ECE 220A/Materials 215A
Semiconductor Device Processing (Fabrication)

Scope:

- Fabrication building blocks
  - *Special topic: advanced versions of building blocks*
- Strong emphasis on *laboratory experience*
  - Homeworks: involve lab processes & analysis (50%)
  - Lab: integrative, long-term, group-based: require planning and design (30%)
  - Final Exam: open book, open notes, may be a take-home design problem (20%)

To Do:

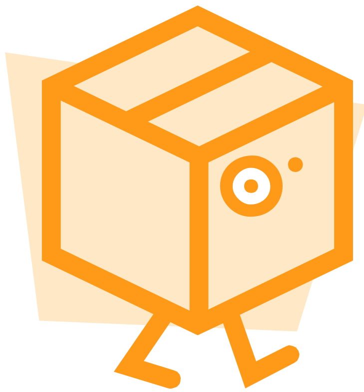
- Fill in and return 'Introductory sheet'
- See Bob Hill in 4110 Harold Frank Hall
  - See safety video, start scheduling demonstrations on equipment
- Get key cards for access to 4110
  - By groups: key held by one group member
  - First floor of Harold Frank Hall
  - *As soon as class list is finalized*

ECE 220A/Materials 215A
Semiconductor Device Processing (Fabrication)

A set of techniques for creating structure and order at the micron -> nanometer scale

- A 'paradigm shift' in fabrication that allowed us to scale dimensions of structures down to nanometer dimensions
- A 'paradigm shift' that allowed massively parallel formation of dense collections of devices/structures
- A 2-dimensional 'printing process' that allows us today to make 3-dimensional nanoscale structures

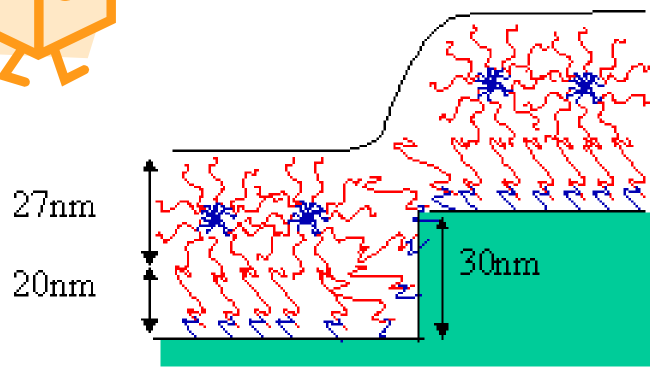
From Material Properties to New Engineering Opportunities



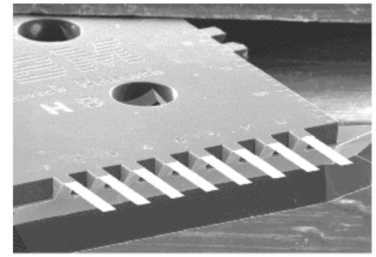
Novel Material = Scientific/ Engineering opportunity
• ceramic
• polymer
• semiconductor
• metal
• oxide

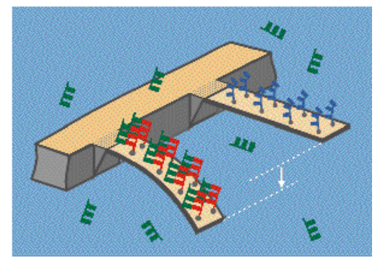
- Optical performance
  - Unusual optical efficiency
  - Accessing new wavelengths
  - Photodetectors, solar cells
- Electronic performance
  - High speed, easily modulated currents
  - superconducting
- Spin-dependent performance
  - Long spin lifetimes
- Mechanical performance
  - Robustness
  - Elasticity, natural frequency

Structuring the Environment to Better Study the Material

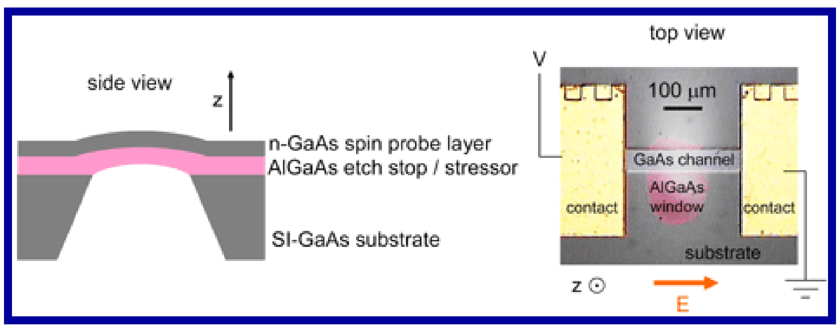


Forming templates to understand ordering of polymers
E. Kramer, Chem. Eng. & Materials

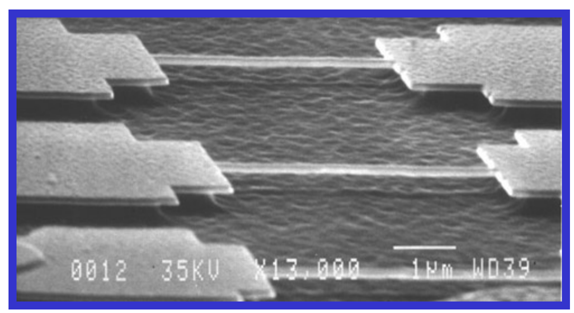




DNA on MEMS,
Gimzewski Lab, UCLA

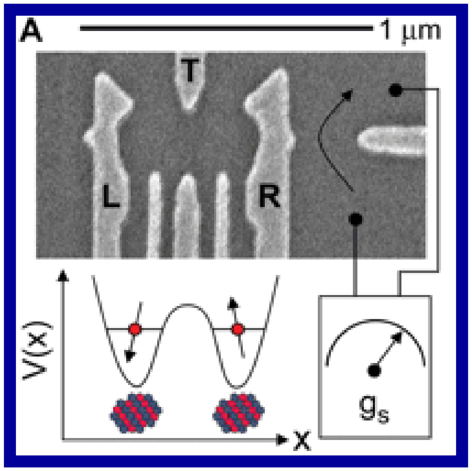


'strained' structures to study spin transport
D. Awschalom, Physics

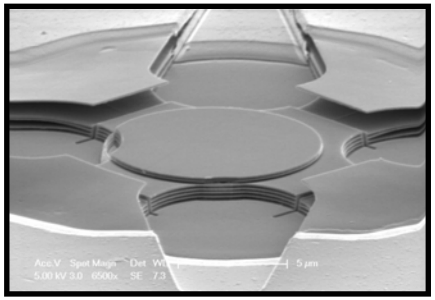


Ultrahigh Frequency AlN Resonators
A. Cleland, Physics

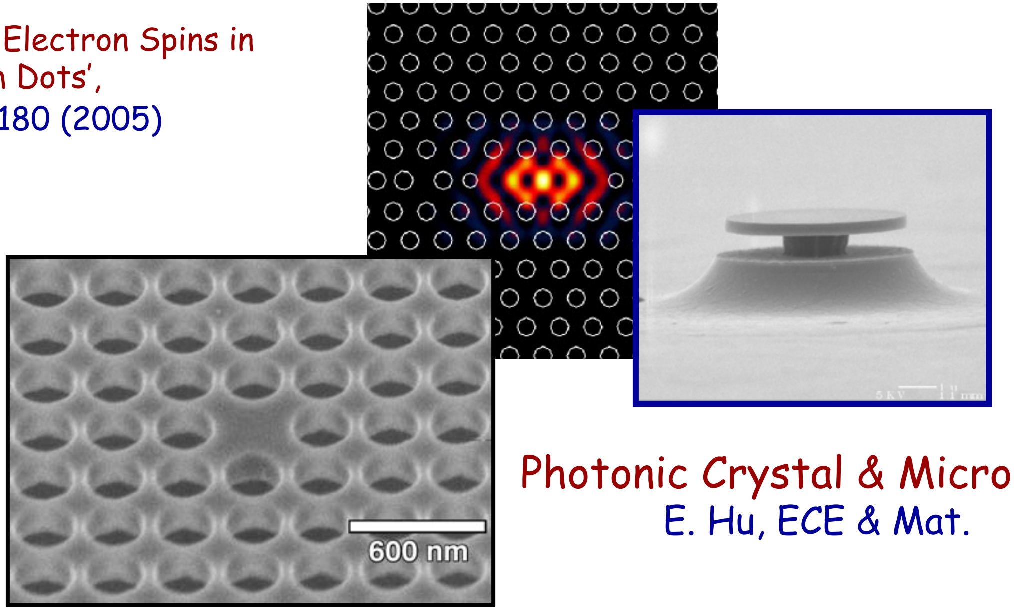
'Coralling' electrons and photons



'Coherent Manipulation of Coupled Electron Spins in Semiconductor Quantum Dots',
Petta et al., Science 309, 2180 (2005)

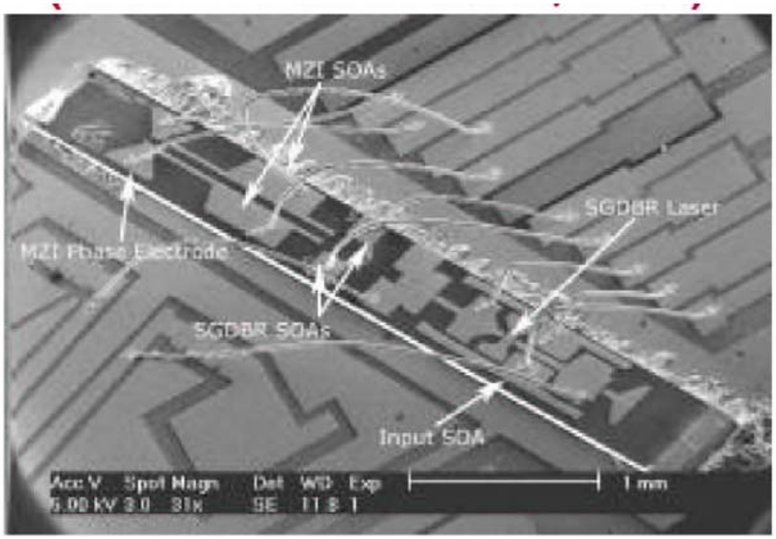


High Reflectivity Mirrors for GaN-Optics
S. Nakamura, S. DenBaars, E.L. Hu
Materials & ECE

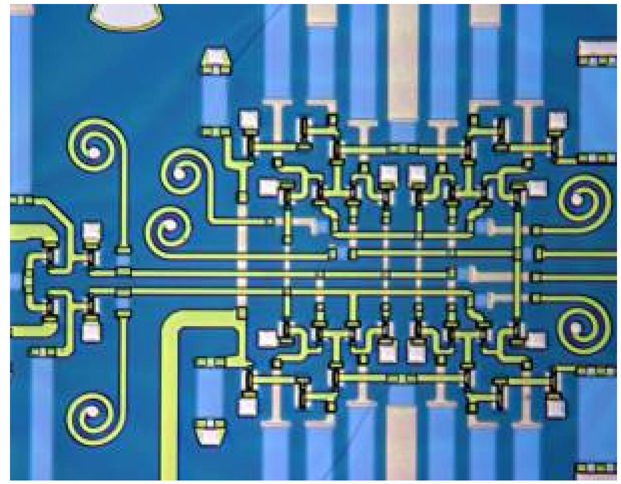


Photonic Crystal & Microdisks
E. Hu, ECE & Mat.

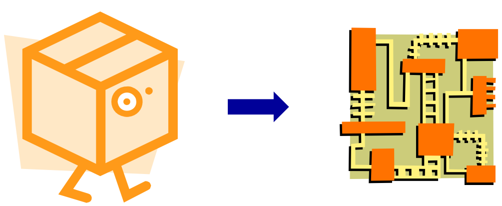
Fabrication for Electronic and Photonic Devices & Circuits



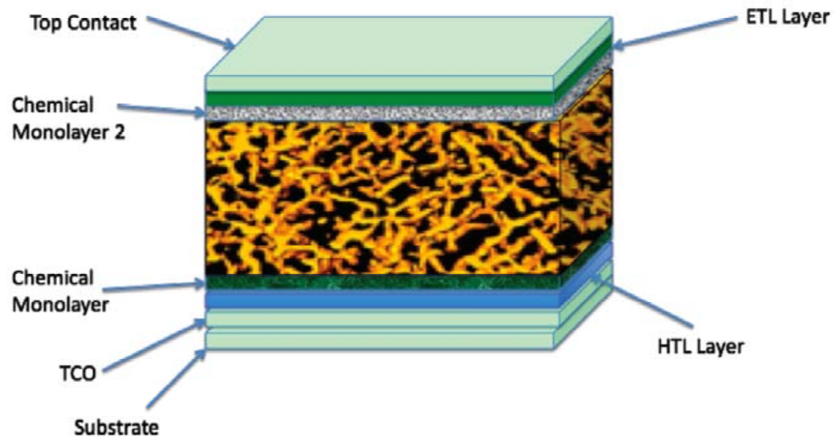
All-optical Wavelength Converter (InP)
D. Blumenthal, L. Coldren, ECE



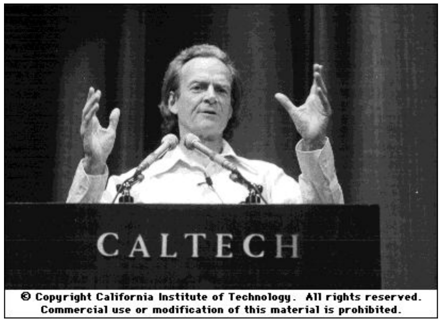
142 GHz InP-based Circuit
M. Rodwell, ECE



Organic Solar Cell
A. Heeger, G. Bazan, M. Chabinyc, et al., Materials



A Way of Accessing the Very Small . . .

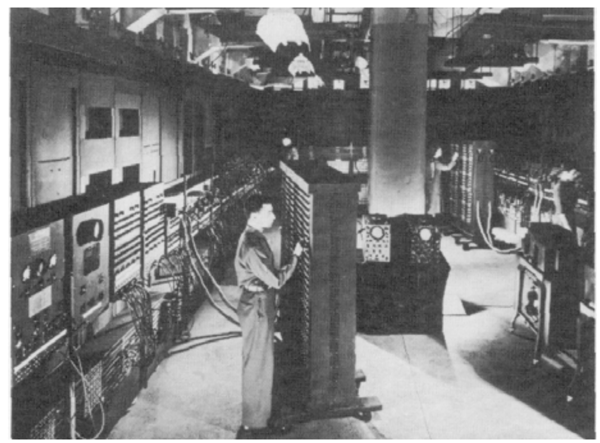


'I would like to describe a field, in which little has been done, but in which an enormous amount can be done in principle.... manipulating and controlling things on a small scale'

Richard Feynman, Caltech 1959
'There's Plenty of Room at the Bottom'

...computing machines are very large; they fill rooms. Why can't we make them very small, ...make them of little elements ---by little, I mean *little.*

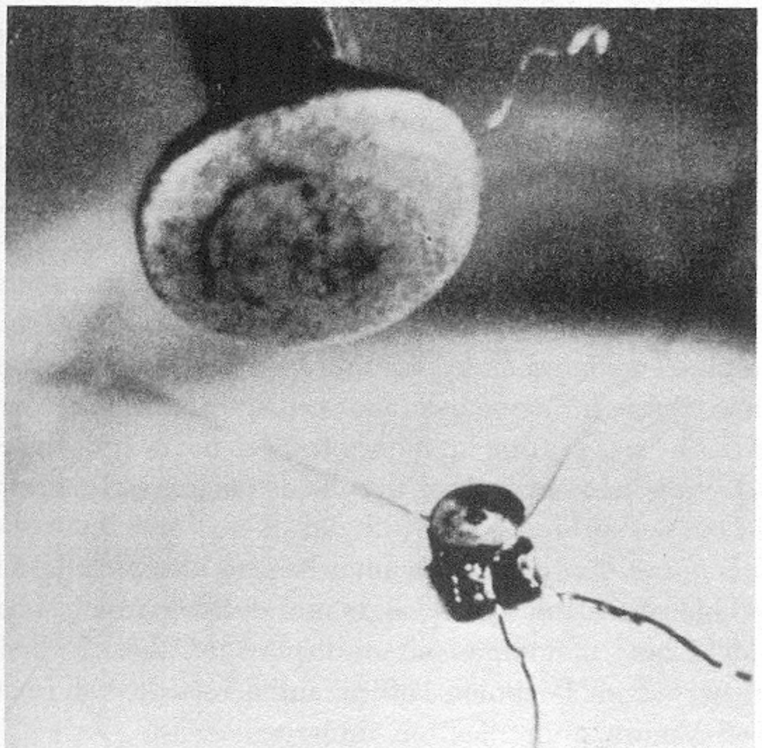
30 tons, 1800 sq ft, 18,000 vacuum tubes →



Electronic Numerical Integrator and Computer
ENIAC

Feynman's Grand Challenges:

…make a motor 1/64 of an inch on a side



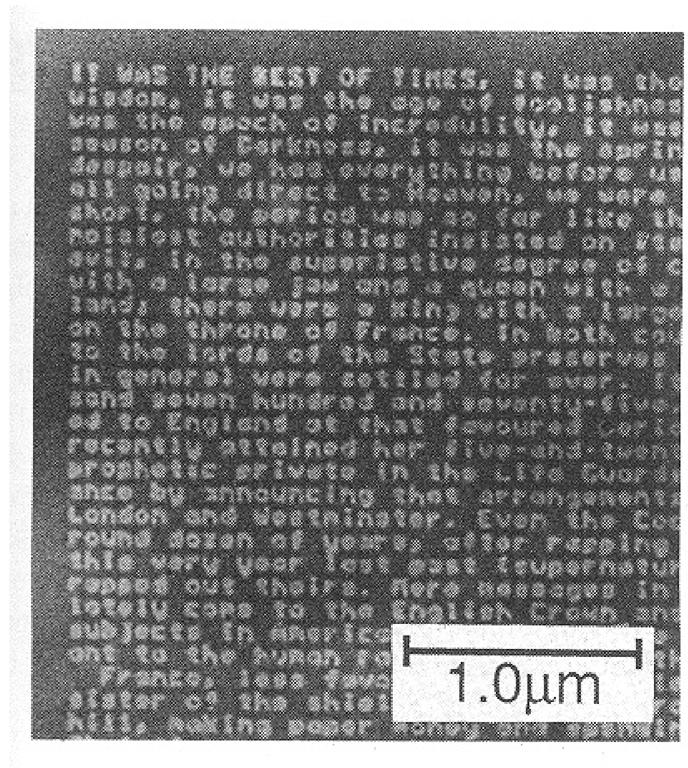
William McLellan's 1/64-inch motor;
awarded the first Feynman prize, 1960. (*James McClanahan*)

- Awarded in 1960 to Willaim McLellan
- 3D fabrication, standard techniques…. only smaller dimensions

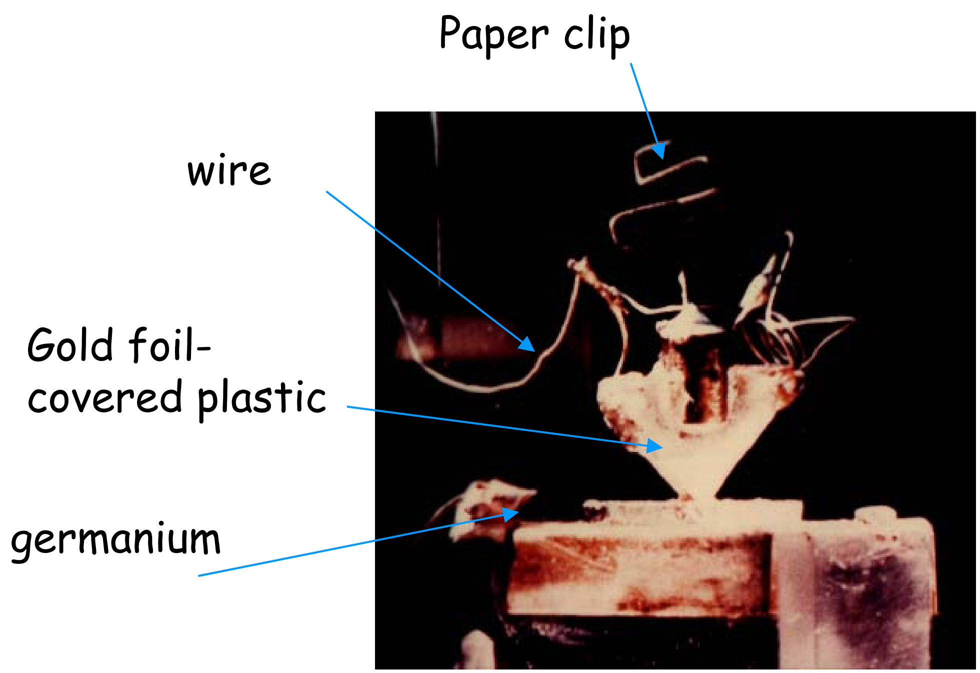
Another Feynman Grand Challenge

…take the information on page of a book and put it on an area 1/25 000 smaller in linear scale….

- Electron beam-written page from *A Tale of Two Cities* - Newman, Williams, Pease, 1987
- 10^{10} characters/cm^2 ; each letter < 0.01 μm^2



First electronic switch made in a semiconductor

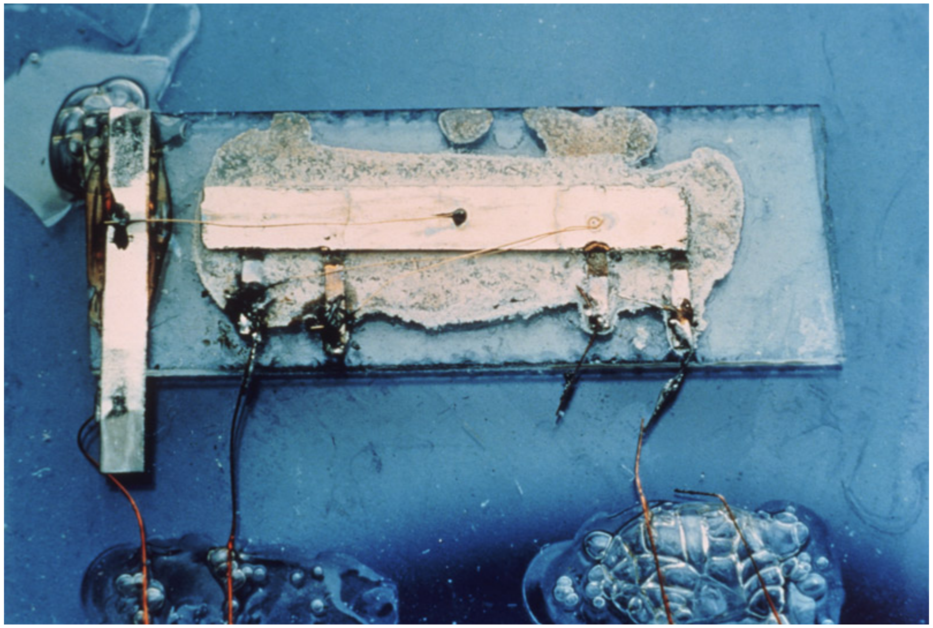


First transistor: 1948
Bardeen, Brattain, Shockley

- long hoped-for replacement for vacuum tube amplifiers
- more compact, more energy-efficient, more robust
- the use of the semiconductor for the transistor material held the potential for incredible scaling down in device size

A Prize-winning Idea (of the Nobel kind)

First Integrated Circuit (1959)

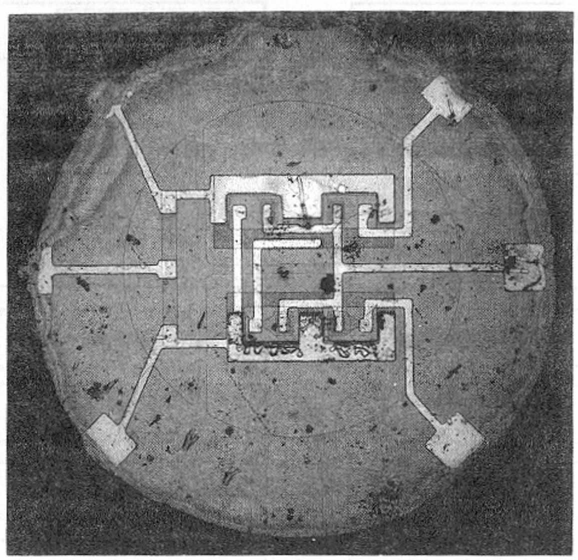


Jack Kilby (2000)

The transforming idea: <u>all</u> the electronic functions of a circuit can be achieved using silicon or silicon-related materials as the basis

Jack Kilby's patent application for Integrated Circuit Fabrication Feb. 6, 1959, Texas Instruments

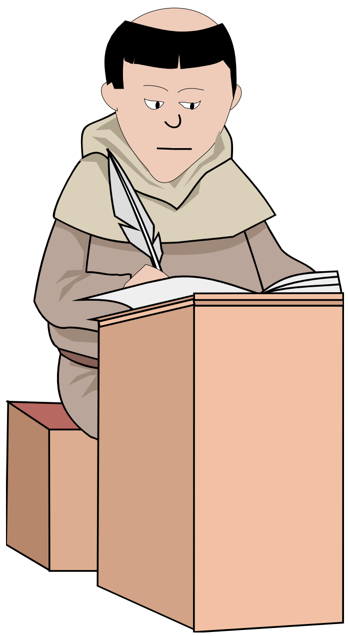
- …the ultimate in circuit miniaturization is attained using only one material for all circuit elements and a limited number of compatible processing steps for the production thereof…..
- … all components of an electric circuit are formed in or near one surface of a relatively thin semiconductor wafer characterized by a diffused p-n junction or junctions….'



(a)

What are the implications?

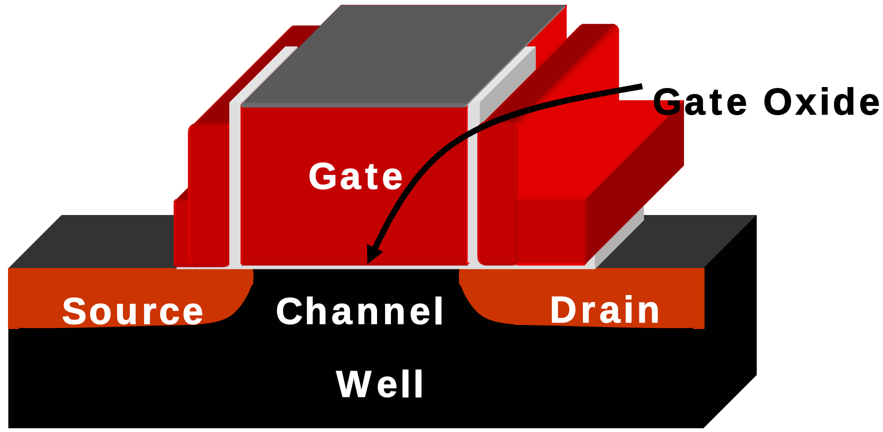
A ‘Paradigm Shift’: Gutenberg’s Printing Press Reappears

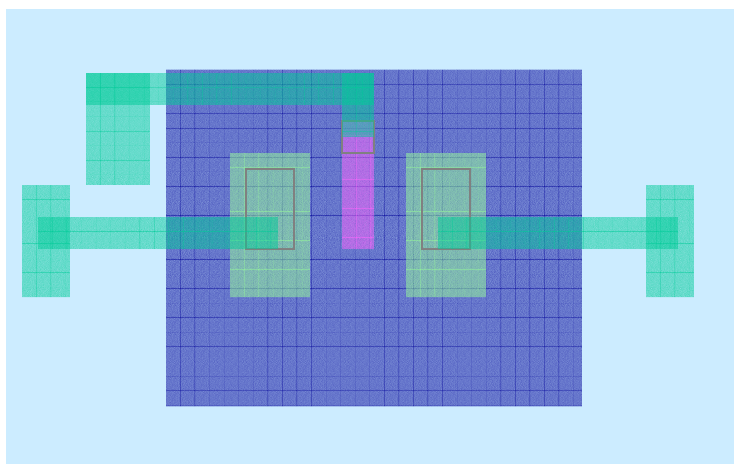


The invention of the printing press made books more easily and cheaply available The widespread availability of written information transformed society.

How do you ‘write’ a transistor?

Building a 3D Structure, layer by layer





Well

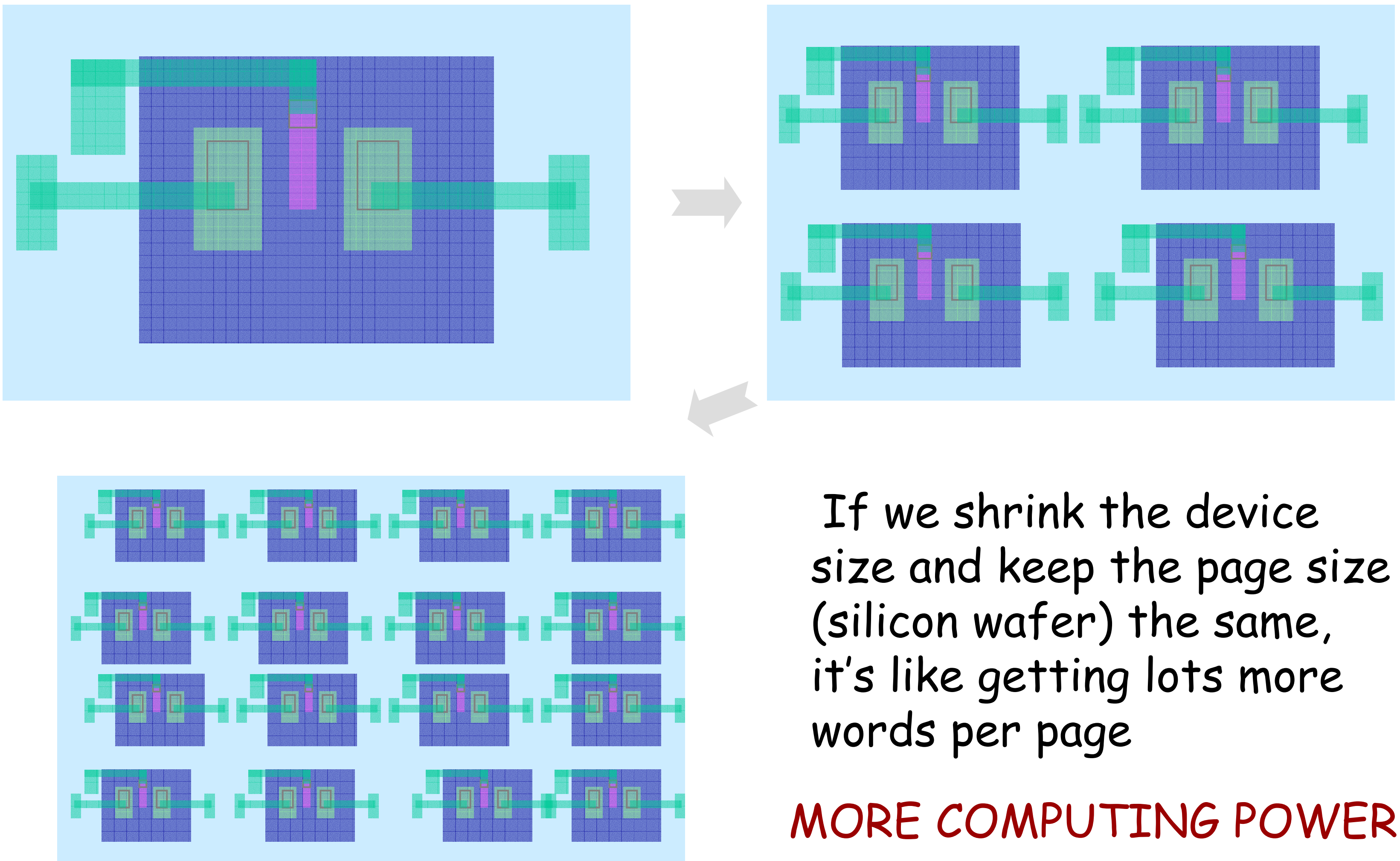
Source and drain

Gate

Windows

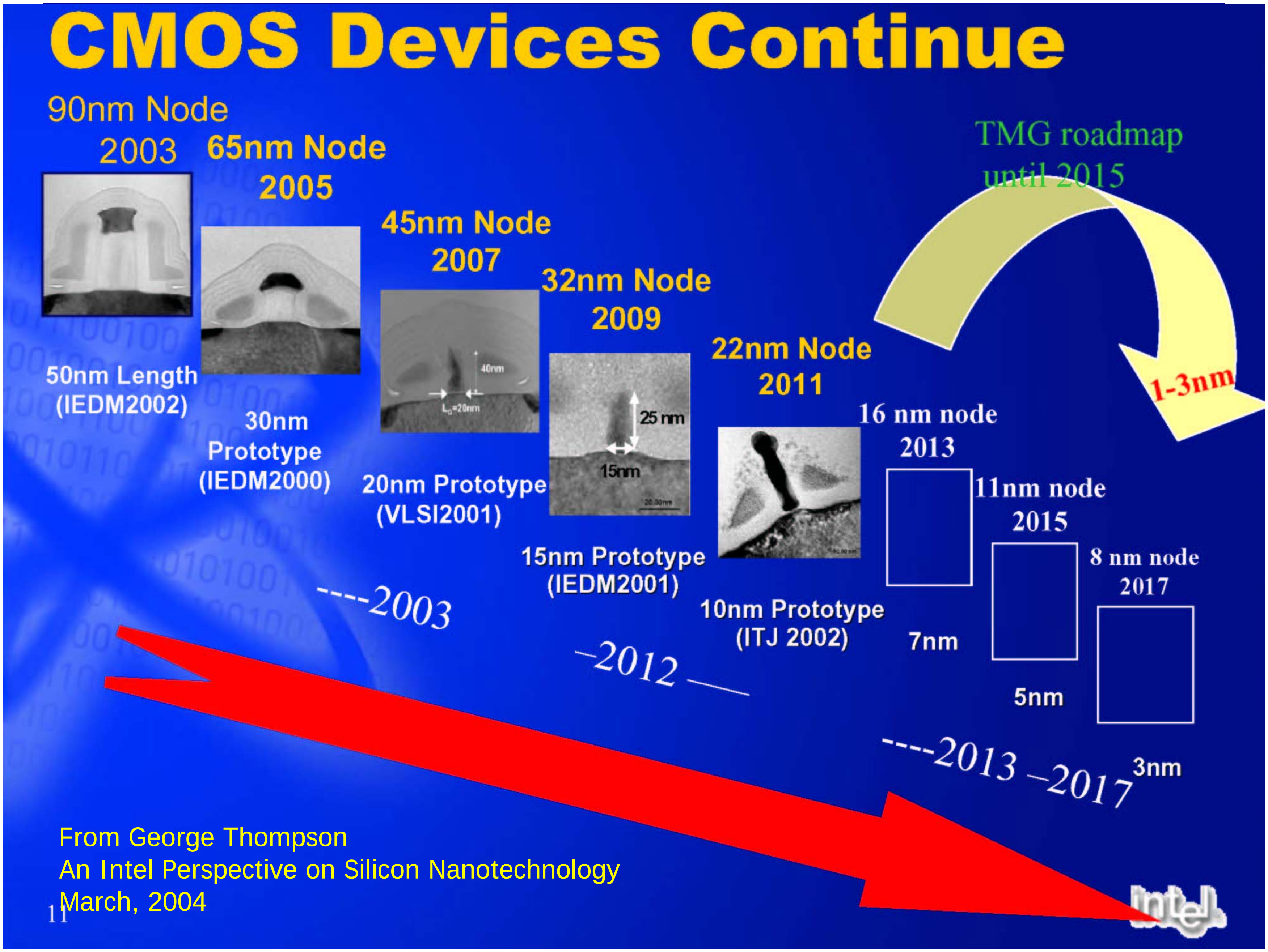
Metal interconnects

The secret behind Moore's Law: the power of the printed bit

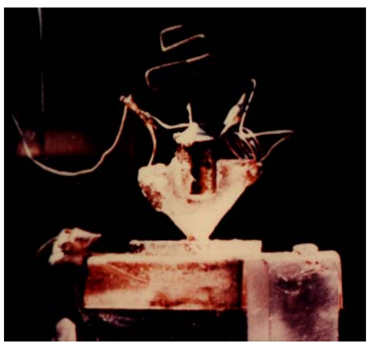


If we shrink the device size and keep the page size (silicon wafer) the same, it's like getting lots more words per page

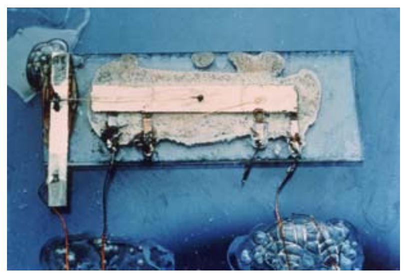
MORE COMPUTING POWER!


CMOS Devices Continue
90nm Node
2003
65nm Node
2005
45nm Node
2007
32nm Node
2009
22nm Node
2011
16 nm node
2013
11nm node
2015
8 nm node
2017
TMG roadmap
until 2015
1-3nm
50nm Length
(IEDM2002)
30nm
Prototype
(IEDM2000)
40nm
20nm Prototype
(VLSI2001)
25 nm
15nm
15nm Prototype
(IEDM2001)
10nm Prototype
(ITJ 2002)
7nm
5nm
3nm
----2003
–2012 ——
----2013 –2017
From George Thompson
An Intel Perspective on Silicon Nanotechnology
March, 2004
11
intel

- The printing paradigm allowed the efficient, economic transition from single transistors to integrated circuits.
- Devices began as largely two-dimensional: tens of microns wide and fractions of microns deep.



First transistor
1948

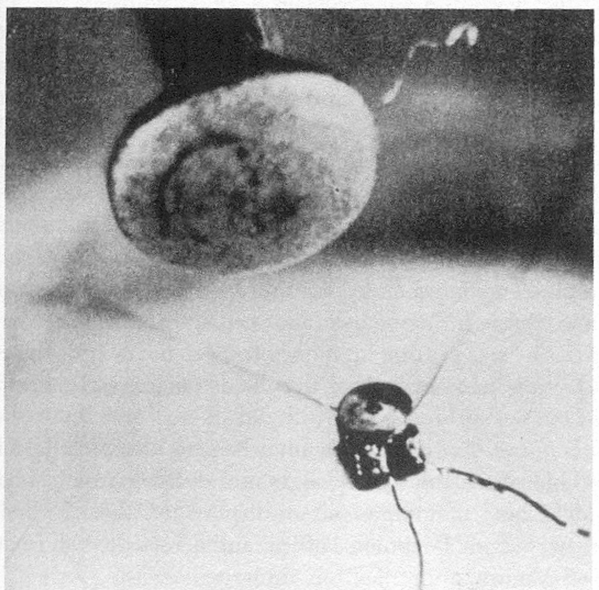


First integrated circuit
1959

Microprocessor chip

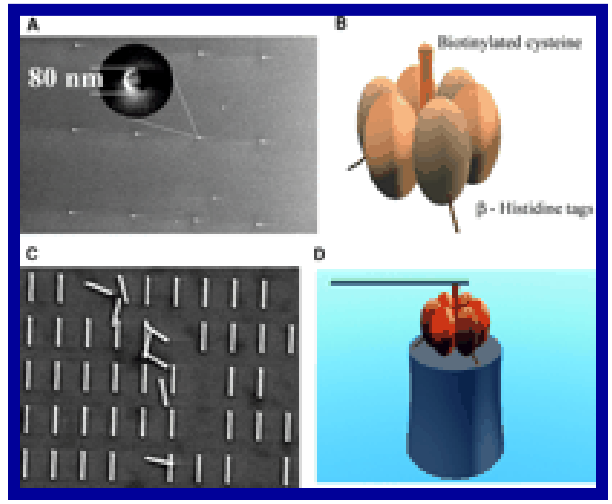
Feynman's Grand Challenges:

…make a motor 1/64 of an inch on a side



William McLellan's 1/64-inch motor; awarded the first Feynman prize, 1960. (*James McClanahan*)

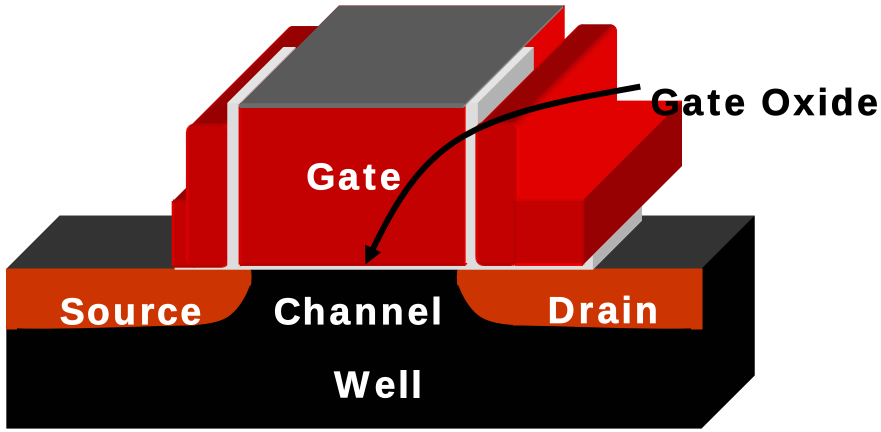
1960 micro-machine (old techniques)



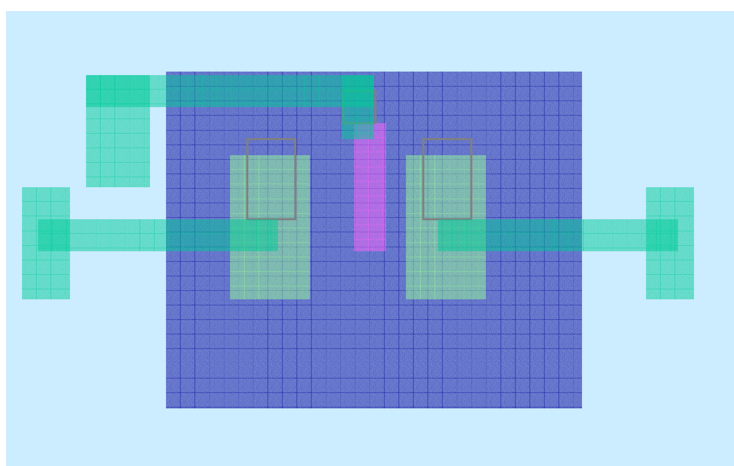
C. Montemagno, 'Molecular' Motor

Sandia National
Labs
Features 10-100 microns

But, remember, it's 'integrated'



A misalignment can ruin your day (and your quarterly earnings)



Well

Source and drain

Gate

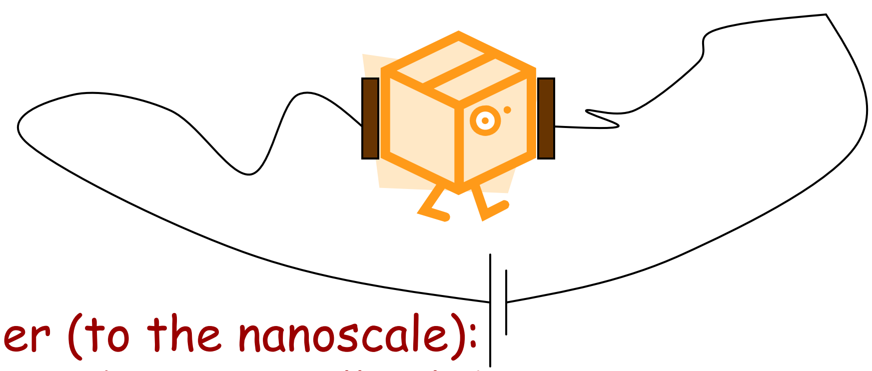
Windows

Metal interconnects

What are the key elements of this 'new' fabrication technology?

- Making a pattern (template) (a)
- Transferring that template into your material (b)

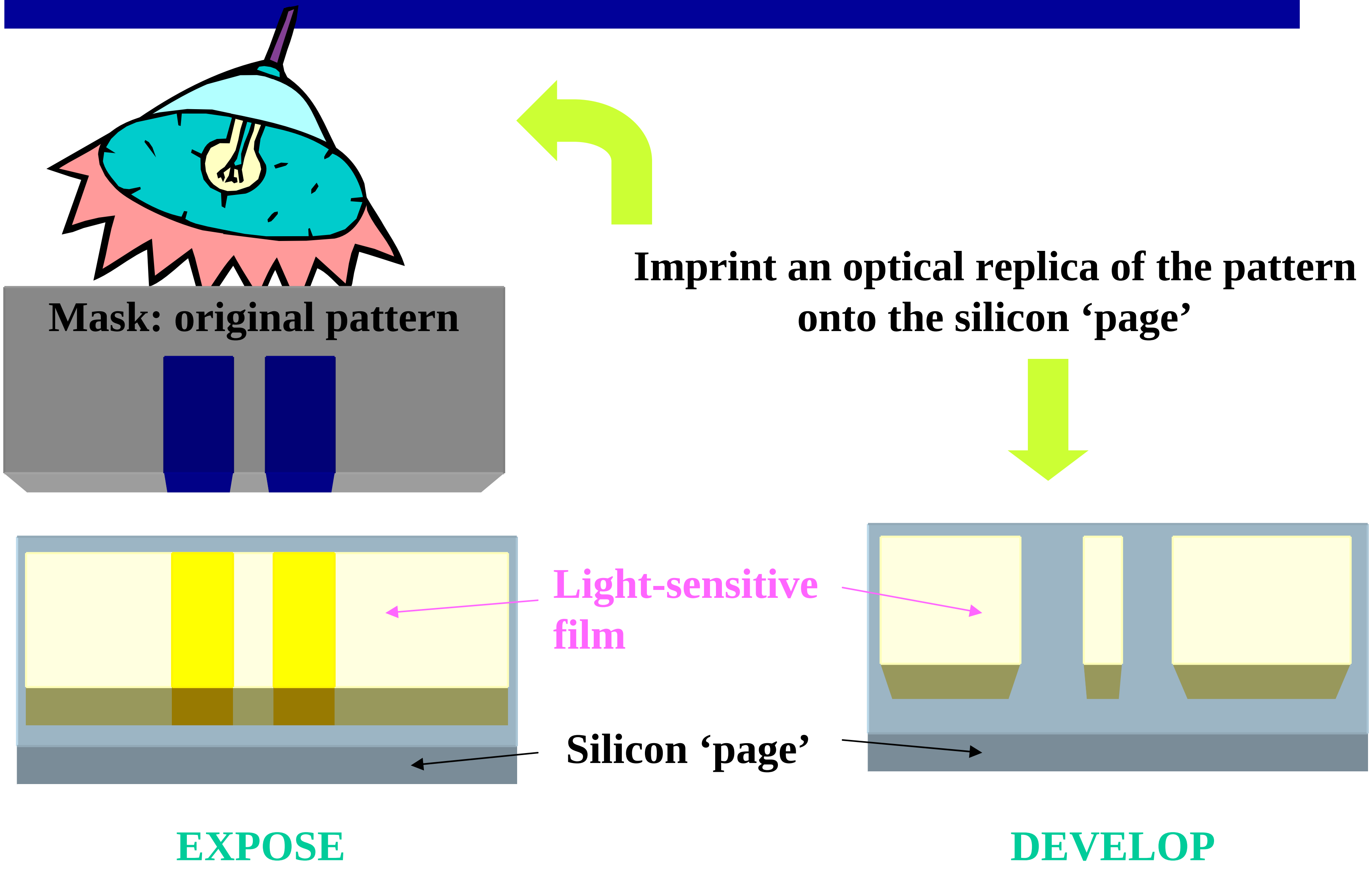
1. Lithography
2. Metalization and making contact to the outside world
3. Defining local electronic behavior: doping
4. Isolating electronic regions: oxidation
5. Carving out different regions of the material: etching



Going smaller (to the nanoscale):

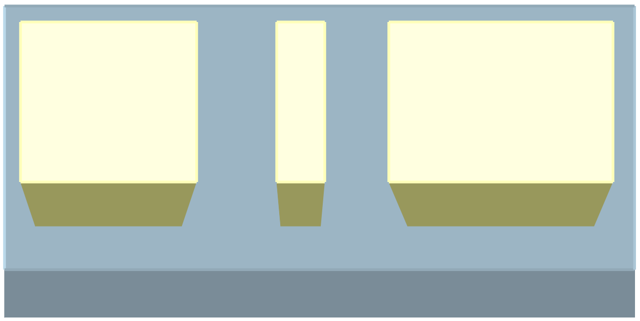
- Are these techniques still valid?
- What different approaches could we use? (c)

Imprinting the pattern onto the page

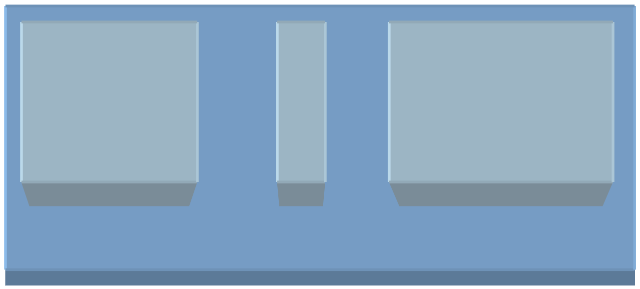


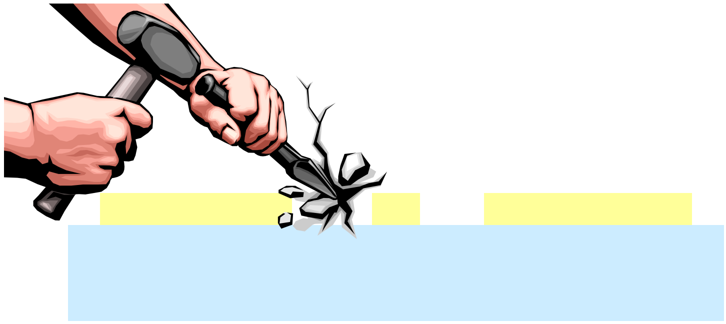
This is Optical Lithography [r]

Transferring the Pattern into the Silicon



top
view

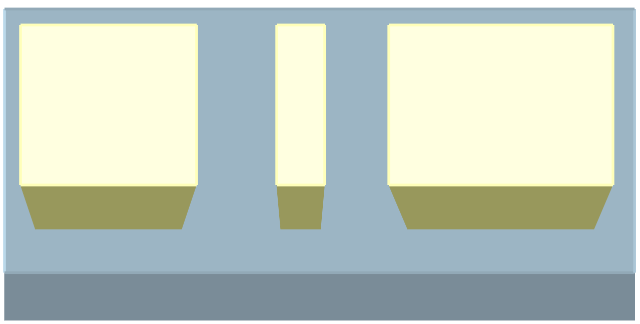




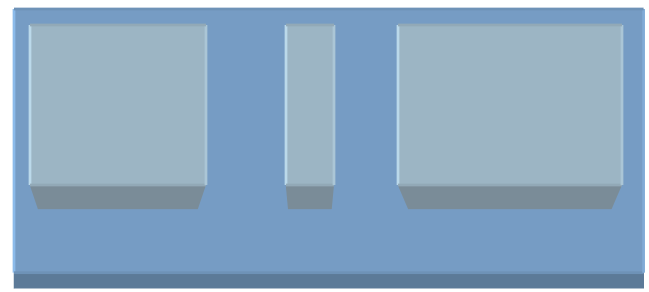
Carving the features into the silicon

side
view

Transferring the Pattern into the Silicon

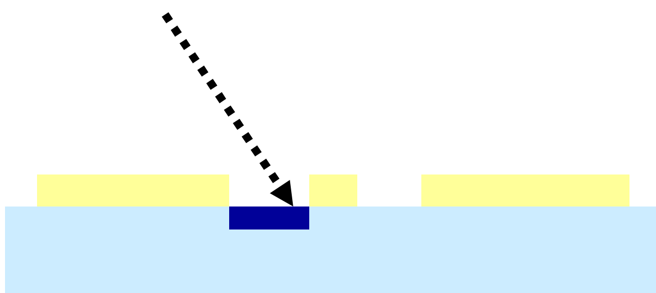


top view



Beam of electrically charge particles

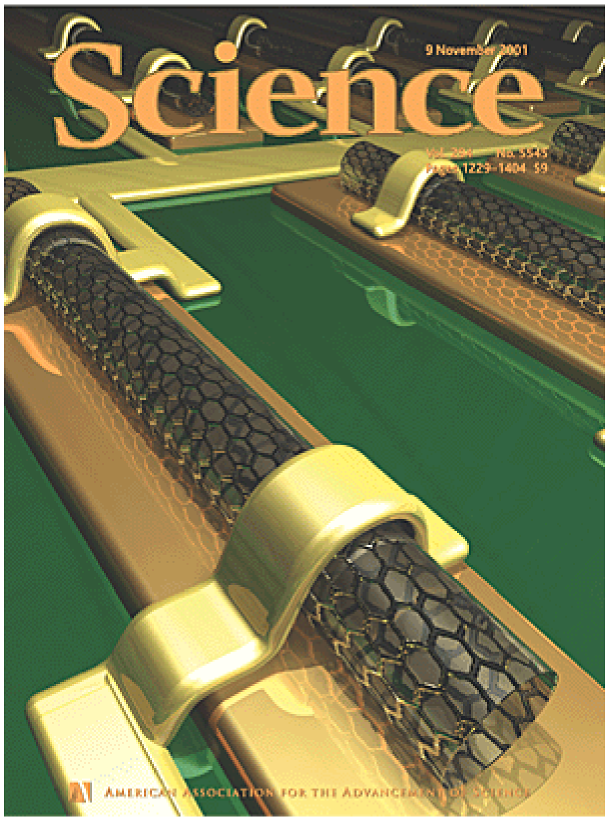
Carving the features into the silicon



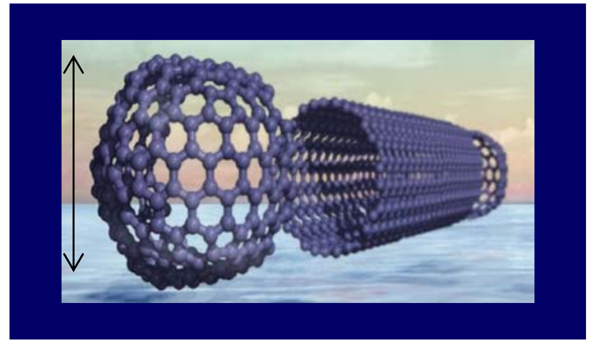
side view

Or creating different regions of conductivity (metal, oxide, 'doped' material) [r]

How Would You Make A Transistor From a Carbon Nanotube?

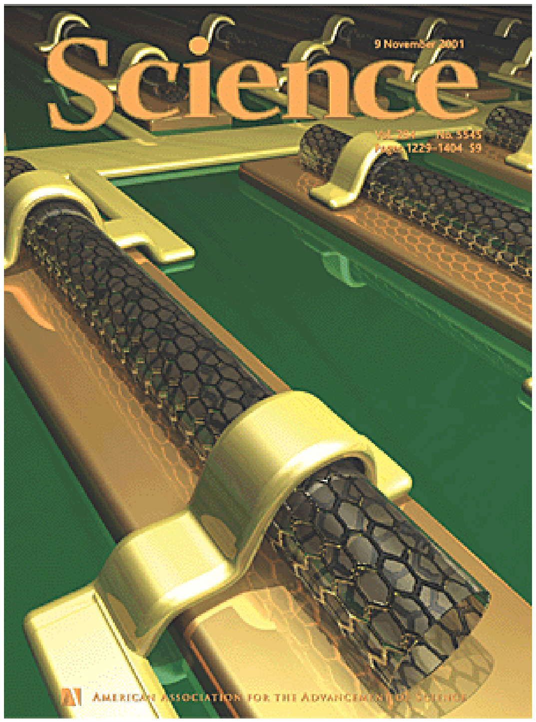


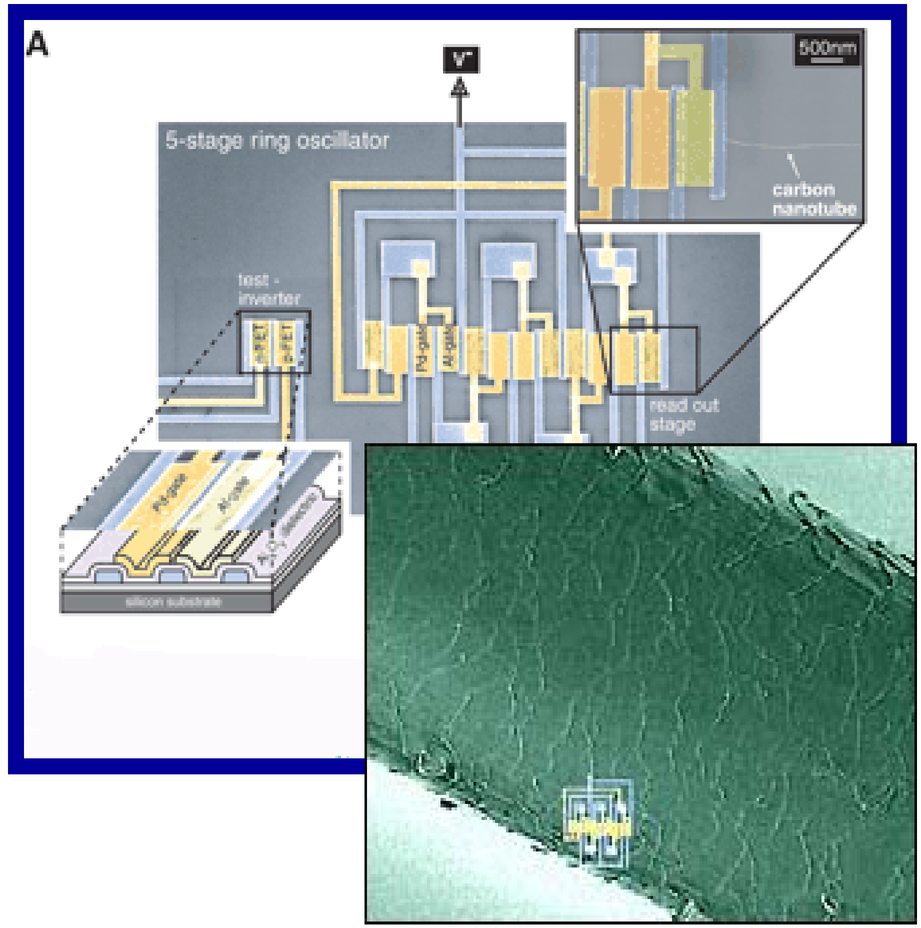
~1-2 nm



Carbon nanotube

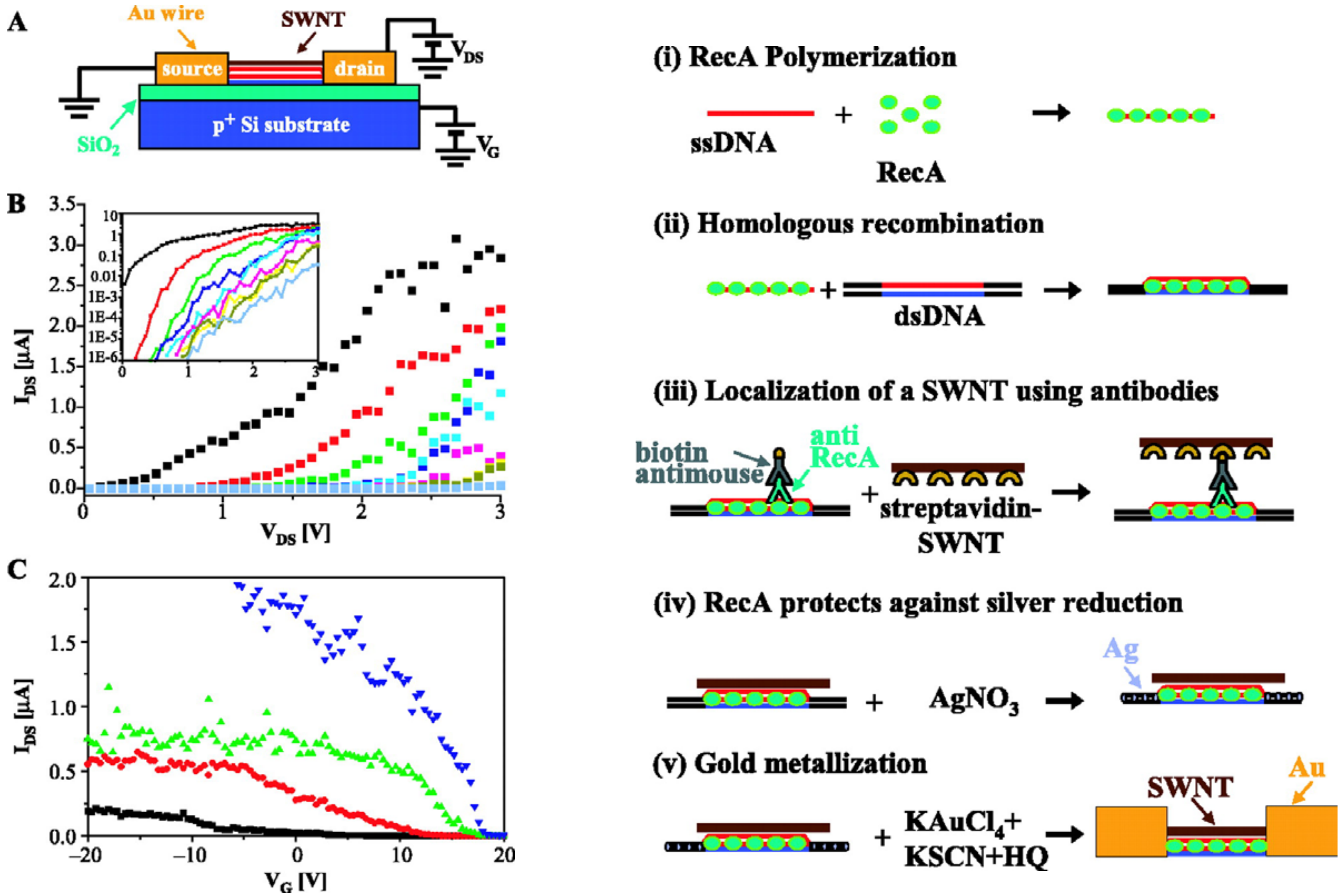
How Would You Make A 'Circuit' From a Carbon Nanotube?





'An Integrated Logic Circuit Assembled on a Single Carbon Nanotube',
Chen et al., Science 311, 1735 (2006)

Transistors Through an All-Biological Process



K. Keren et al., Science 302, 1380 -1382 (2003)

ECE 220A/Mat. 215A

Teaching Cleanroom
4110, Harold Frank Hall

Bob Hill*