Additive Manufacturing of Functional Materials in Health Applications using Ink-Jet Technology

NSF Workshop on Additive Manufacturing for Health

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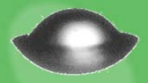

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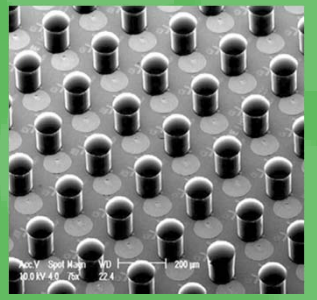
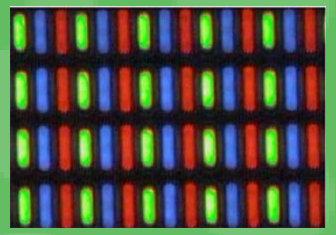
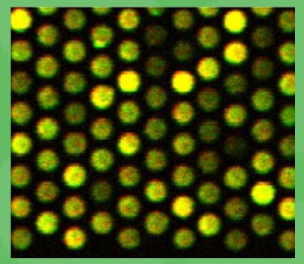
Some Thoughts on AM …..

- vs. subtractive
  - machining, photo-lithography, etching, etc.
- vs. AM that is:
  - contact, not direct-write / digital / high res.
  - screen printing, molding, contact dispensing, cvd, sputtering, etc.
- Manufacturing is the sum of separate processes.

Why Ink-Jet for Manufacturing?

- Additive
- Inherently digital
  - Flexible, no tooling
- Direct-write
  - no waste
- High resolution
  - 20-100 μm and pL-nL's
- Non-contact
  - no crosstalk between processes
  - non-flat / complex surfaces OK
- Materials
  - Biologicals, drugs, coatings
  - electronic, photonic, semiconducting



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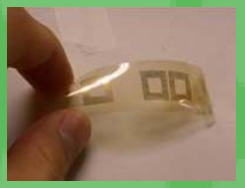
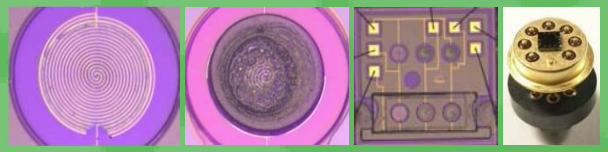
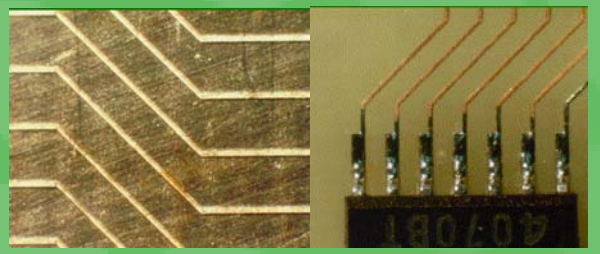
IJ for AM: Not a new idea!

- Lewis for direct write of materials: 1967
- Vest, et al. for hybrid microelectronics: 1983
- Kimura, et al. for ISFET biosensors (glucose): 1988
- Hayes, et al. for medical diagnostics: 1988
- Southern for DNA synthesis: 1988
- Wallace for electronics manufacturing: 1989







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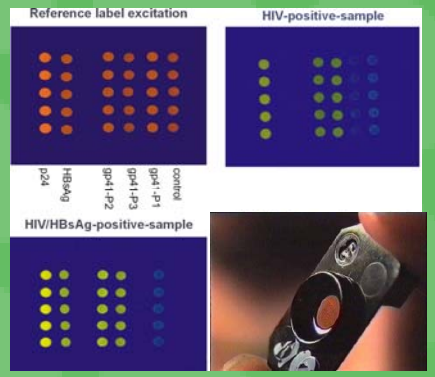
Printed Diagnostics

- 1985: technology demo
- 1990 – current: production
  - >$5B worldwide
- 1997: MicroSpot prototype
  - Miniature & multiplex
- 2012: TB test
  - Integrated microfluidics and electronics



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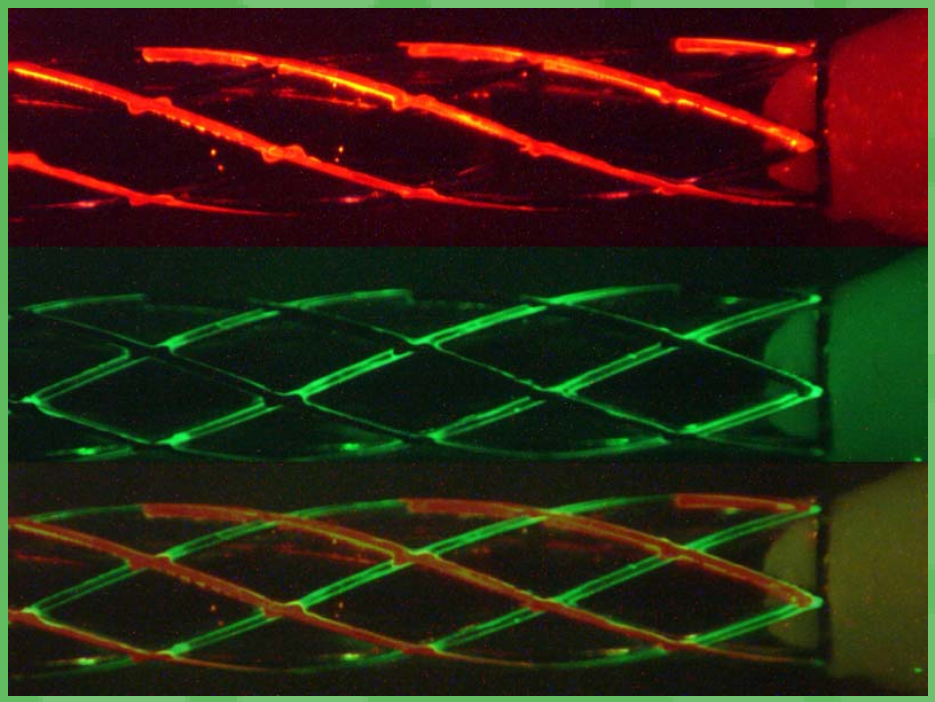
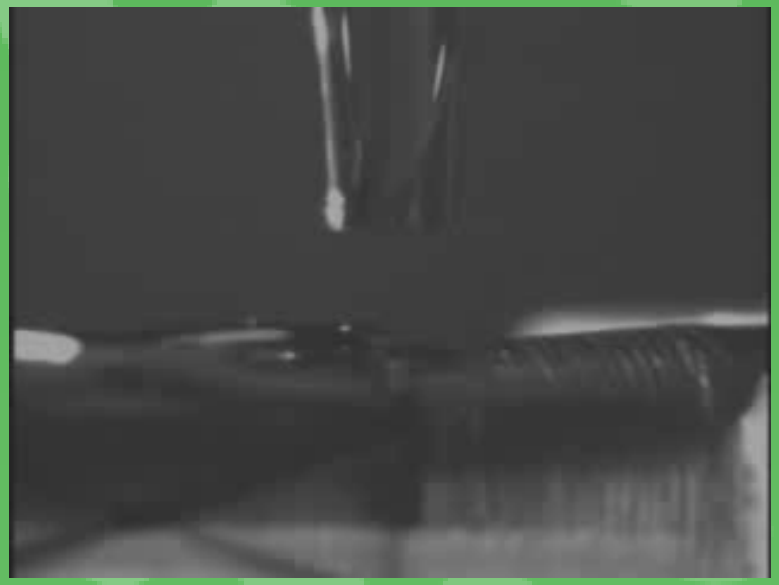
Coating

- Drug Eluting Stents
  - Requires high speed, high spatial & volume accuracy
  - Typical stent: 1mm diameter, 15mm long, 50-150µm wide structural features. Active material on outside only.
  - Right: Model stent, coated with two fluorescent dyes (non-overlapping).



Coating

- Drug Eluting Stents



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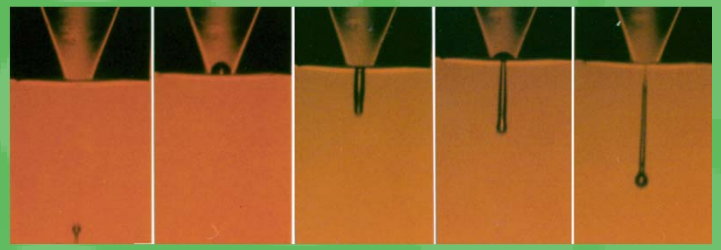
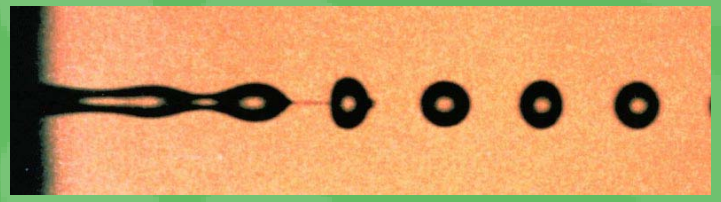
Ink Jet Technology (ies)

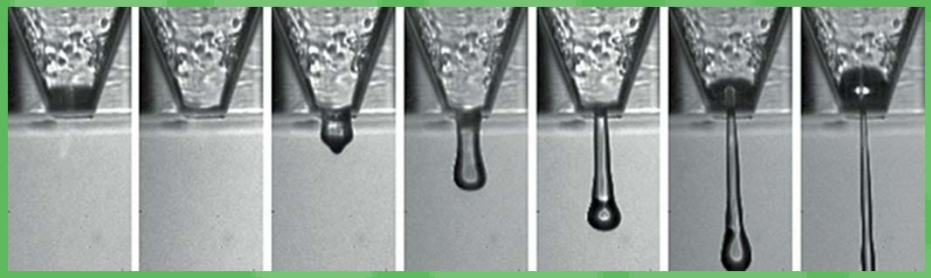
- Multiple, very different technologies referred to as IJ
  - Piezo & thermal demand mode
  - Rayleigh breakup, aka continuous mode
  - High speed valves
  - Mechanical impact actuators
- Large diversity of implementations over multiple technologies – application driven

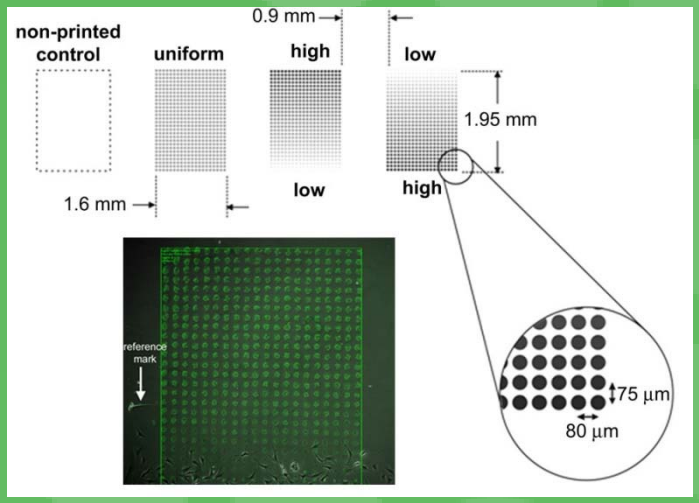


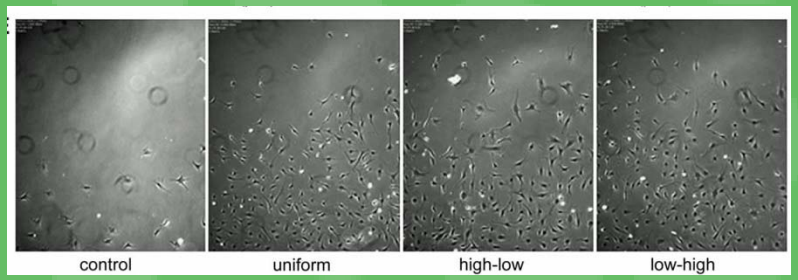


Tissue Engineering

- High value materials
  - Cells
  - growth factors
- ECM
  - Yes & no
  - Depends on material, size & thickness, hi-res or not







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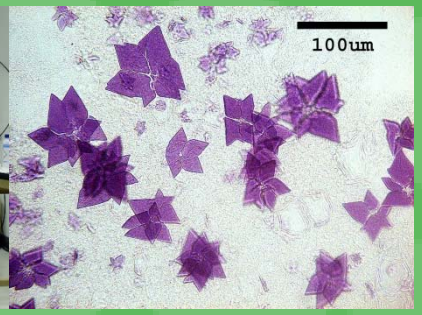
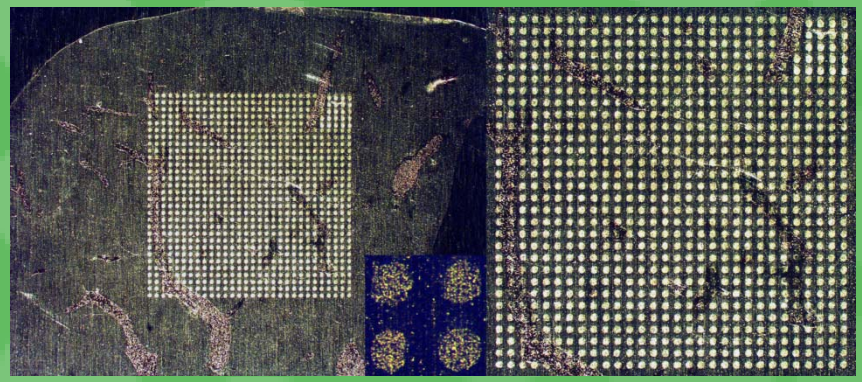
Instruments?

- Is this Manufacturing?
- Protein crystallization
  - Same configuration as DNA & protein arrays
- Proteomic analysis
  - 2-D separations or tissue
- Olfactory testing
  - Quantitative testing for early onset of neurodegeneration





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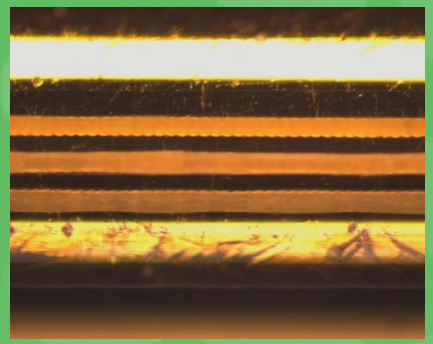
All AM is for Health?

- MEMS brain probe
  - Electrodes coated with Enzyme
- AM neuro stimulator
  - Leverage off decade long $B focus on Printed Electronics
- Integrated systems
  - biological, sensor, control, computation, & communication functions
  - Processes must be compatible ….. AM+



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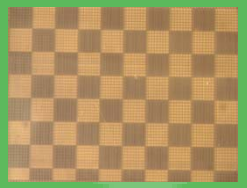
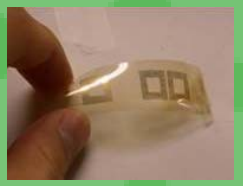
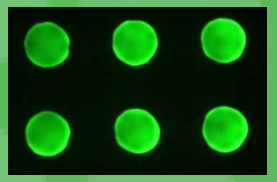
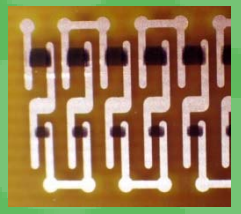
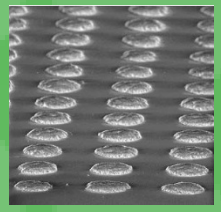
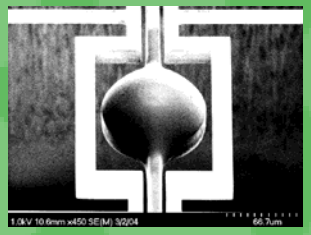
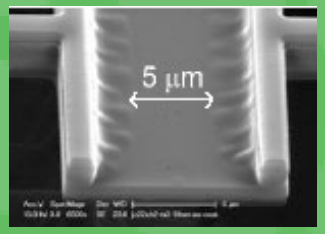
AM for Integrated System

- Printed
  - Semiconductors, photovoltaics
  - conductors, resistors, dielectrics
  - Light sources
    - (LEP, phosphor, LC
  - Lenses, waveguides
  - sensors



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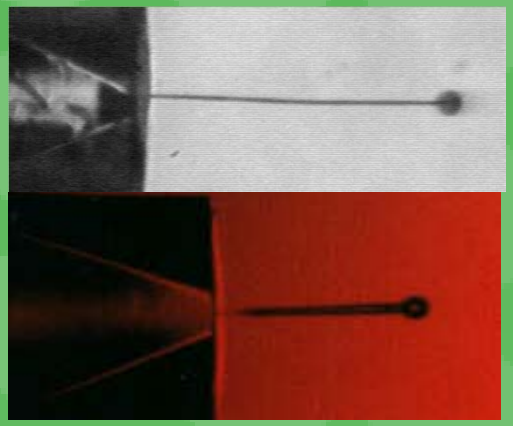
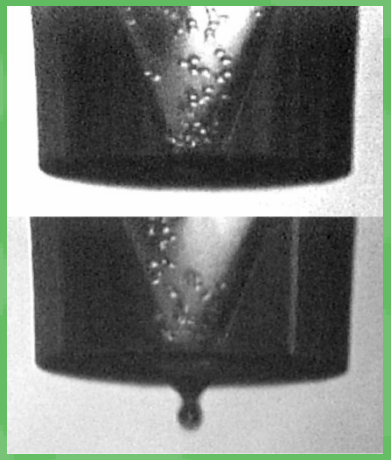
Gaps: Making Drops

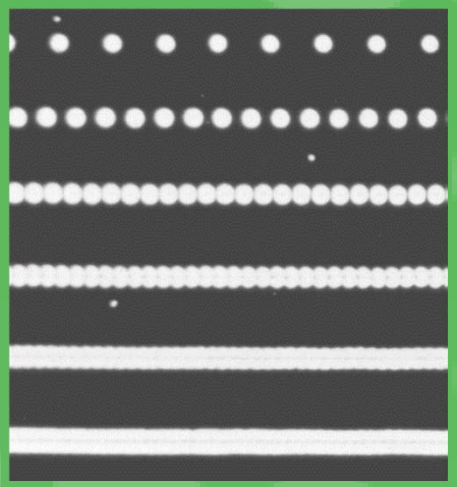
- Polymers
  - non-Newtonian effects
  - dynamic surface tension
- Suspensions
  - Large or dense particles, non-homogeneity create unsteady flow / drop formation
- Fluid properties
  - Cannot measure at the shear & extension rates in IJ

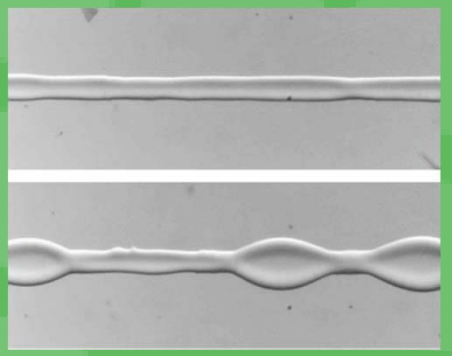


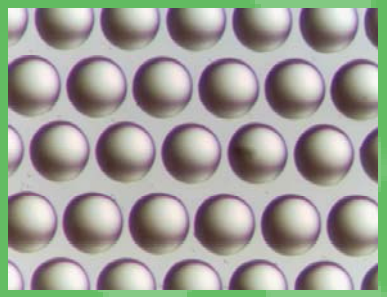


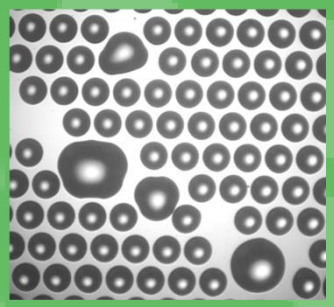
Gaps: Feature Formation

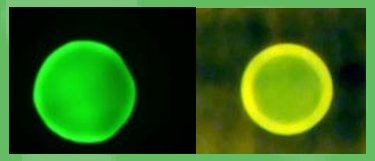
- Control & repeatability of size.
- Uniform distribution in feature.
- Examples of good, bad, and ugly.

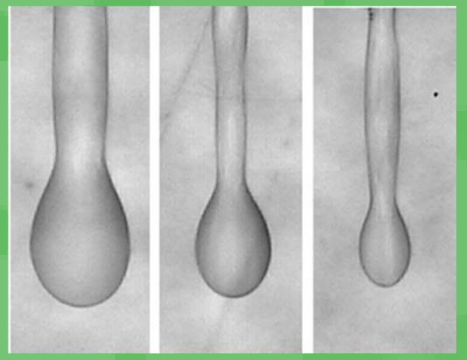












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Gaps: Cells

- How to keep cells happy in high-performance automated AM equipment?
  - Fabrication integrated into cell growth and processing environments?
- Printing performance
  - Formulations for jetting
  - dispersion methods