



HP's Thermal Inkjet Technology and beyond – a micro to nano story

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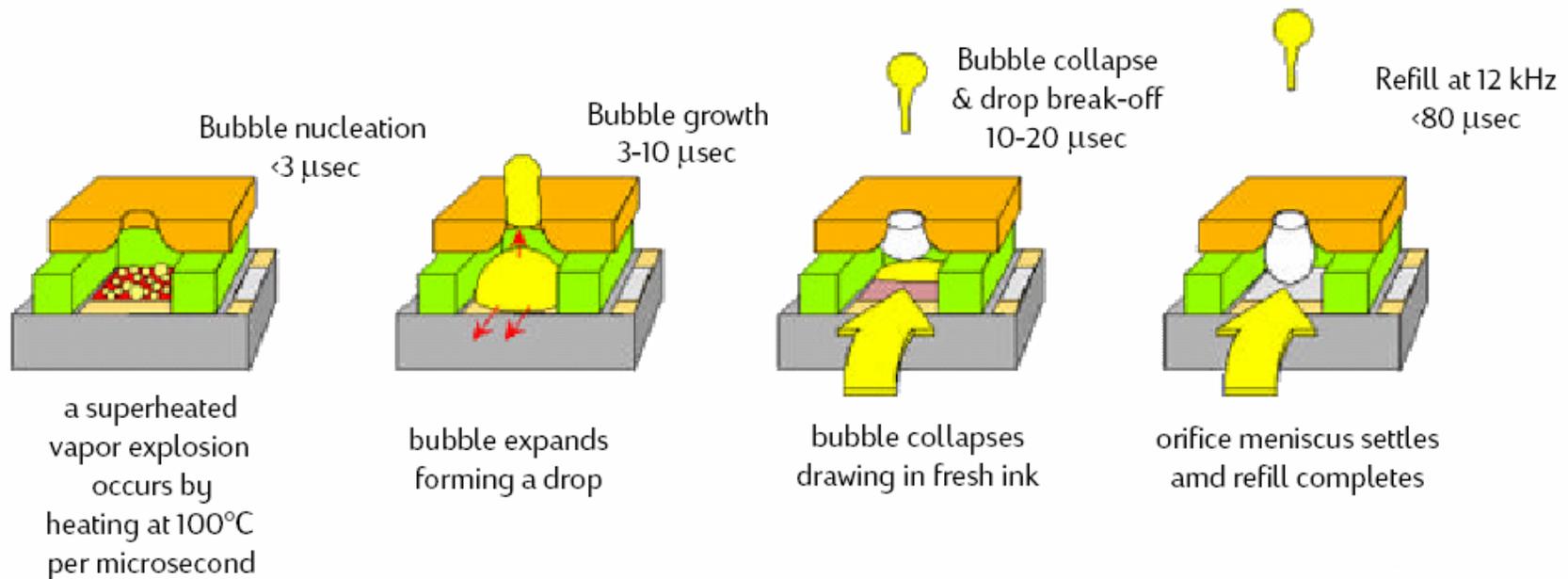
July 2004



Elements of HP TIJ Technology

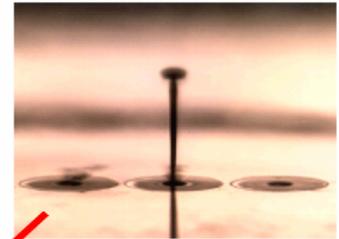
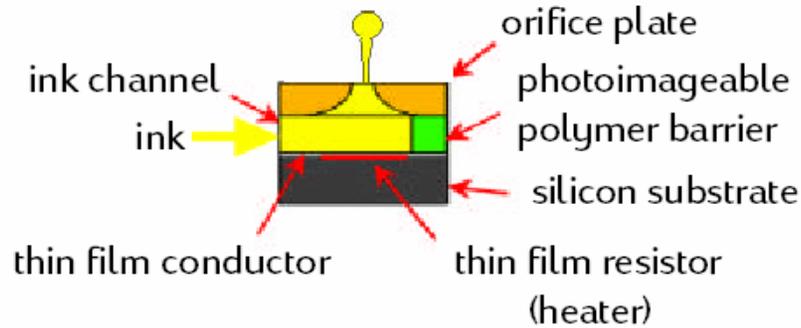
TIJ drop ejection process

- ✓an electrical resistor heats ink at more than 1,000,000 °C/second
- ✓a film of ink about 0.1 micrometer thick is heated to about 340 °C
- ✓a vapor bubble forms to expel the ink - it doesn't "boil"



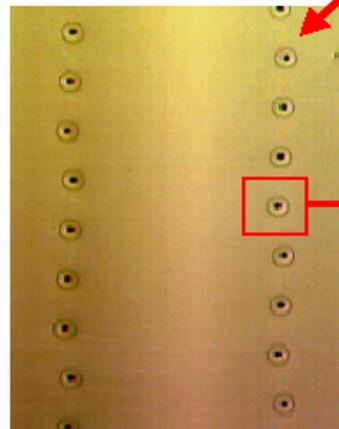
Elements of HP TIJ Technology

printhead detail

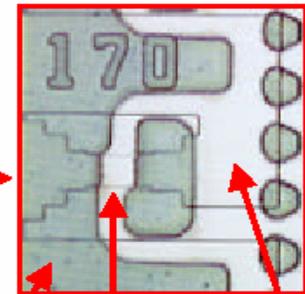


staggered orifices compensate for firing order and allow accurate dot placement at high firing frequencies

orifice plate detail

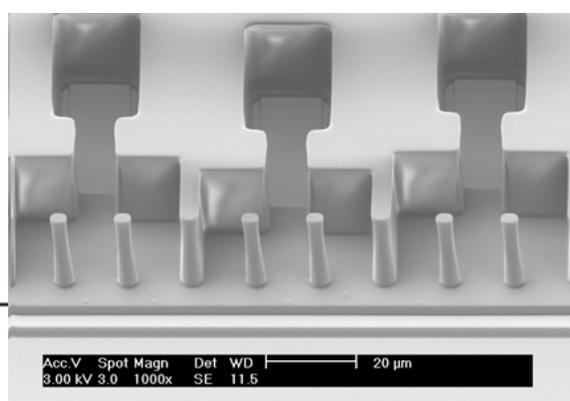


substrate detail (DeskJet 895C)

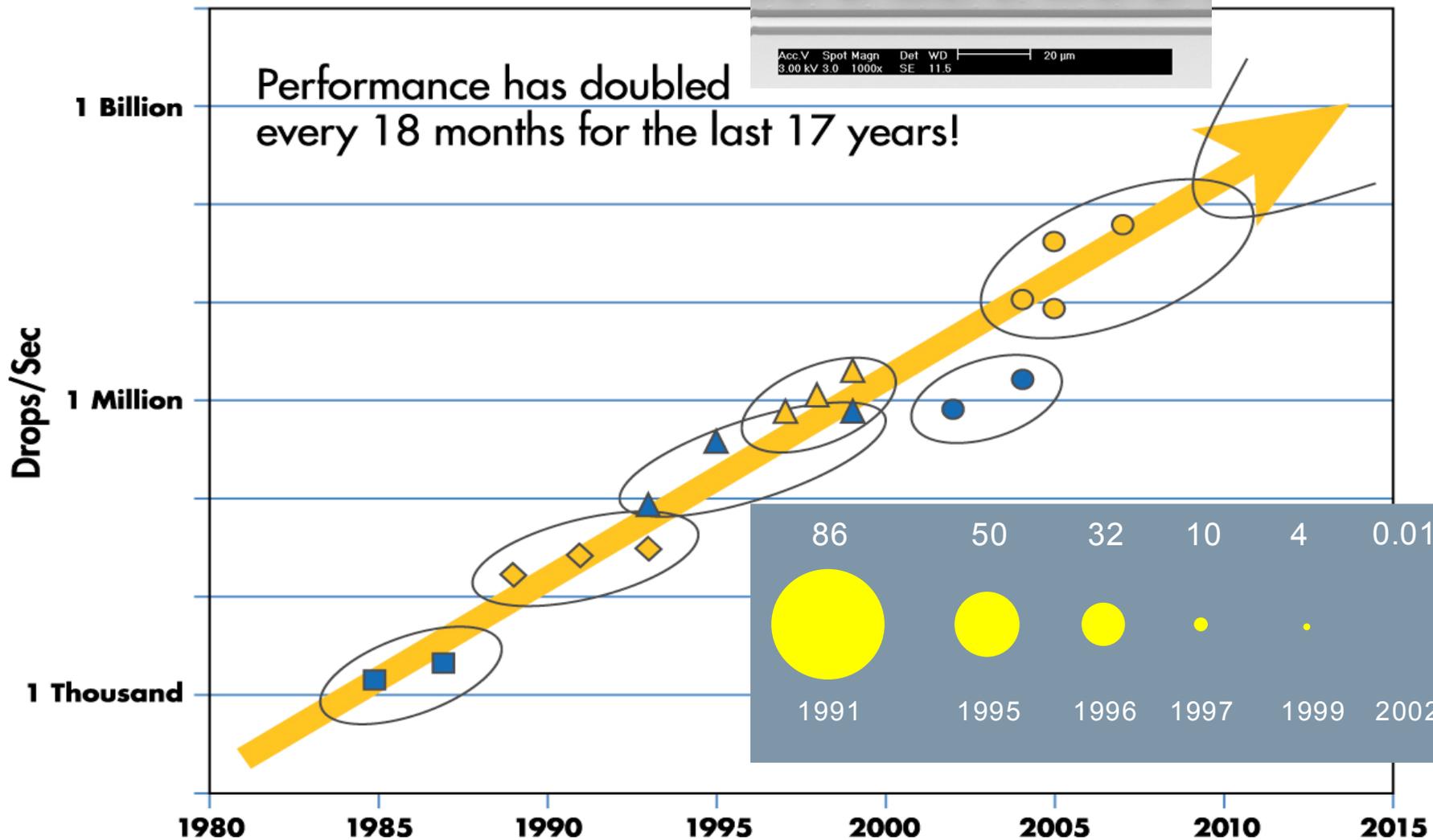


barrier heater ink channel

TIJ Progress



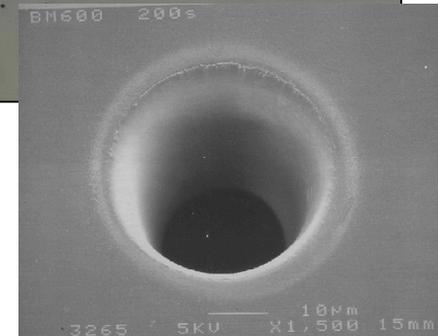
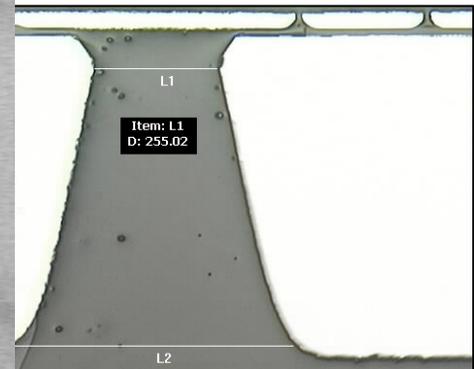
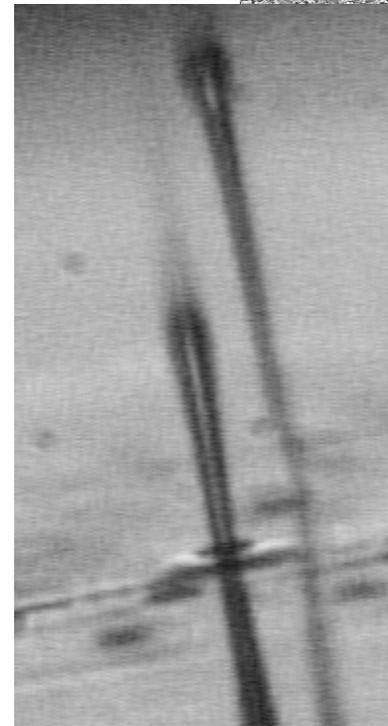
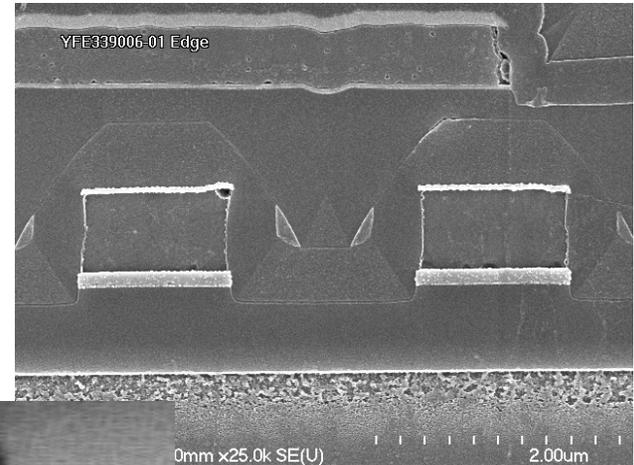
Performance has doubled every 18 months for the last 17 years!



HP Thermal Ink Jet (TIJ)



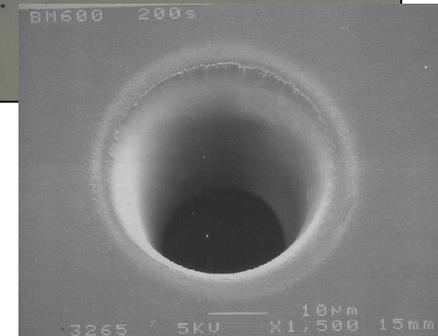
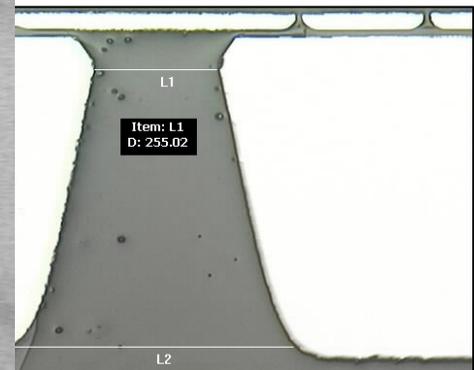
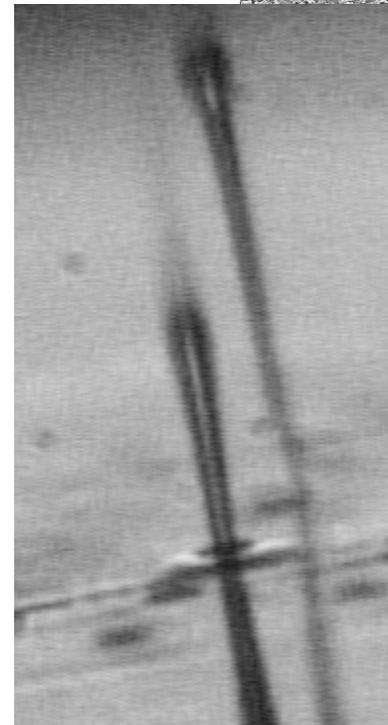
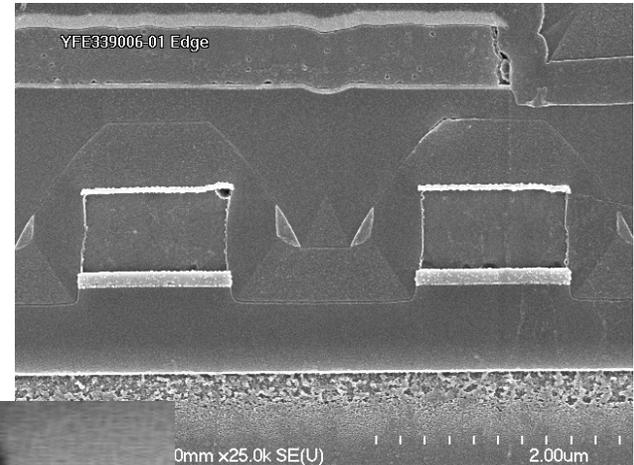
- 3.72×10^{18} drops printed by HP ink jet.
- Equal to every person in the world writing:
 - 1 dot/second
 - 24 hours/day
 - every day
 - 18 years



HP Thermal InkJet (TIJ)



- Industry leading integrator of μ electronics (0.5m), μ machining and μ fluidics in high volume (i.e. 50M/month)
- HP Corvallis has driven the Inkjet Moore's Law
- Technical foundation for further product R&D





Printed Materials and Devices



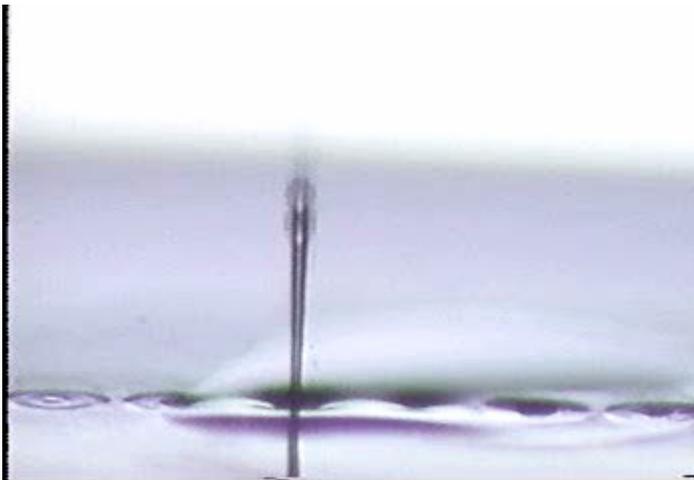
Some facts about Thermal Ink Jet

The world has:

- Ink-jetted the semiconductor components of organic transistors
- Ink-jetted conductors out of solutions

And has not yet:

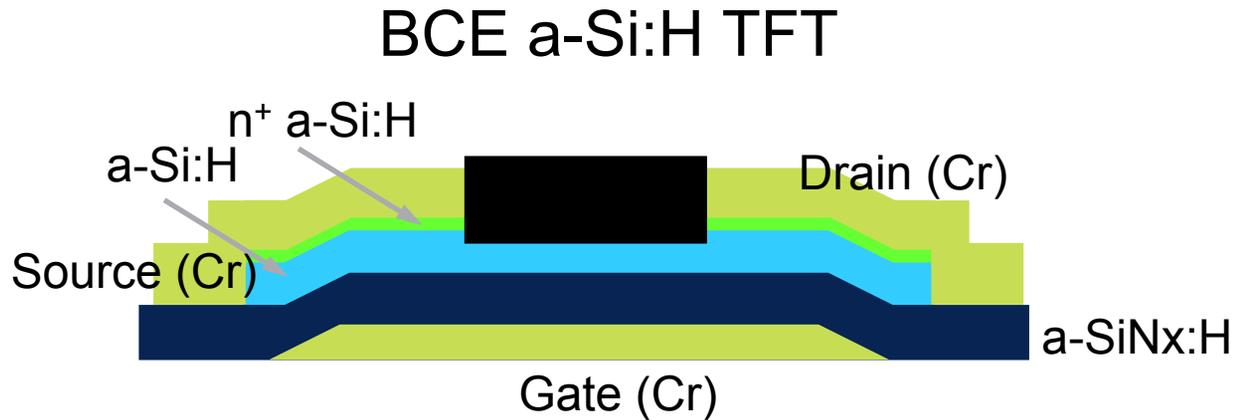
- Built entire functioning circuits, (including source and drain contacts)
- Ink-jetted anode and cathode for OLED displays



HP has jetted the following materials:

- PEDOT (polymeric solution)
- PANI (Polyaniline)
- P₃HT
- Nanoparticle solutions
- Other chemical precursor solutions
- Methanol
- Toluene
- Gasoline
- UV Curable Adhesives
- Color Filters
- Inorganic semiconductor mat'ls

Amorphous-Si Thin Film Transistor



General TFT Needs:

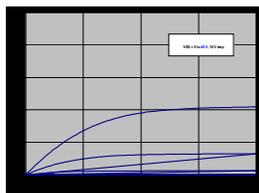
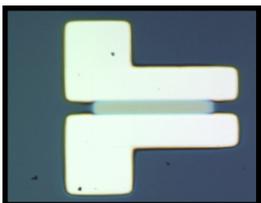
- Ohmic contact between Source/Drain and Semiconductor
- Pinhole free dielectric (a-SiNx:H)
- High quality Dielectric/Semiconductor interface

i.e., smooth, no trapped electrons, no fixed charge, ...

Printing Active Devices

Bottom Gate

Sputtered

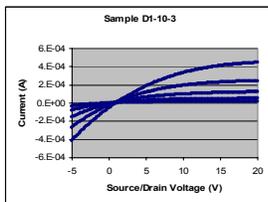
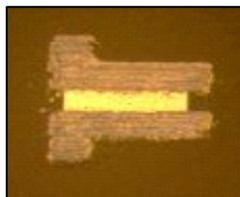


- Printed interfaces: 0
- Patterned components: 2

Sputtered

Printed Source-Drain

Bottom Gate

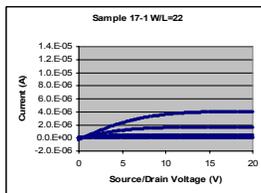
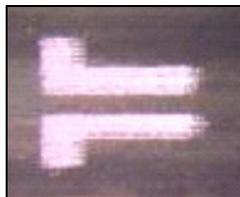


- Printed interfaces: 1
- Patterned components: 2

Printed Source-Drain

Printed Channel and Source-Drain

Bottom Gate



- Printed interfaces: 2
- Patterned components: 1

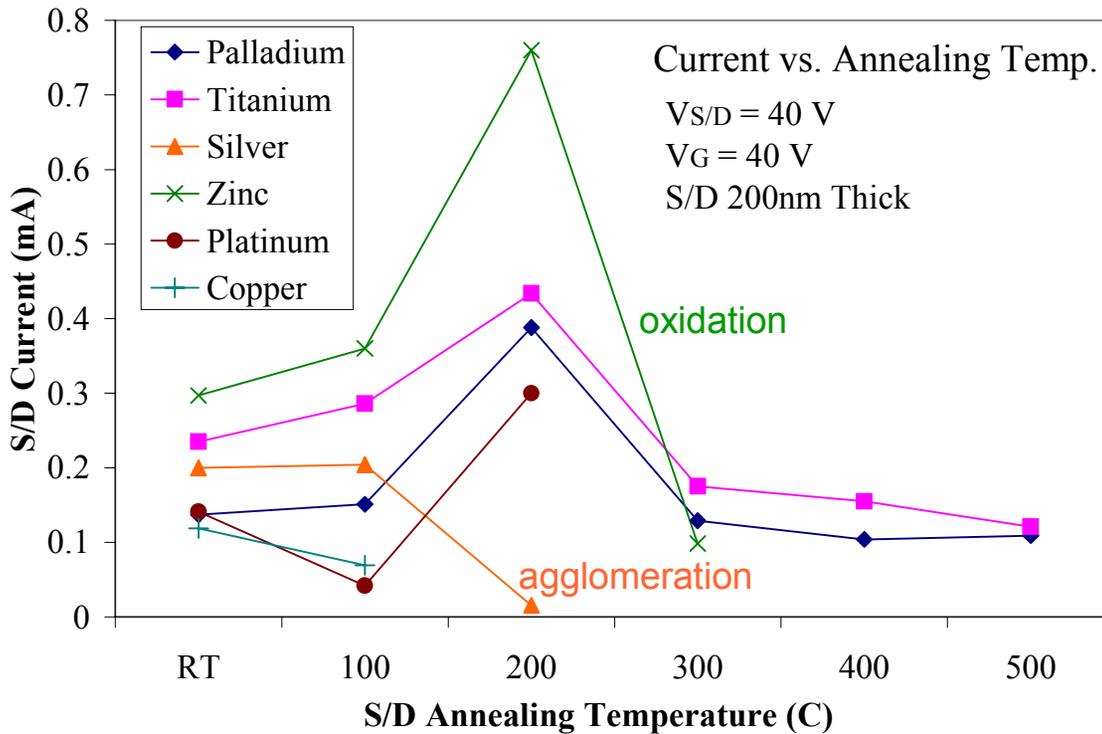
Printed Channel and Source-Drain

Increasing
Complexity
And
Challenges

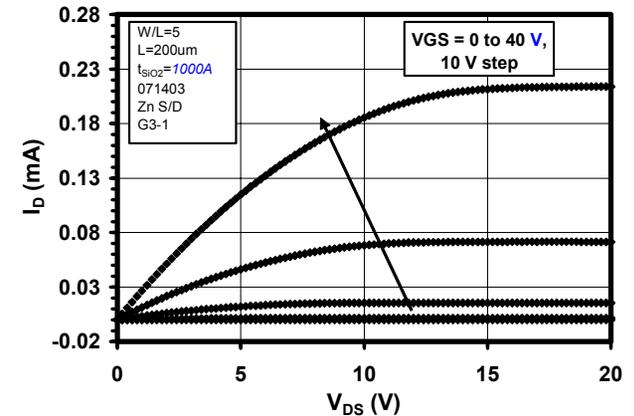
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Source-Drain/Semiconductor Contacts

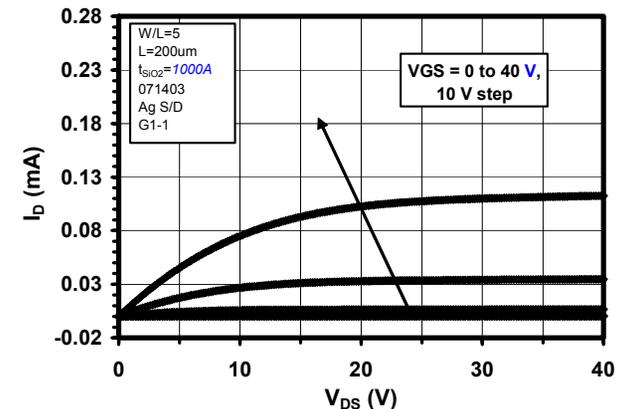
Evaluate vacuum processed materials



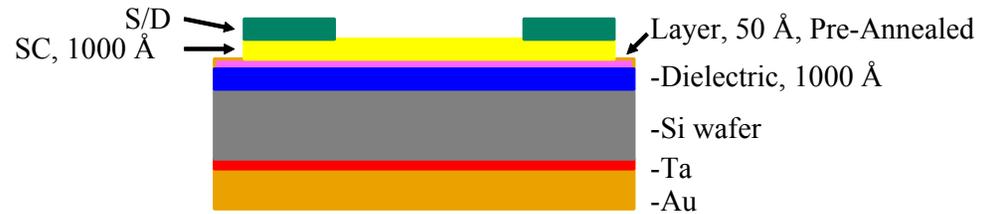
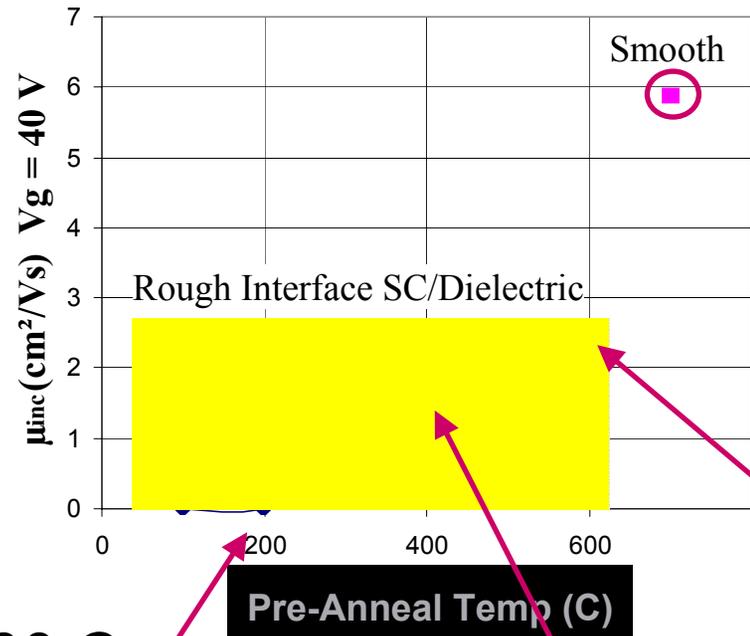
Zn Source and Drain



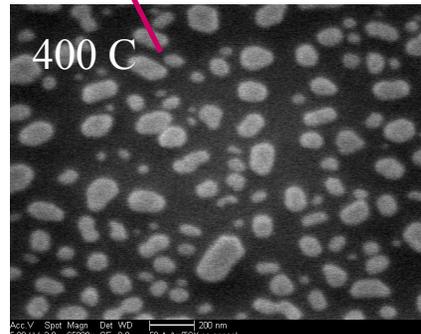
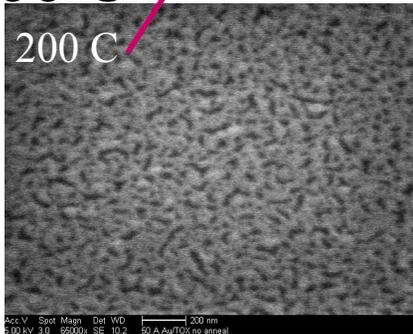
Ag Source and Drain



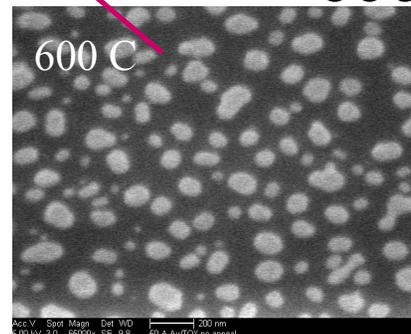
Effect of Rough Dielectric/Semiconductor Interface



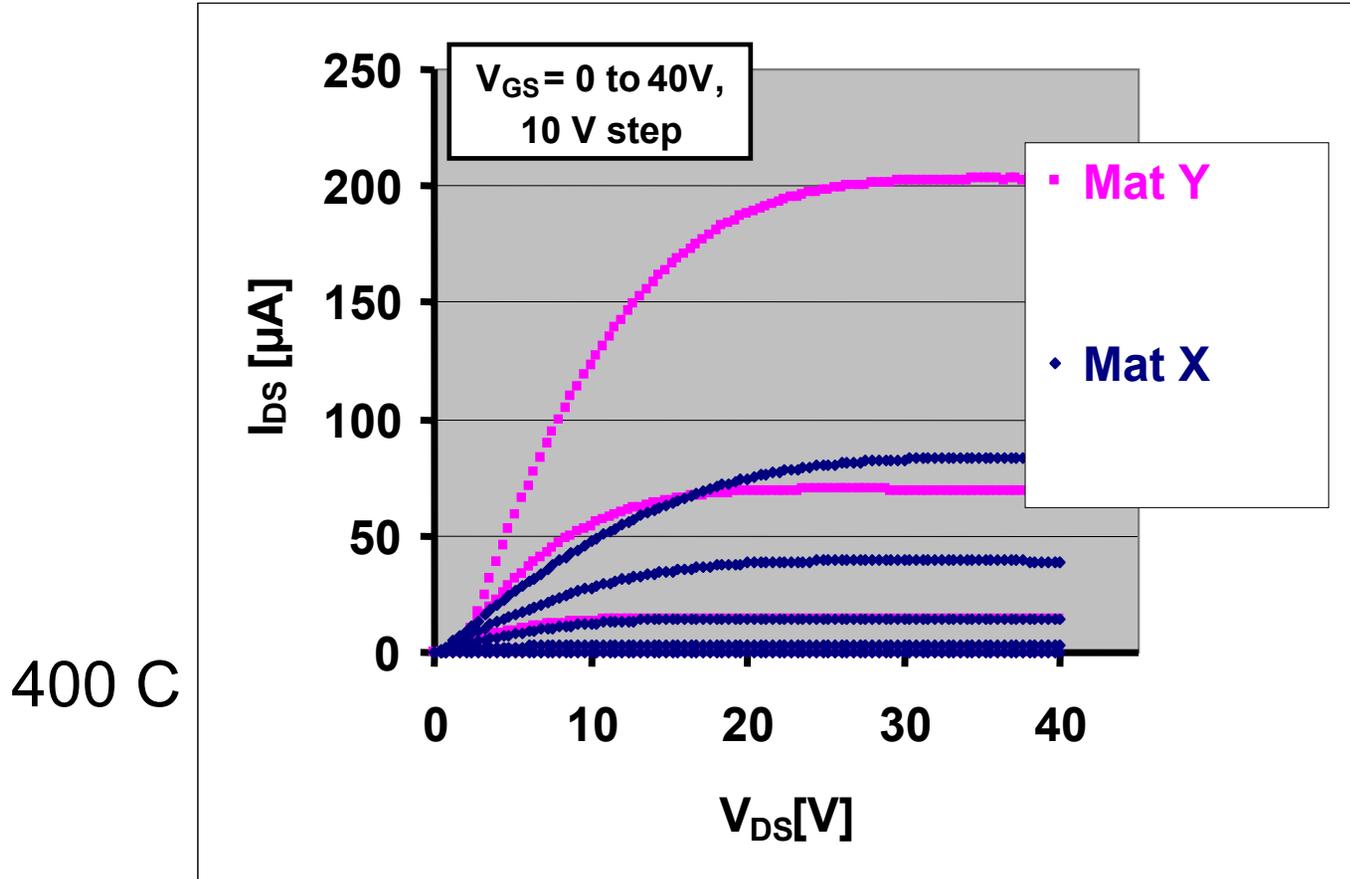
400 C



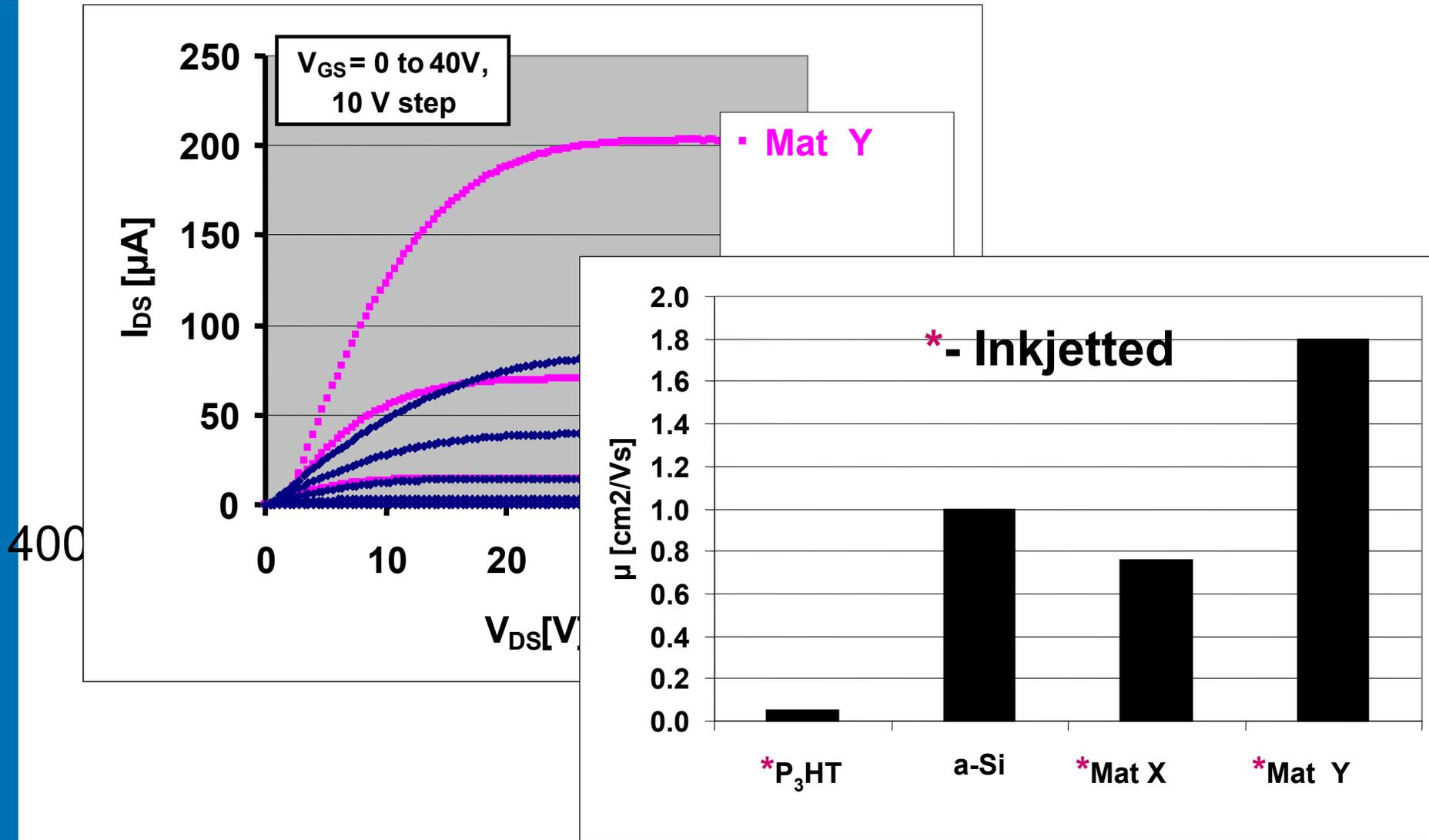
600 C



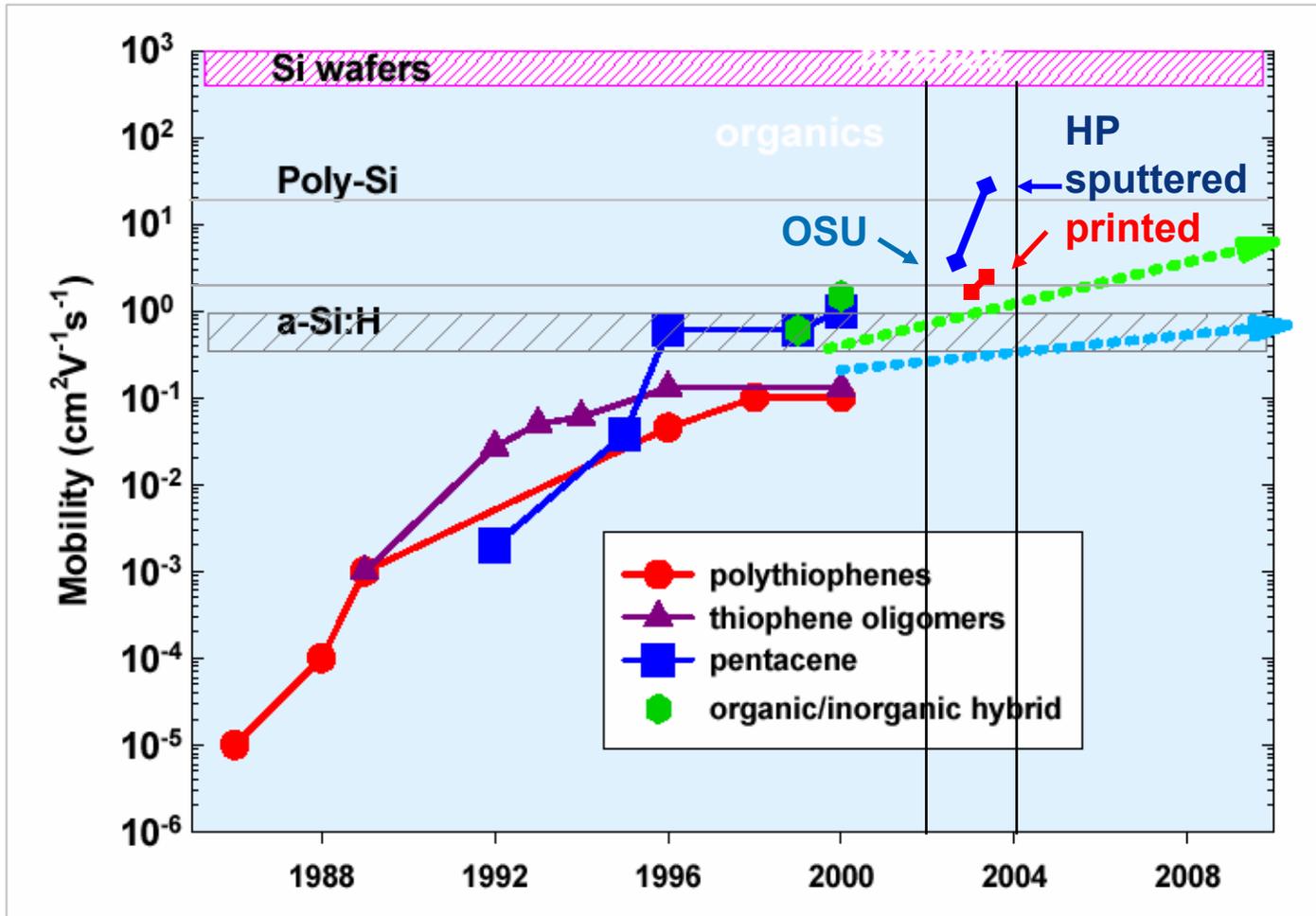
Inkjet Printed Semiconductors



Inkjet Printed Semiconductors



Semiconductor Material Benchmark



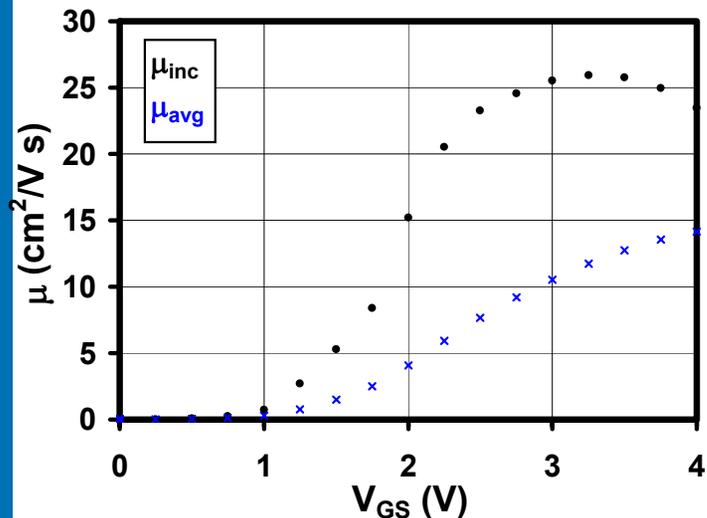
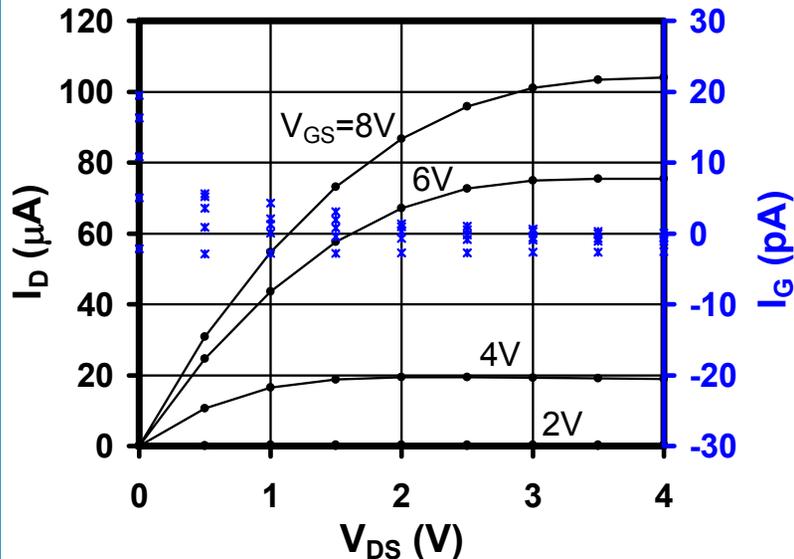
Today's processors

Low cost IC's

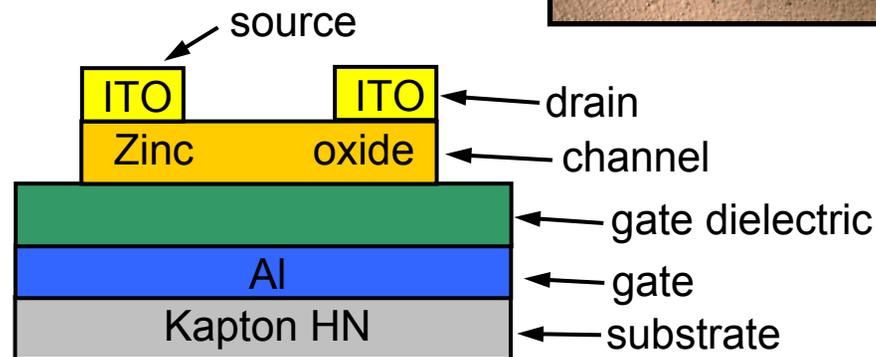
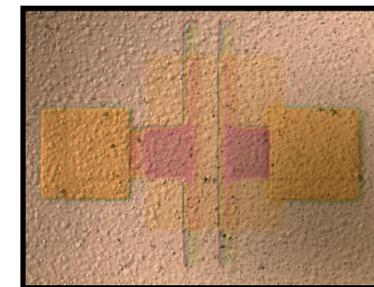
Smart Cards, displays

E-paper

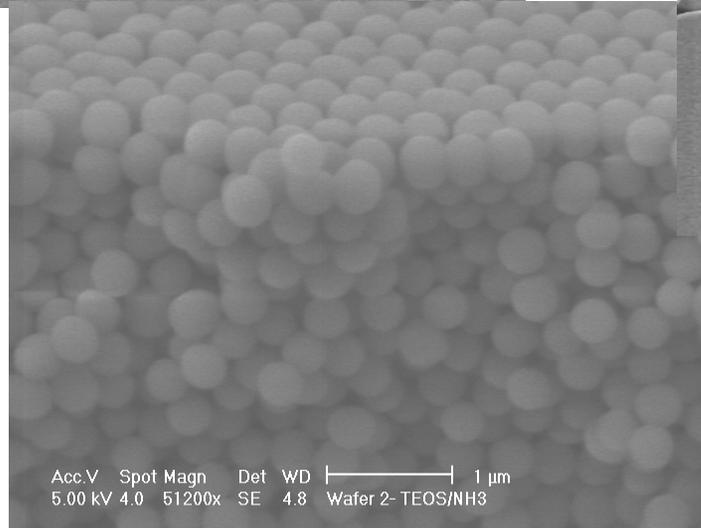
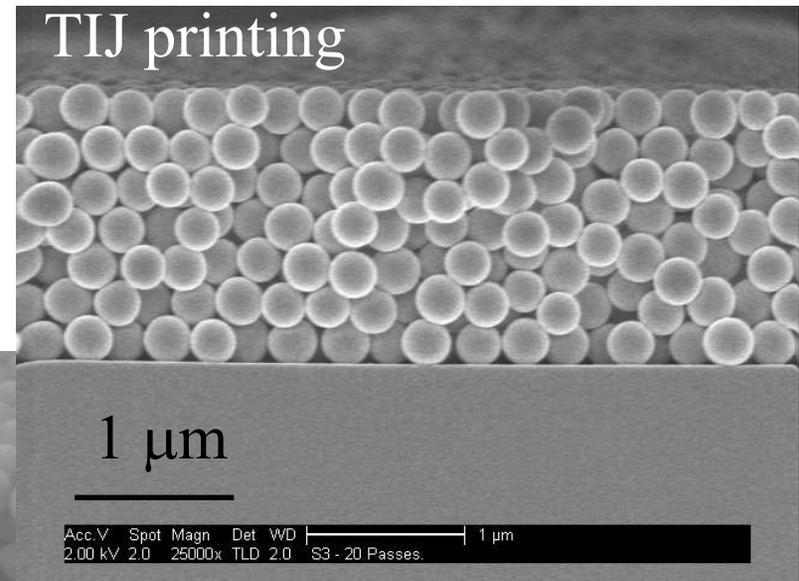
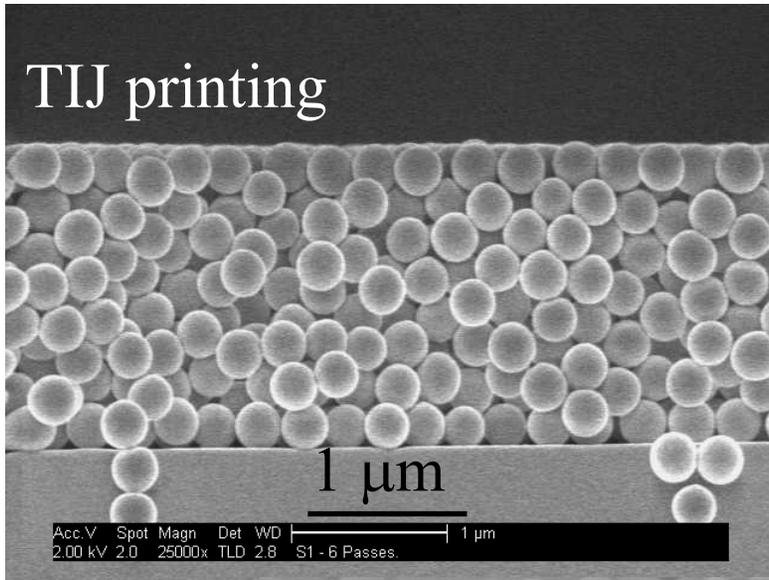
Flexible TFTs



- Kapton HN flexible substrate
- Anodized gate dielectric
- Low-temp sputtered zinc oxide semiconductor
- Maximum processing temperature $125\text{ }^\circ\text{C}$ (thermal anneal)
- Peak mobility (μ_{inc}) $\sim 25\text{ cm}^2/\text{V s}$
- I_D on/off ratio $\sim 10^7$



TIJ Self Assembled Opals



Summary

Printed passive and active electronic devices by thermal ink-jet have passed the feasibility test

The capability to build circuits is an emerging reality

Lots of work needs to be done

- Materials optimization, device modeling
- Ink-jet architecture design, materials compatibility

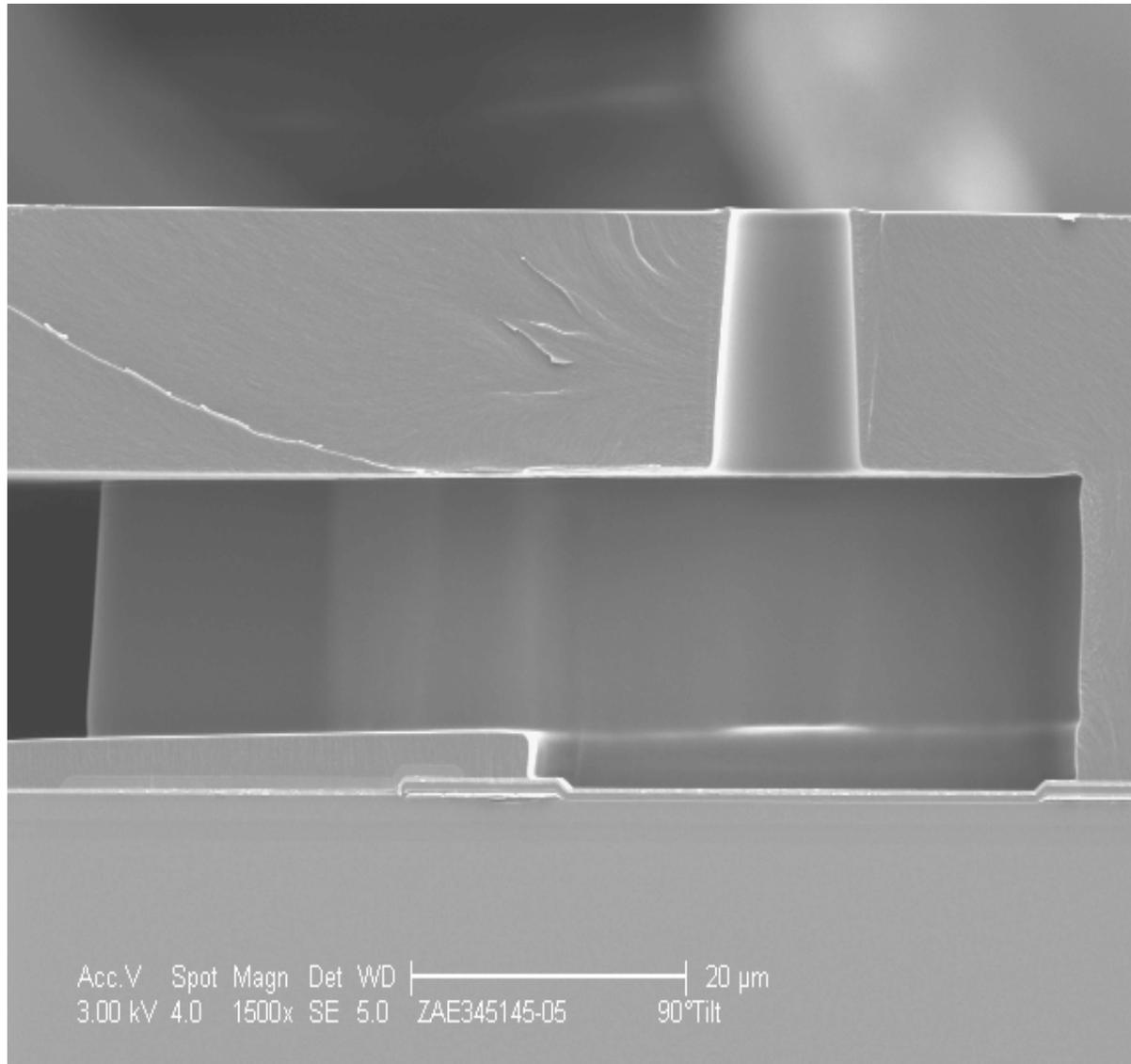
=> Lots of opportunities



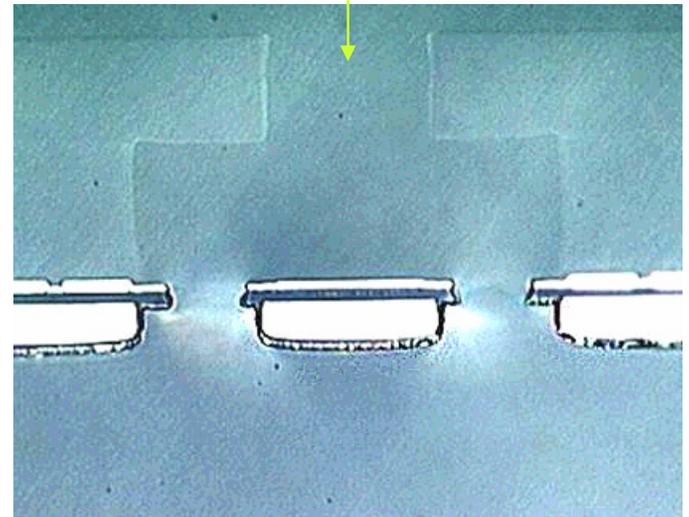
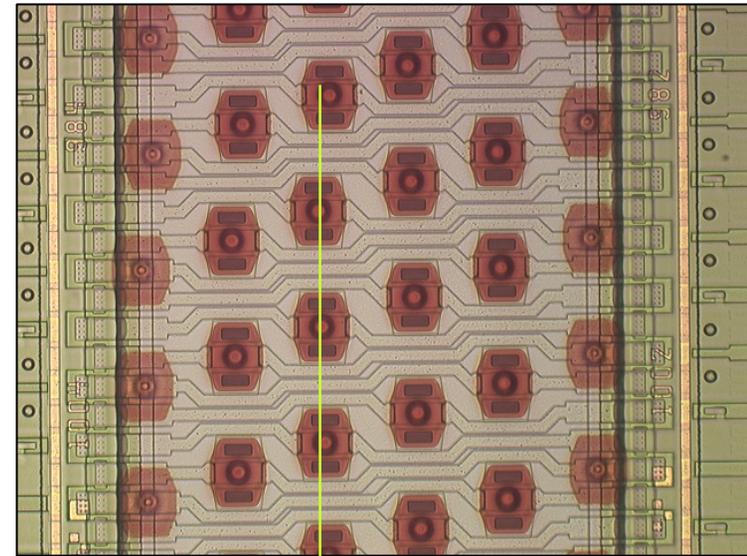
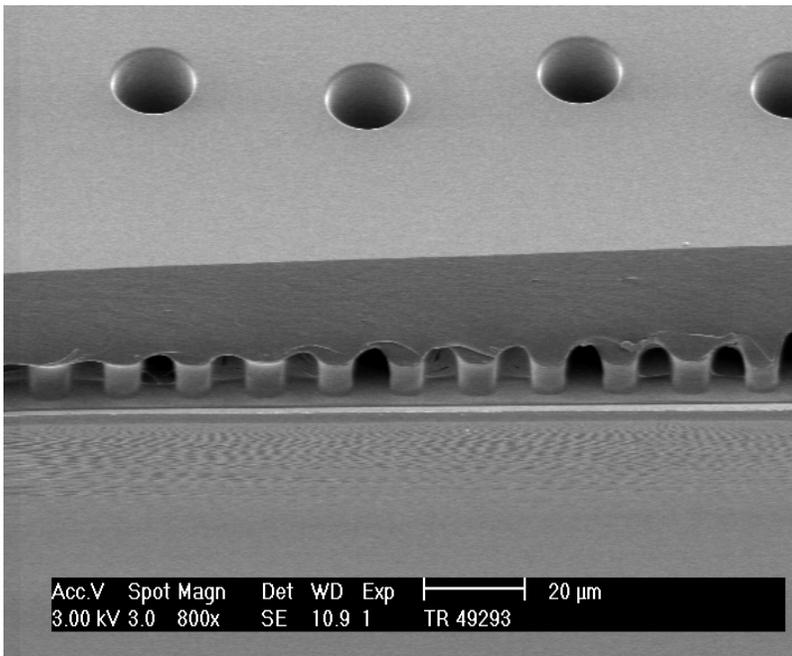
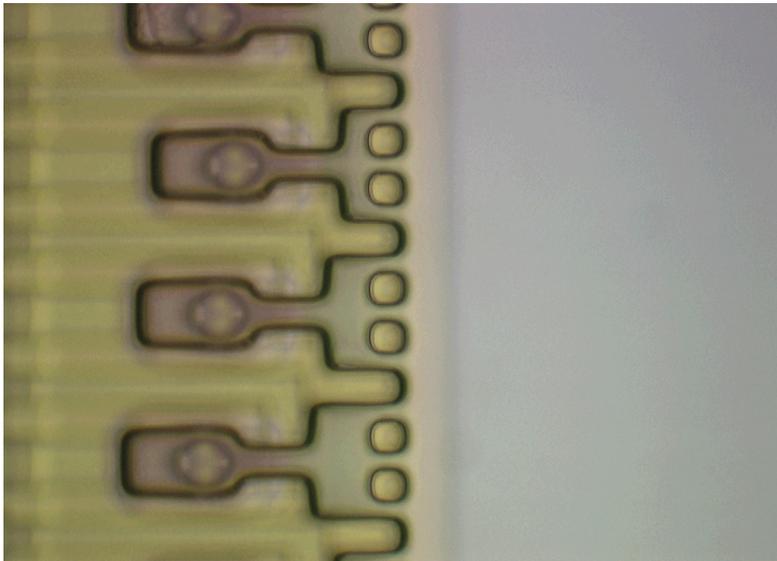
MEMs



Firing Chamber Cross-Section



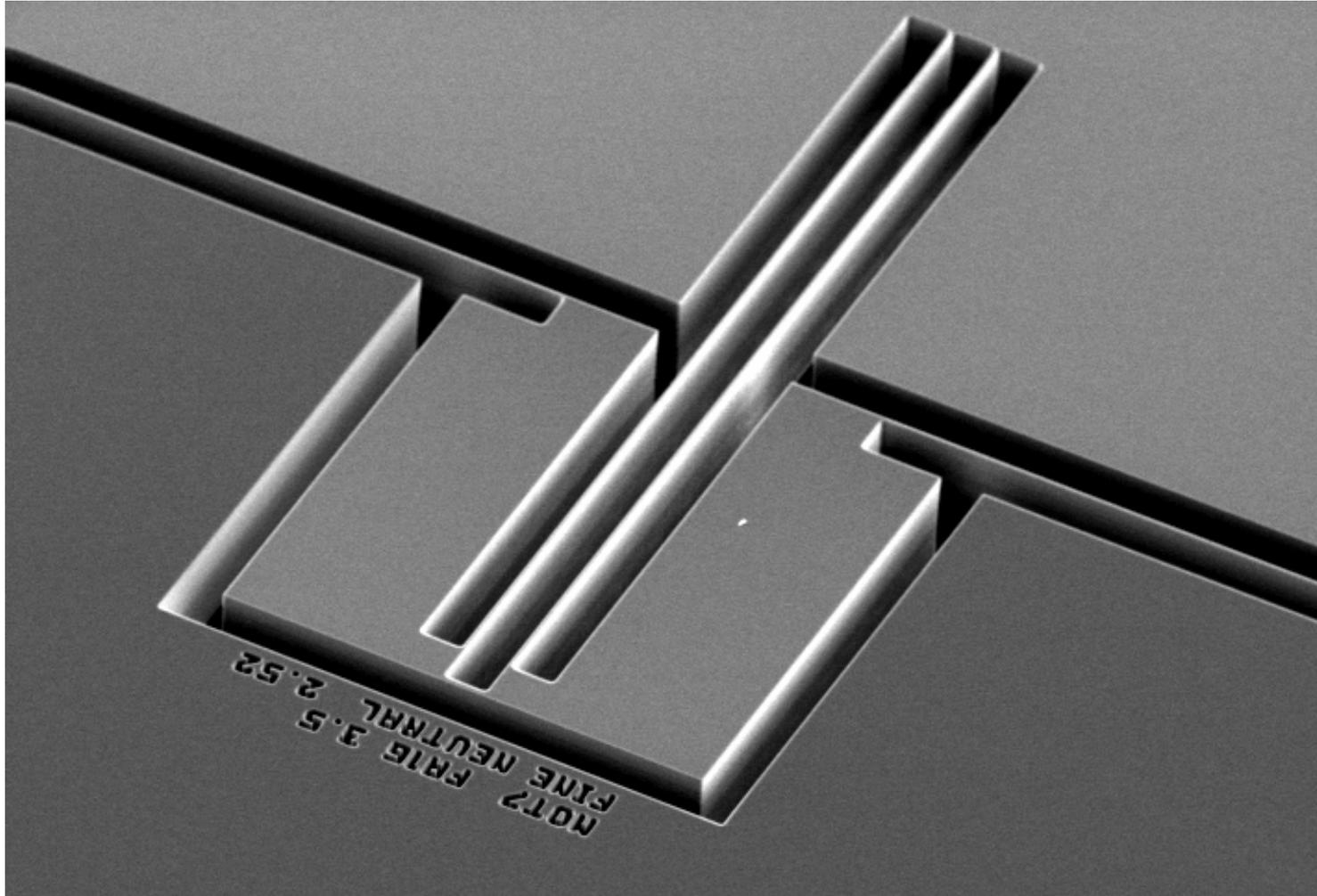
TIJ 4 – New FIT options



XY Table

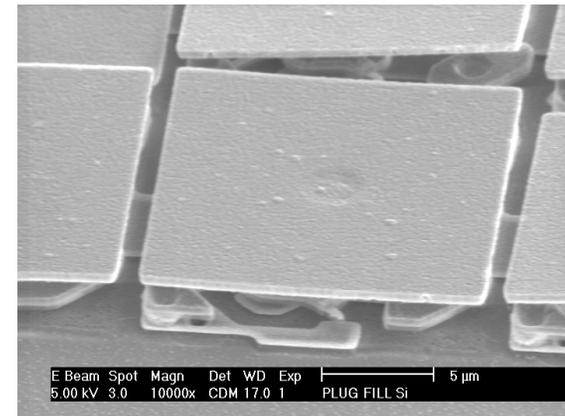
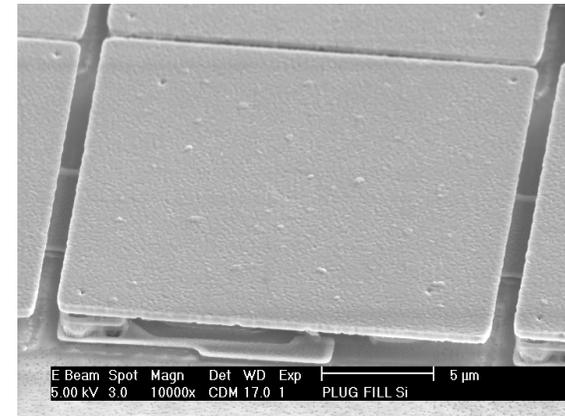
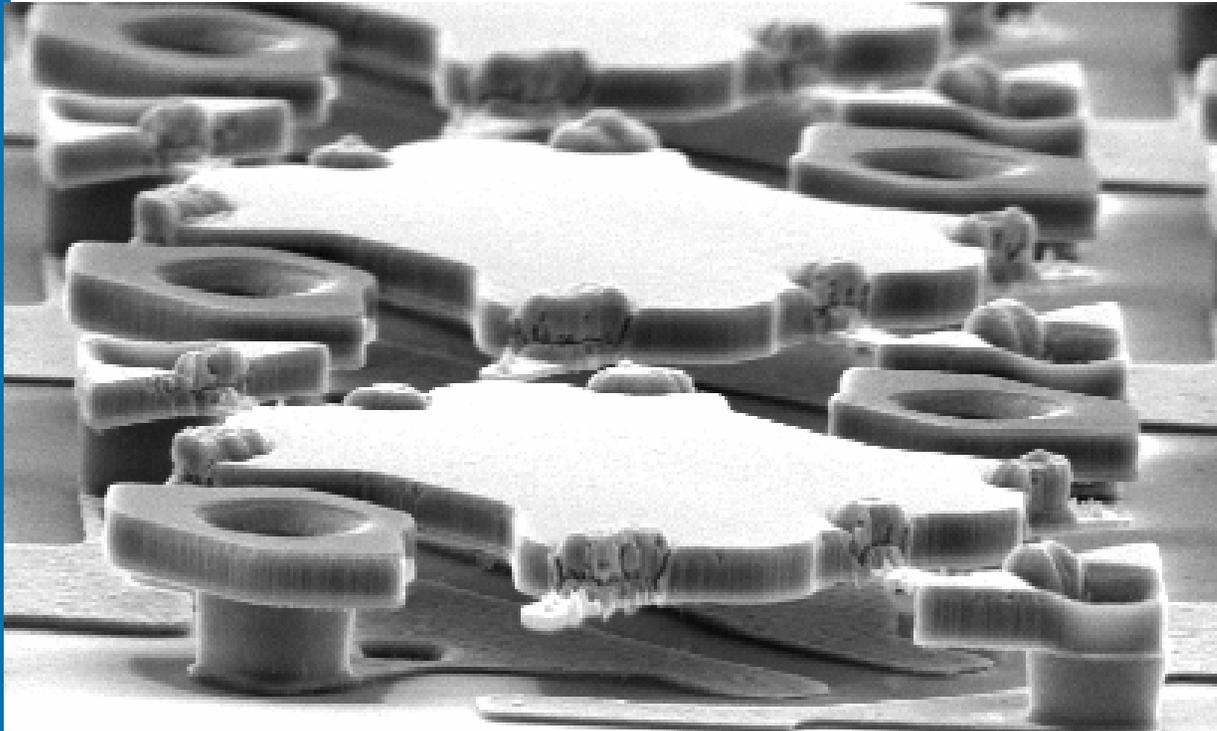


- +/- 20 μ m range
- +/- 4nm open loop
- +/- 1nm closed loop



HP TDO MEMs

A complex electrostatically driven
spring loaded structure.





Nanoscience/Technology Capabilities

HP TDO calls it Applied Molecular
Systems (AMS)

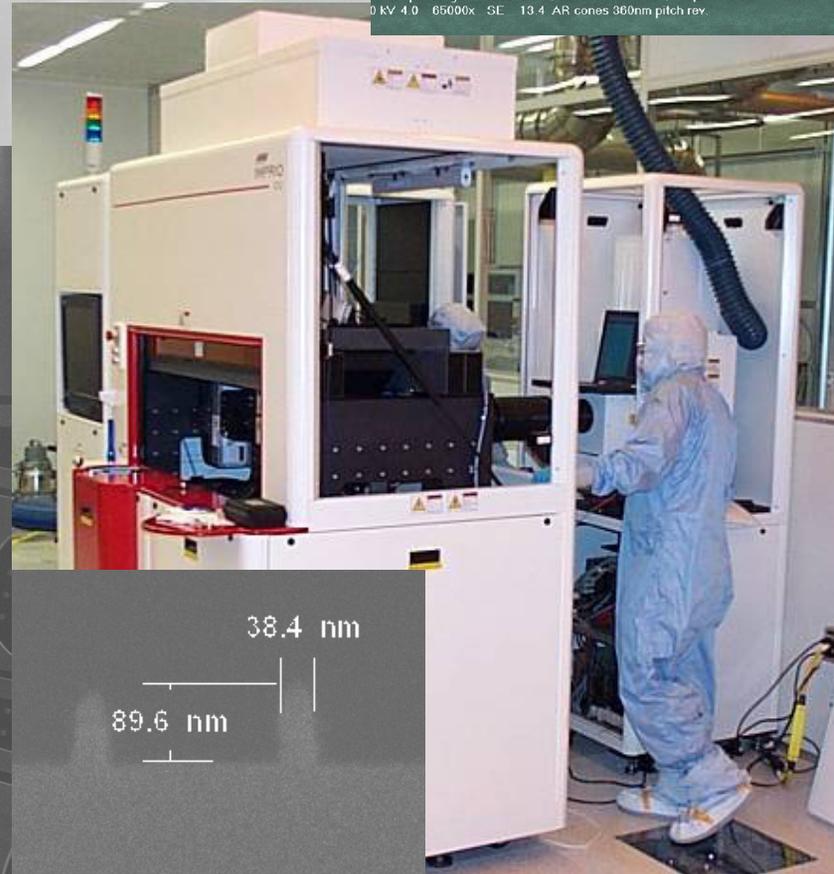
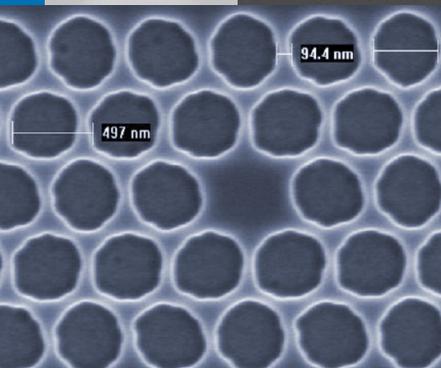
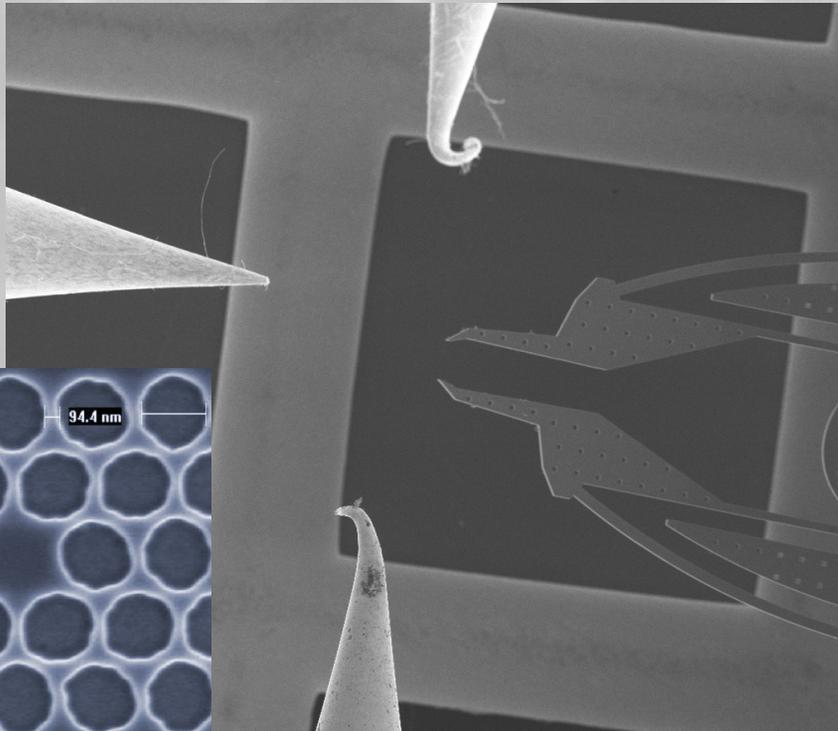
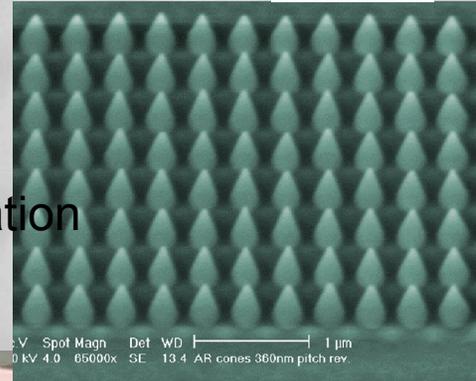


Current Nanotechnology Capabilities Portfolio



- Imprint Lithography
- Nanoscale quick proto (Ebeam/FIB/Zyvex)
- Self Assembly
- MEMs/IC/Fab integration
- Microbond Packaging

- Materials Research
- "Full Periodic Table" deposition
- Physical Nanoscale Modeling
- Nano Scale Device Characterization

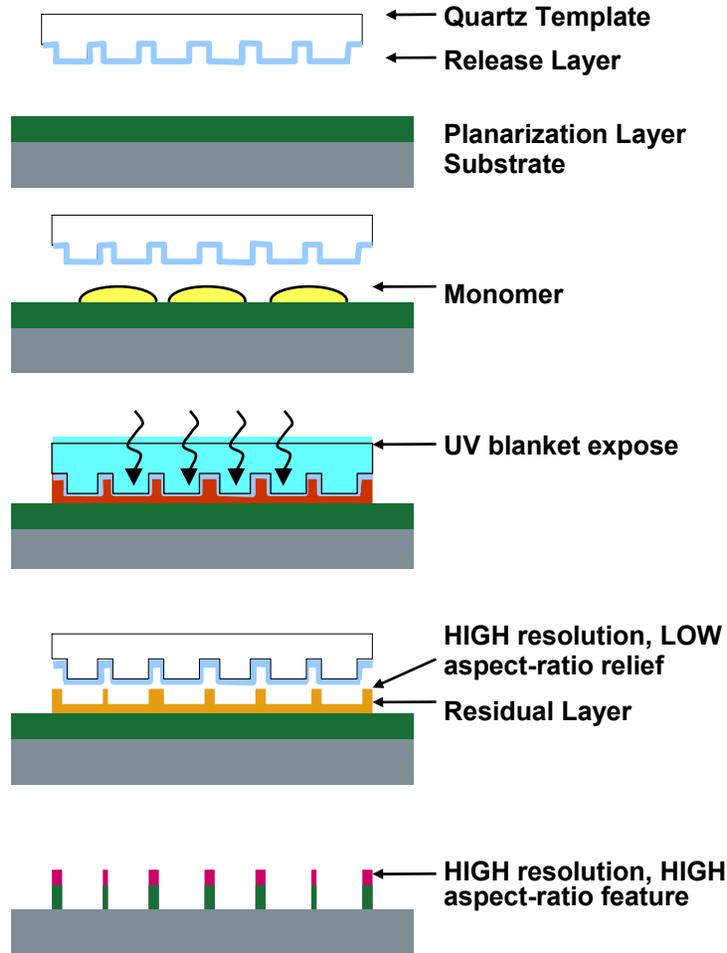


Spot Magn Det WD | 1 μm kV Det SED | 100 μm
Zyvex in B7 DB235-02

Nano Imprint Lithography Development



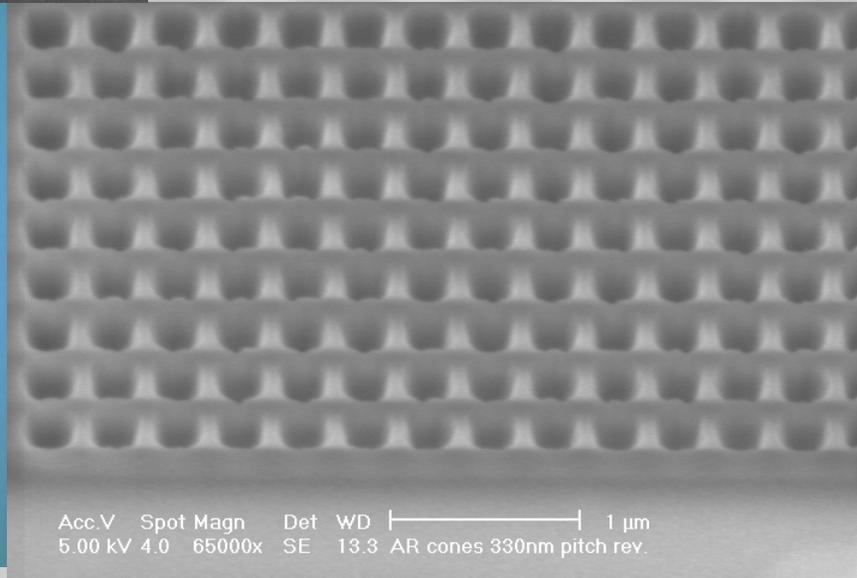
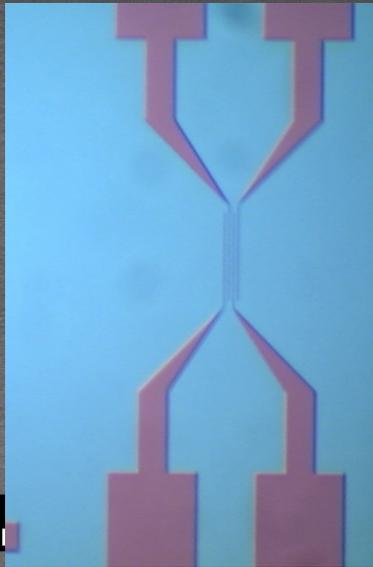
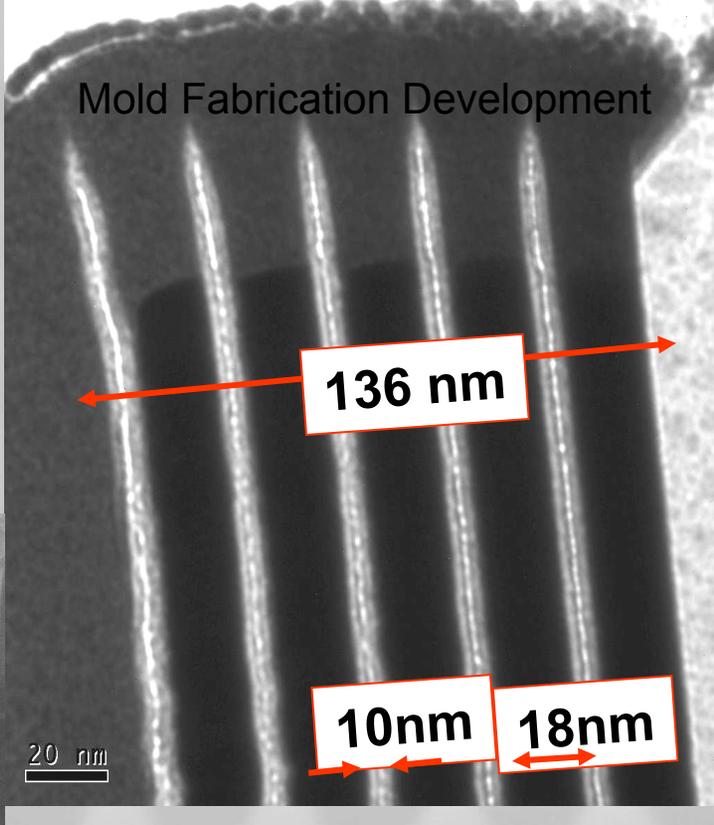
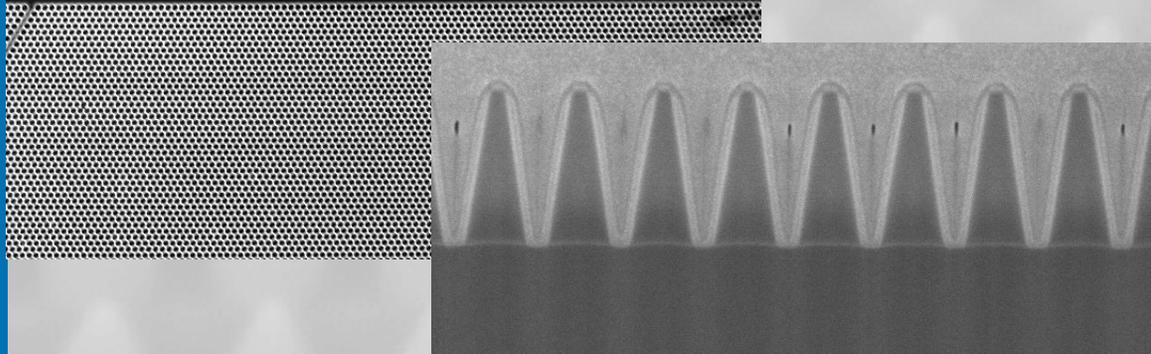
Step and Flash Imprint Process



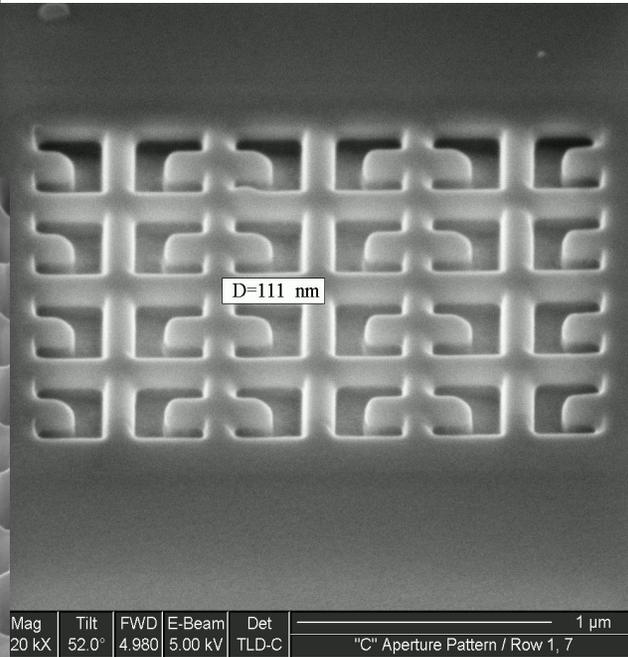
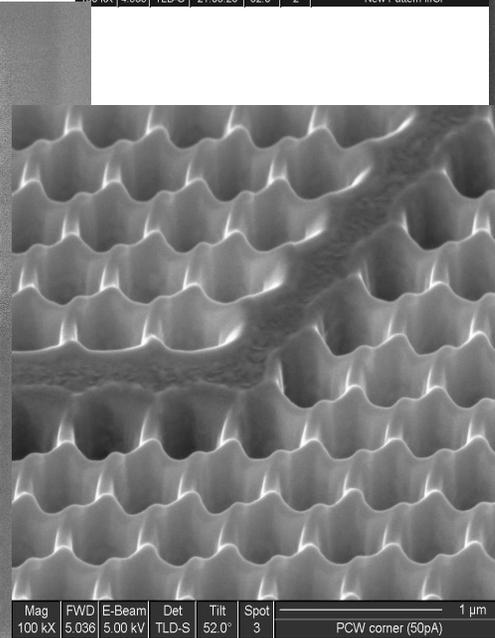
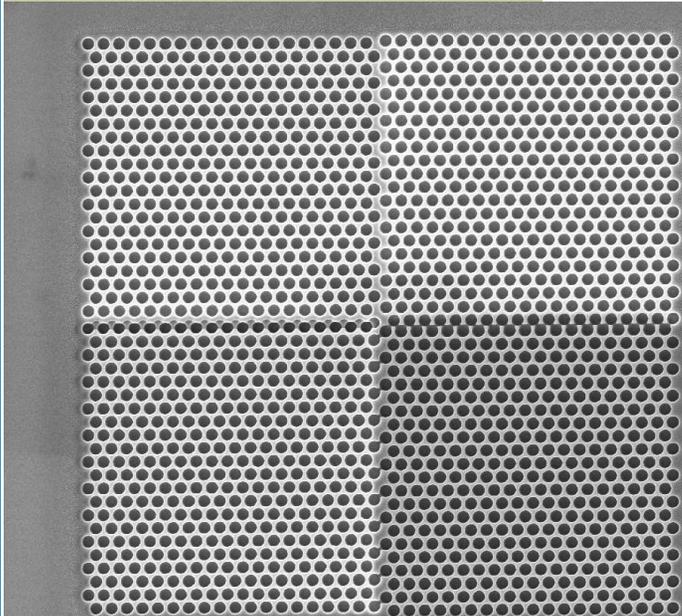
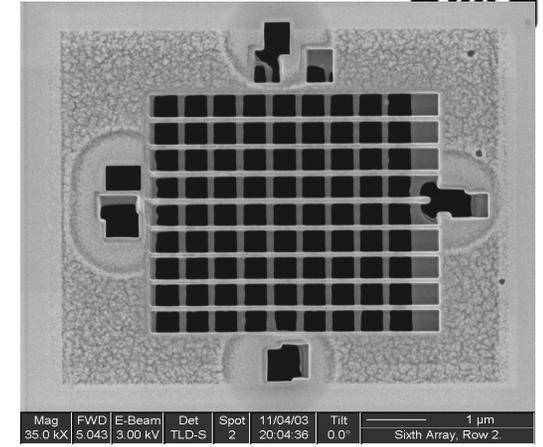
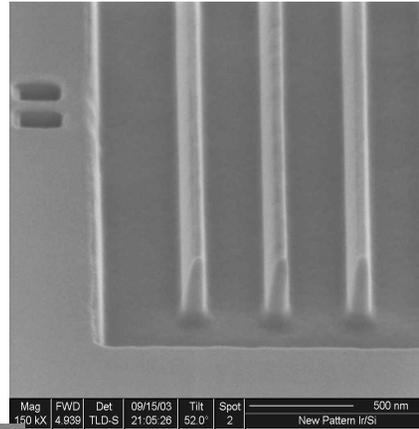
Feature sizes
<50nm
Imprint Area 150mm
Compatible with
many Polymers
Low Residual
Thickness

Disadvantages:
Large Mold Creation
High Pressure /
Temperature
Overlay Alignment
Accuracy
Thermal stress
Pressure
Induced stress
Film Induced
Stress

Nano Imprint Structures

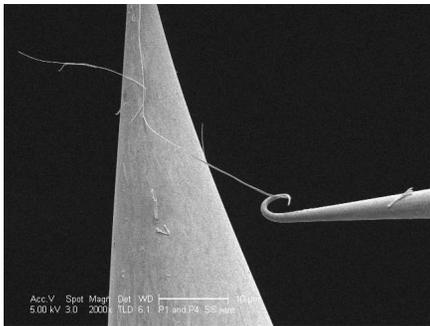
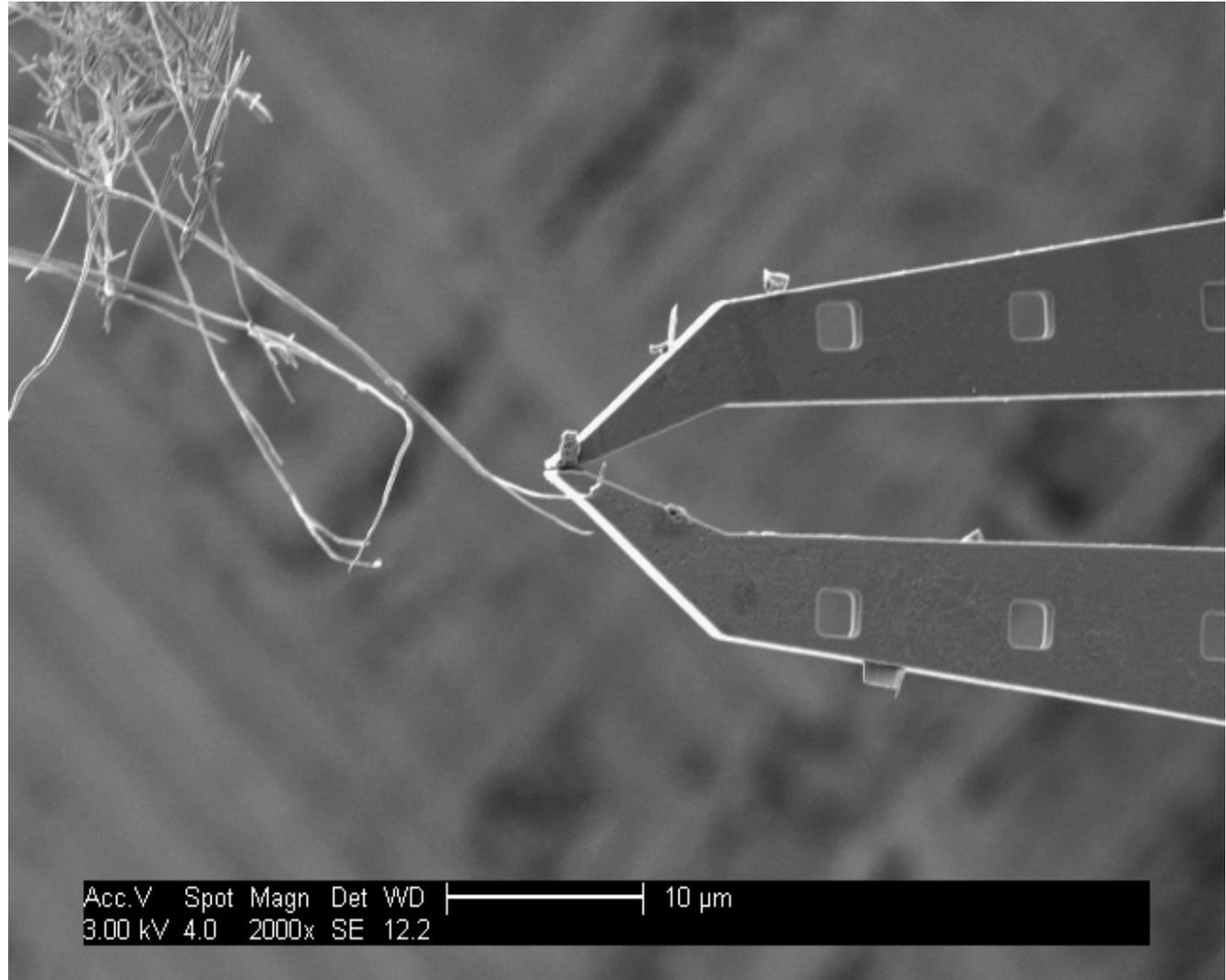


Nanomachining and Fabrication

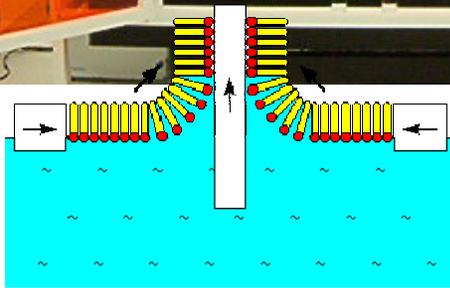
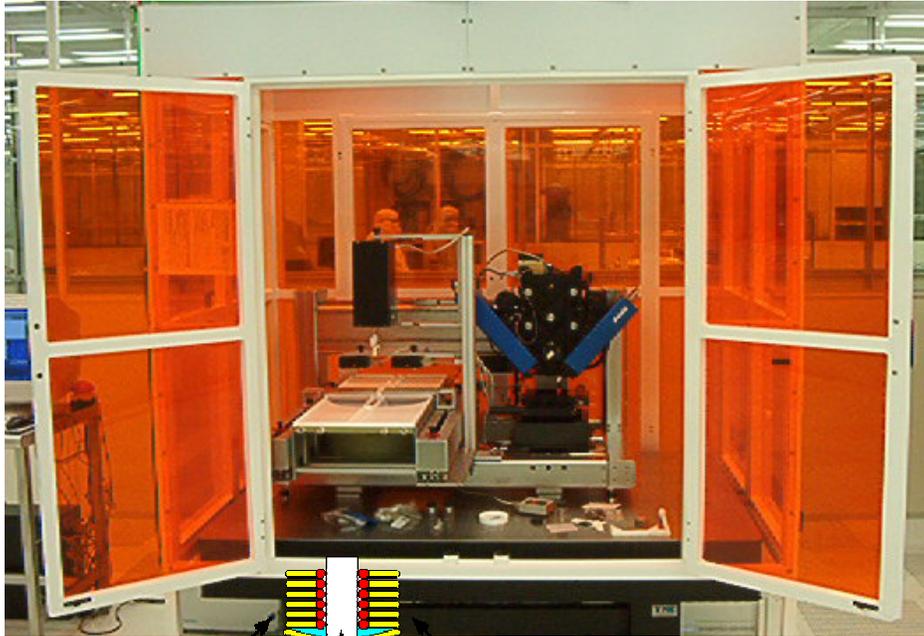


Nanomanipulator (Zyvex)

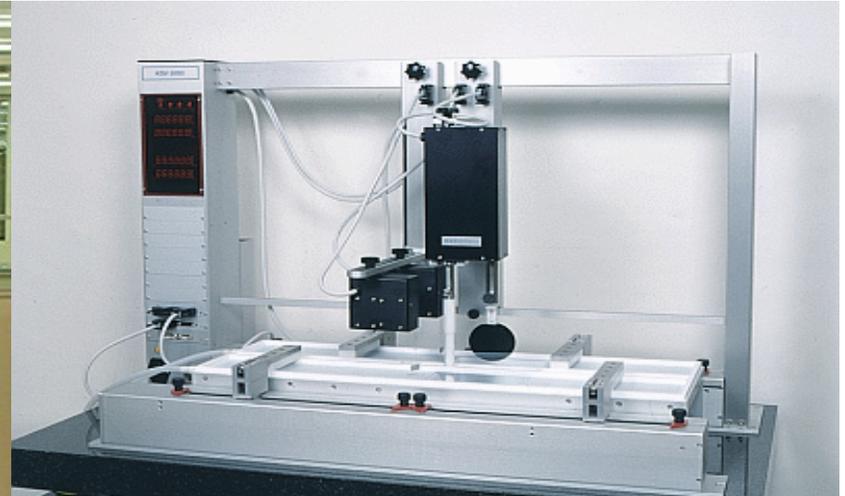
Mounted in an SEM, allows us to manipulate nanoscale devices to nanometer accuracy in x, y, and z.



Self Assembled Films



Langmuir Blodgett Film Deposition



- Low Cost Deposition
- Low Tech
- No Vacuum Required
- Low Temperature
- Wide Process Margin
- 8" Wafer Capable

Applied Molecular Systems Status



Subwavelength (SW) coatings and optical elements

Program Objectives:

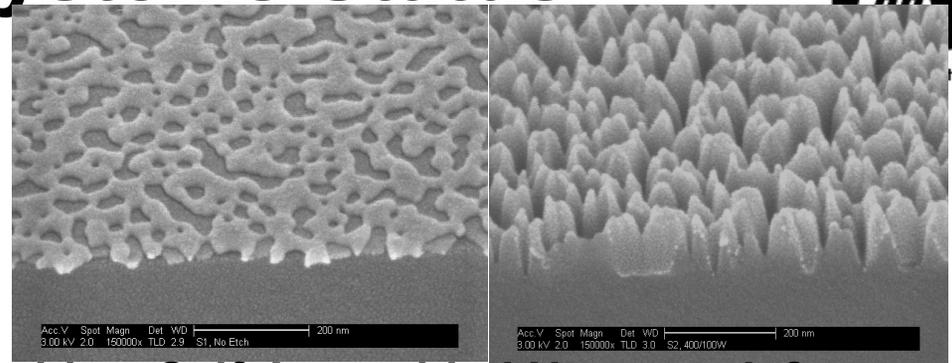
Development and characterization of anti-reflection coatings and optical elements in support of our Displays and Display systems related efforts.

Capabilities Synergies:

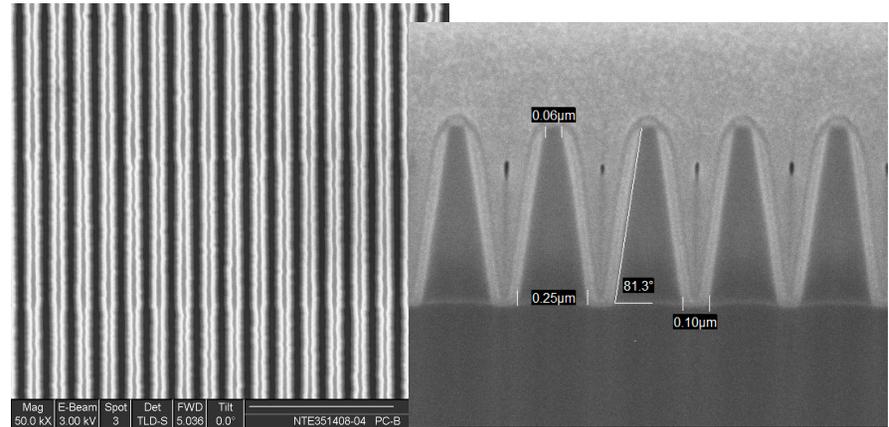
- Imprint Lithography
- Self assembly layers
- Modeling and simulation
- Optical device characterization
- Fab integration

Control Points:

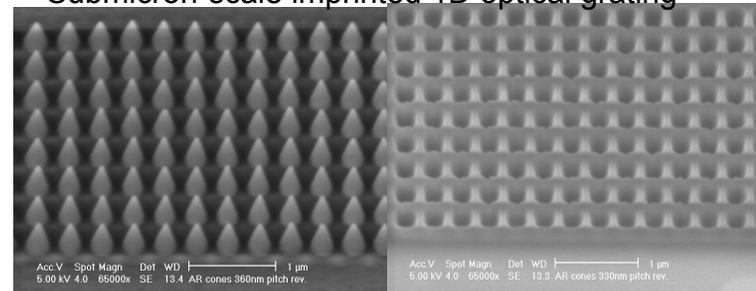
Development of novel manufacturing methods using self assembly and imprint lithography enabling the fabrication of sub-wavelength structures, components and devices



Gold as Self-Assembled Nanomask for Creating Graded Index AR Surfaces



Submicron-scale imprinted 1D optical grating

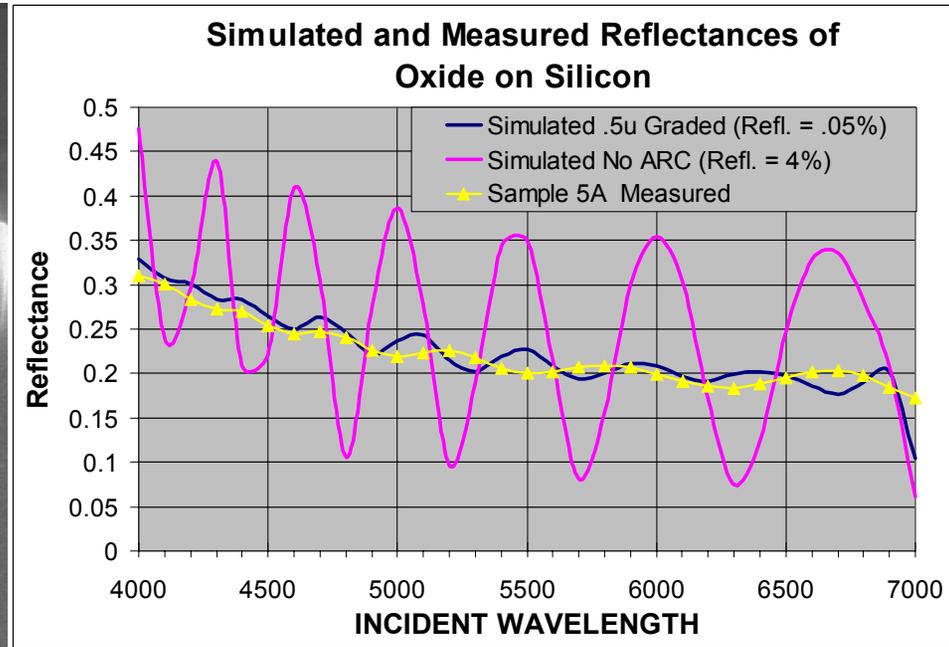
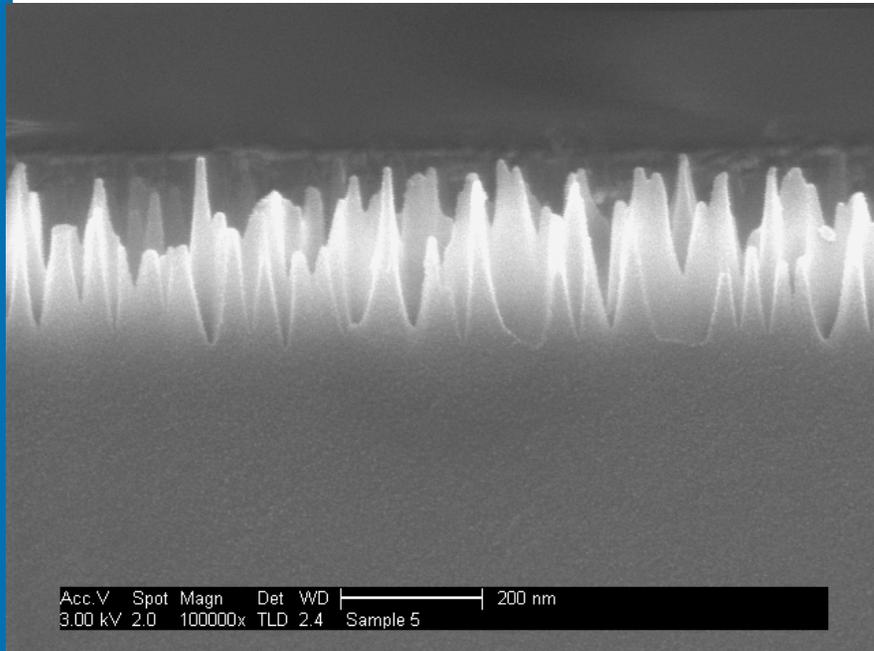


Submicron-scale imprinted 2D optical structures

Self-Assembled Antireflection Surfaces



Nano-Scale Structures have the potential to provide easily processed and very low reflectance surfaces



0.1-0.5% Total Reflectance on Black State Wafers Achieved

Best Fit Simulated Reflectance of Oxide on Silicon for this result implies $R < .02\%$

Applied Molecular Systems Status



Haleakala (Nanophotonics)

Program Objectives:
Development and characterization
of photonic structures.

Capabilities Synergies:

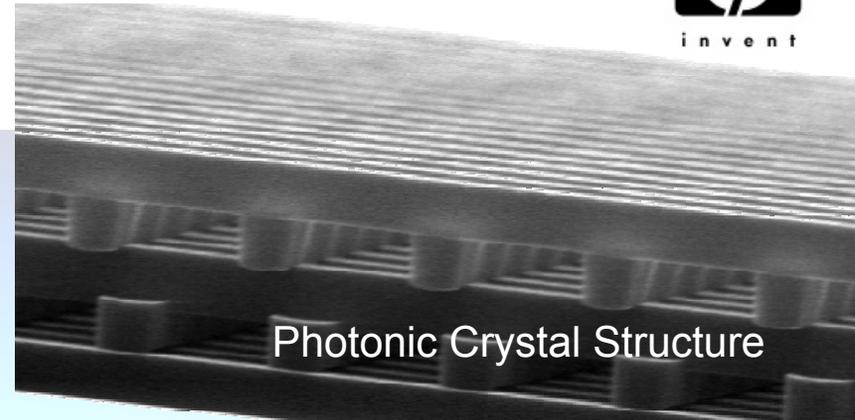
- Imprint Lithography & Self Assy
- MEMs/IC/Fab integration
- Modeling and characterization
- Microbond Packaging
- Materials Development

Control Points:

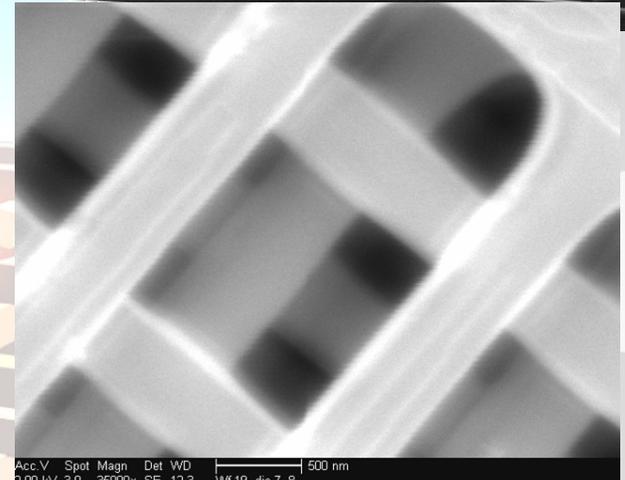
- Basic physics
- Data transmission integ
- Production methods

AMS generated IP:

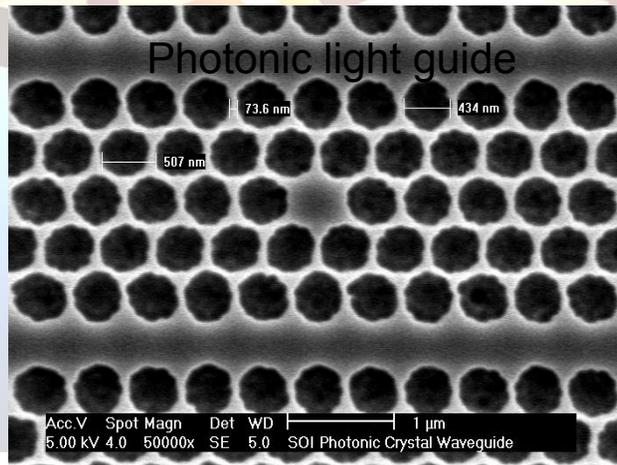
- 12 disclosures



Photonic Crystal Structure

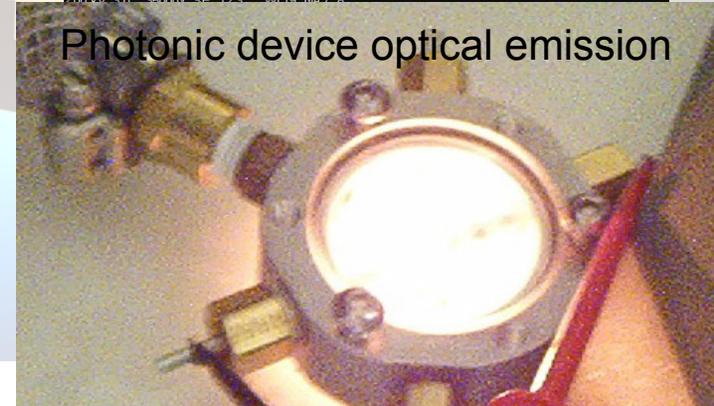


Photonic device optical emission



Photonic light guide

Acc V Spot Magn Det WD | 1 μm
5.00 kV 4.0 50000x SE 5.0 SOI Photonic Crystal Waveguide



Applied Molecular Systems Status



Bio-Sensor and Transduction Physics

Program Objectives:

Development and characterization of nanowire-based bio-sensor structures

Capabilities Synergies

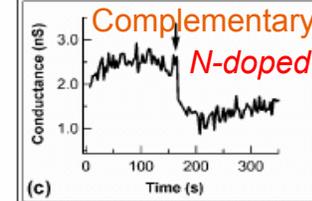
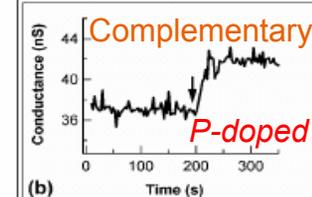
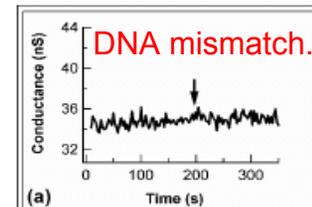
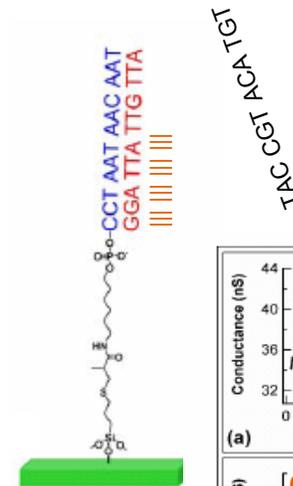
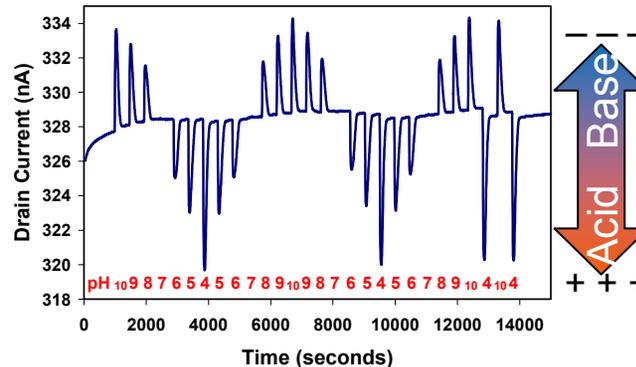
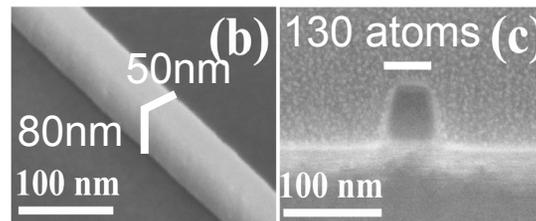
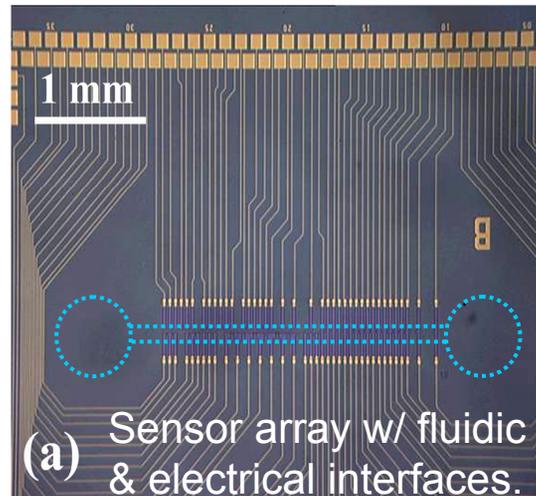
- Imprint and E-beam Lithography
- Modeling and simulation
- Device Characterization
- MEMS/IC Fab, Integration
- Silicon surface functionalization
- Nano-/Meso-/ Micro-Fluidics

Control Pts:

- Nanoscale Fabrication
- Integration (Nanoscale + uFluidics)

IP Filed

- devices: 7 Applications
- demux circuits: 2 Applications
- functionalization: 3 Applications



Detect 25pM DNA.

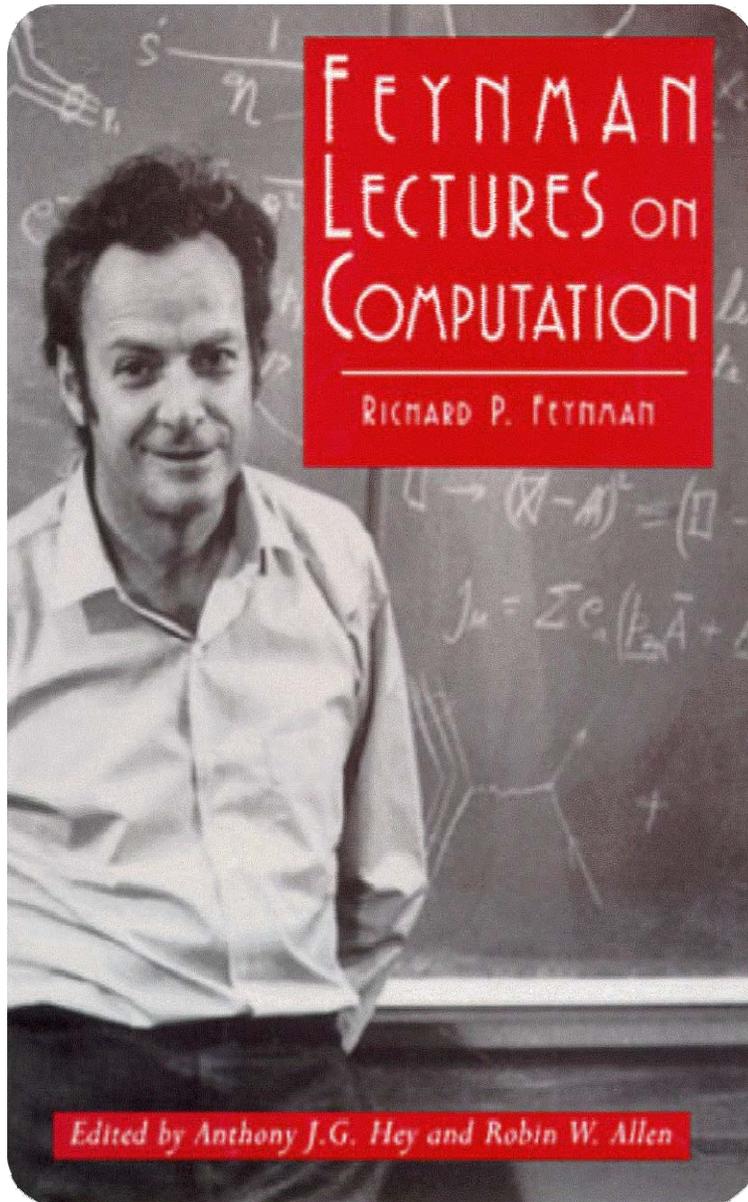
→ First steps in protein detection are pH, DNA.



What's next?



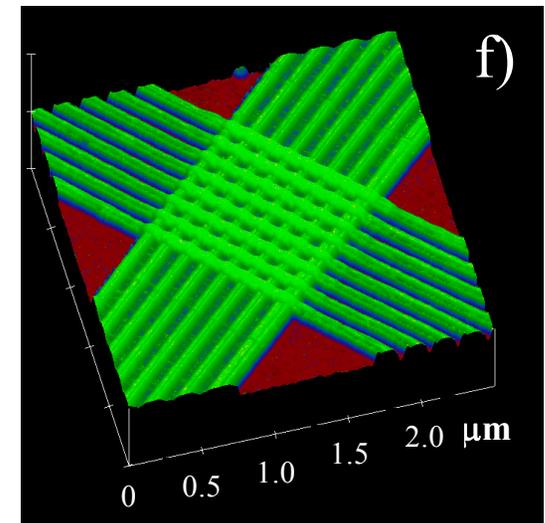
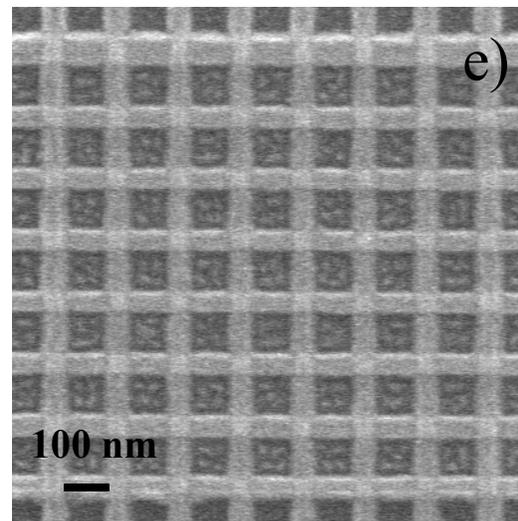
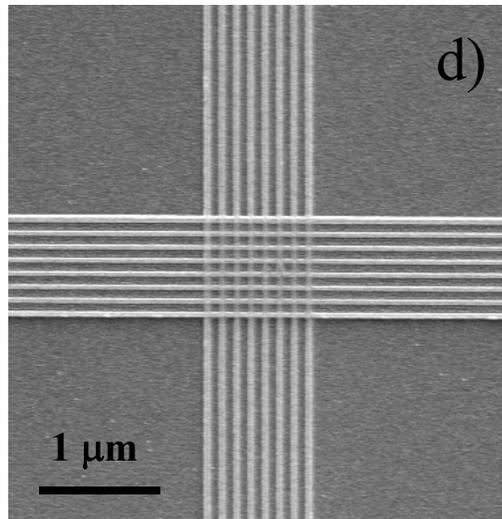
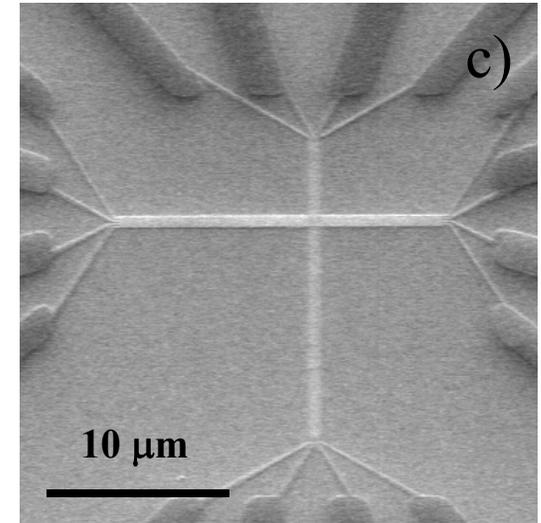
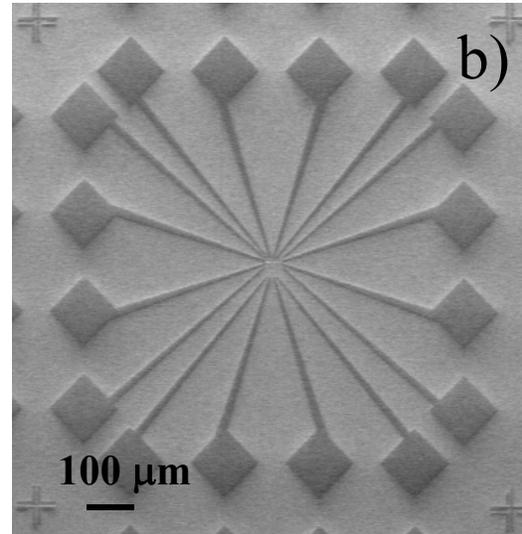
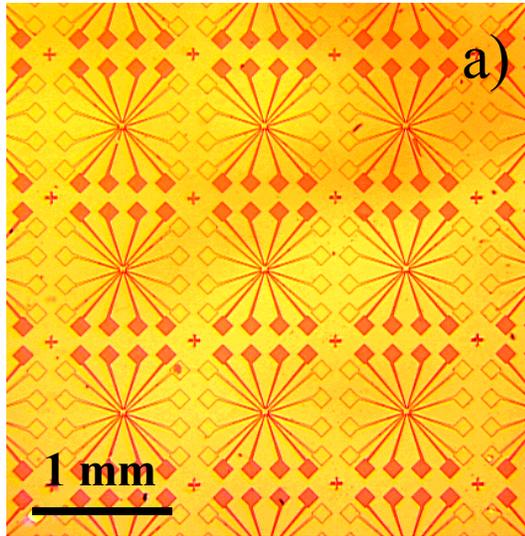
Plenty of Room at the Bottom!



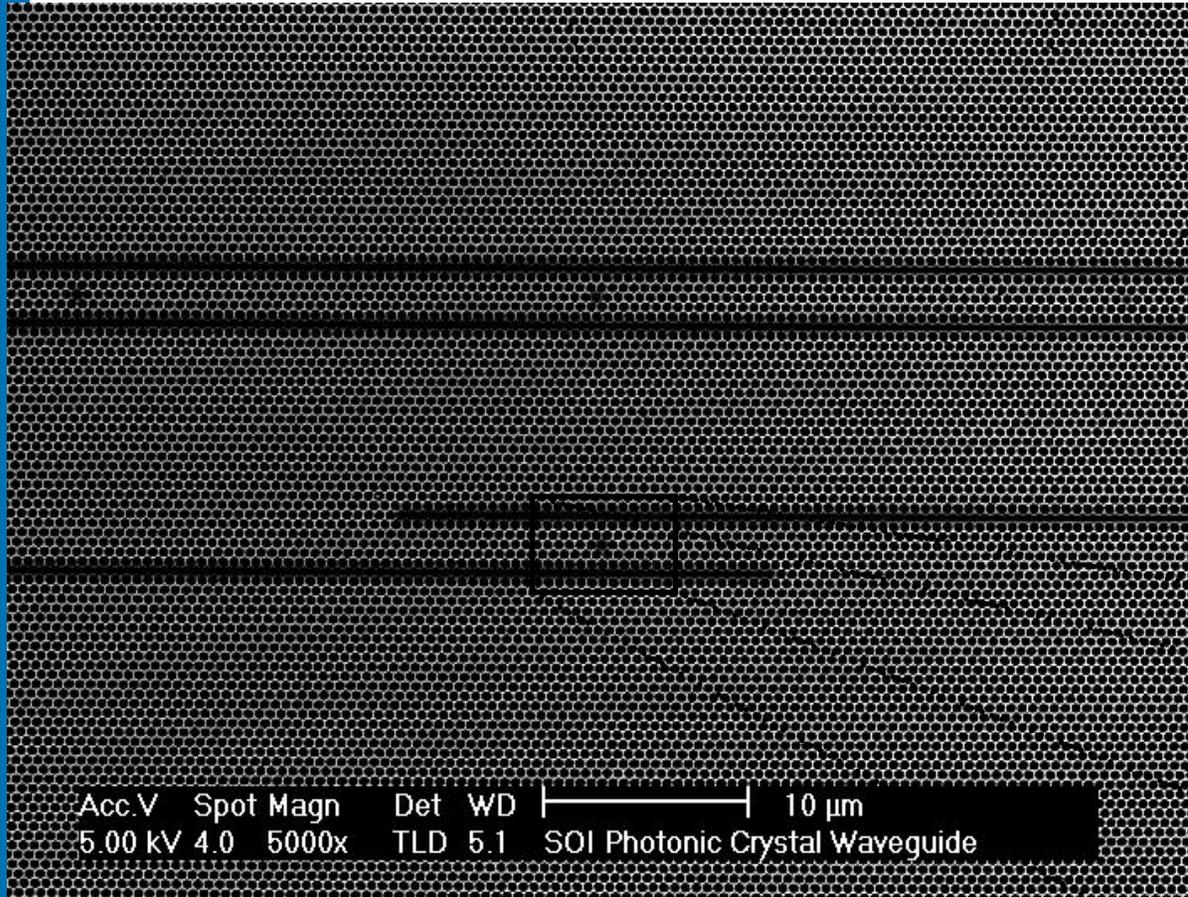
The Age of Computing has not yet begun ...

It is physically possible to build a hand-held device that can outperform all the Earth's present computers, but it may take 50 years!

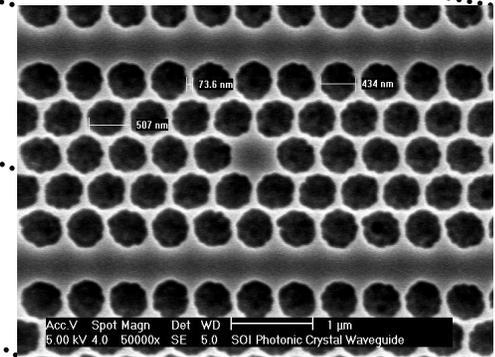
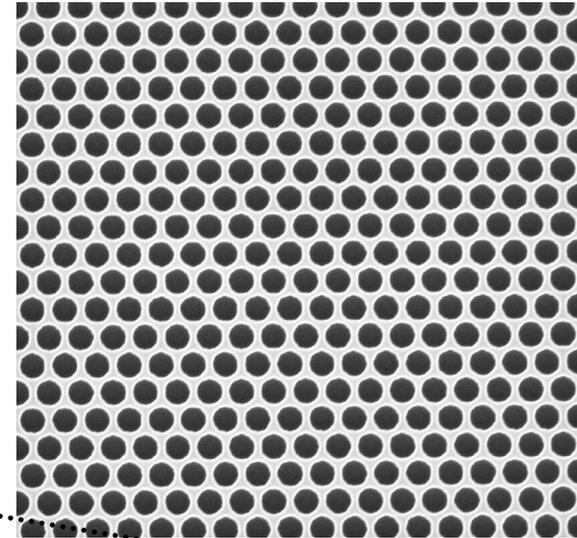
QSR Molectronics



Nanoimprint Lithography for Photonic Crystal Fabrication



Neal Meyer/HP-TDO (Corvallis)



Jim Ellenson/HP-TDO (Corvallis)



i n v e n t