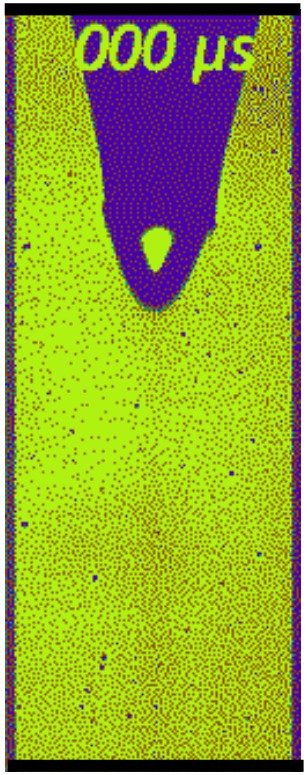




•*MRS bulletin*, 28, 830 (2003) •*Nature Mater.*, 3, 171 (2004) •*Nature Biotech.*, 18, 438 (2000) •*Appl. Optics* **38**, 1481 (1999)

Electrohydrodynamic Jet (E-jet) Printing



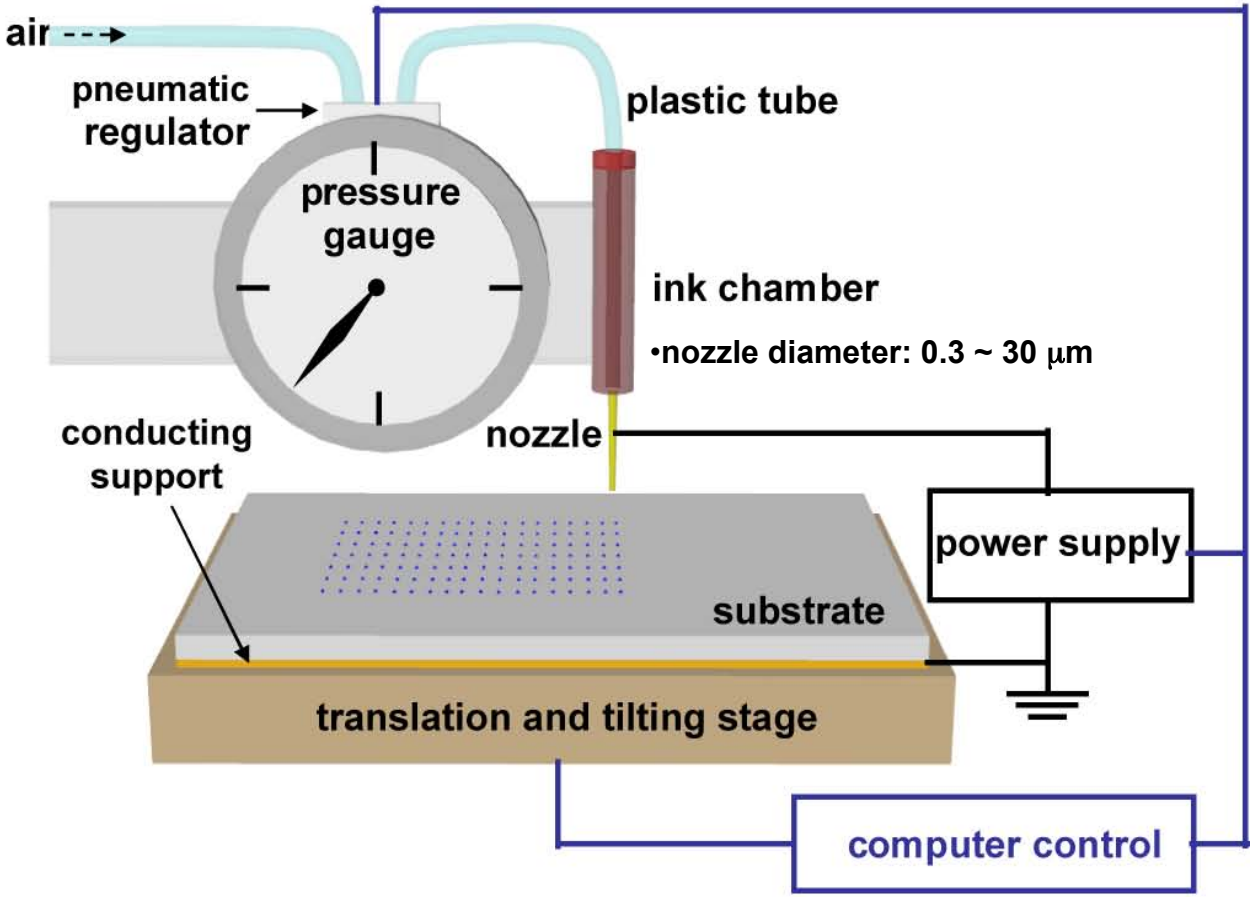


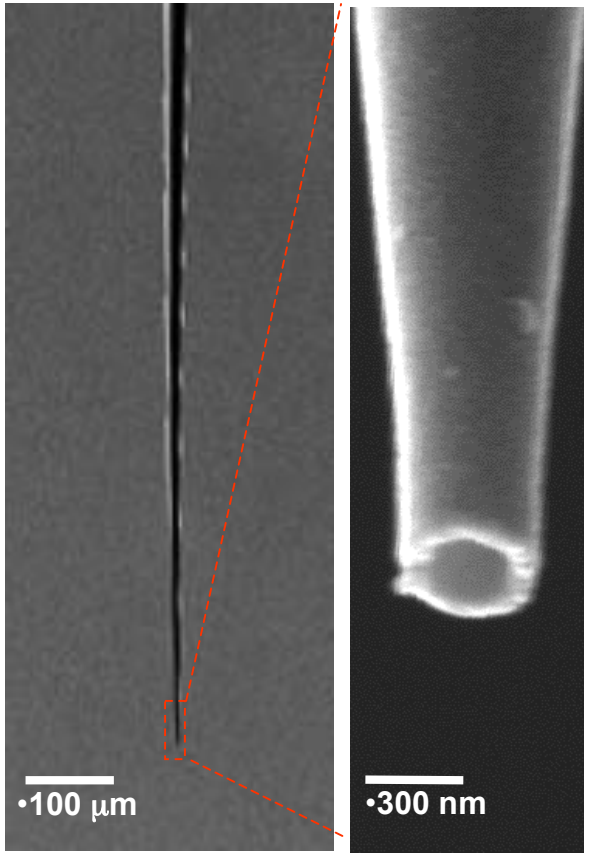
$$Q \approx \frac{\pi d_N^4}{128 \mu L}\left(\Delta P + \frac{1}{2}\varepsilon_0 E^2 - \frac{4\gamma}{d_N}\right)$$

•*Appl Phys Lett 92, 123109 (2008)*

•*Nature Mater.*, *6*, 782 (2007)

High Resolution E-Jet Printing





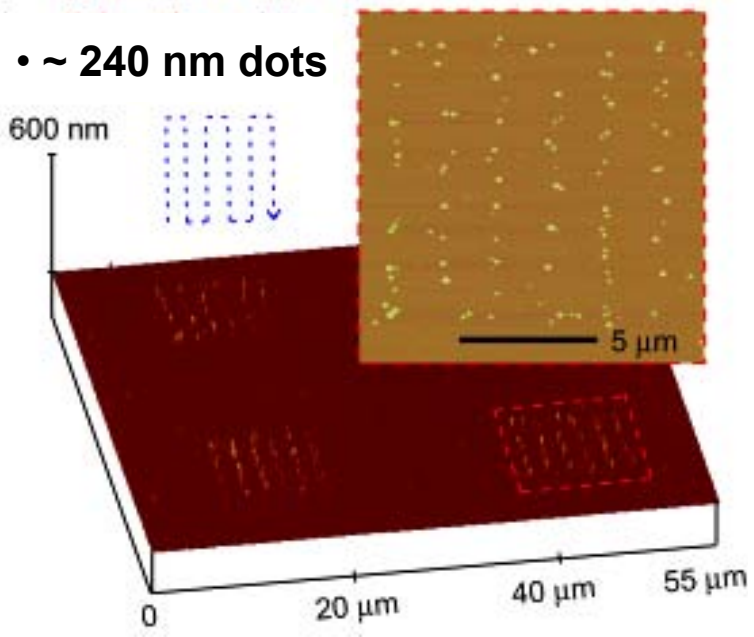
•***Nature Mater.*, *6*, 782 (2007)**

High Resolution E-Jet Printing

inkjet (incl. research)

J. Micro/Nanolith. 6, 43003 (2007)

• ~ 240 nm dots

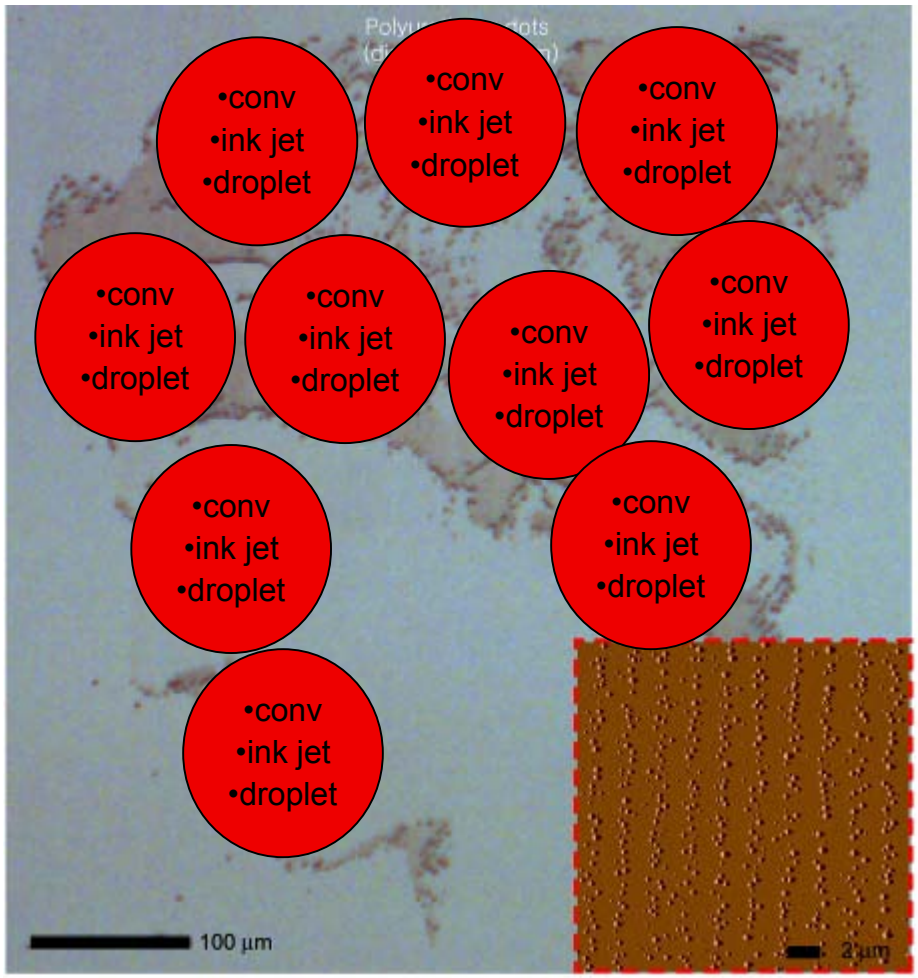


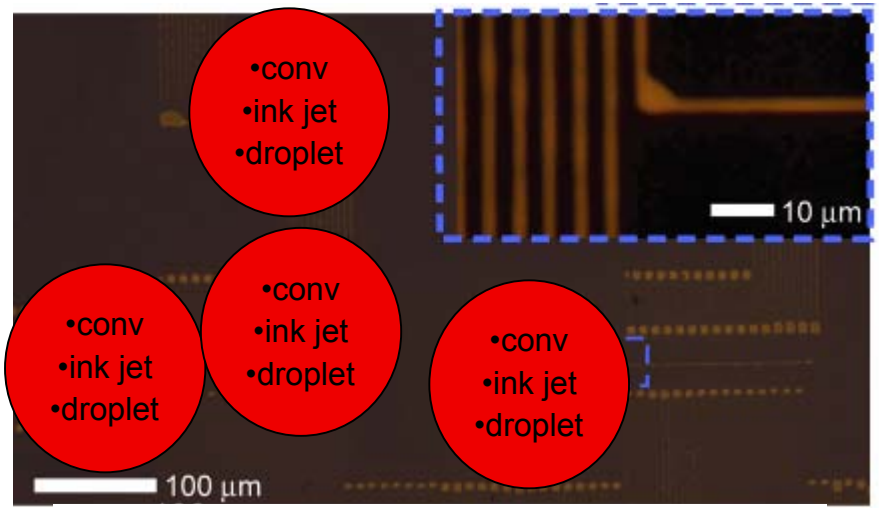
e-jet

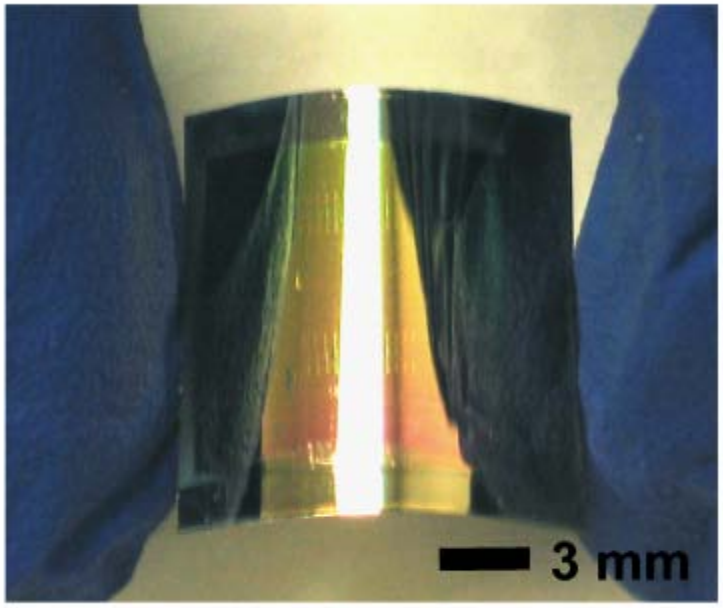
•dot ~ $(\text{nozzle})^{1/2}$

- *Nature Mater.* **6**, 782 (2007) -- UIUC
- *PNAS*, 105, 4976 (2008) -- AIST

Printed Patterns

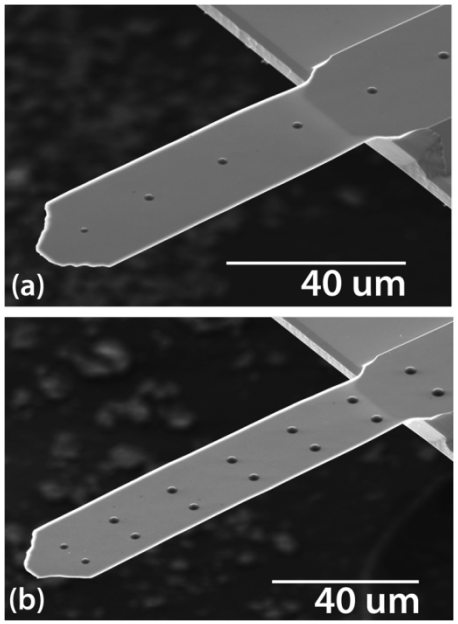




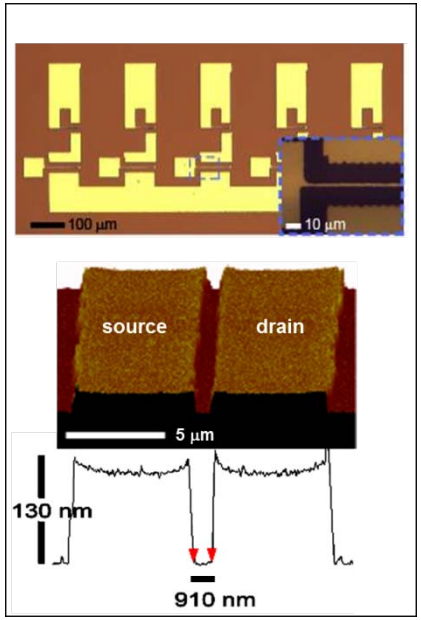


•***Nature Mater.*, *6*, 782 (2007)**

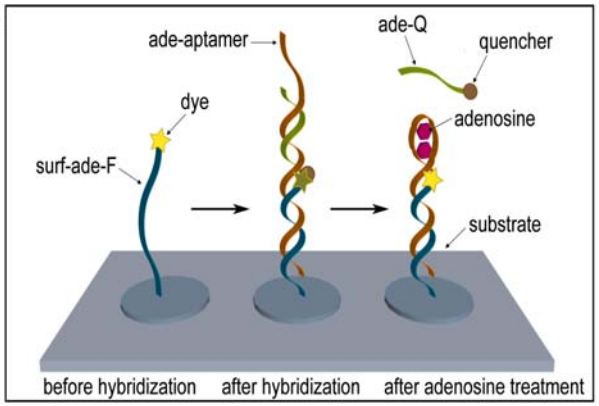
Diversity of Materials

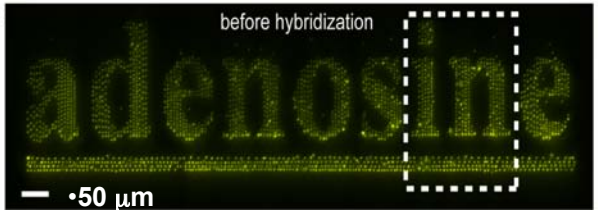


Polymers

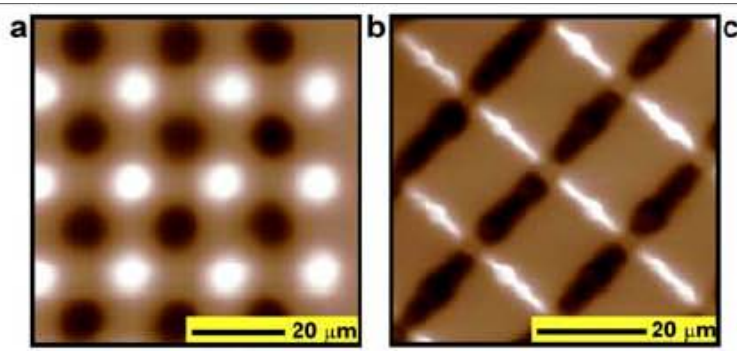


SWNT Source & Drain Electrode Printing

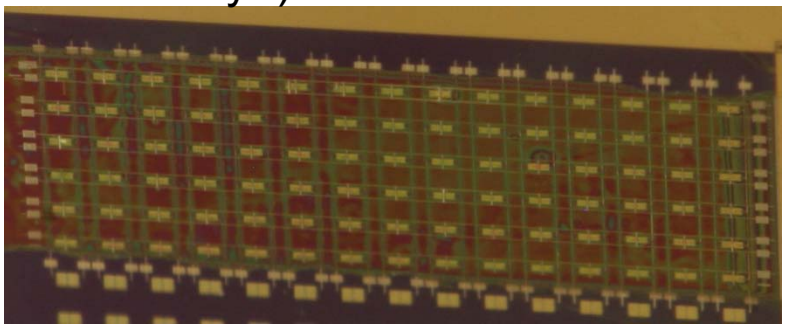




ss-DNA (with biotin & fl dye)



Charge Printing

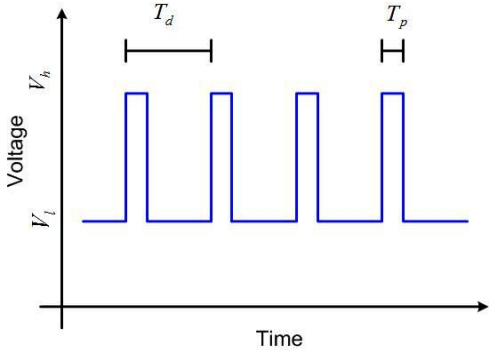


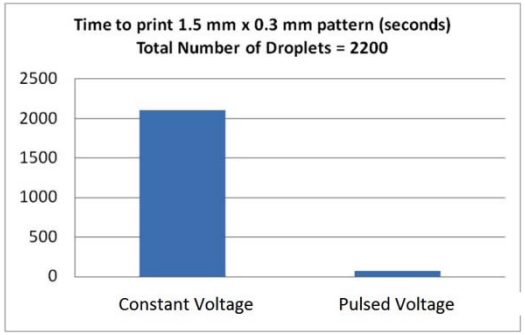
Ag pads/interconnects for 6x15 TFT array

- ***Various papers (2007-2010)***

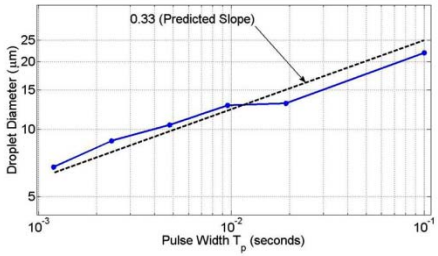
Manufacturing Capabilities

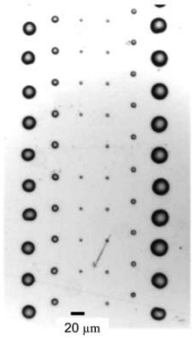
- High Throughput
  - 25k drops/sec

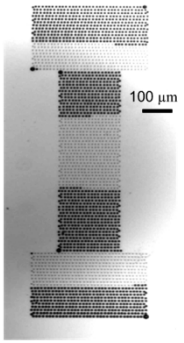


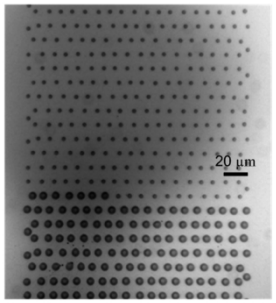


- Size control
  - On the fly

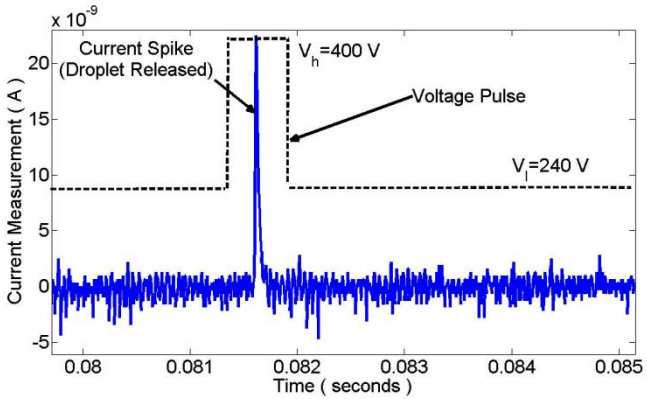








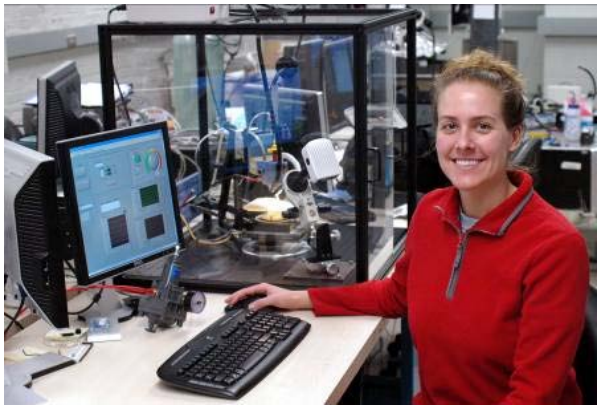
- Drop on demand
  - Overlay control



•*JMM (2010)*

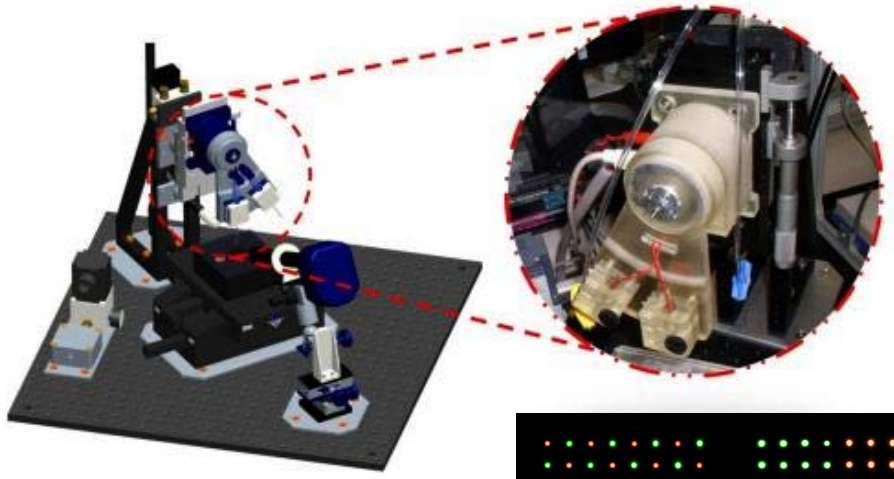
Manufacturing Capabilities

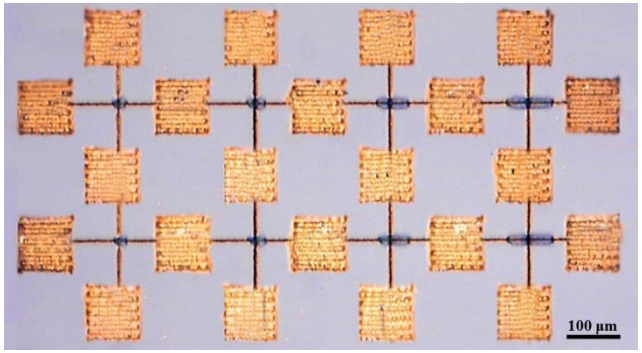
- Desktop E-jet system
  - **E-jet printer that can be used for research, testing, development**
  - **Designs available**
  - **Installations at 2 larger industry sites to date**
  - **Multiple university disseminations**



•IFAC CEP (2010) & Unpublished

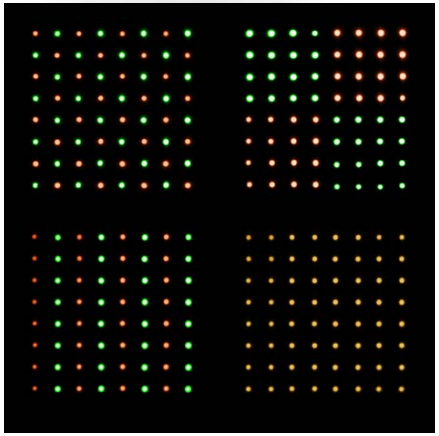
- Multi-nozzle print head





Silver interconnects

w/ Kayuzo Shigeti
& Youngkwan Kim



Rhodamine & FITC drop-on-demand

(8 micron drops, limited by FL detection)