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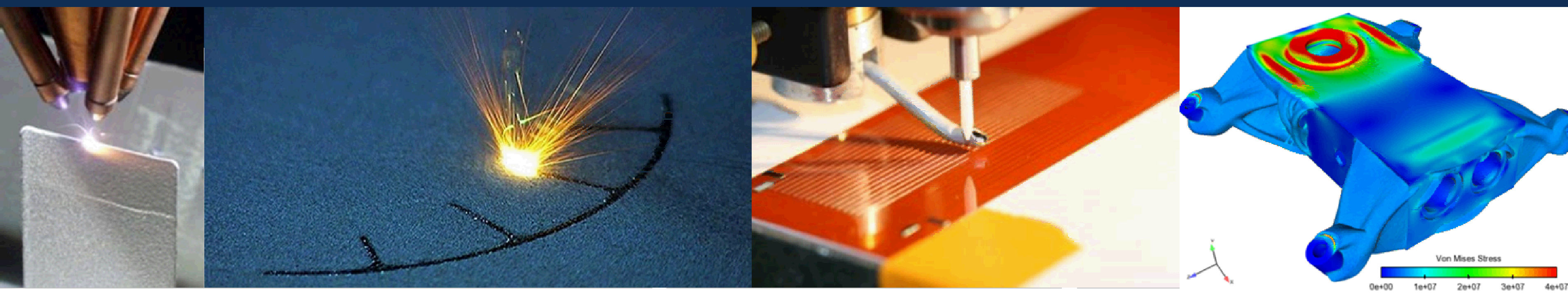

Process Optimization of Aerosol Based Printing of Polyimide for Capacitor Application

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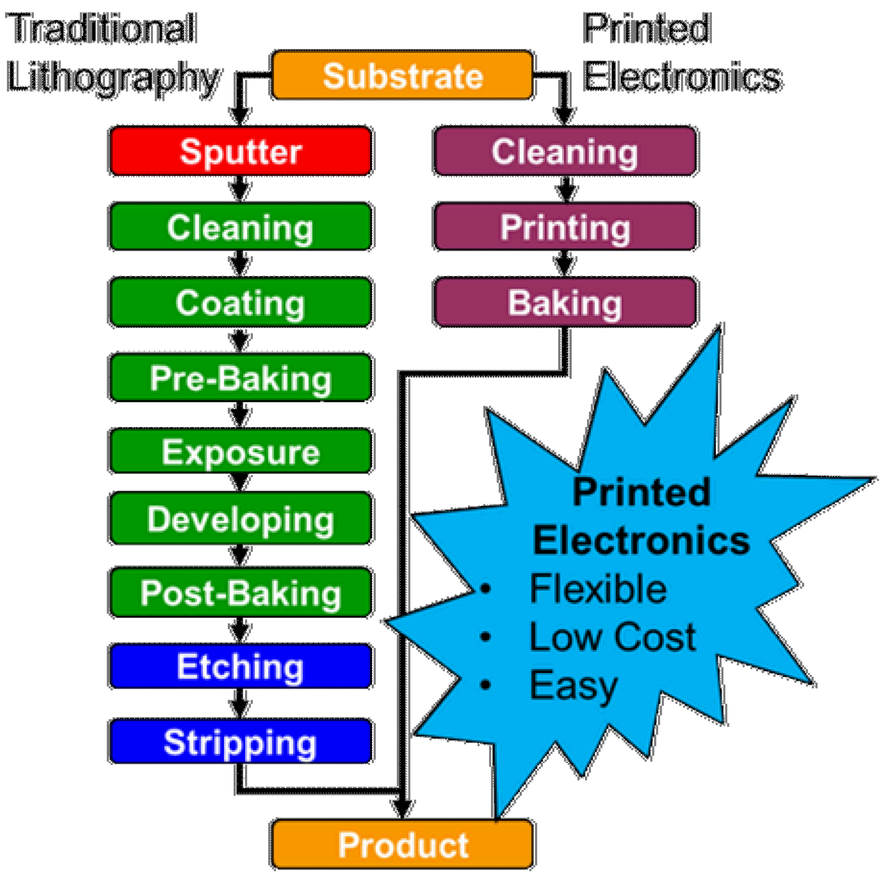
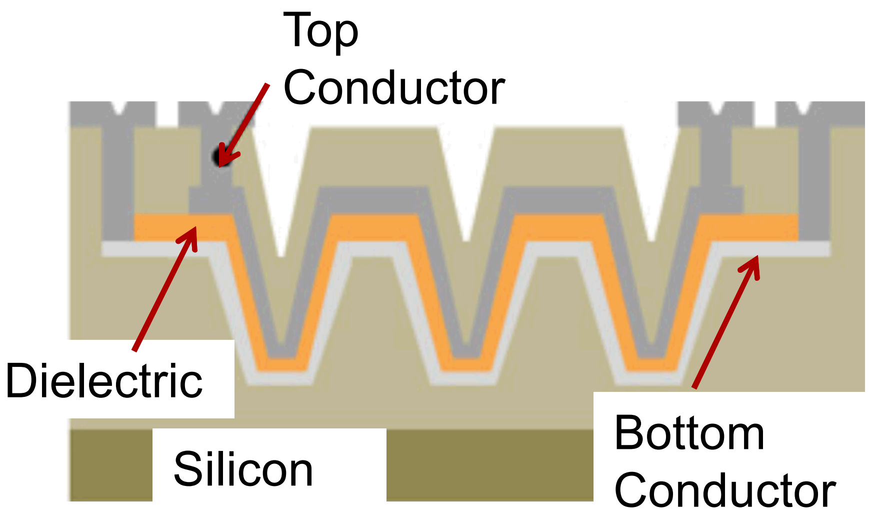
Why Printed Electronics?

- Minimize capital equipment
- Reduce tooling needs
- Digital manufacturing environment
- Highly configurable, agile manufacturing environment
- Reduced process steps
- Customizable for low volume/high mix productior
- Miniaturization



Conformal/Distributed/3D Capacitors

- Conformal Caps provide Opportunity to Integrate Electronics onto Structures
- Distributed Electronics Provide Increase Real Estate for Printed Electronics
- 3D Capacitors Provide Opportunity to Miniaturize Capacitors



3D Trench Capacitors in Si Provide Gain in Capacitance with Increased Dielectric Thickness

M. Detalle, M. Barrenetxea, P. Muller, G. Potoms, A. Phommahaxay, P. Soussan, K. Vaesen, W. De Raedt, "High density, low leakage Back-End 3D capacitors for mixed signals applications", Microelectronic Engineering **87** (2010) 2571–2576.

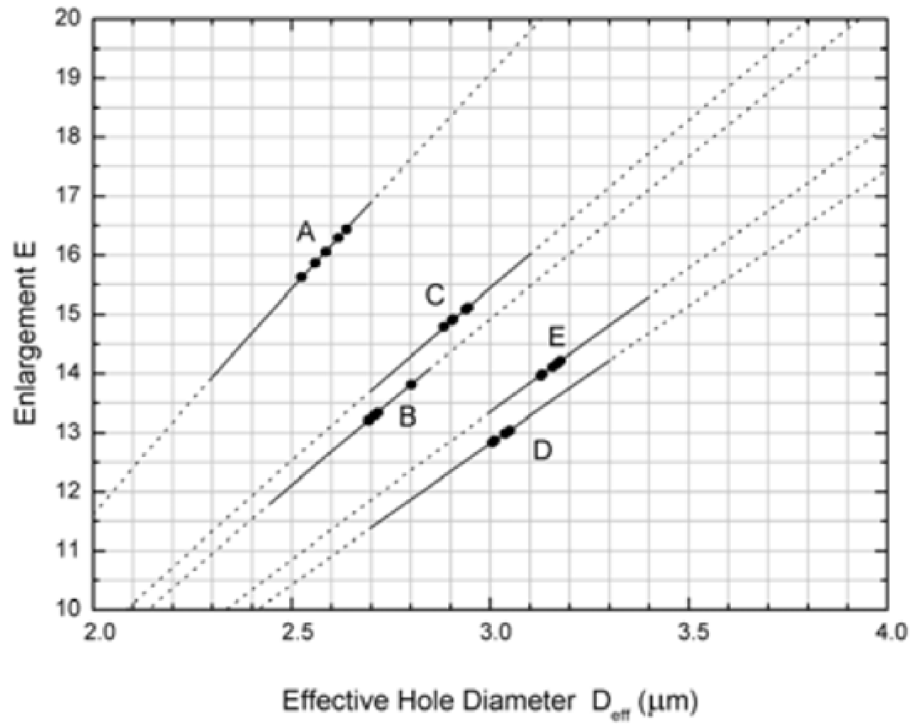
Example of Miniaturization

Conformal/Distributed Capacitor

- Component container = 319 cm^2
- Capacitor surface area = 88 cm^2
- Equivalent cap. = 27% of container surface area
- Double cap area improves margin

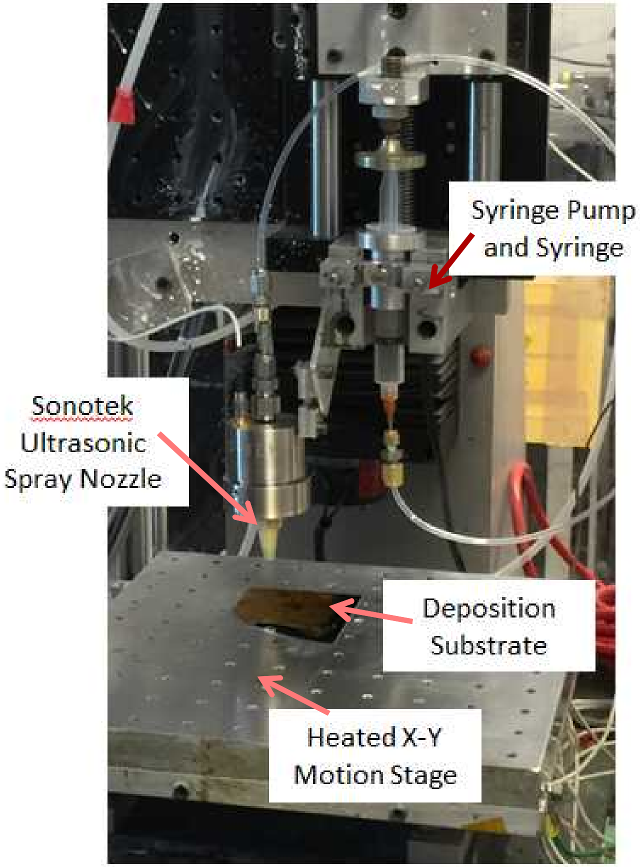
3D Capacitor Benefit

- Based on reported enhancements equivalent 3D capacitor could be <6 cm^2

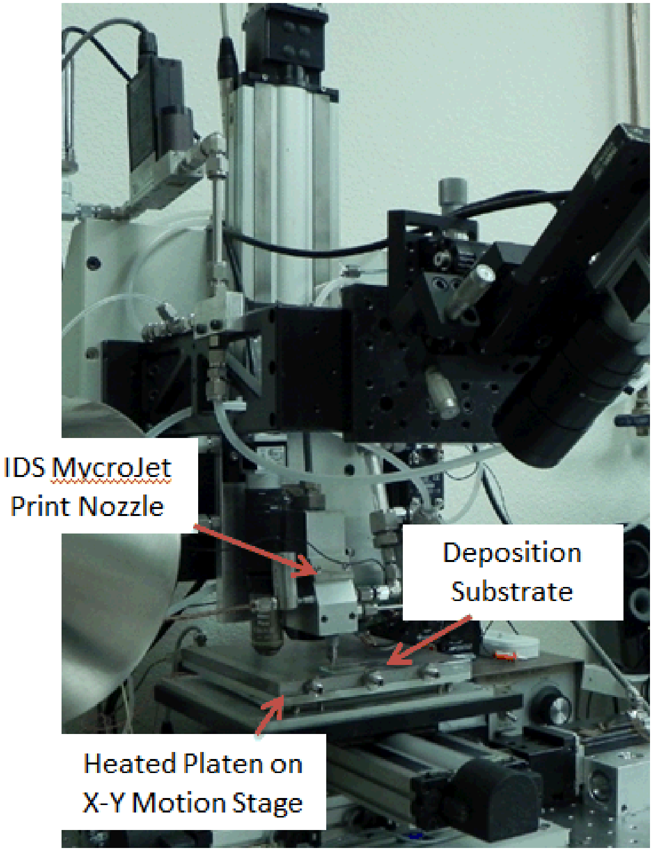


S. E. Berberich, A. J. Bauer and H. Ryssel, "High Voltage 3D-Capacitor", 2007 European Conference on Power Electronics and Applications, Sept. 2007, pp1-9.

Experimental Setup



Sono-Tek ultrasonic spray nozzle used for depositing 30-40 µm droplets



MycroJet print head used for depositing 0.5-3 µm droplets

Sono-Tek Print Conditions and Pattern

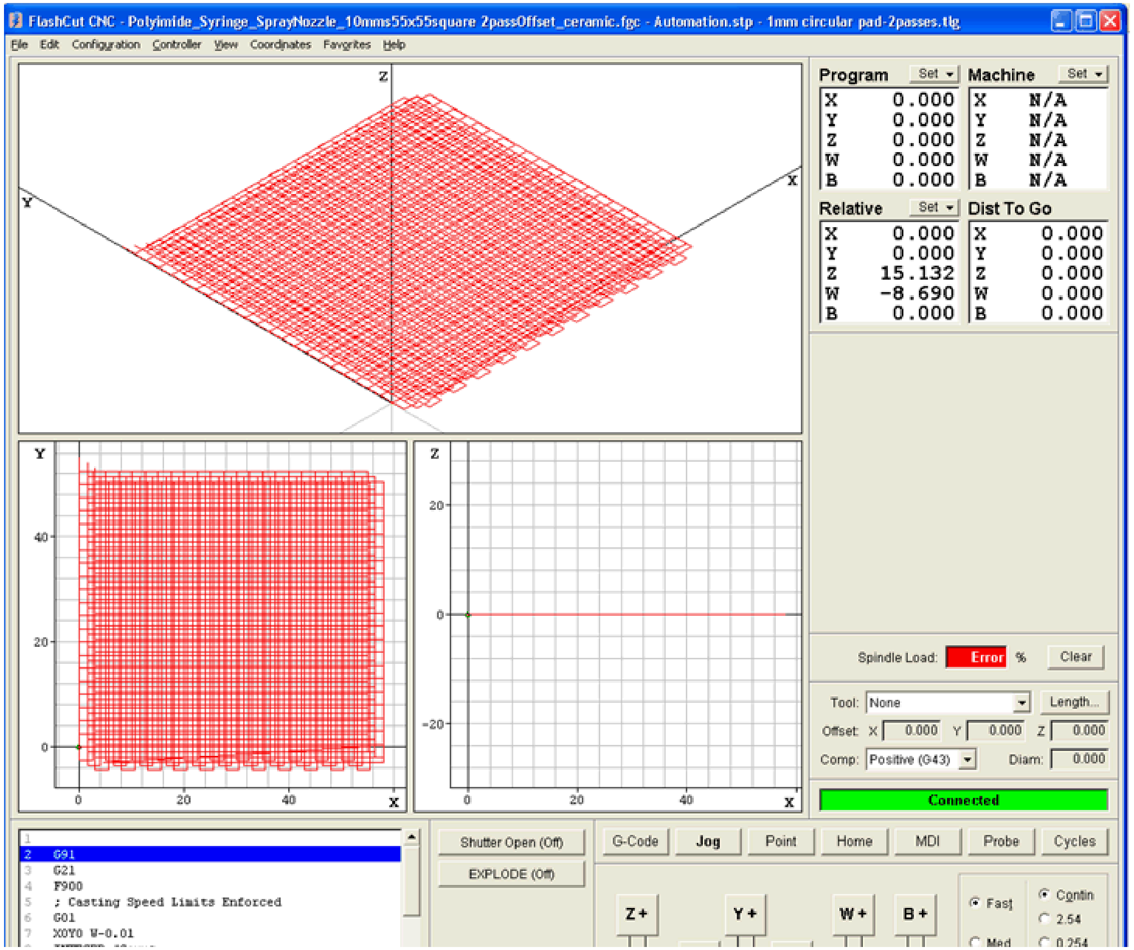
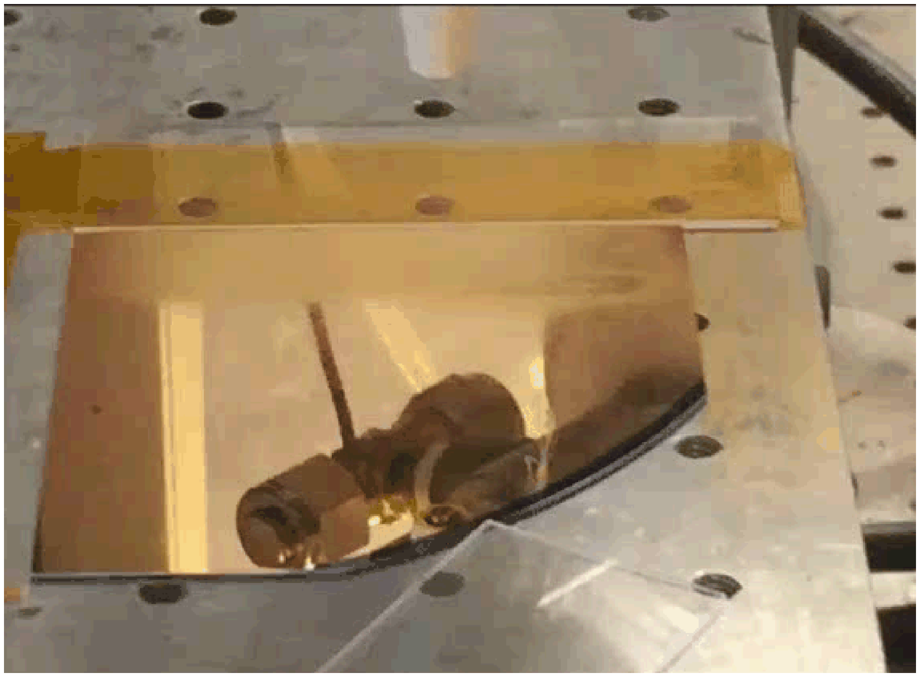
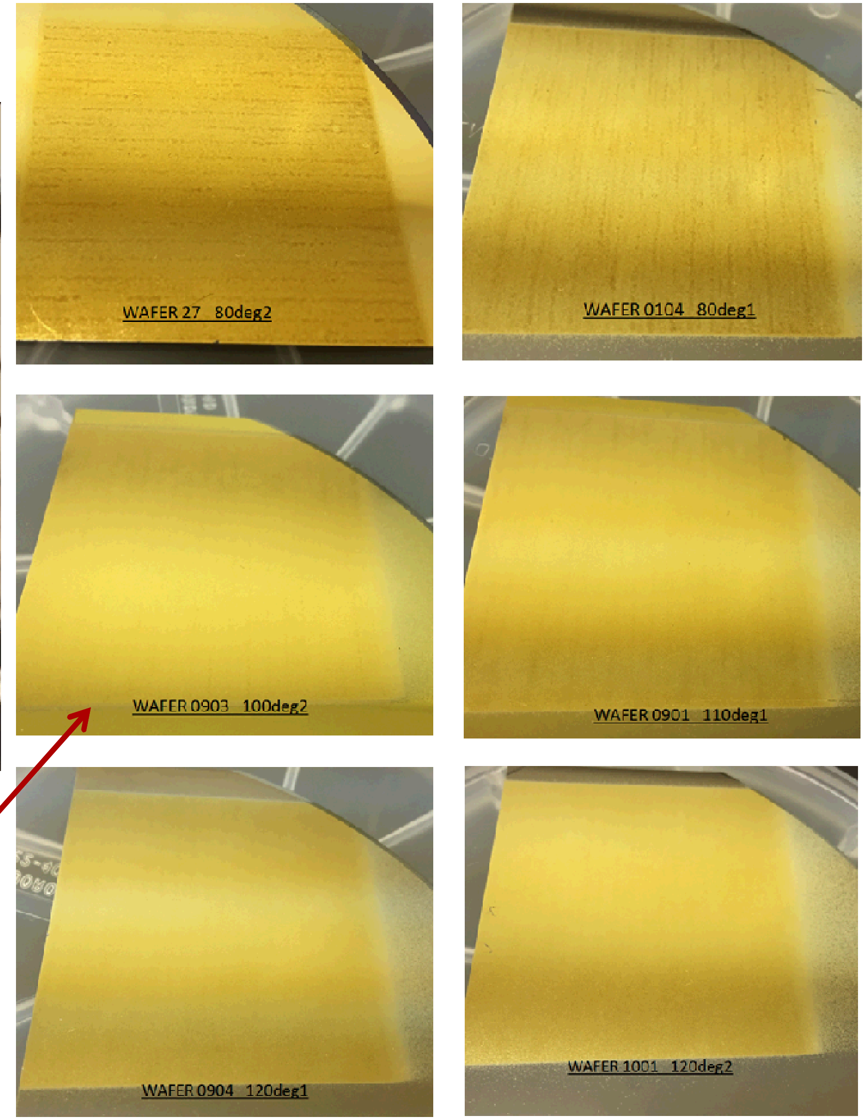


Image of FlashCut GUI showing offset pattern used for printing of PI films.

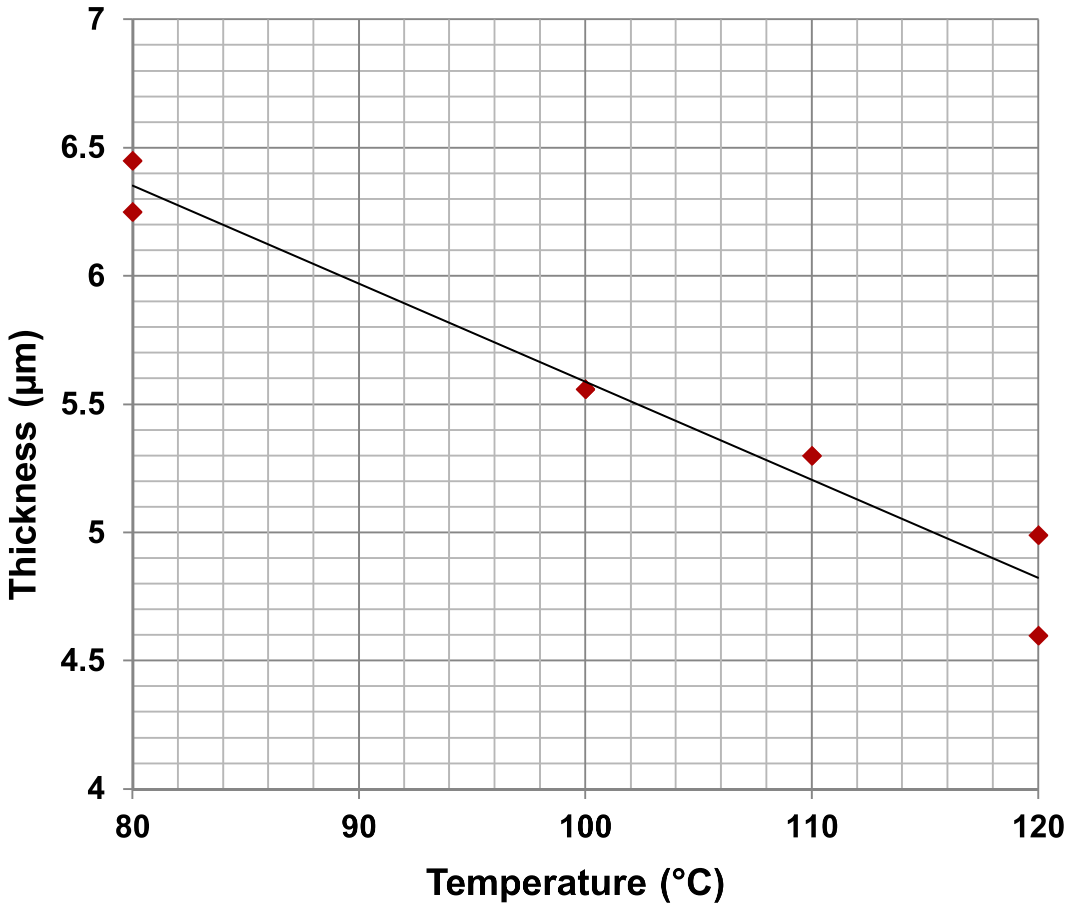
Spray Deposited Polyimide Films





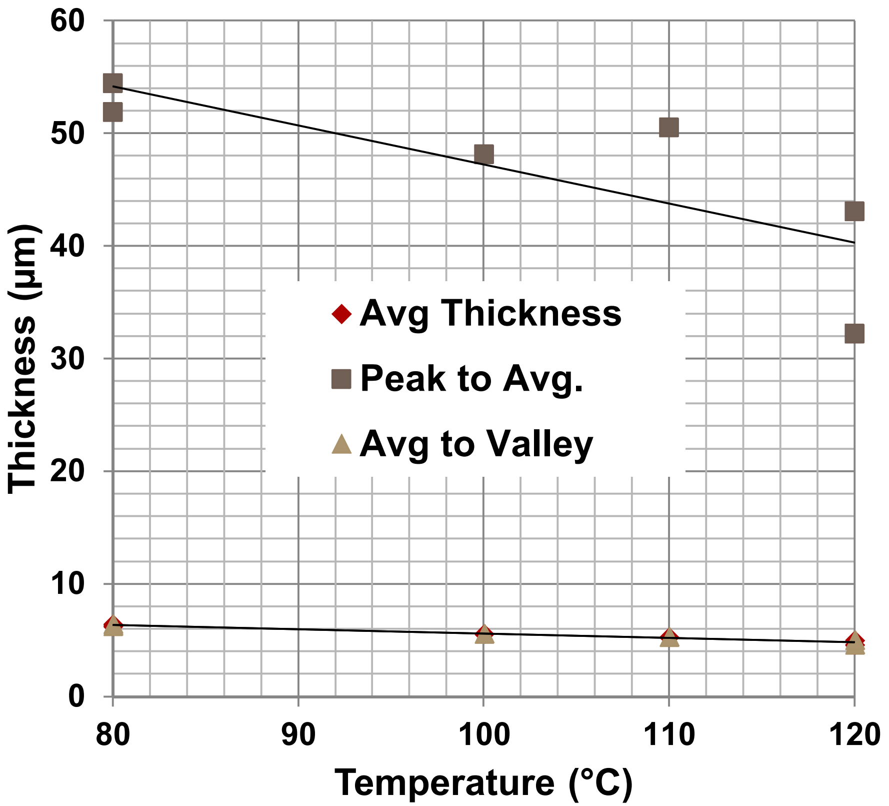
Au coated Si wafers spray coated with UTDPI solution at various substrate temperatures. Temperature varied 80°C to 120°C

Substrate Temperature

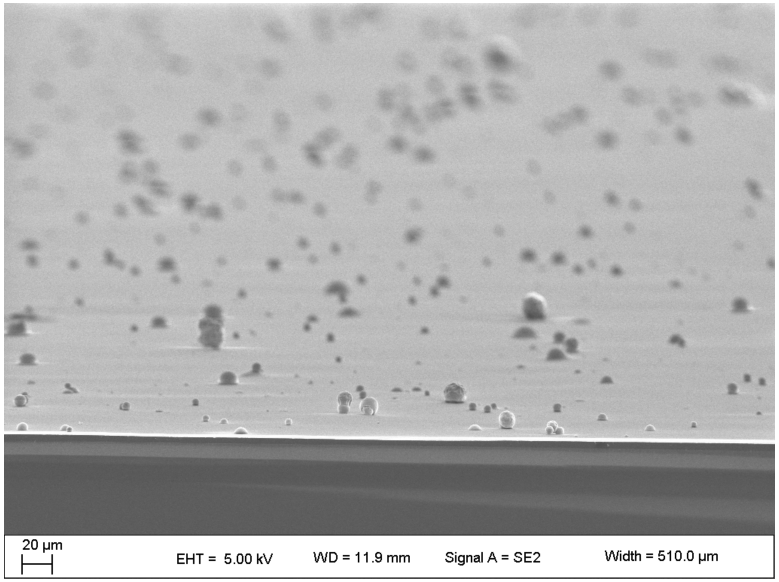


Increasing Temperature Decreases Film Thickness

Surface Roughness



Printed film thickness measurements



Cross-sectional view of STA spray UTDPI sample, showing surface roughness and overspray of polymer on the film surface

Printed Dielectric Film Properties

Sandia National Laboratories

Dielectric breakdown strength

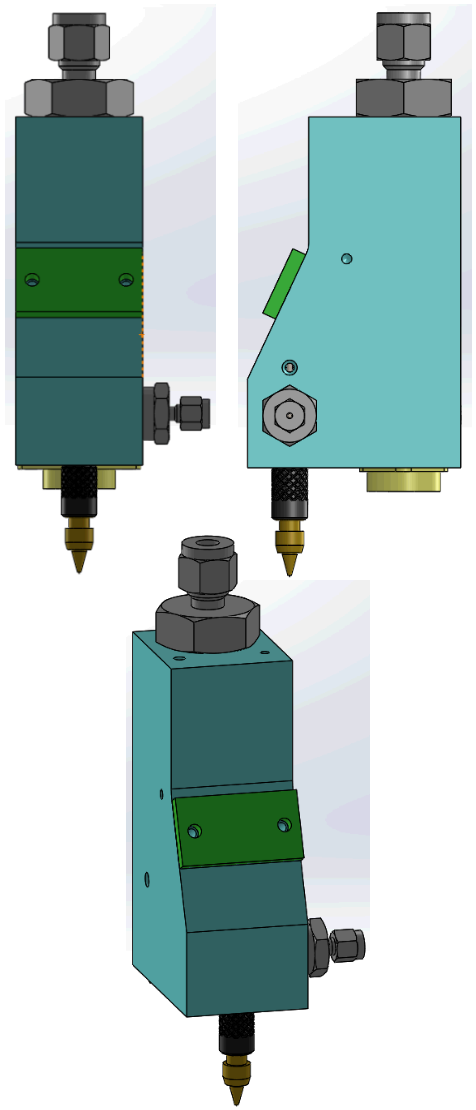
Group	N	Weibull α (kV/cm)	Weibull β
AM spray UTD PI	69	2402	1.5
solvent cast UTD PI	54	2060	1.0
commercial	89	4891	13.0

Permittivity and Dielectric Loss Mean (St. Dev)

Group	N*	avg. thickness (μm)	κ	Df
AM spray UTD PI	81	6.6 (1.8)	3.05 (0.77)	0.0021 (0.0005)
commercial	90	13.3 (0.2)	3.25 (0.02)	0.0021 (0.0004)
solvent cast UTD PI	31	2.6 (0.9)	3.25 (0.64)	0.0036 (0.0005)

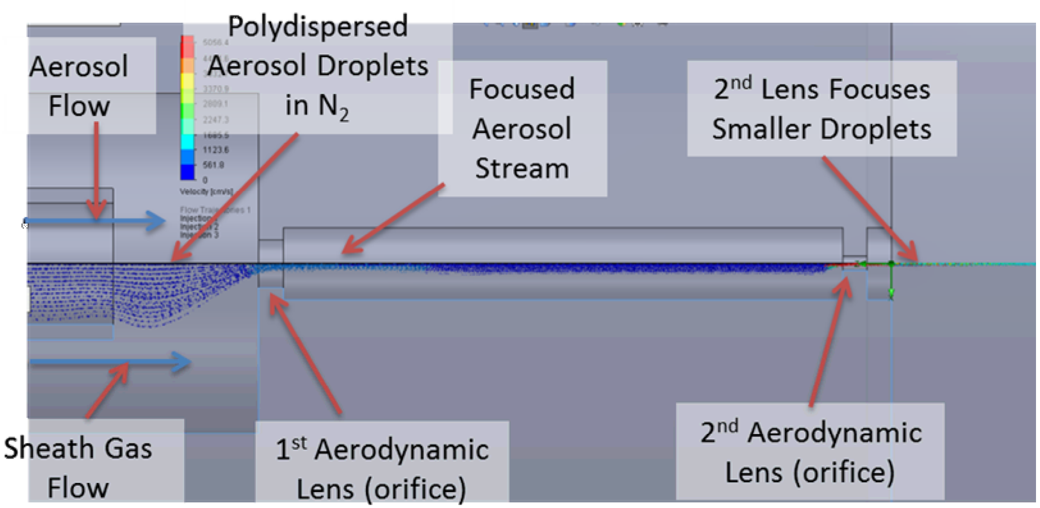
Monolithic Microjet Print Head

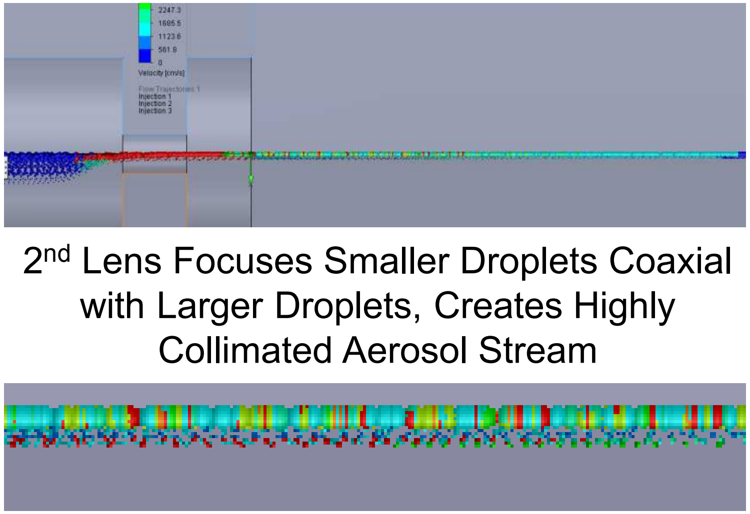
- Design based on cold spray technology
  - Provides tightly collimated aerosol stream
- Multiple aerodynamic lenses provide efficient collimation of polydispersed aerosols
- Monolithic design provides stable output for many hours of continuous operation
- Well controlled aerosol printing with minimum overspray
- Moves technology toward cartridge based system



Modified Nozzle Design Modeling

- Multiple Aerodynamic lens aerosol focusing
- Poly dispersed aerosol source
  - Droplets range from 500 nm to 3µm.
  - Multiple Aerodynamic Lenses
    - Optimal focusing of all droplets sizes
    - Highly collimated print stream
  - Minimizes overspray/satellites of smaller droplet sizes

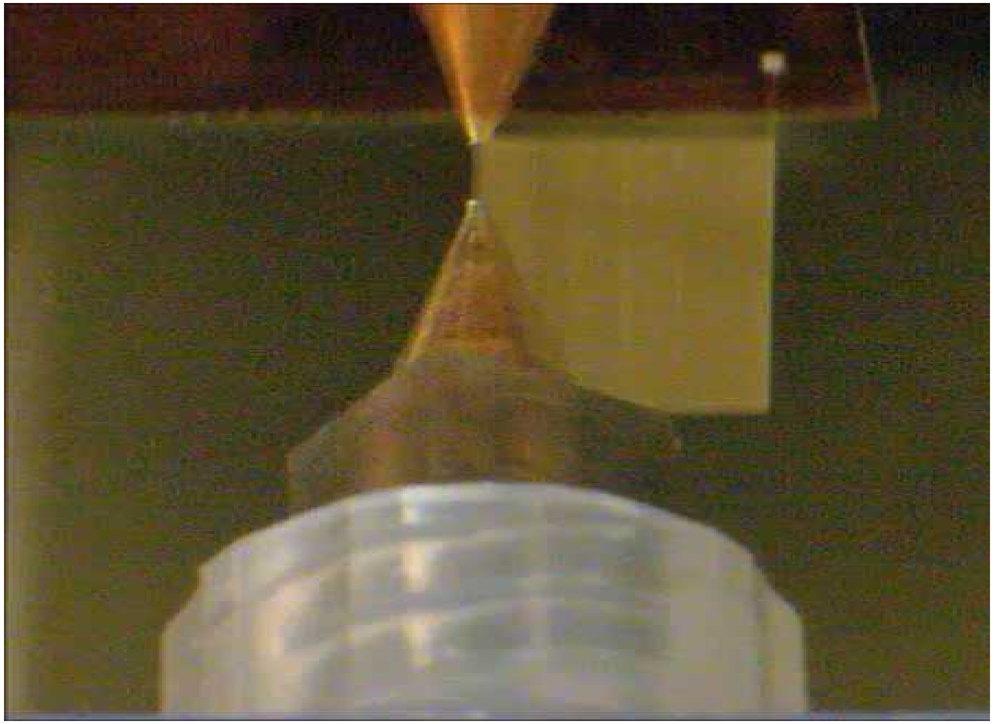




2nd Lens Focuses Smaller Droplets Coaxial with Larger Droplets, Creates Highly Collimated Aerosol Stream

Multiple Aerodynamic Lenses Enhance Focusing for Polydispersed Aerosol

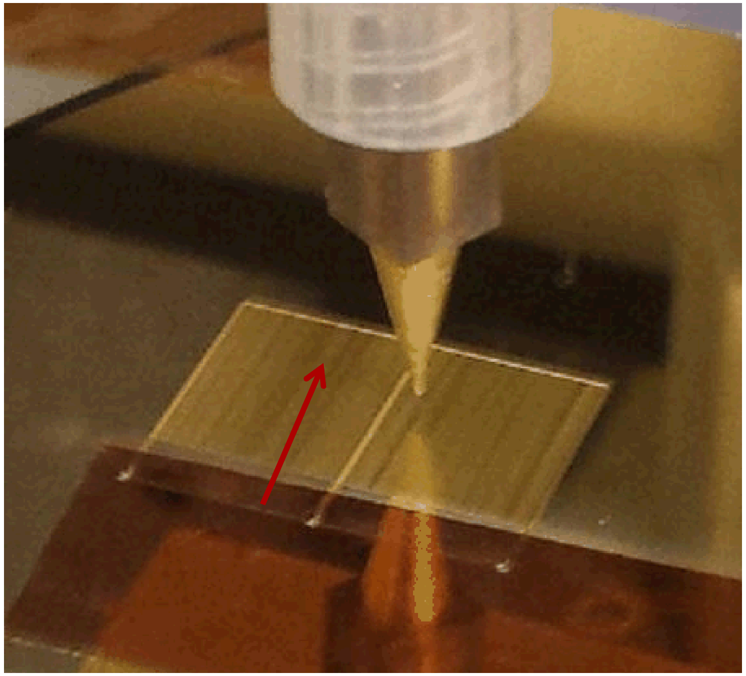
MycroJet Printing of Polyimide



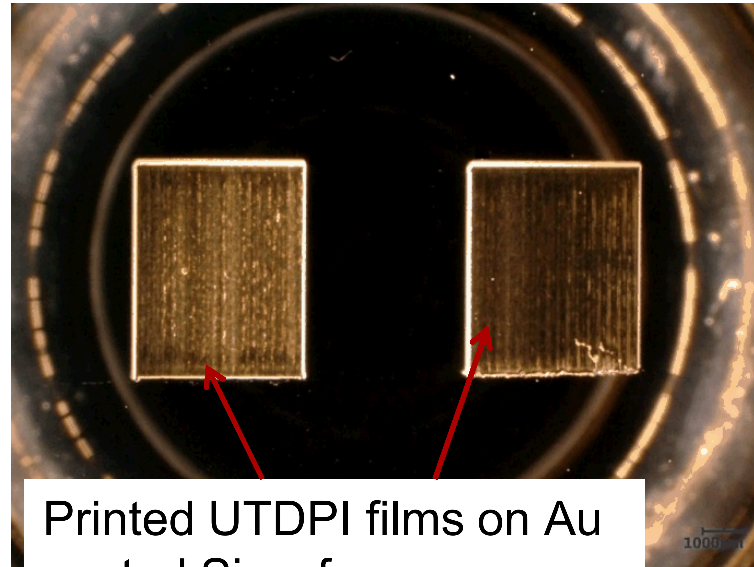
Video showing MycroJet printing of polyimide Films

MycroJet Print Conditions	
Aerosol Flow Rate (ccm)	20
Sheath flow rate (ccm)	45
Print speed (mm/s)	5
Substrate temperature (°C)	60
Number of passes	8-16

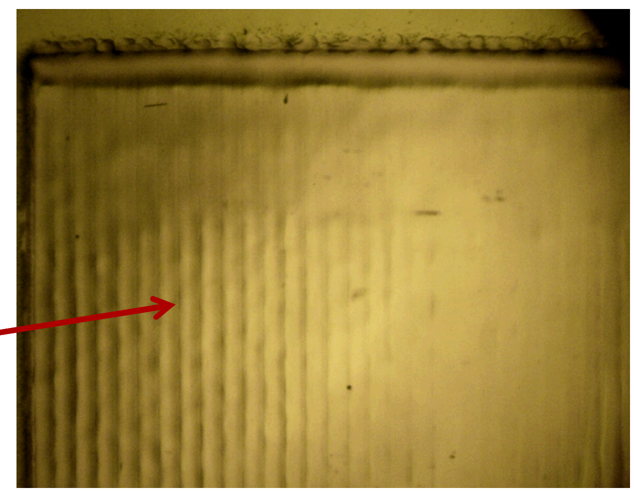
MycroJet Aerosol Deposition Work



MJ printing of UTDPI dielectric film



Printed UTDPI films on Au coated Si wafer

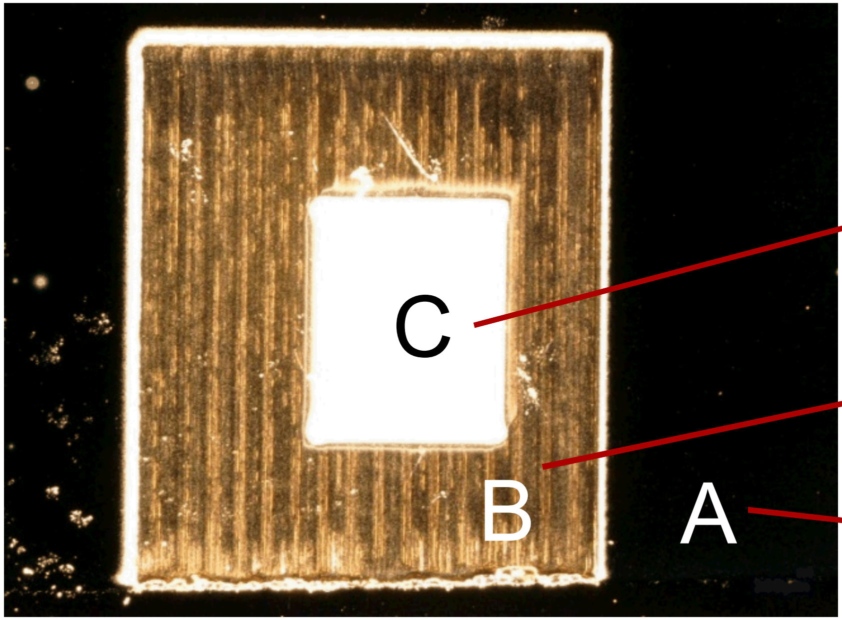


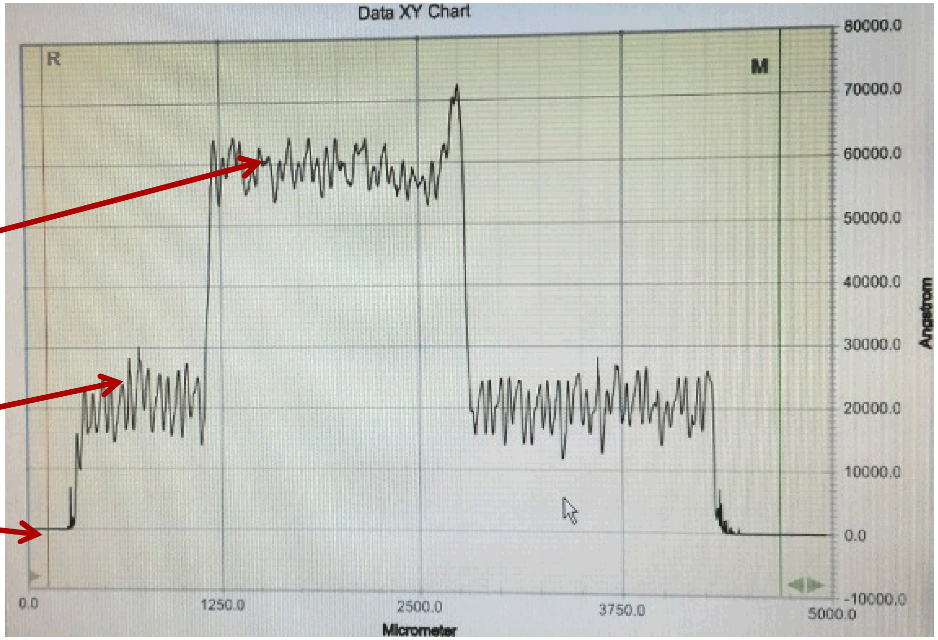
High magnification optical image of MycroJet printed polyimide film

MycroJet Aerosol Printing

Photomicrograph showing printed capacitor (a) Au on SI wafer, (b) polyimide printed and cured on Au layer and (c) Au printed pad on top of printed polyimide

Dektak profilometer plot showing thickness of printed capacitor (note surface roughness ~±0.5μ)



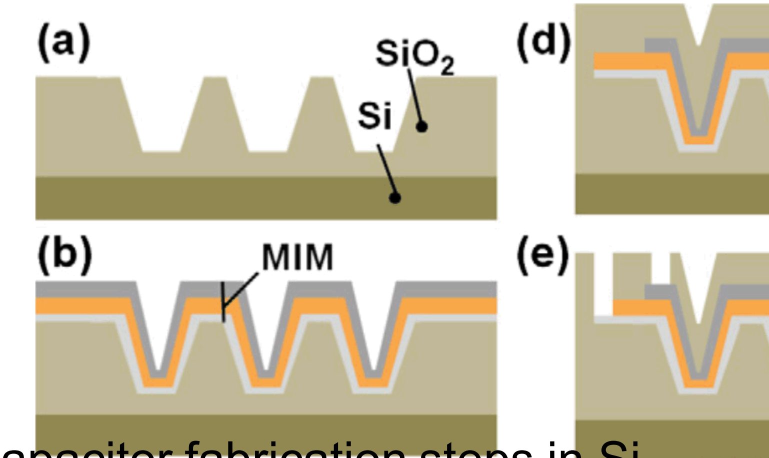


Conclusions

- Two methods have been demonstrated to print polyimide films for capacitors.
- Both methods should be capable of printing capacitors onto non-planar surfaces with uniform coating thickness.
- Electrical breakdown strength of the spray coated polyimide films is much less than that of a commercial film
- Current breakdown strength is very good given the maturity of the printing processes.
- Focus on improving surface roughness of the printed films should provide improvements in the printed film quality and performance.

Predicting 3D Capacitor Performance

- Modeling assumes parallel plate capacitors (Note: Etched Trenches)
- Models will be refined and expanded to include pin and socket structures
- Electromagnetic field modeling will guide novel capacitor designs.
- Thermal modeling will aid in material selection and predicting margins.



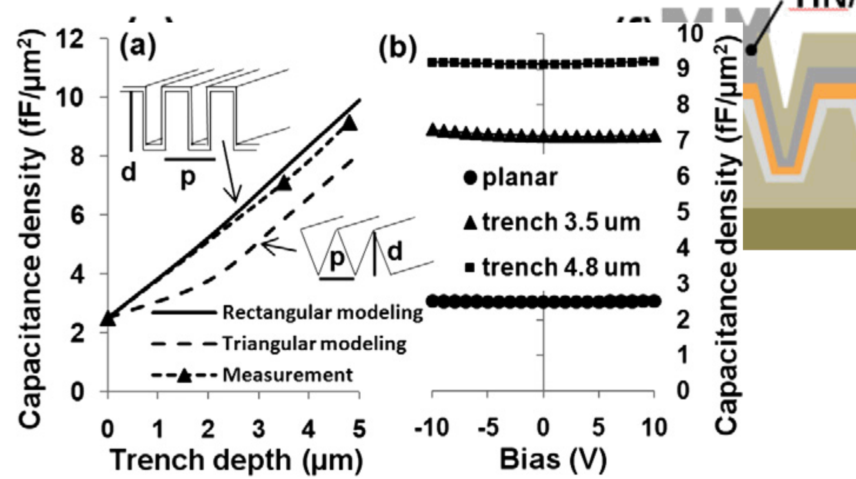
Capacitor fabrication steps in Si

Current level of modeling reported in literature

$$C_{d3D} = \frac{K.\varepsilon_0}{t}\frac{A_{3D}}{A_{2D}}$$

$$A_{3D} = \left(1 + 2.\frac{d}{p}\right)$$

$$A_{3D} = 2.\sqrt{\frac{1}{4} + \frac{d^2}{p^2}}$$



Calculated and measured results for 3D capacitors in Si.