Nanoimprint Lithography and Applications at Hewlett Packard Labs

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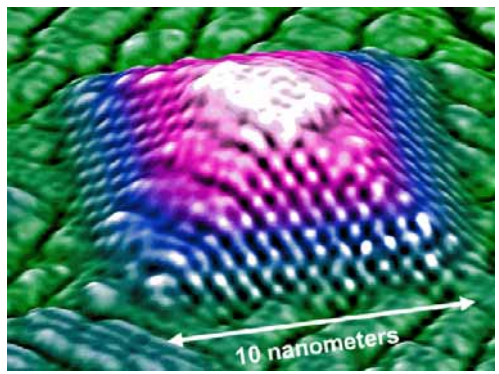
Outline

- Background
- Motivation
- Nanoimprint lithography at HP labs
- Applications based on nanofabrication
  - Molecular memory and logic
  - Nanowire biological sensor
  - Nano-enhanced spectroscopy (unpublished)
- Future work
- Summary

Quantum Science Research

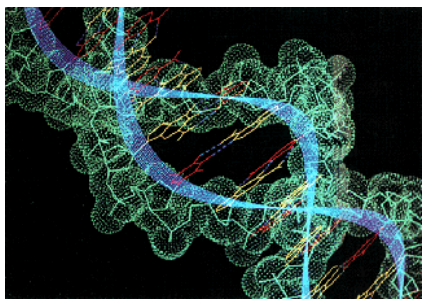
- Part of Advanced studies, HP labs
- Duty: Exploring “the next big thing” for HP
- Built and directed by Dr. R. Stan Williams, HP Senior Fellow
- 30 people

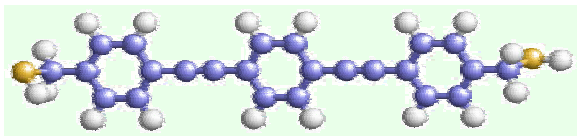


Nano is Great but…

- **New frontier of science**
  - o Fundamental knowledge
  - o Convergence of physics, chemistry and biology.
- **Potential commercial impact**

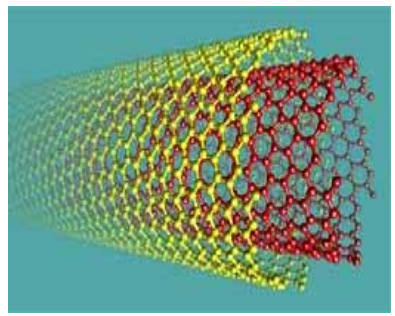
DNA





Molecular electronics

Carbon nanotubes



- **Technological challenge – Lithography!**

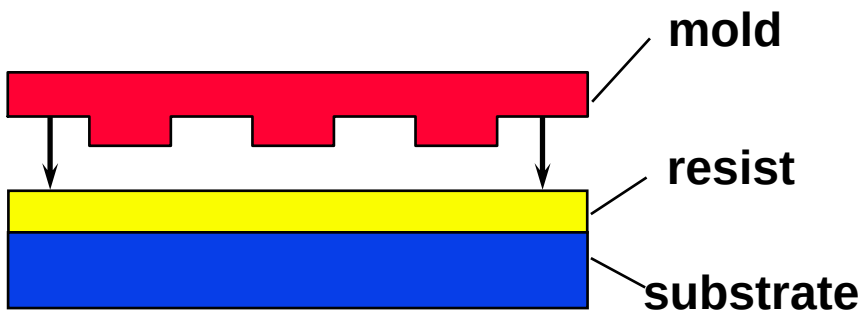
Next generation lithography (NGL) tools:

- Extreme UV lithography (EUV)
  - –Extremely expensive
    (complex optical system, expensive and fragile mask)
- X-ray lithography
  - –Expensive light source (synchrotron preferred)
  - –Mask material
- E-beam direct write lithography (EBL)
  - –Extremely slow (serial process)
- E-beam projection lithography (EPL)
  - –Mask material
  - –Distortion due to heat

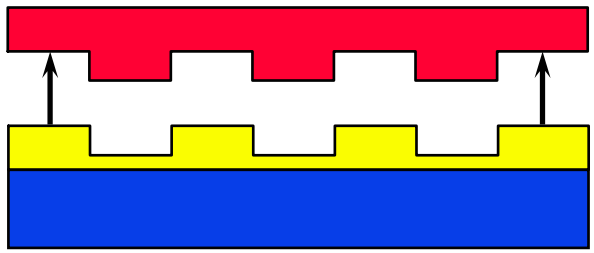
Nanoimprint Lithography (NIL)

1. Imprint

•Press Mold

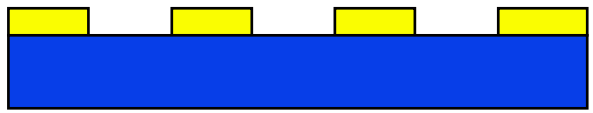


•Remove Mold



2. Pattern Transfer

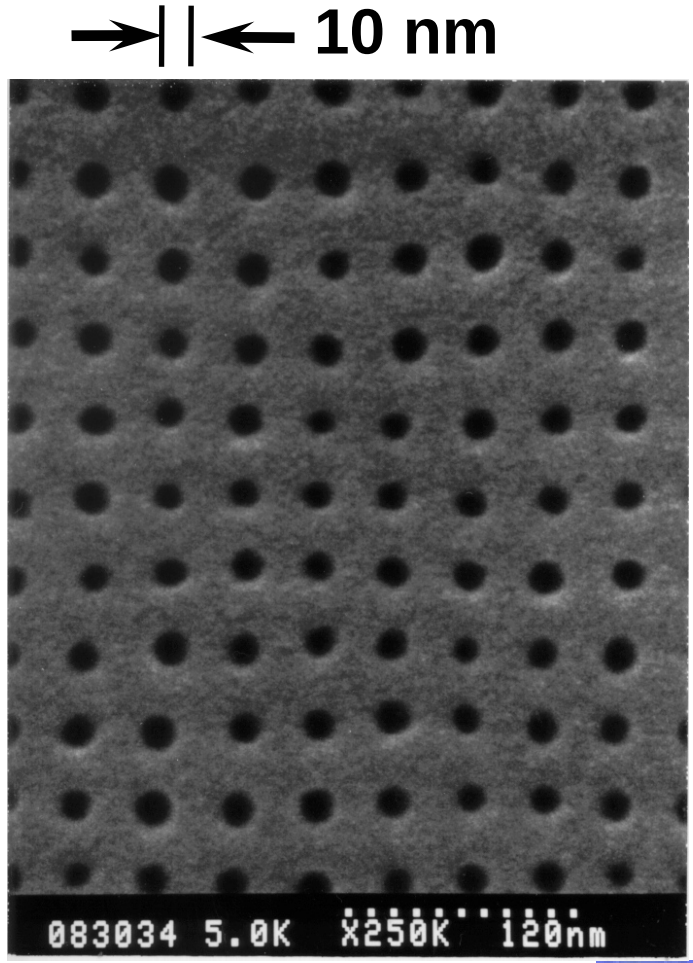
•RIE



Chou, Krauss, and Renstrom, APL, Vol. 67, 3114 (1995); Science, Vol. 272, 85 (1996)

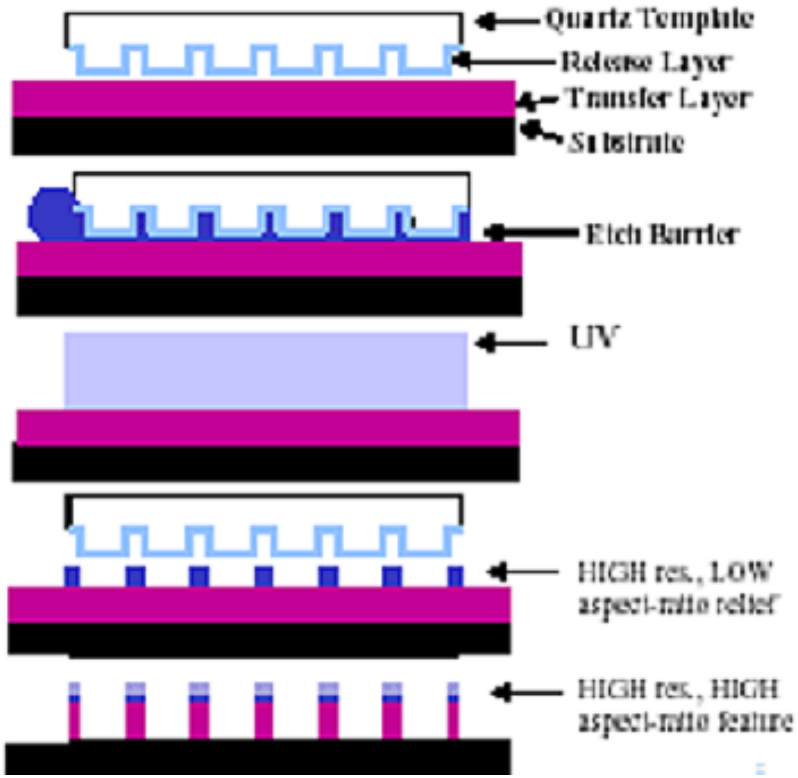
Nanoimprint Lithography (NIL)

- **High resolution**
  - **-not limited by wavelength**
- **High throughput**
  - **-parallel process**
- **Low cost**



Chou, Krauss, and Renstrom, APL, Vol. 67, 3114 (1995); Science, Vol. 272, 85 (1996)

Step & Flash Imprint

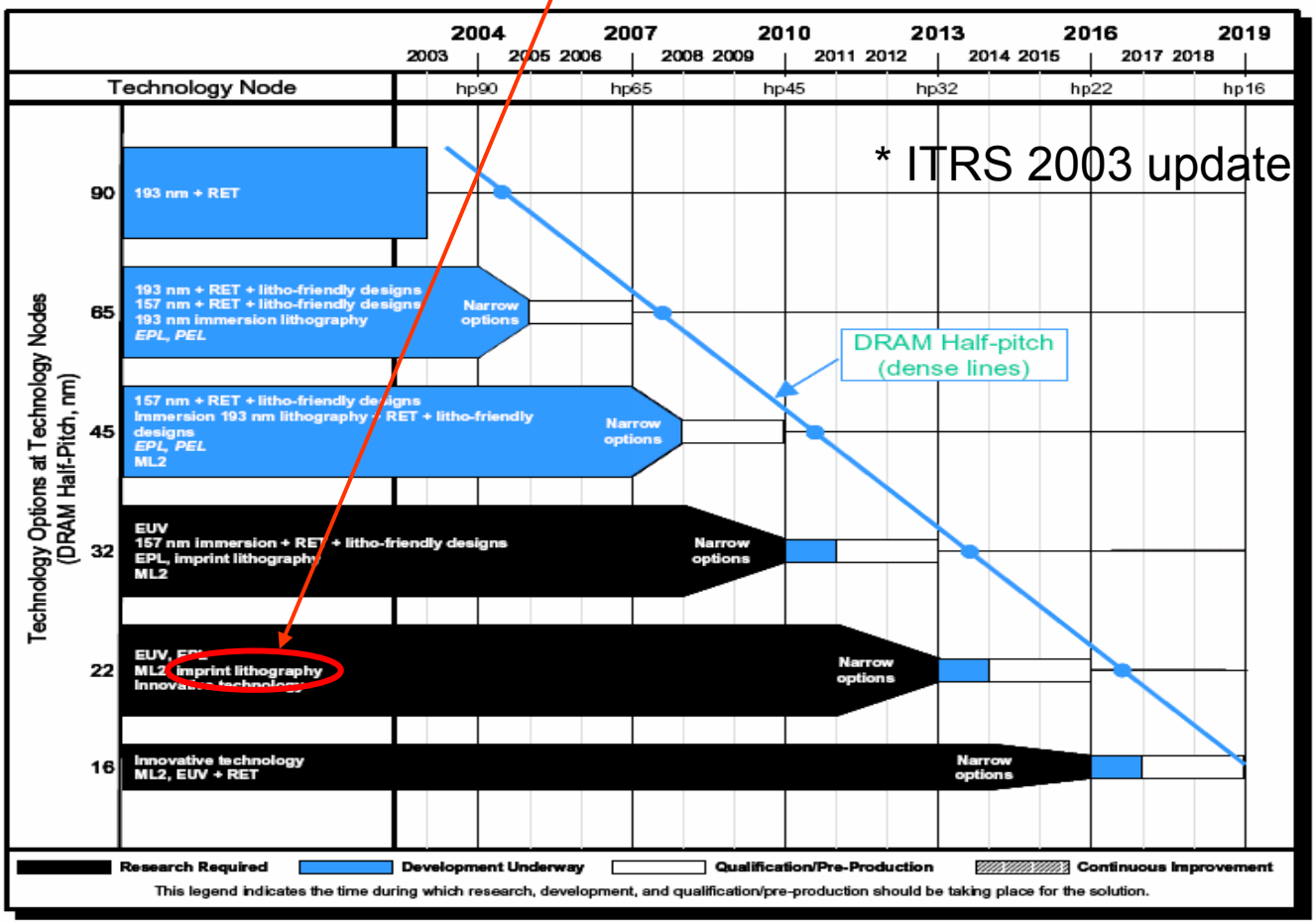


- UV curable process
- Room temperature
- Low pressure
- UV polymer is applied by droping

M. Colburn, A. Grot, G. Wilson's et al SPIE 2000

NIL is on ITRS (international technology roadmap for semiconductors)

We helped to put NIL on ITRS



Technologies shown in italics have only single region support.
RET—resolution enhancement technology EUV—extreme ultraviolet EPL—electron projection lithography
ML2—maskless lithography PEL—proximity electron lithography

Major Players

Princeton University ---- Nanonex

University of Taxes at Austin ---- Molecular Imprints

University of Michigan

Hewlett-Packard

Motorola

Micro resist…

Europe:

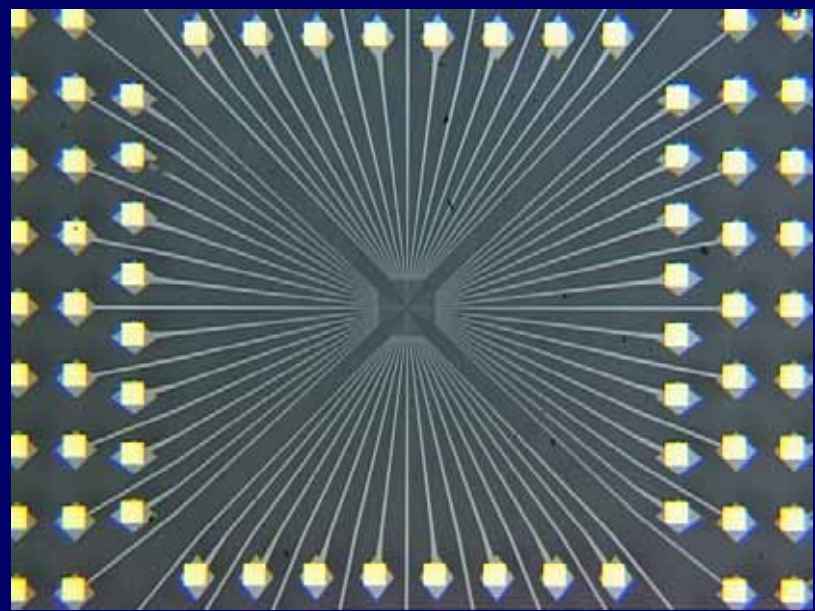
Aachen University. Lund University…

Obducat, EVG, SUSS…

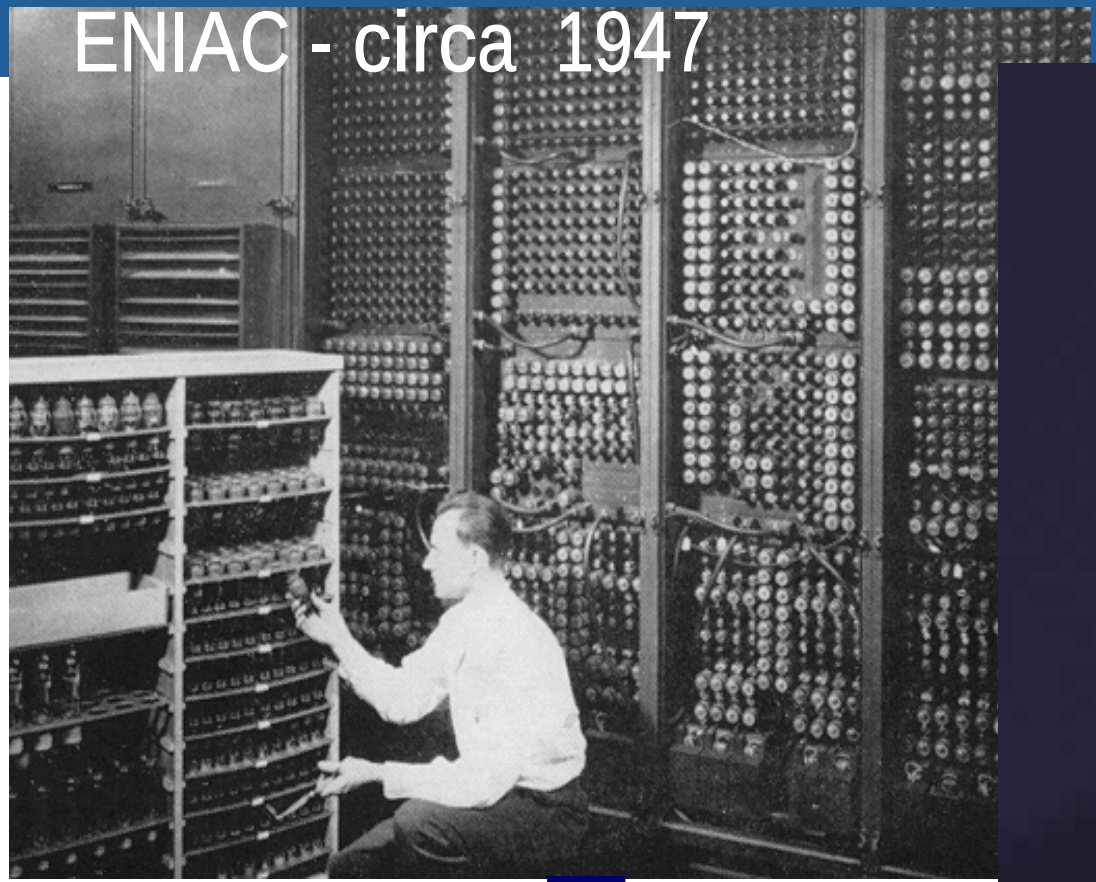
Japan:

Hitachi…

Crossbar Molecular Electronics by NIL



What is Next?



Shrink by 10^8

Improve power efficiency by 10^8

An Architecture for Molecular Molectronics

circa 1995

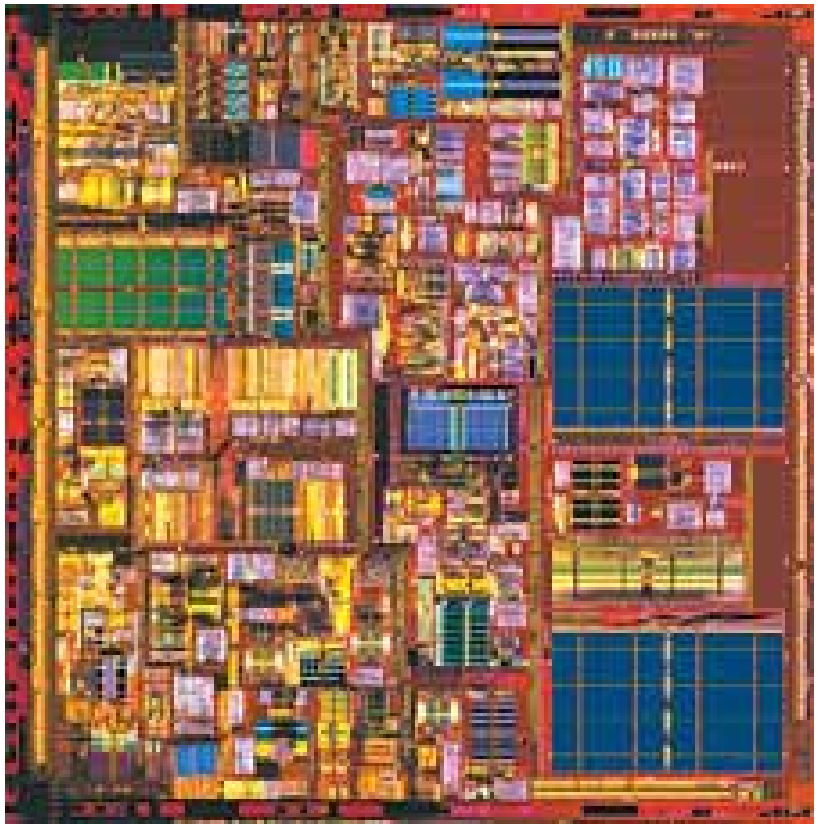
HPL TeraMAC

1 THz multi-architecture computer

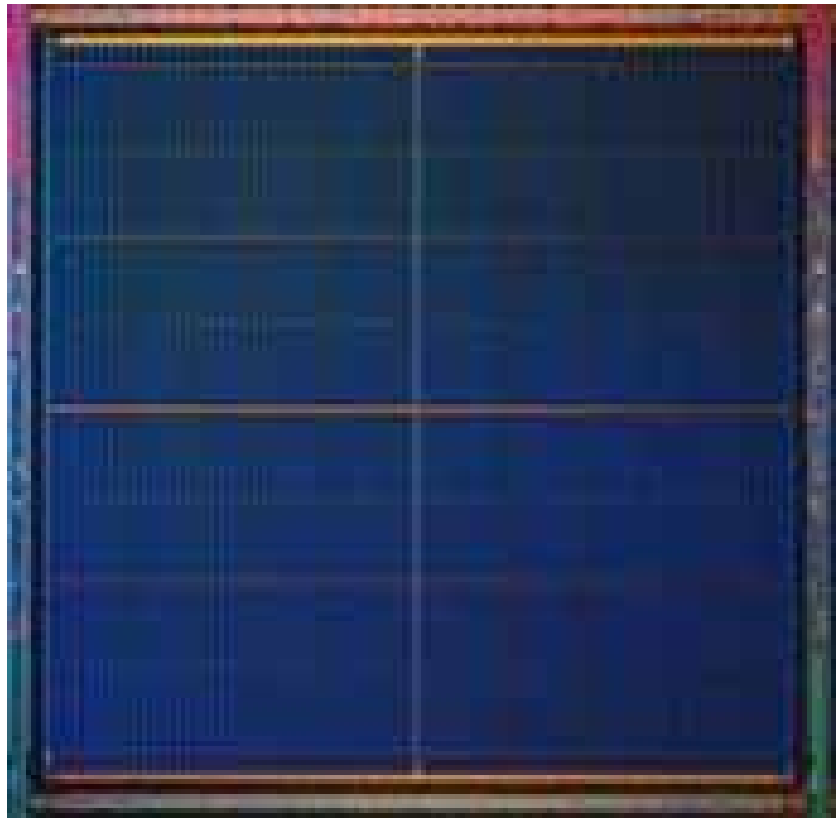
- 10^6 gates operating at 10^6 cycle/sec
- Built from programmable gate arrays (FPGA's)
- Computes with look-up tables
- Largest defect-tolerant computer
- 220,000 (3%) defective components

Heath, Kuekes, Snider, Williams, *Science* 280, 1715 (1998)

An Architecture for Molecular Electronics

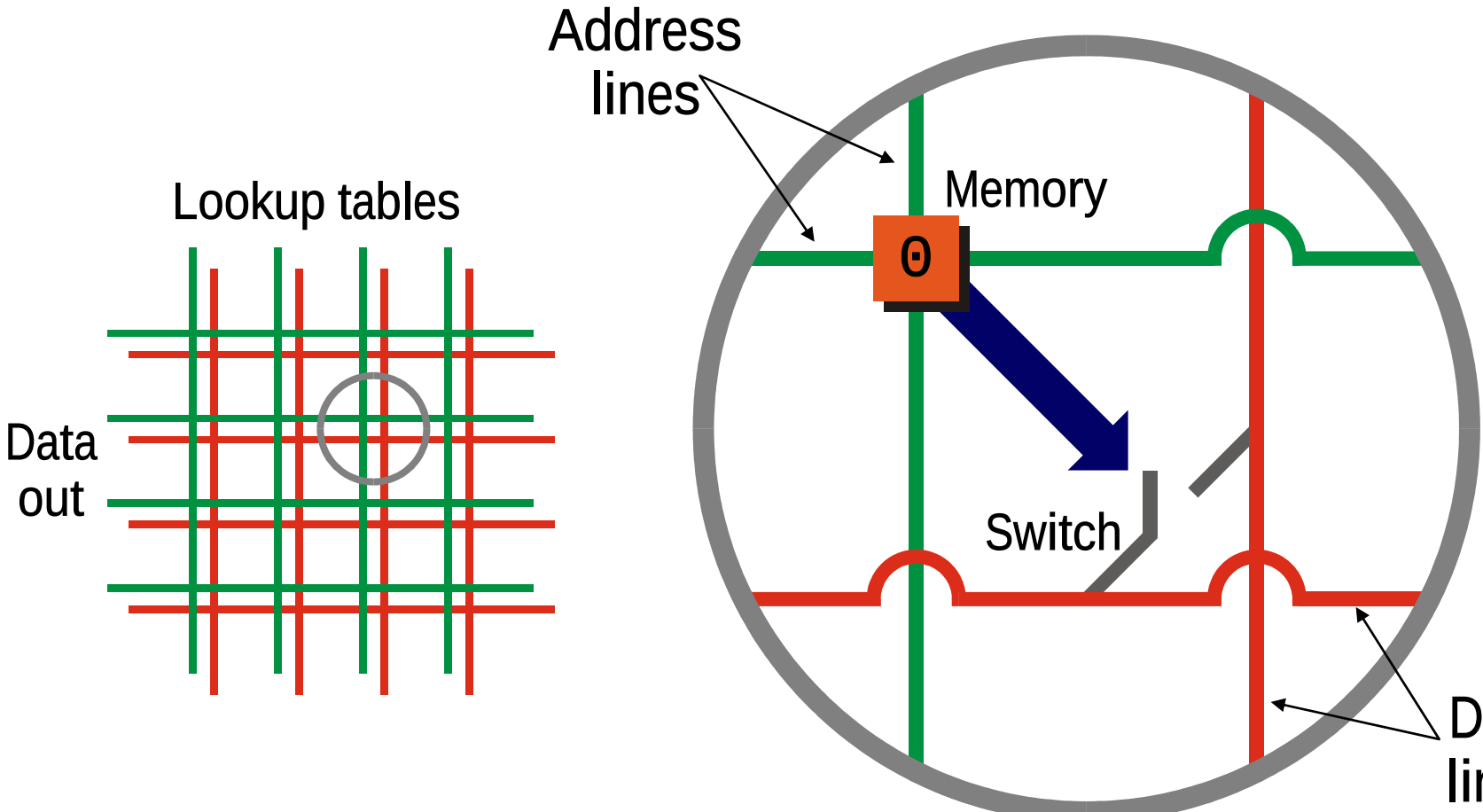


A microprocessor (intel P4)

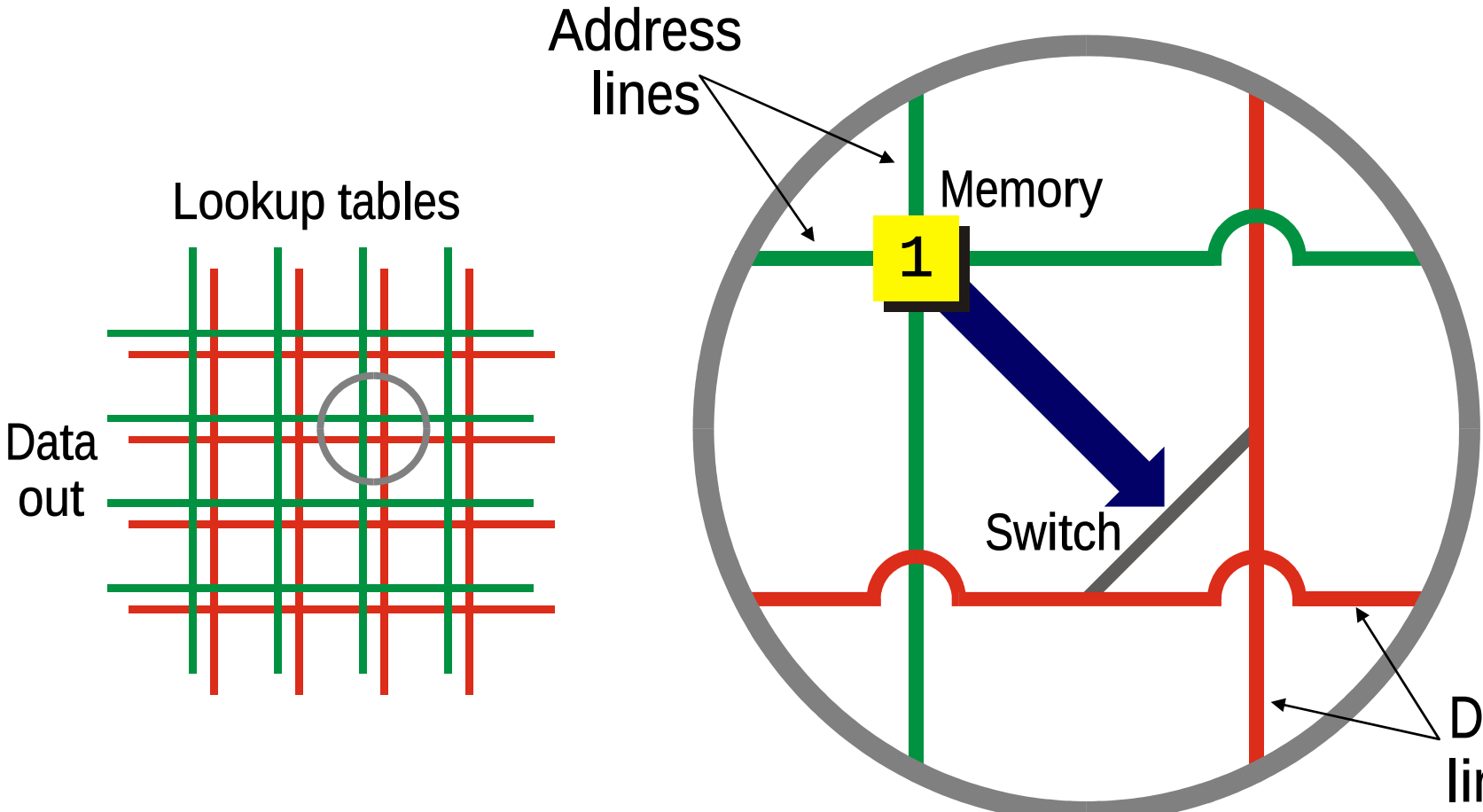


A reconfigurable device (FPGA)

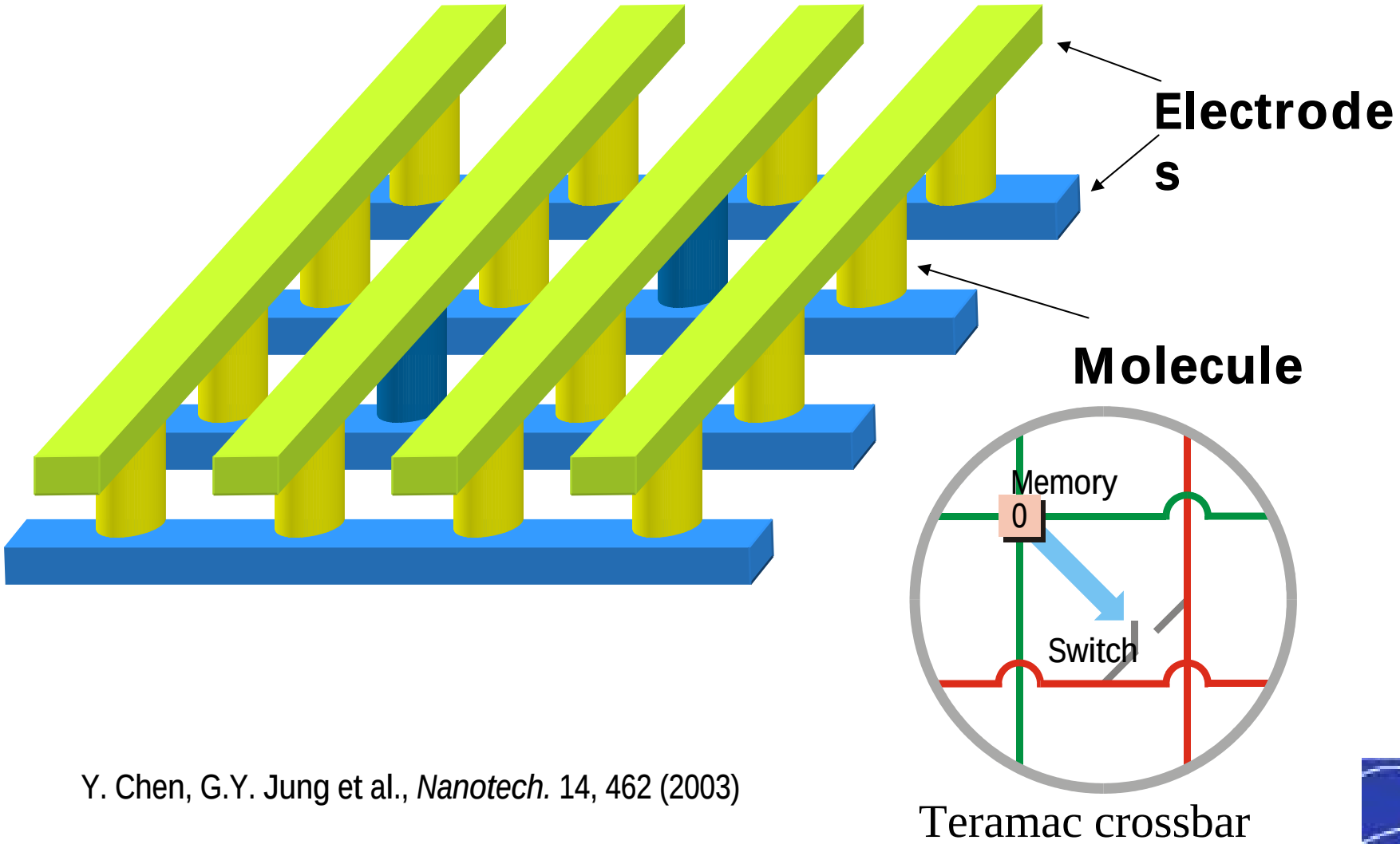
Teramac Crossbar Architecture



Teramac Crossbar Architecture



Nano-circuit Crossbar Architecture

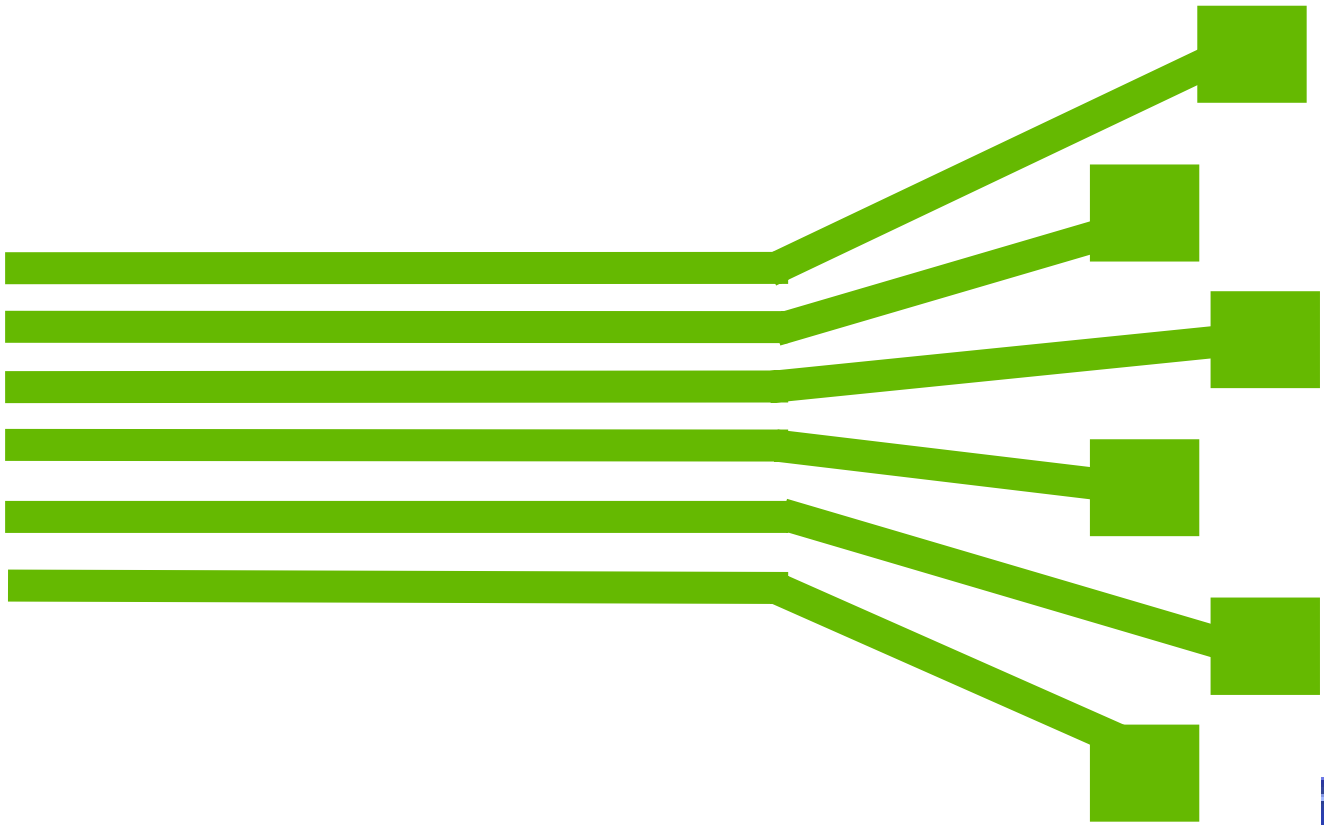


Y. Chen, G.Y. Jung et al., *Nanotech.* 14, 462 (2003)

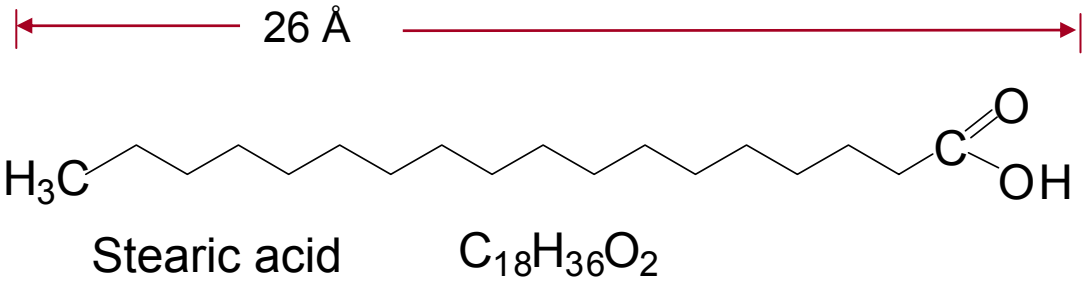
Teramac crossbar

Crossbar Fabrication: Bottom Electrode

Nanoimprint

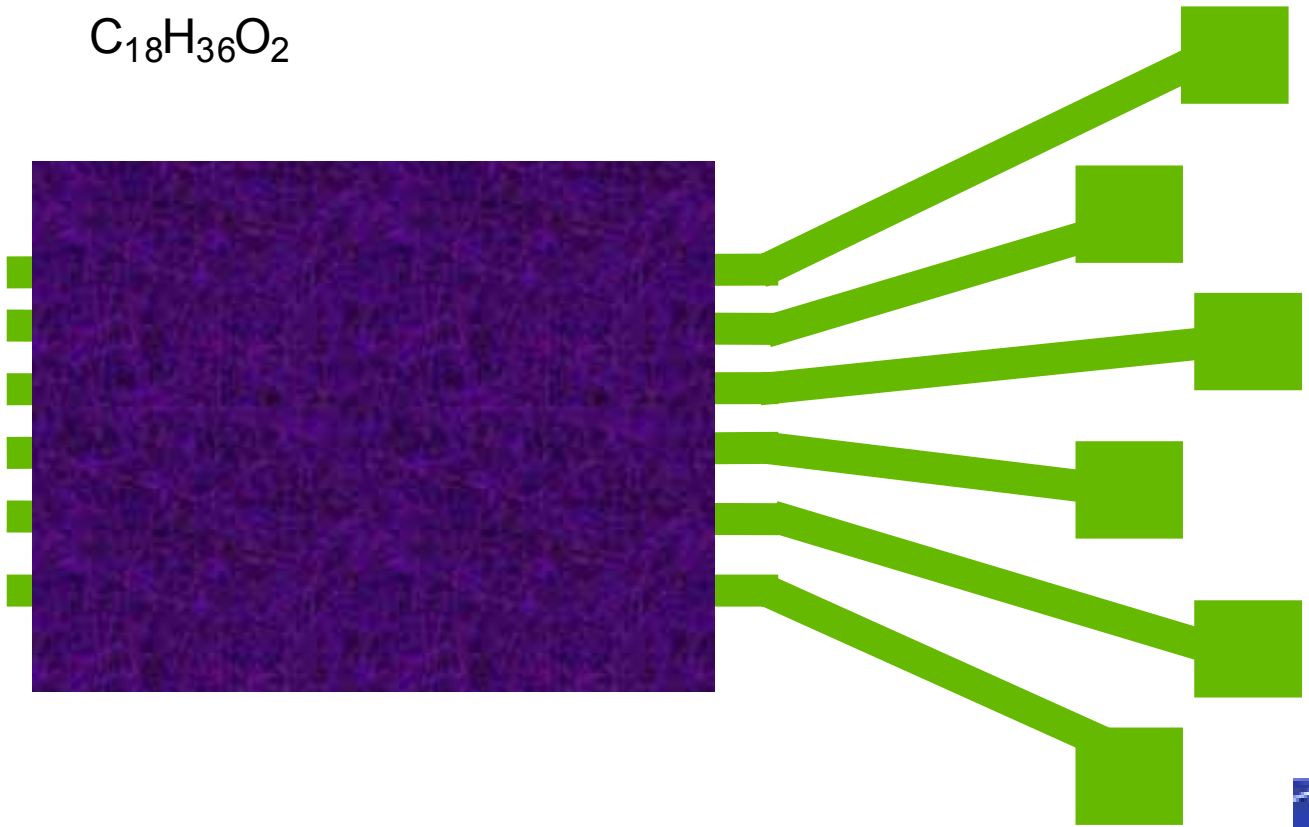


Crossbar Fabrication: Molecule Deposition

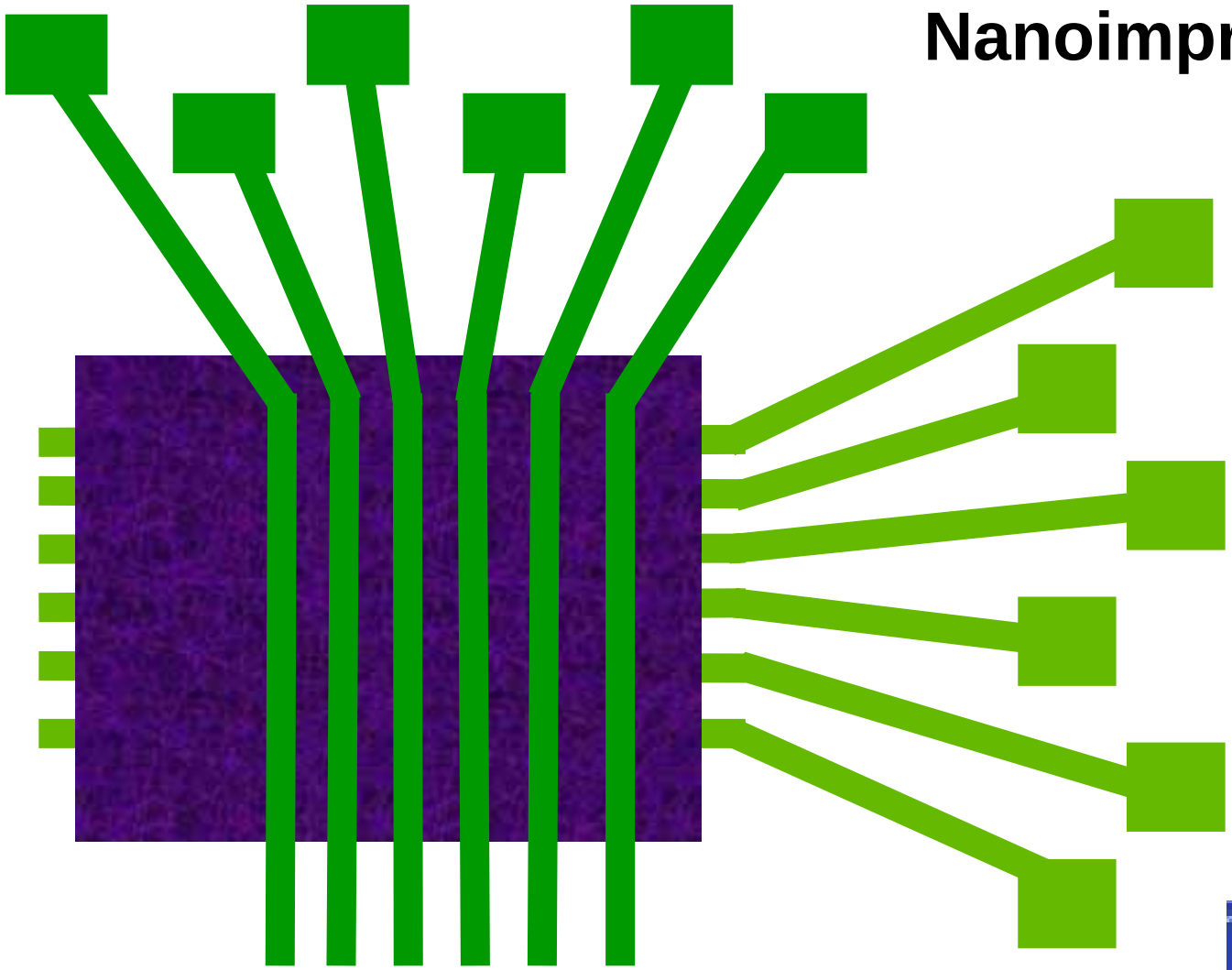


Stearic acid $C_{18}H_{36}O_2$

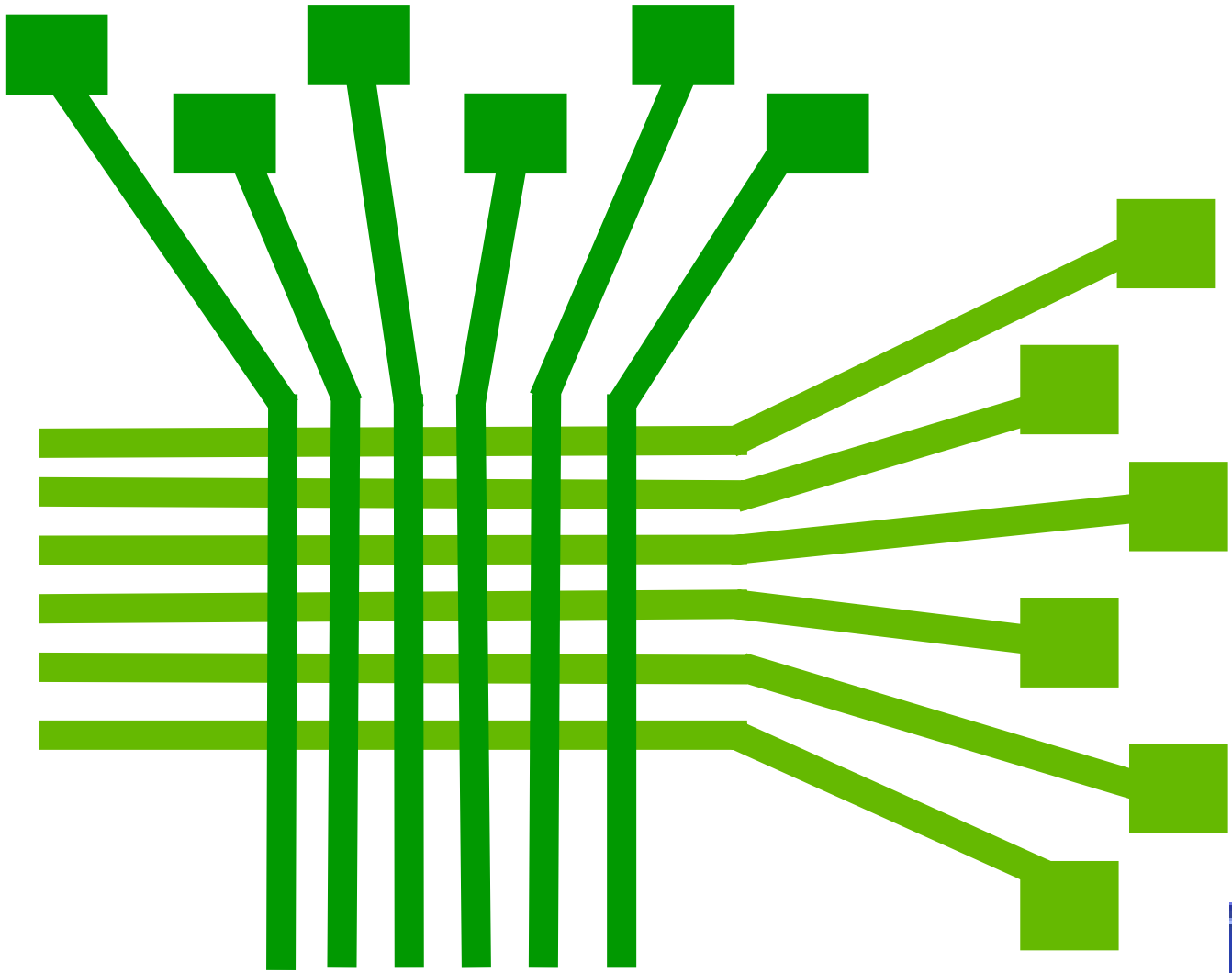
Langmuir-Blodgett



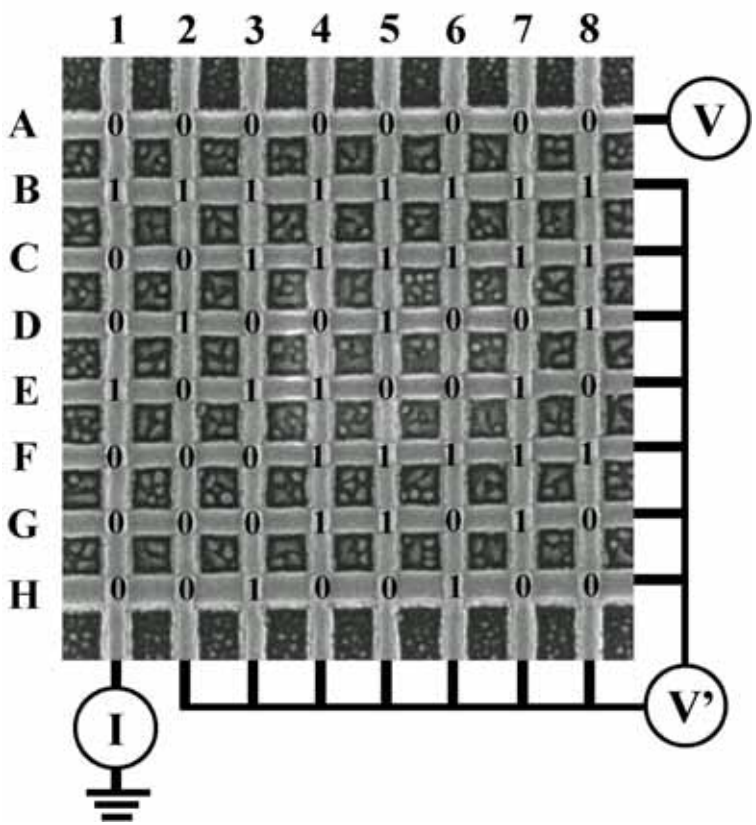
Crossbar Fabrication: Top Electrode

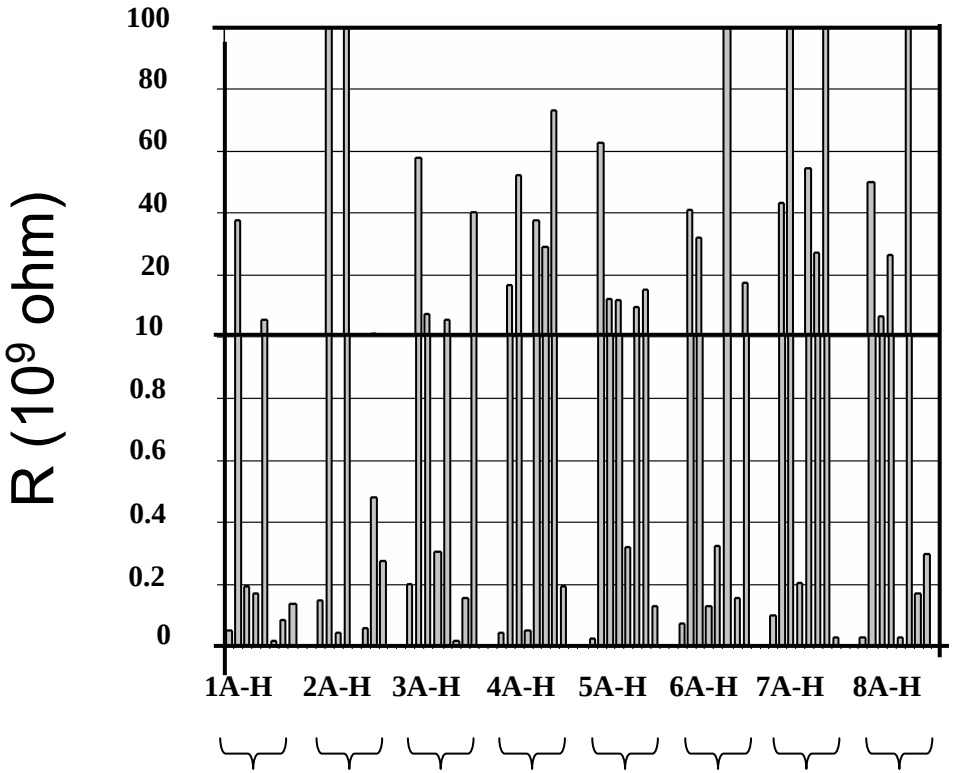


Crossbar Fabrication: Etch Back



64 bits Cross-bar Memory at 60 nm Half-pitch by Thermal Nanoimprint Lithography



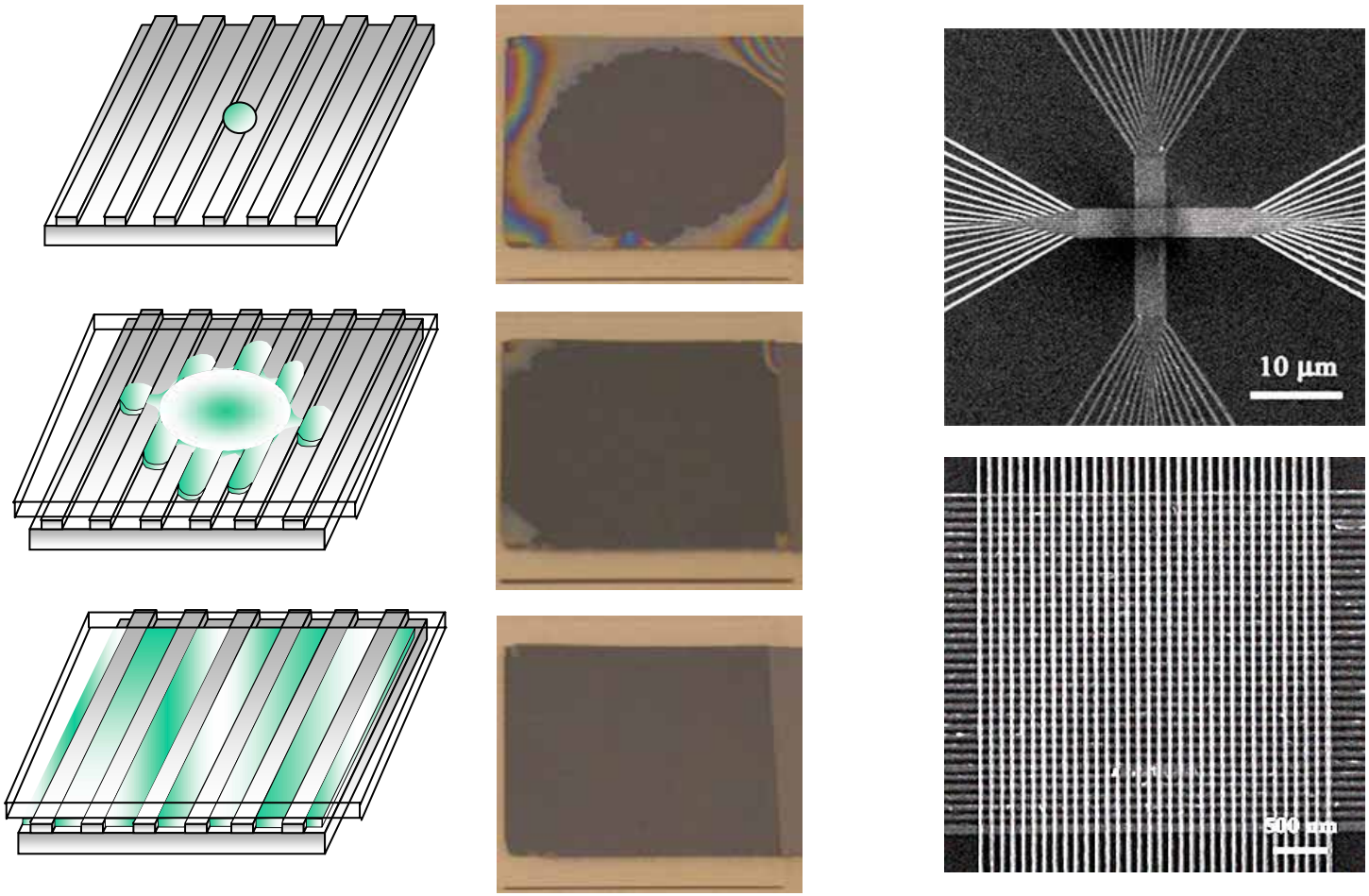


HP invent

- **First working circuit fabricated using NIL**
- **First working Molecular memory circuit**

Y. Chen, G.Y. Jung et al., *Nanotech.* 14, 462 (2003)

34X34 Cross-bar Structure at 50 nm Half-pitch by UV-curable NIL with Dropping Resist



G.Y. Jung, S. Ganapathiappan et al. Nano Letter 4 (2004),

Next Goal: 1Kb @ 30nm Half-pitch

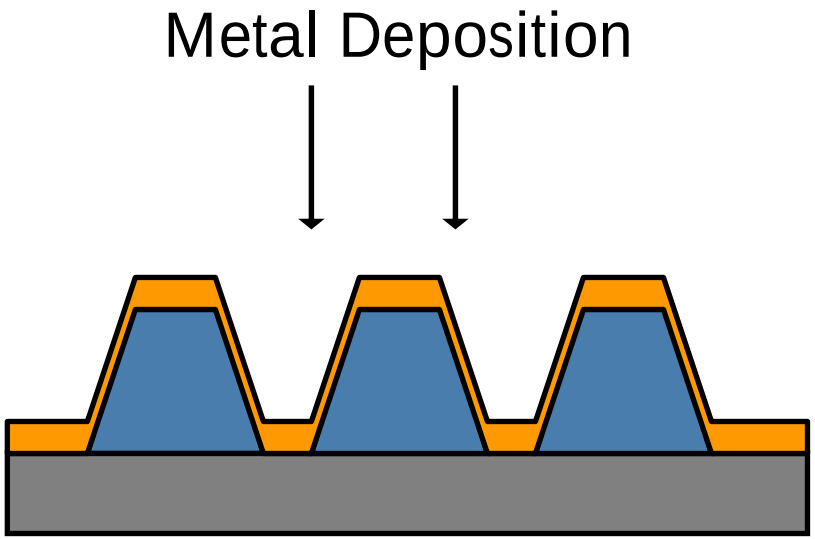
Challenges:

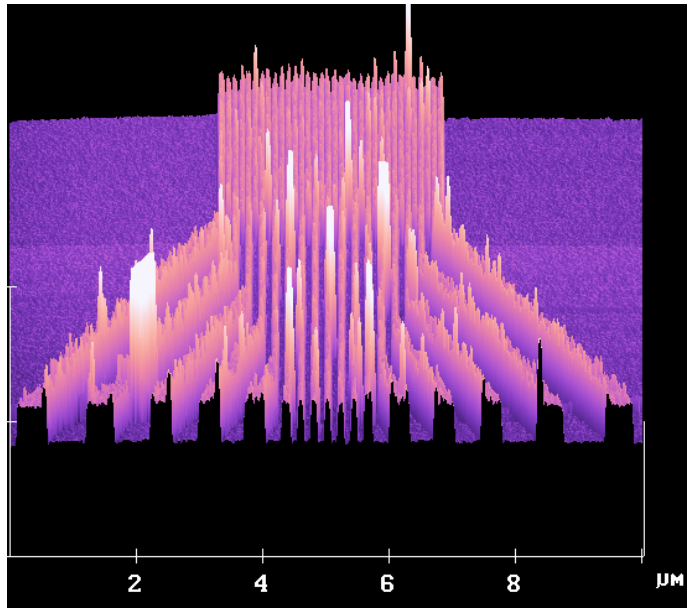
- Resist stick to the mold

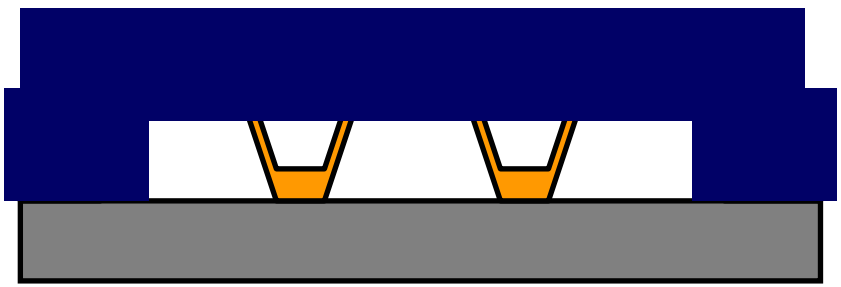
  Mechanical properties and lift-off properties have to be comprimised

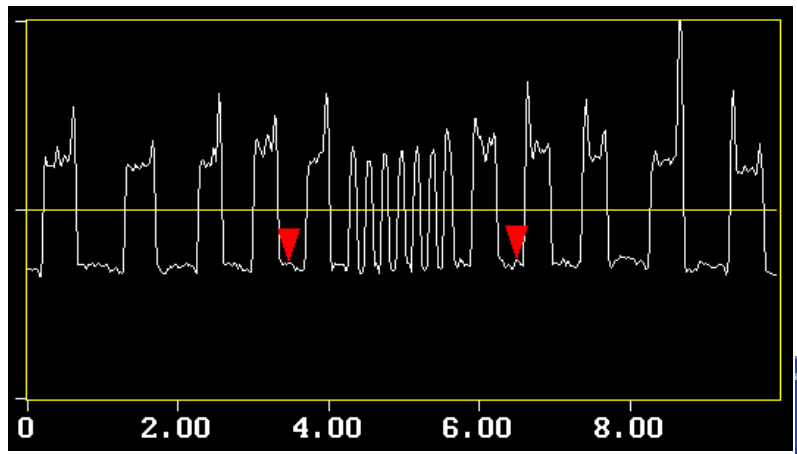
- “Rabbit ears” problem

“Rabbit ears” Problem





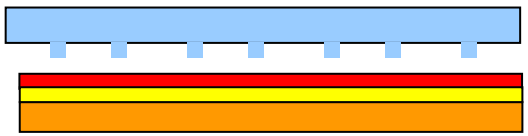




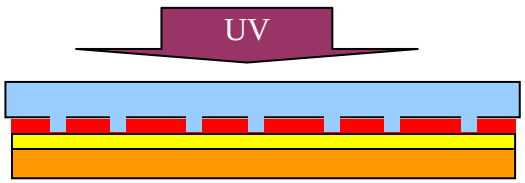
Undesirable metal “rabbit ears”

UV-curable NIL with Double-layer Spin-on Resist

1. Prepare substrate, **spin** under layer and resist (Nanonex NXR 2010) on



2. Alignment



3. Press and exposure

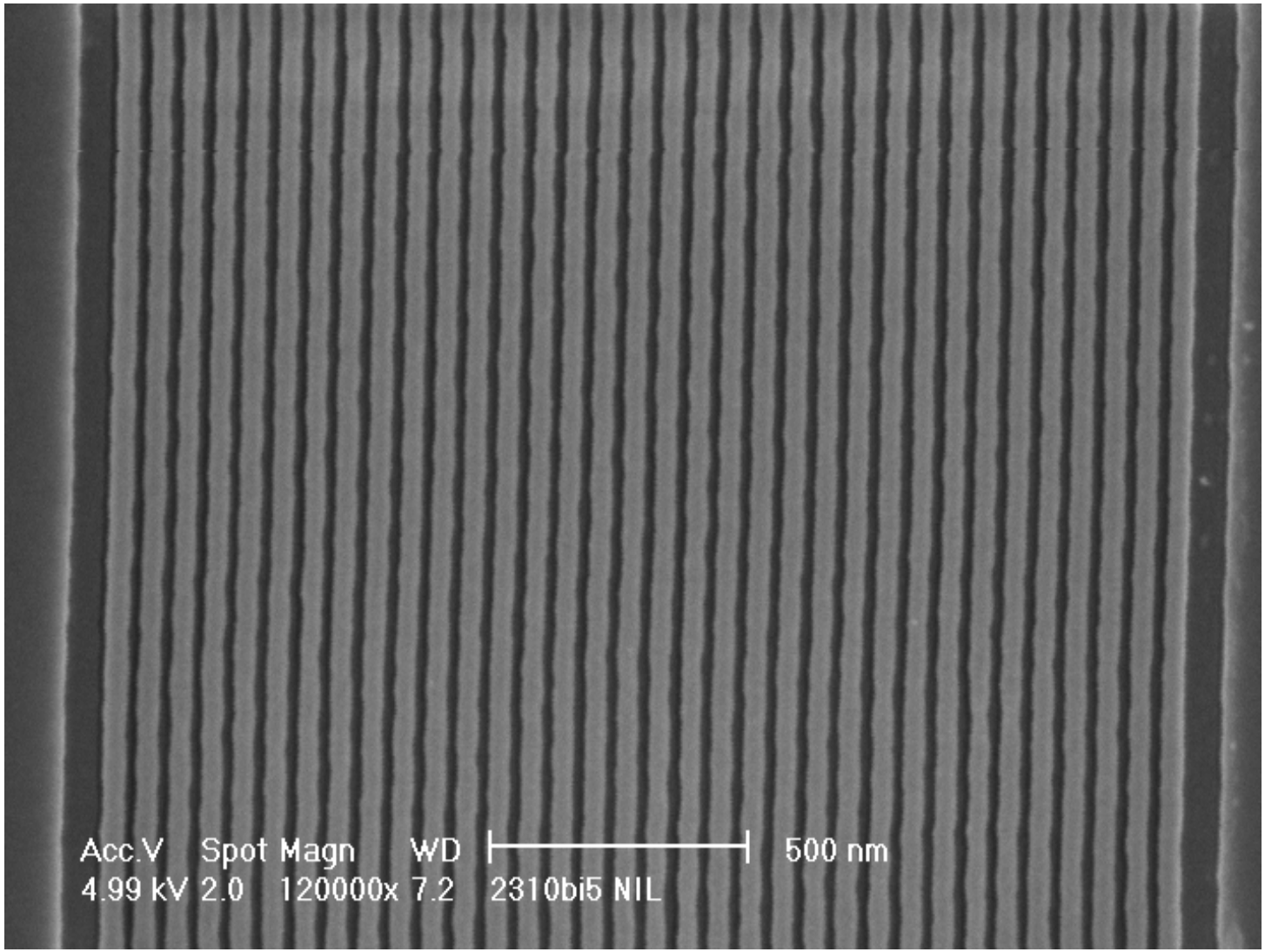
4. Mold and substrate separation

5. Residue layer and under layer etching

6. Metal evaporation and lift-off

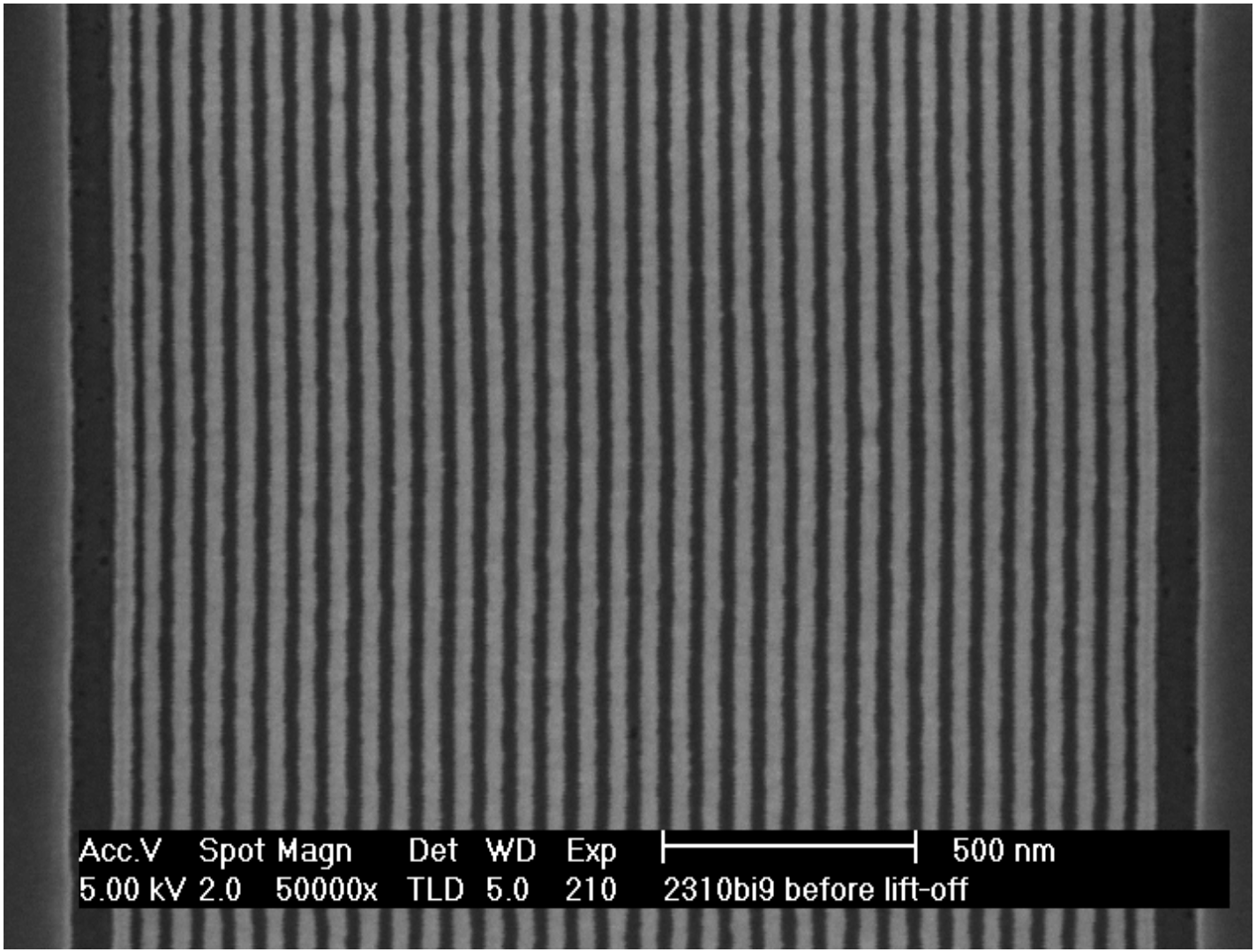
W. Wu, H. Ge, S.Y. Chou et al., EIPBN 2004

Imprinted 30 nm Half-pitch Nanowires on NIL Resist



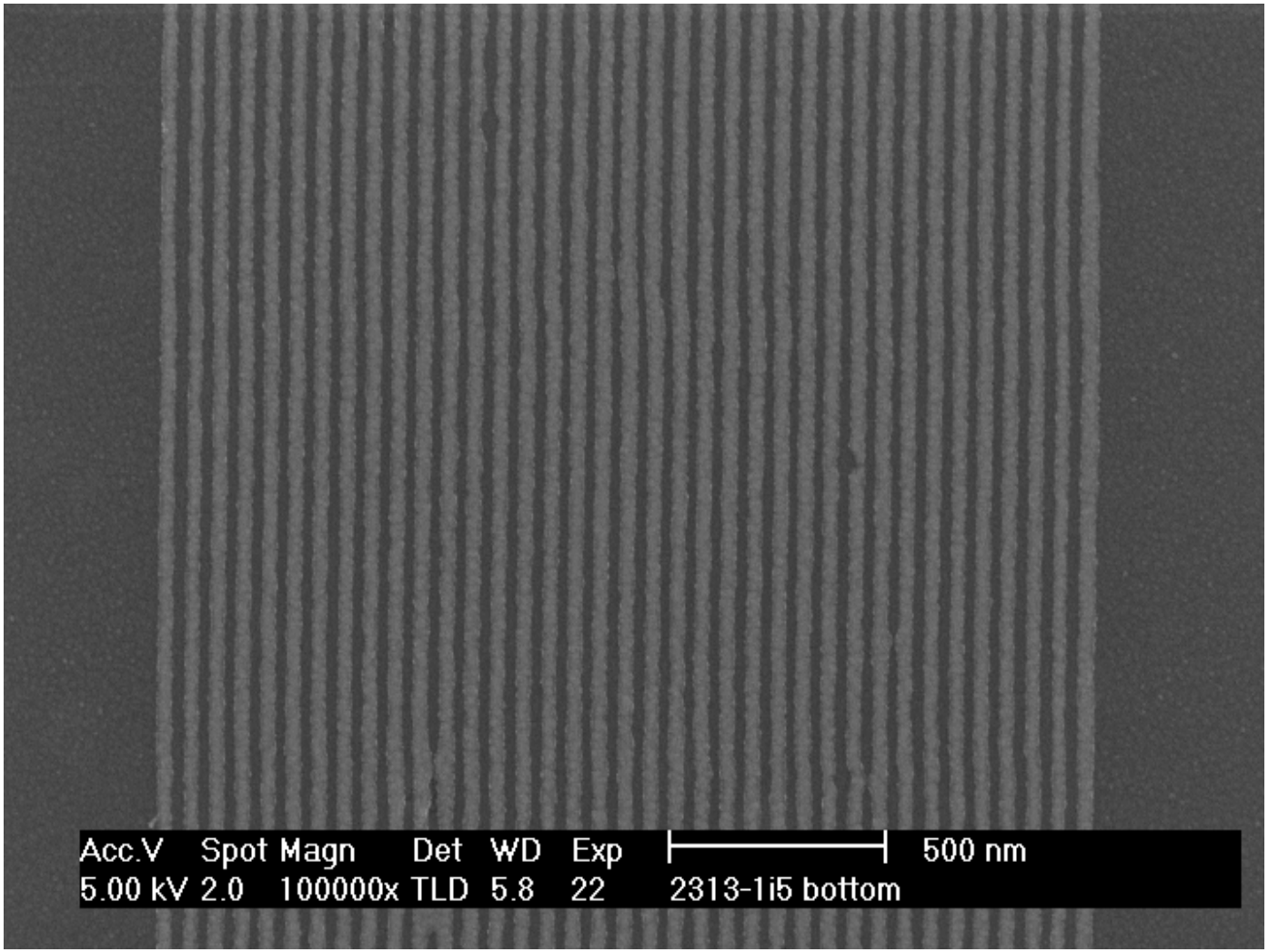
W. Wu, G-Y Jung, SY Wang, R. S. Williams et al., Applied Physics A in press

Imprinted 30 nm Half-pitch Nanowires Etched into Under-layer



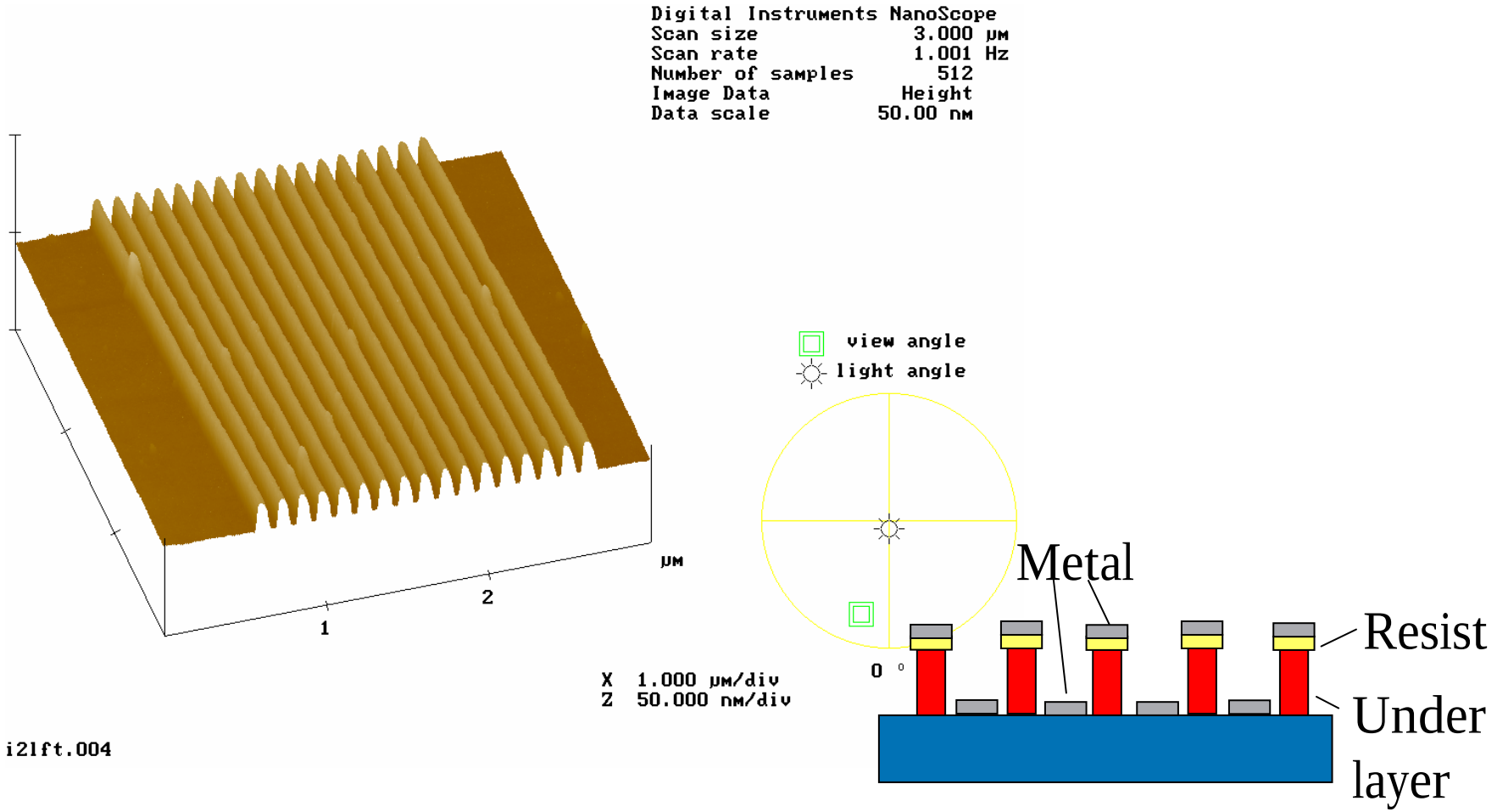
W. Wu, G-Y Jung, SY Wang, R. S. Williams et al., Applied Physics A in press

Ti/Pt Nanowires at 30 nm Half-pitch Fabricated Using NIL and Lift-off



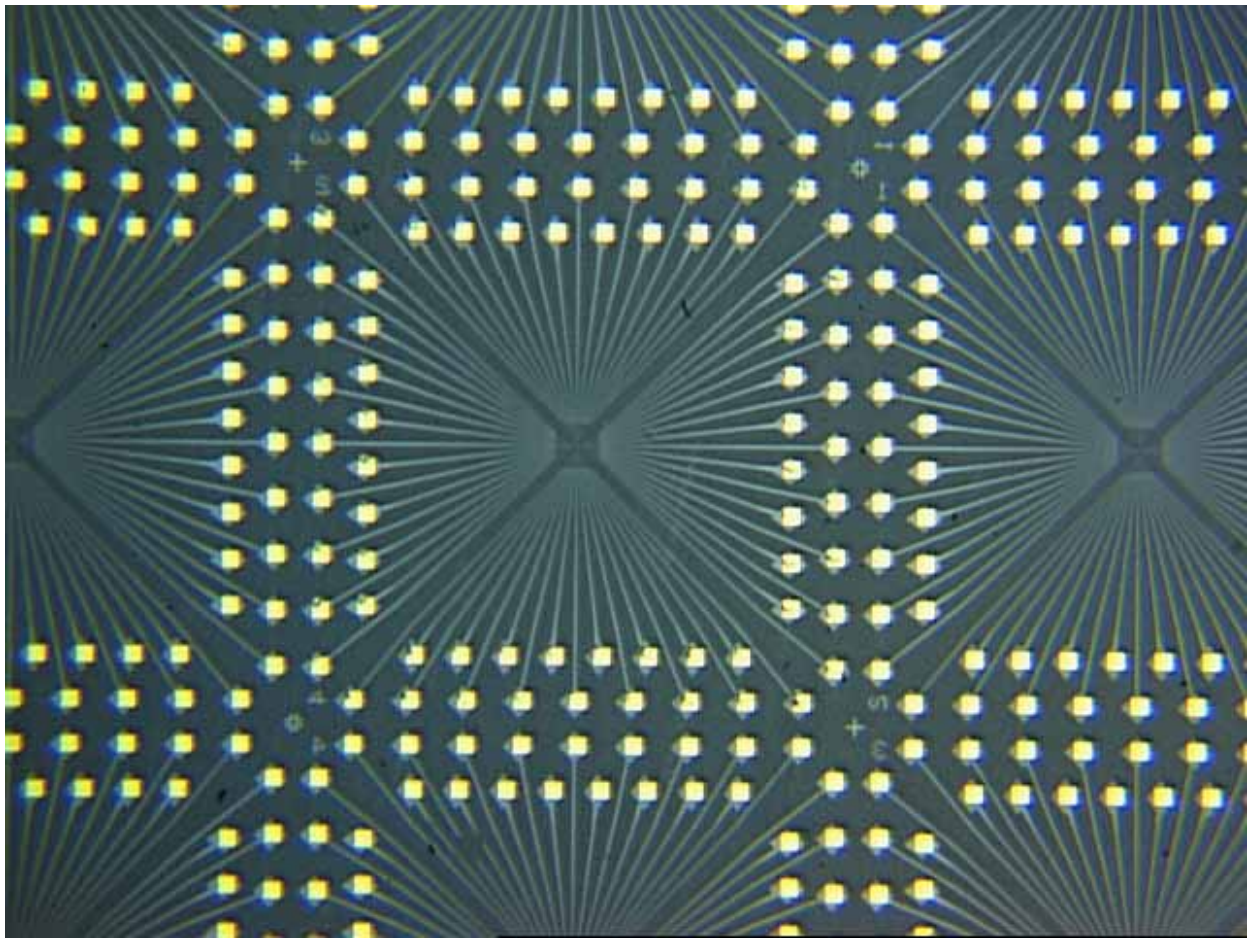
W. Wu, G-Y Jung, SY Wang, R. S. Williams et al., Applied Physics A in press

Rabbit Ears" Solved with Controlled Under-cut



W. Wu, G-Y Jung, SY Wang, R. S. Williams et al., Applied Physics A in press

30 nm Half-pitch 34X34 Crossbar Molecular Memory Fabricated using NIL and Lift-off



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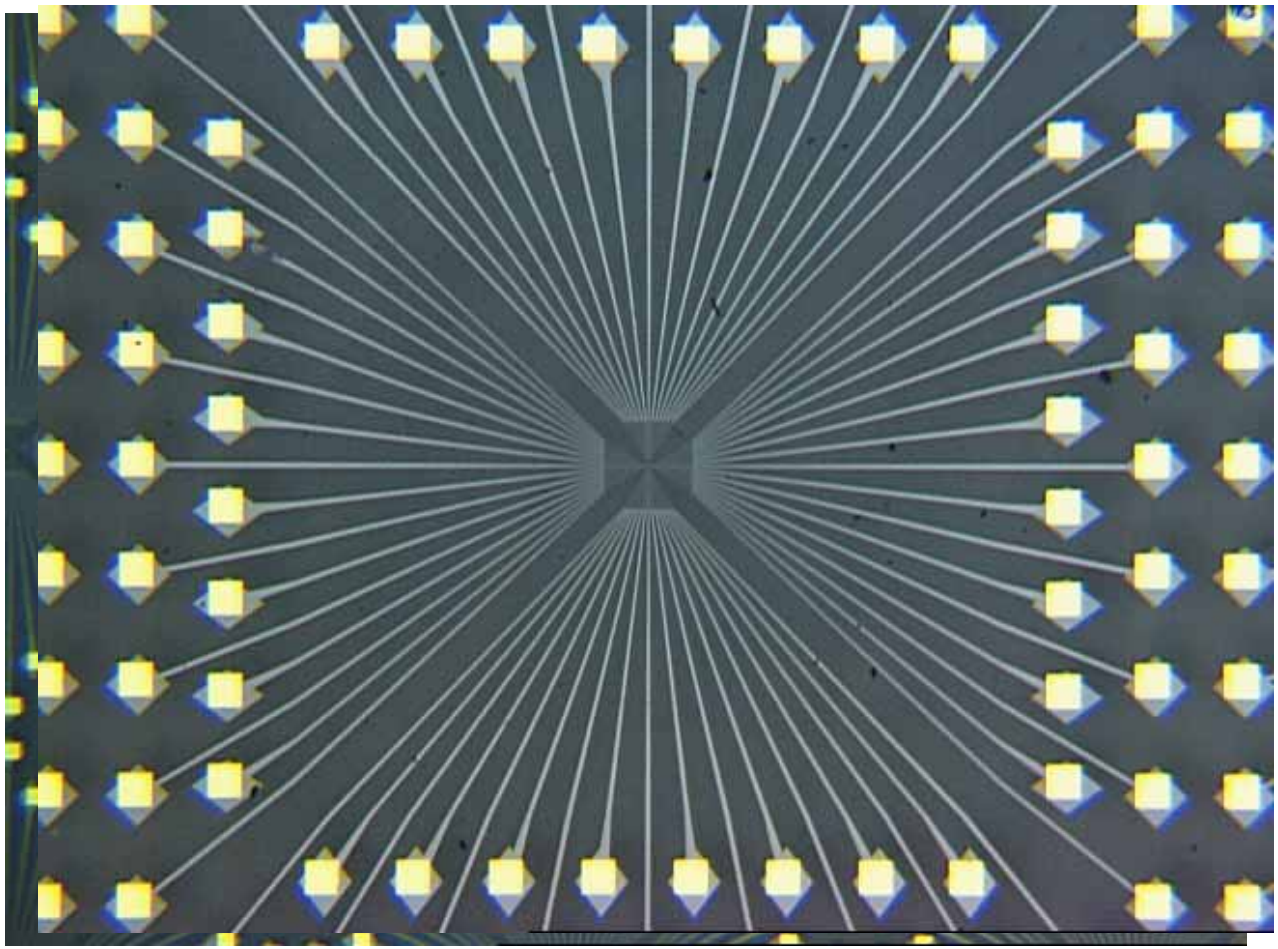

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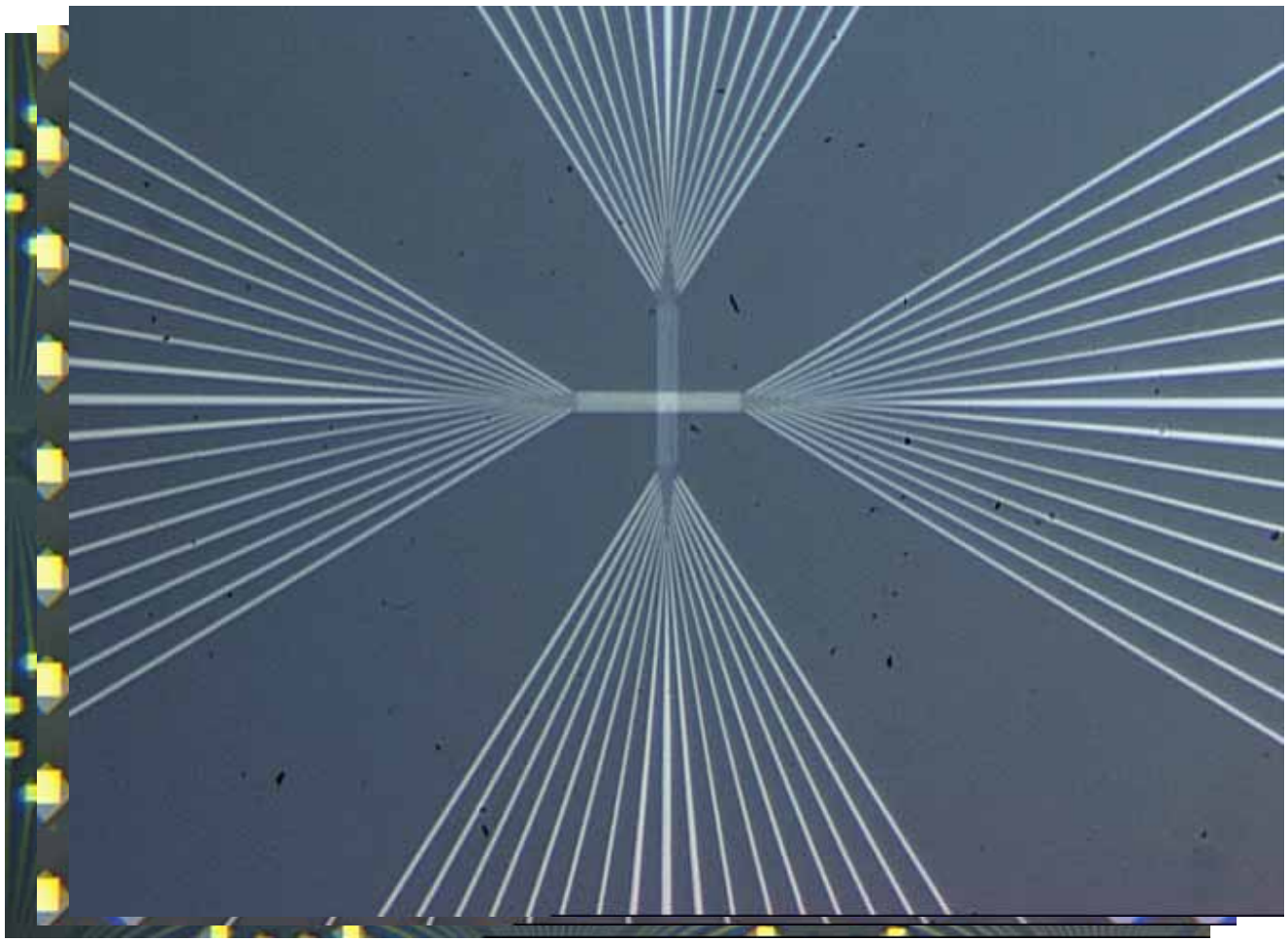

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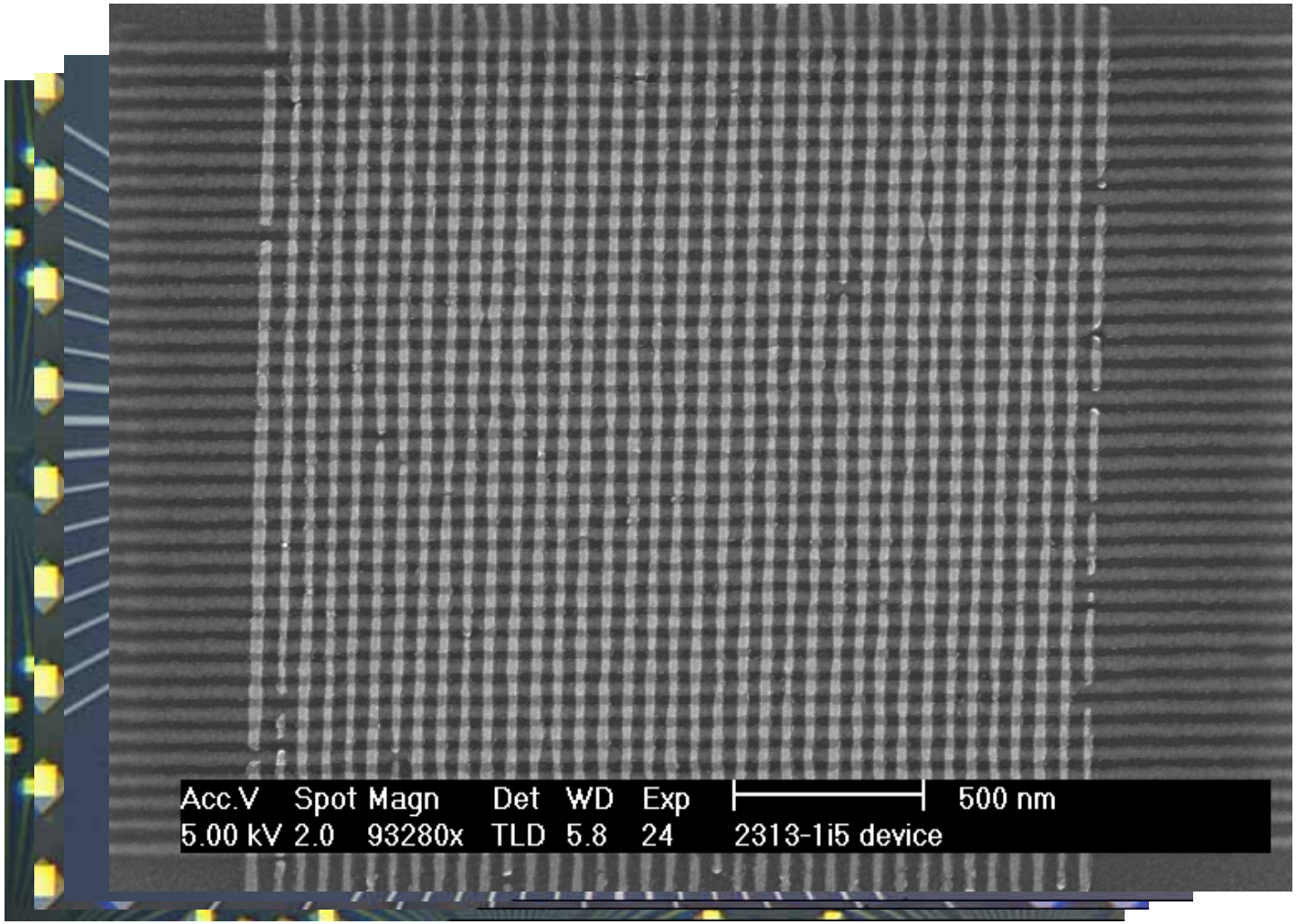

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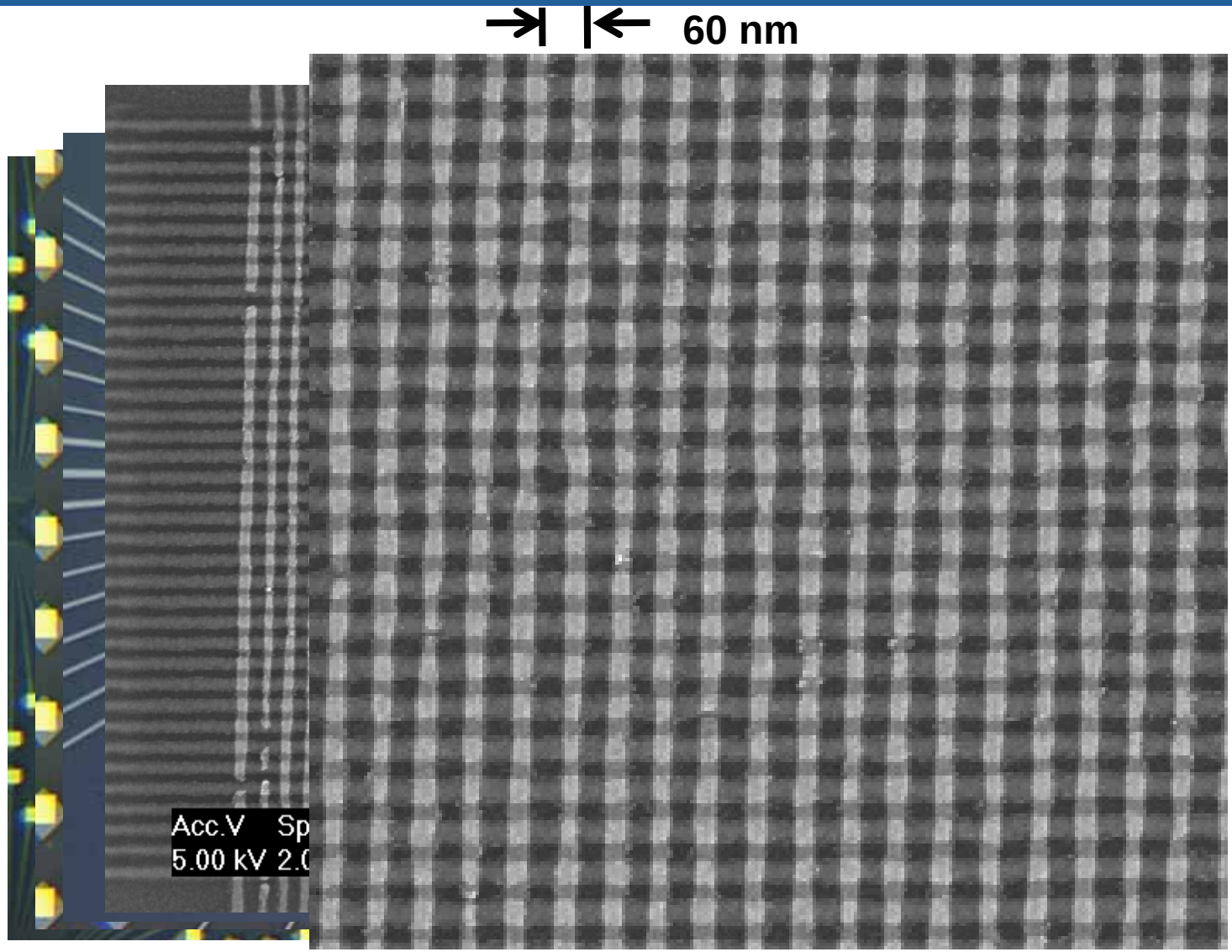

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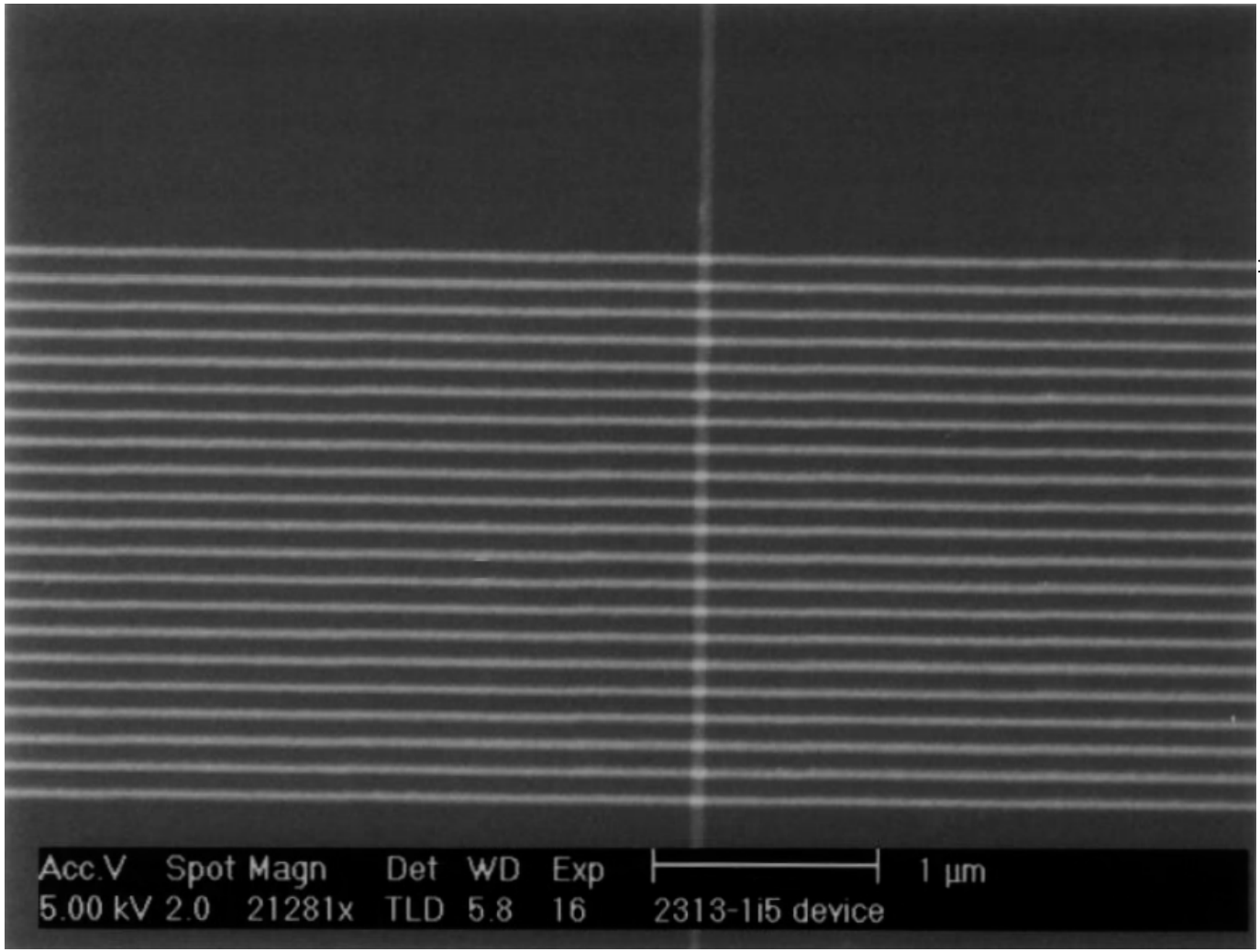
1X17 Testing Devices Array



40 nm

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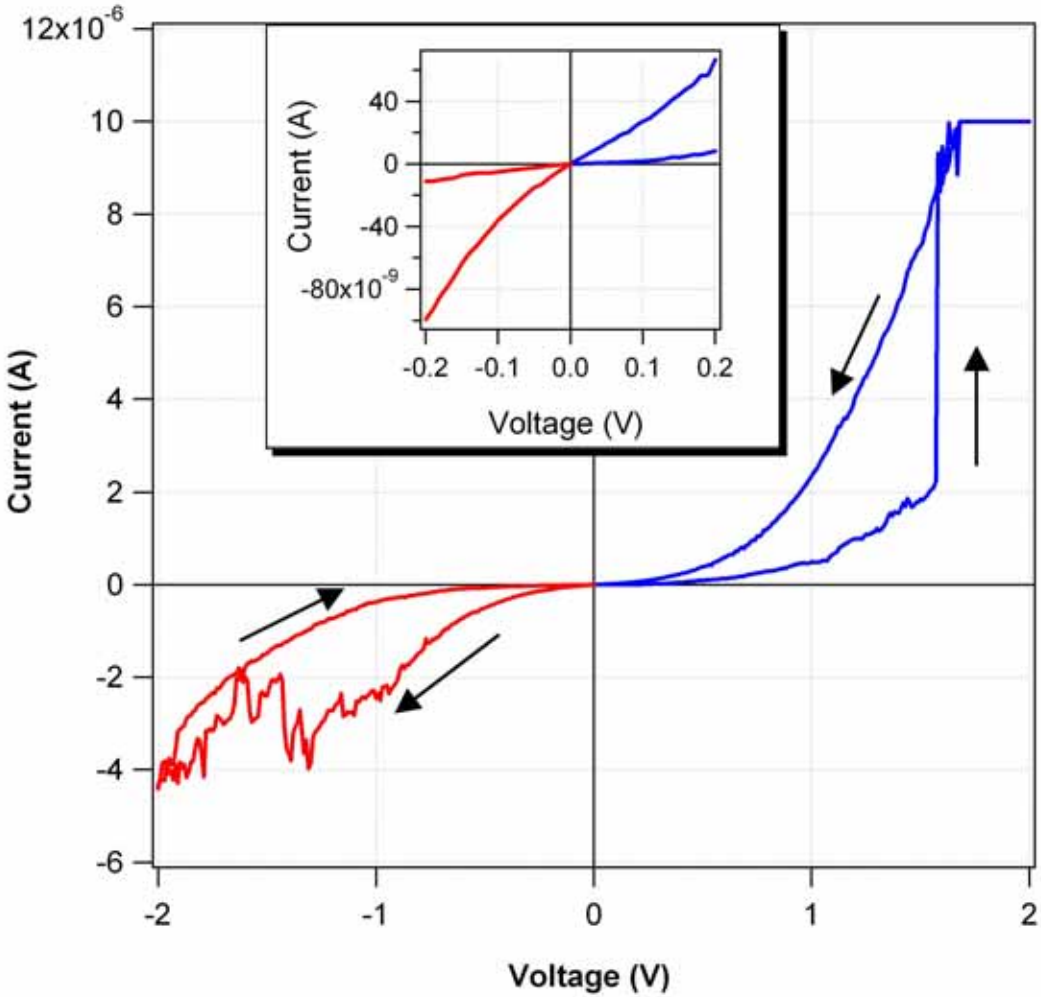
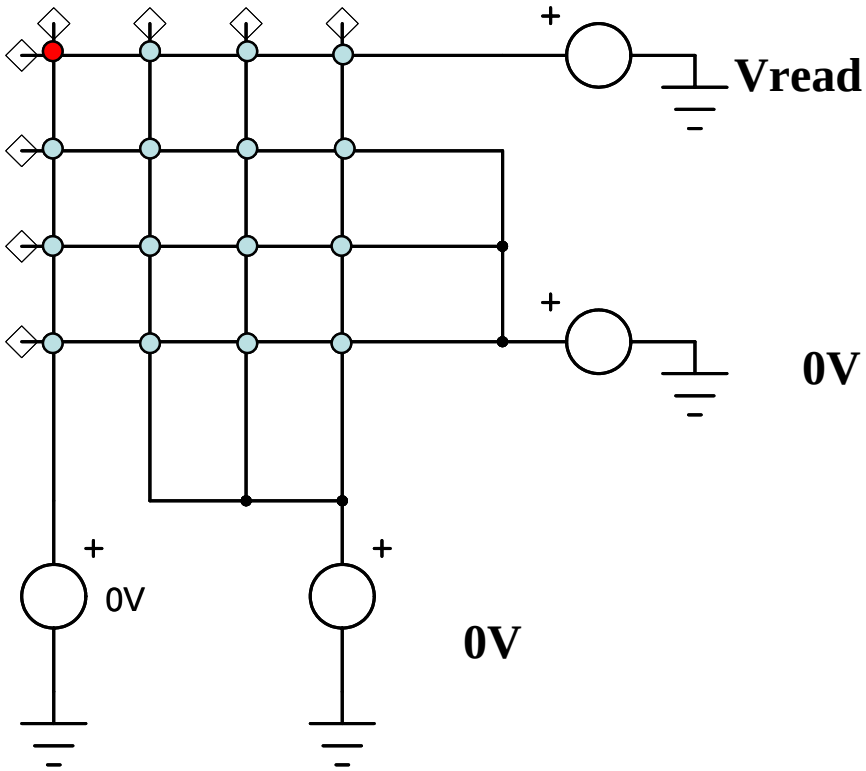
I-V Curve of Single Device

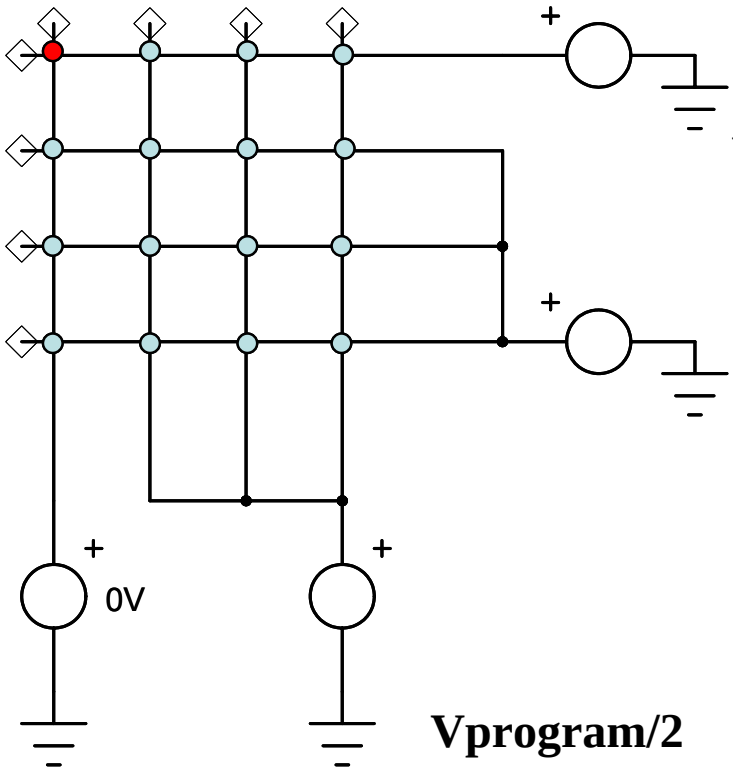


Array Characterization Setup



Read

Array Characterization Setup

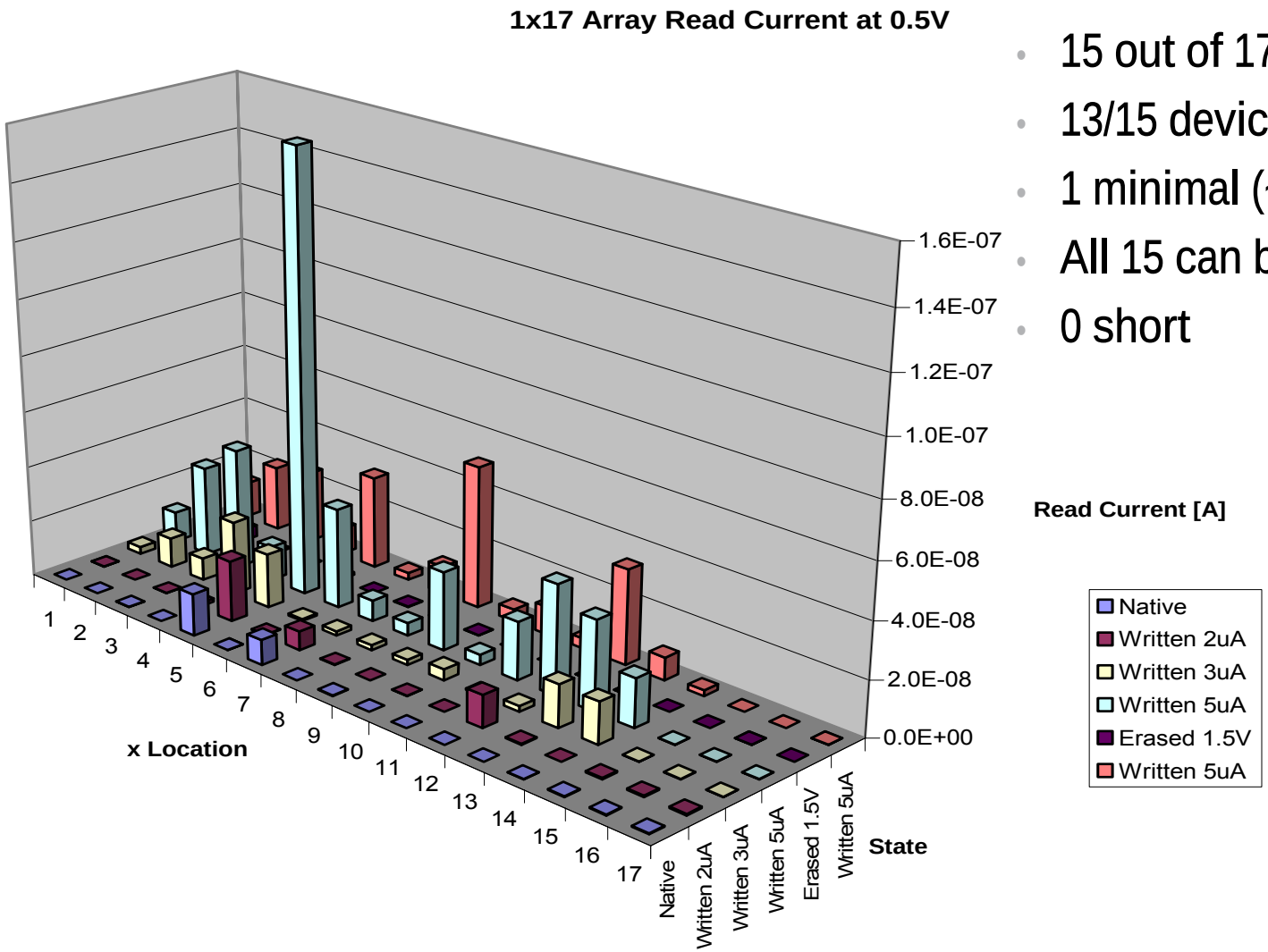


Program

Write with current

Erase with voltage

Read, Write and Erase of 1X17 Array

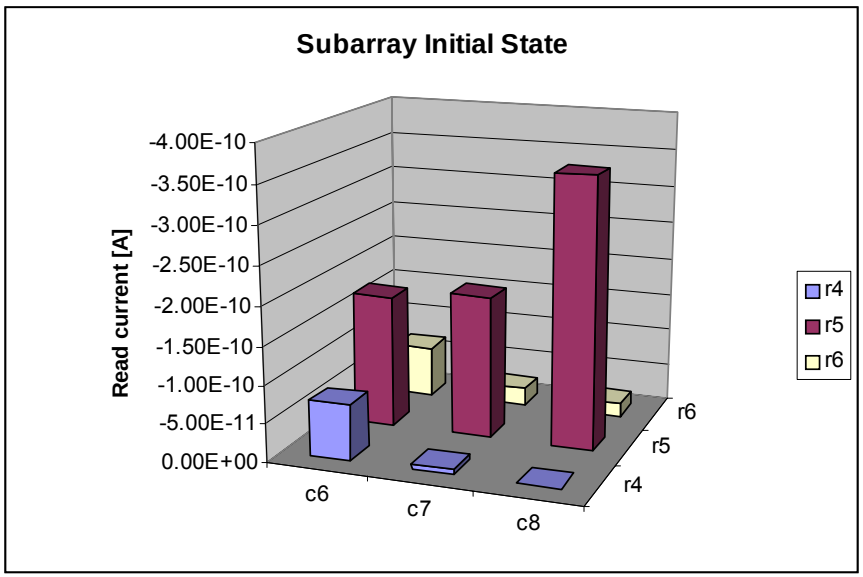


- 15 out of 17 electrodes good
- 13/15 devices switch (> 10)
- 1 minimal (~3x)
- All 15 can be erased
- 0 short

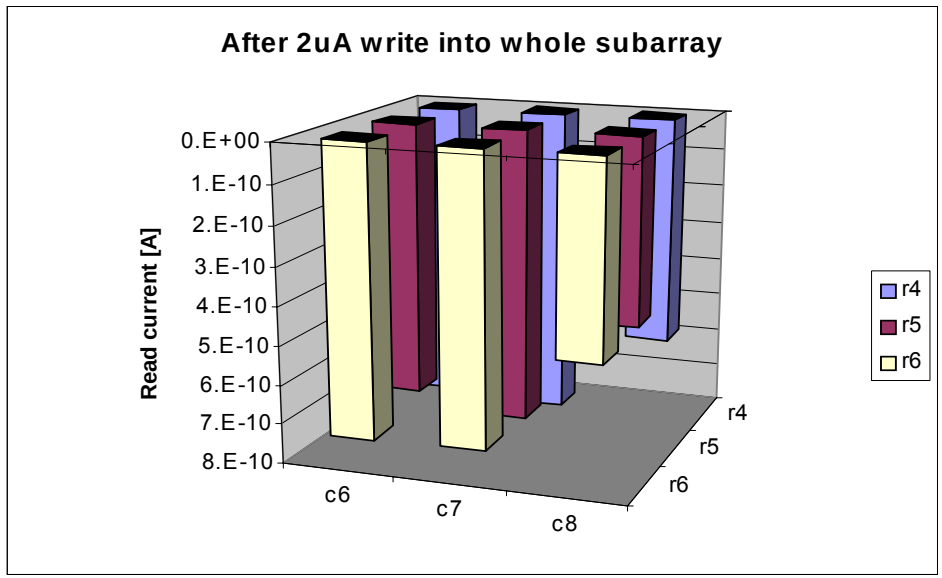
W. Wu, G-Y Jung, SY Wang, R. S. Williams et al., Applied Physics A in press

Programming

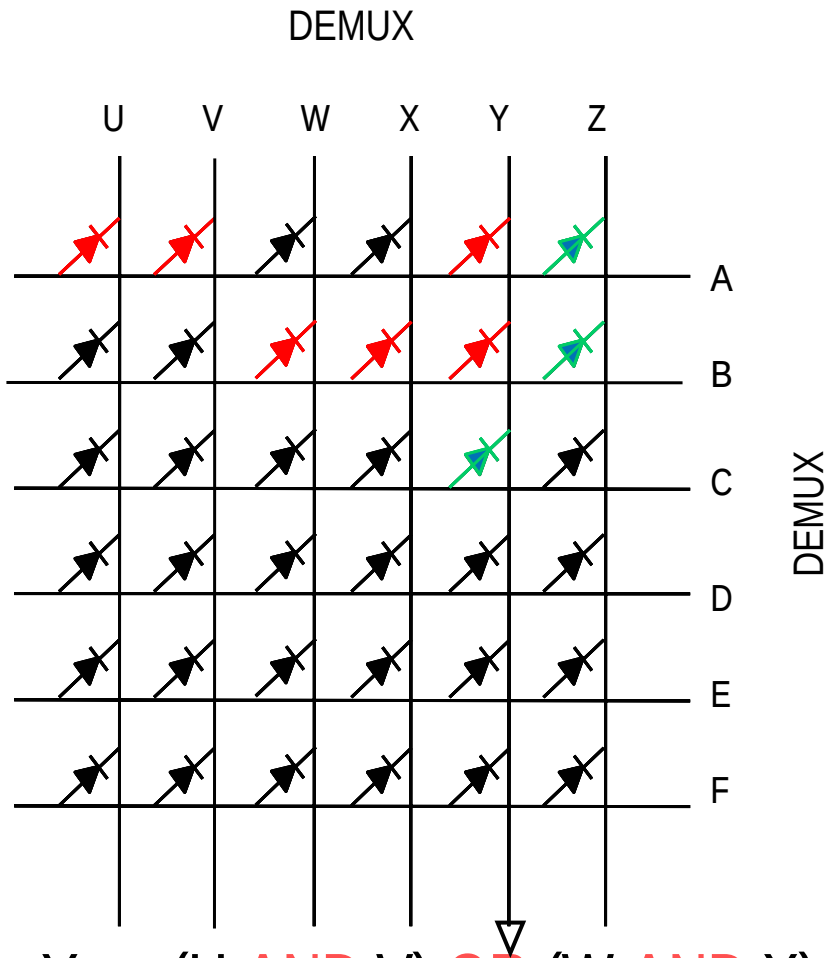
Initial state of a subarray



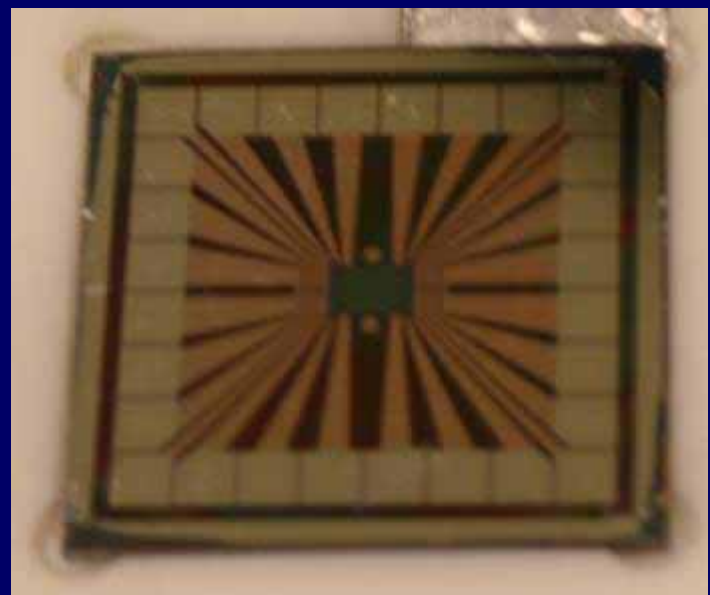
After writing into whole subarray



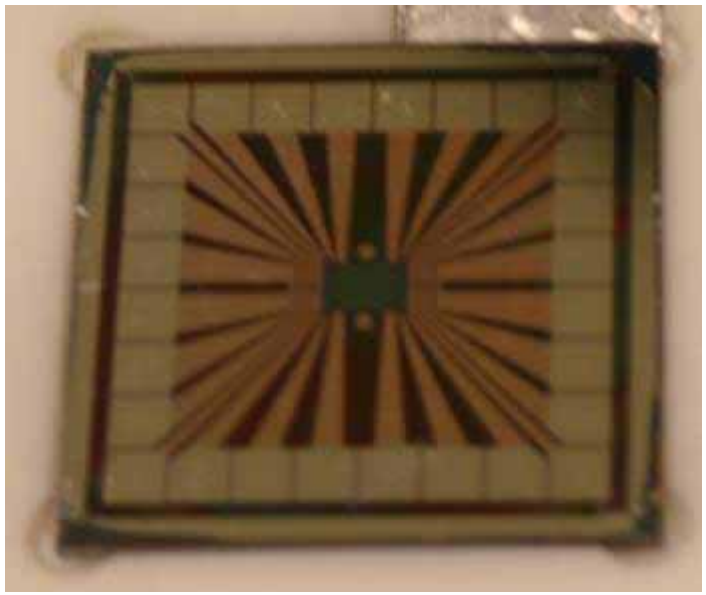
Crosspoint diode logic array: half-adder



Nanowire Biological Sensor



Sensor chip structure



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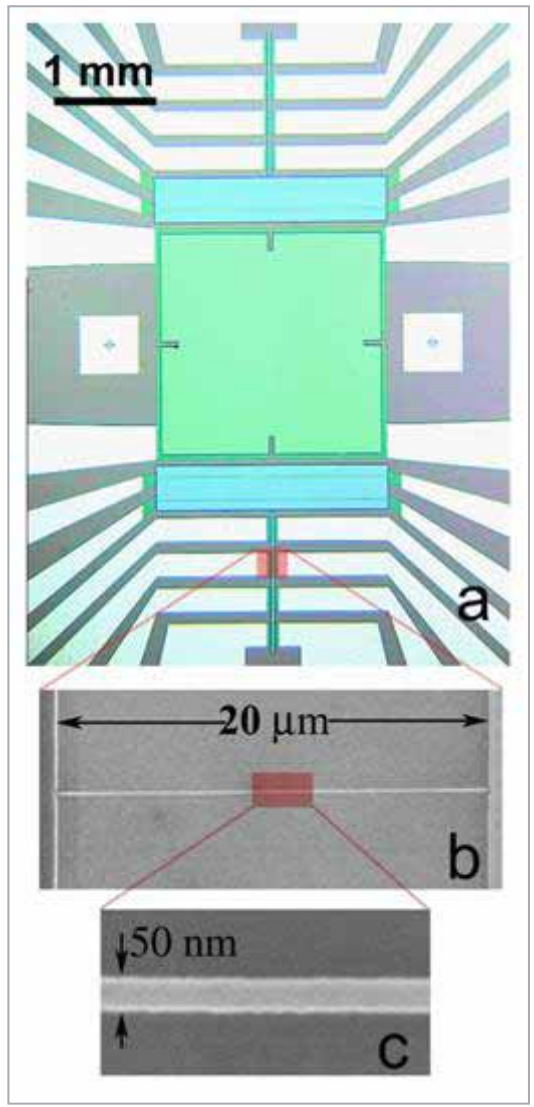
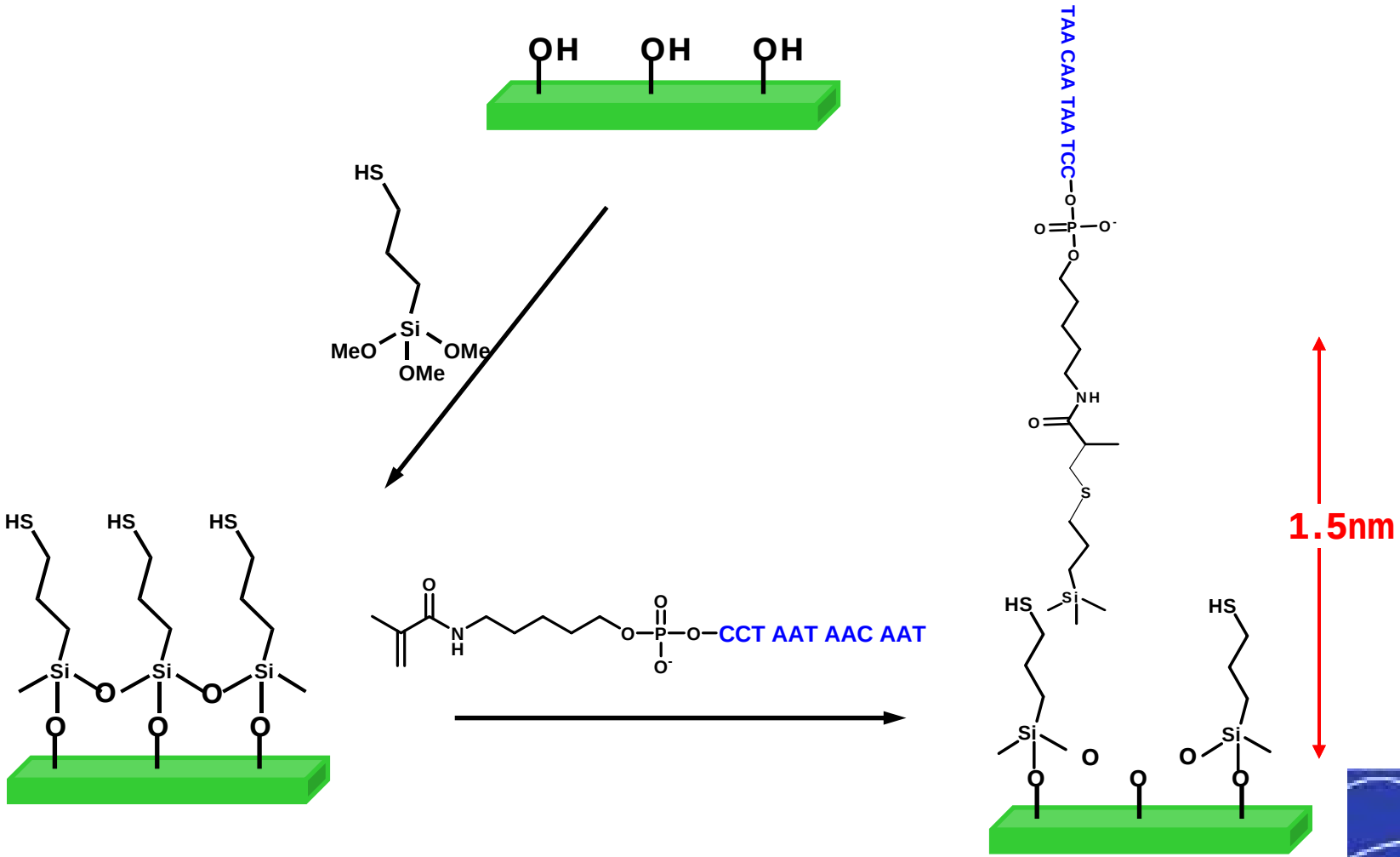


Covalent attachment of ss-DNA on SiNW



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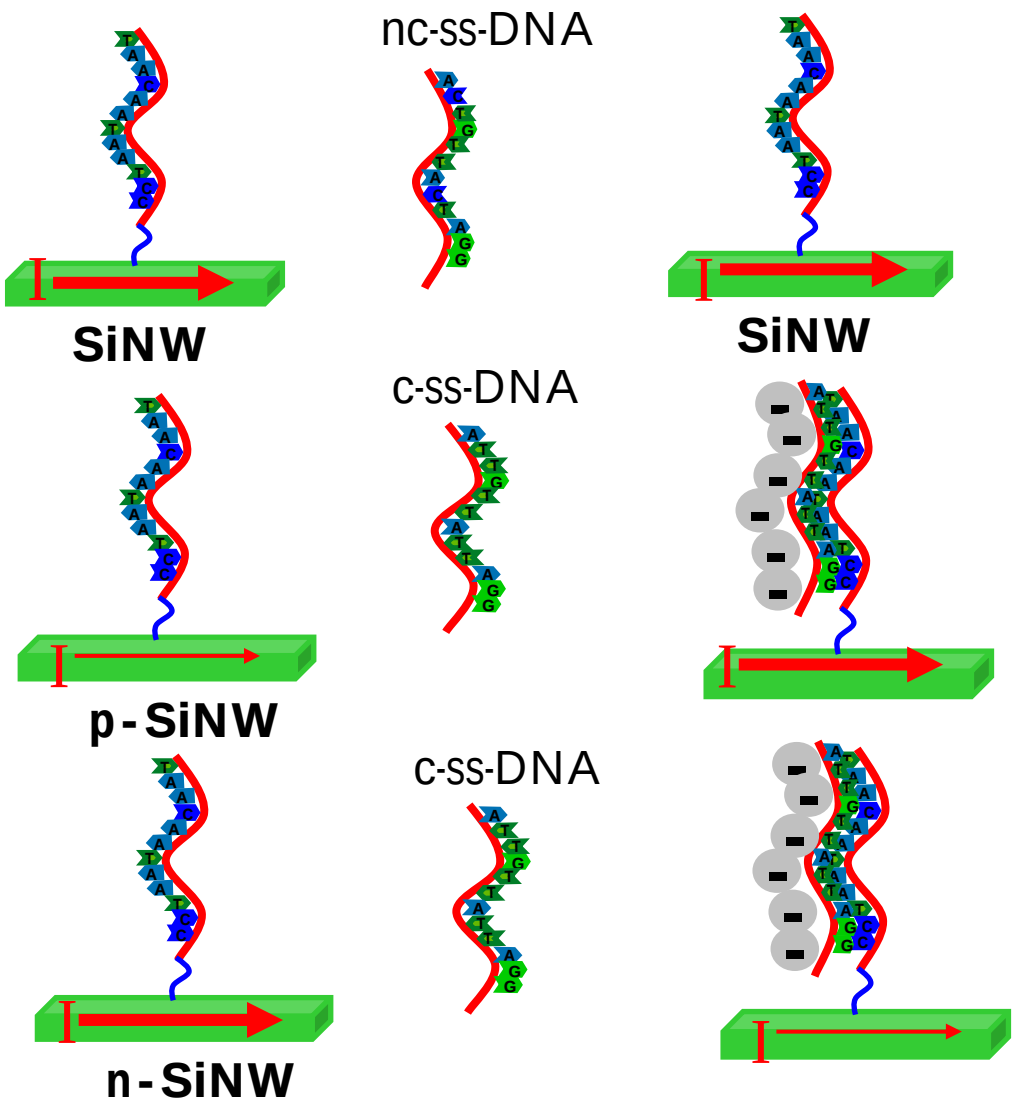
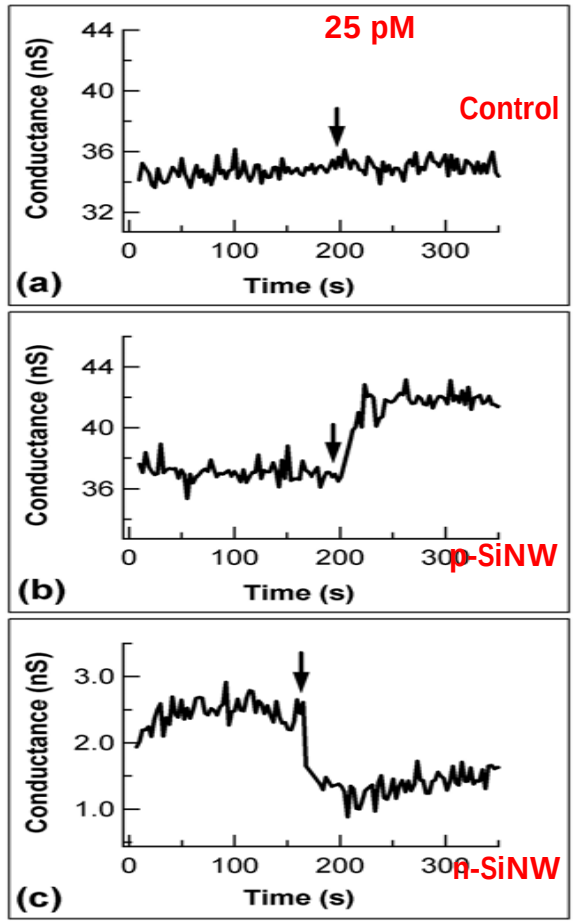
DNA sensing





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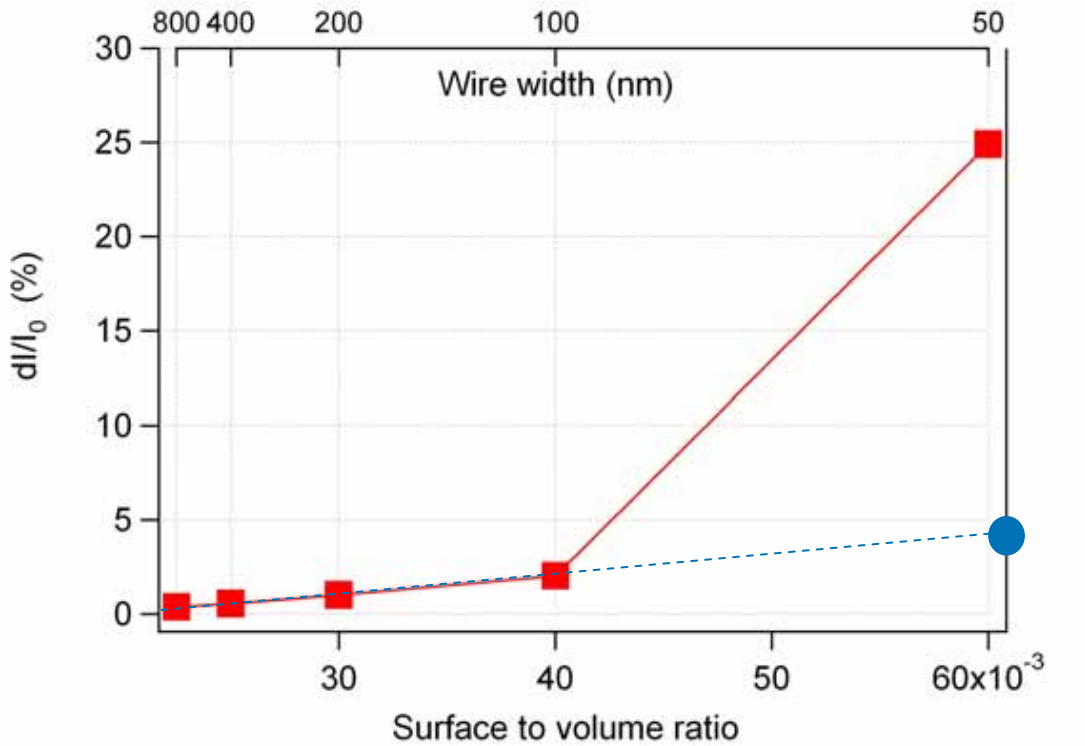
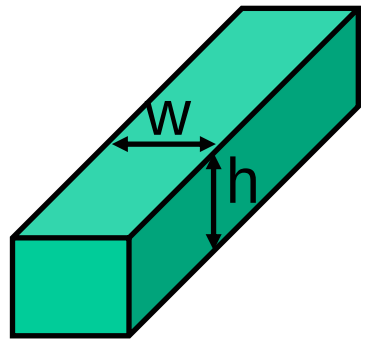
Size matters – dI/I_0 vs aspect ratio of wires





$$\text{Aspect ratio} = \frac{w+2h}{wxh}$$

unit: nm^{-1}

Z. Li, X. Li and R. S. Williams et al. Applied physics A in press

Future Work: Next Generation Nanoimprint Machine

Challenges of NIL:

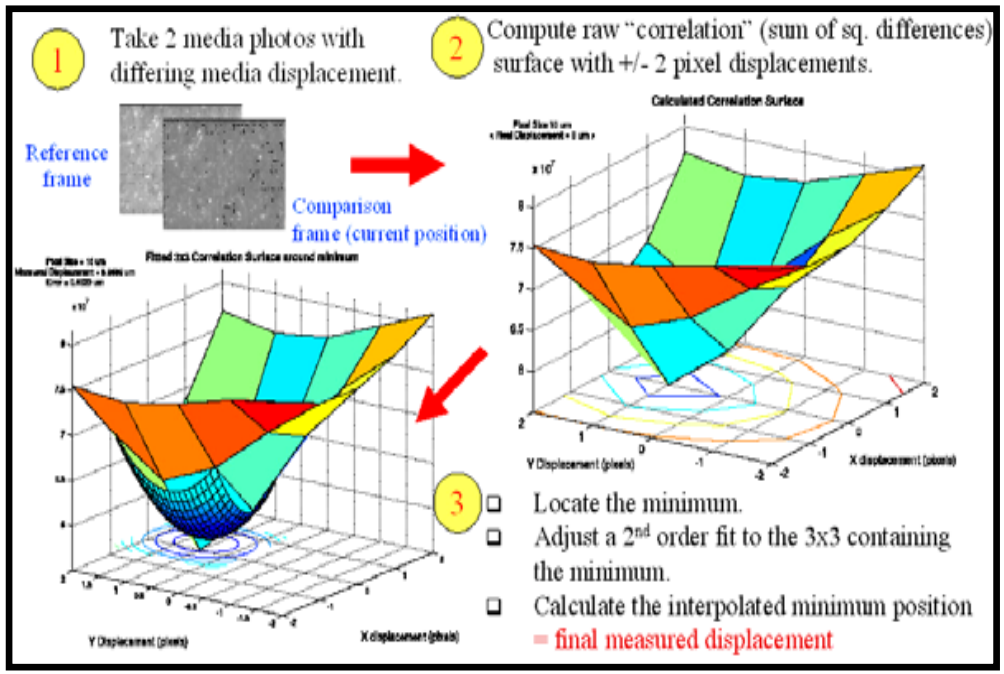
- Yield (It will be improved over time.)
- Alignment accuracy is currently 10x worse than resolution

  -Alignment must be achieved without high cost

Answer:

Next generation nanoimprint machine

Nano Displacement Sensing & Estimation (NDSE) Technology (HTL/ Precision Imaging Program)



- Used in HP large format printers
- Total cost of optics: $60
- 1/50 pixel size displacement detection

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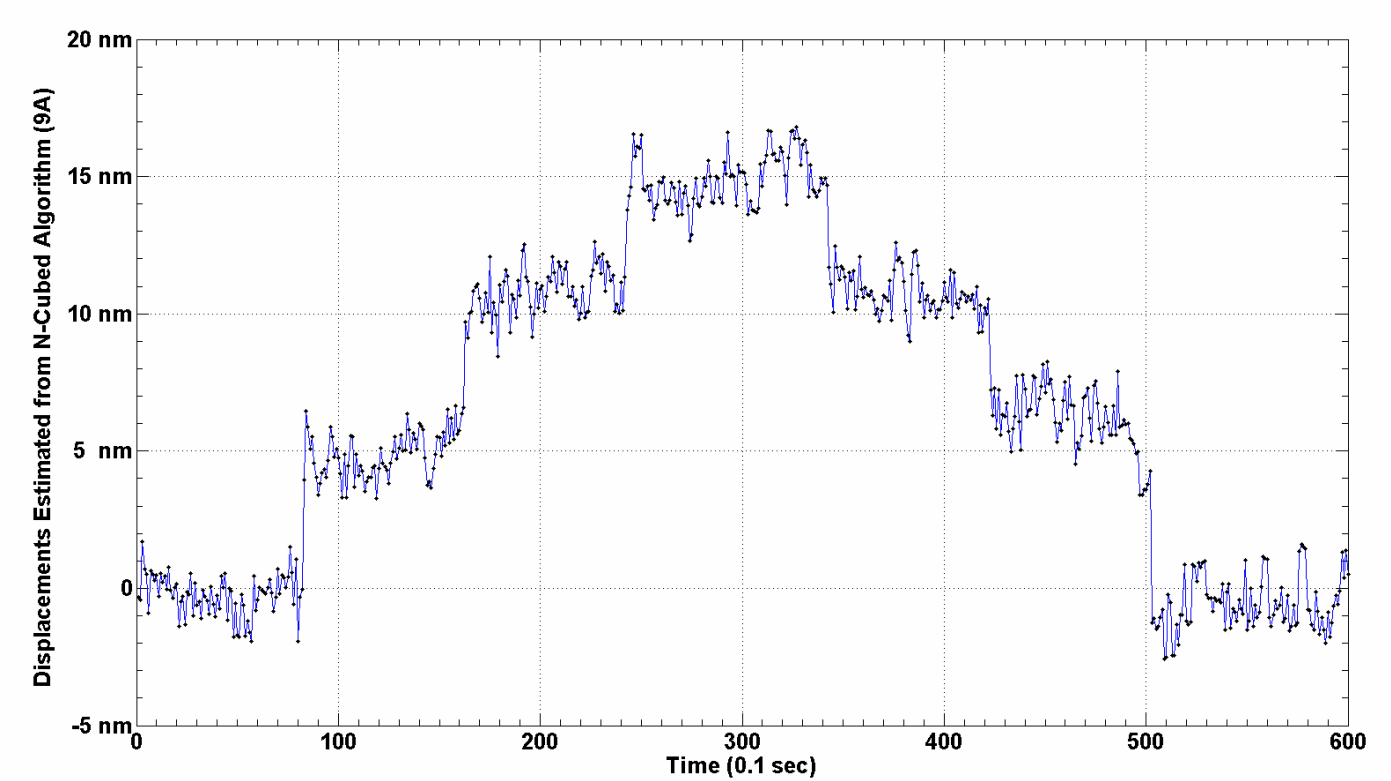
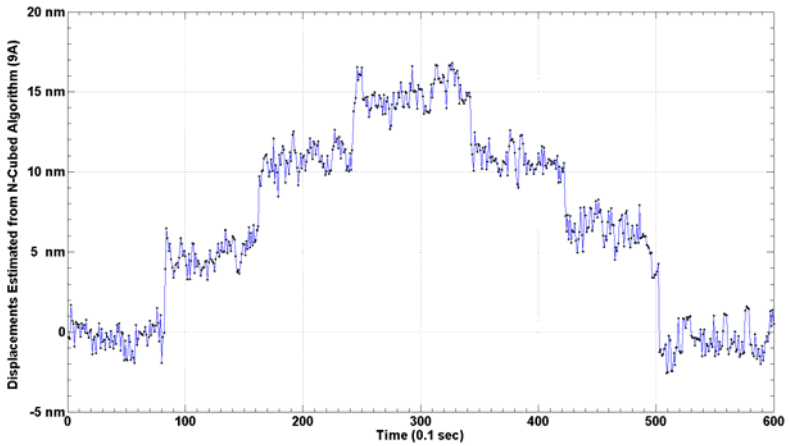
5 nm Displacement sensing using NDSE



J. Gao, C. Picciotto, E. Hoarau, W. Jackson and W. Wu NNT 2004 and Applied physics A in press

Next Generation Nanoimprint Machine

Nanoimprint +



Summary

- HP is one of the earliest company/university to investigate NIL.
- QSR of HP labs is the first group made working circuit using NIL.
- Crossbar molecular memory with record density of 28 Gb/cm^2 (30 nm half pitch) were fabricated using NIL.
- NIL is capable of making real applications.
- Three generations of nanoimprinters were built by QSR.
- Fast and low-cost mold duplication process was developed to lower the cost of NIL further.
- Next generation nanoimprinter will integrate NIL and HP's precision imaging technology.

Acknowledgement

- My colleagues and collaborators
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- You


hp
invent