THE POTENTIAL OF DNA IN MICROELECTRONIC
OUTLINE

- Lithography challenges
- Bio inspired and bio-sourced patterning
- DNA: attractive brick for nano-paterning
- Sub-10 nm DNA based lithography
- DNA for Nano-packaging: a Promising Bottom-up Approach
Photolithography is a process used in microfabrication to pattern parts of a thin film. It uses light to transfer a geometric pattern from a photomask to a light-sensitive chemical "photoresist" (resist) on the substrate. (*wikipedia*)

Same mask used many times to print thousand of wafers

\[
CD = k_1 \frac{\lambda}{NA}.
\]

- **CD**: pattern resolution
- **\(\lambda\)**: exposure wavelength
  - *(193nm today in production)*
- **\(k_1, NA\)**: constants

Light wavelength dictates patterning resolution (diffraction limits)
Moore's law, enounced in 1965 by Gordon Moore, the co founder of Intel, is the observation that the number of transistors in a dense integrated circuit doubles approximately every two years.

After the 28nm node, we can continue to make transistors smaller, but not cheaper. EETimes
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Water-Based Photo- and Electron-Beam Lithography Using Egg White as a Resist

Bojing Jiang, Jie Yang, Chen Li, Liangliang Zhang, Xu Zhang, and Peng Yang

UV exposure:
- 254nm wave length,
- 10min/2000µWcm⁻² + 10min/8000µW/cm⁻²
- Resolution: 5 µm (projection photomask)

E-Beam exposure:
- 30keV, 3000µCcm⁻²
- Resolution: 100nm lines

Etching transfer into Si/SiO₂/Au/Cu

Coast:
- HSQ Negativ resist: 25,17[$g^{-1}$]
- Egg whit resist: 0,37[$¢mL^{-1}$]
Self-assembly: a process in which a disordered system of pre-existing components forms an organized structure or pattern as a consequence of specific, local interactions among the components themselves, without external direction. (wikipedia)
SELF-ASSEMBLY EVERYWHERE IN THE NATURE

BUT KEEP IN MIND HIGH RESOLUTION
NANOTECHNOLOGY: SIZE AND SCALE
**WHAT IS DNA?**

**DNA: DeoxyriboNucleic Acid**

- Is the hereditary material in almost all organisms.
- Nearly every cell in a person’s body has the same DNA.
- Is a double helix formed by base pairs attached to a sugar-phosphate backbone.

**Source:** [www.compoundchem.com](http://www.compoundchem.com)
**DATA STORAGE WITH DNA**

*Nature 537, 22–24, 2016*  
doi:10.1038/537022a

<table>
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<th>Hard disk</th>
<th>Flash memory</th>
<th>Bacterial DNA</th>
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<tr>
<td><strong>Read–write speed</strong></td>
<td>~3,000–5,000</td>
<td>~100</td>
<td>&lt;100</td>
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<td>(µs per bit)</td>
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<tr>
<td><strong>Data retention</strong></td>
<td>&gt;10</td>
<td>&gt;10</td>
<td>&gt;100</td>
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<td>(years)</td>
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<td><strong>Power usage</strong></td>
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<td>~0.01–0.04</td>
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<td>(watts per gigabyte)</td>
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<tr>
<td><strong>Data density</strong></td>
<td>~10¹³</td>
<td>~10¹⁶</td>
<td>~10¹⁹</td>
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<tr>
<td>(bits per cm³)</td>
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**WEIGHT OF DNA NEEDED TO STORE WORLD’S DATA**  
~1 kg
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Pioneered by Seeman in the 80’s

*Structural DNA Nanotechnology: State of the Art and Future Perspective, Fei Zhang et al, JACS 2014*
DNA ORIGAMI HONEYCOMB 2D LATTICES

Collaboration with prof. Yonggang Ke, Emory university

Folding DNA to create nanoscale shapes and patterns

Paul W. K. Rothemund

Source https://www.youtube.com/watch?v=5yH5LTXxFzK
DNA 3D SELF-ASSEMBLY : ORIGAMI

Three-Dimensional Structures Self-Assembled from DNA Bricks. Yonggang Ke et al, Science 2012
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I/ Design: cadnano

II/ Synthesis:

III/ Process:

1- DNA adsorption on Si-SiO₂
2- DNA pattern transfer by HF vapor etching
3- DNA mask removal

R.Tiron | MIDI MINATEC | April, 2017 | 20
SUB 10 NM PATTERN TRANSFERRED INTO SiO2


AFM images of DNA and SiO$_2$ substrate before and after HF vapor etching.

*All values are given in nm. Scale bars: 50 nm.*
COMPLEX STRUCTURE: VERSATILE PITCH AND RESOLUTION
HIGH ASPECT RATIO PATTERN TRANSFER BY DRY ETCH

1. Grafting of DNA origami (mask) on a thin layer of SiO₂/SiO

2. HF etching of SiO₂ substrate with a high resolution, high contrast and total transfer

3. Plasma Etching of Si substrate with a high resolution and high contrast

H = 1.7 ± 0.2 nm

H = 10.1 ± 0.2 nm

H = 65 ± 4 nm

CD-SEM image
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DNA FOR NANO-PACKAGING: A PROMISING BOTTOM-UP APPROACH

**DNA metallization process:**
- **activation** step consisting in an exchange of metallic cations on the DNA backbone,
- cluster **NW growth** by electroless plating process,
- achievement of a uniform and **continuous metallic nanowire**.

*C.Brun et al, IEEE Nanotechnology Magazine, Vol. 11 (1), 2017*

**AFM images after metalization**

**Christophe BRUN**
Postdoc 2014-2016
METALLIC CONDUCTIVE NANOWIRES
BY METAL DEPOSITION ON SUSPENDED DNA BUNDLES

SEM images of the fabricated Ti/Au NWs from suspended DNA wires

I/V curve for 80-nm diameter metallic NWs

CONCLUSION

• High resolution high density versatile templates available with DNA origami.

• We demonstrated a sub-10-nm patterning with DNA origami template
  • First into SiO2 using HF vapor etching process for time ranging (3 to 10nm high)
  • Then by SiO2 hard mask into Si by dry etch (up to 60 nm high)

• Chemical electroless reduction and PVD metallization process: promising paths to fabricate gold electrical conductive NWs (diameter 80 nm)
NEXT GENERATION LITHOGRAPHY:

TOP-DOWN OR BOTTOM-UP

PROBABLY BOTH TOGETHER
Nano-bioreactor

Chem 2017 2, 359-382DOI: (10.1016/j.chempr.2017.02.009)

Nano fabrication

Cargo mimic

A DNA nanorobot

A drug in a box

Biosensing
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