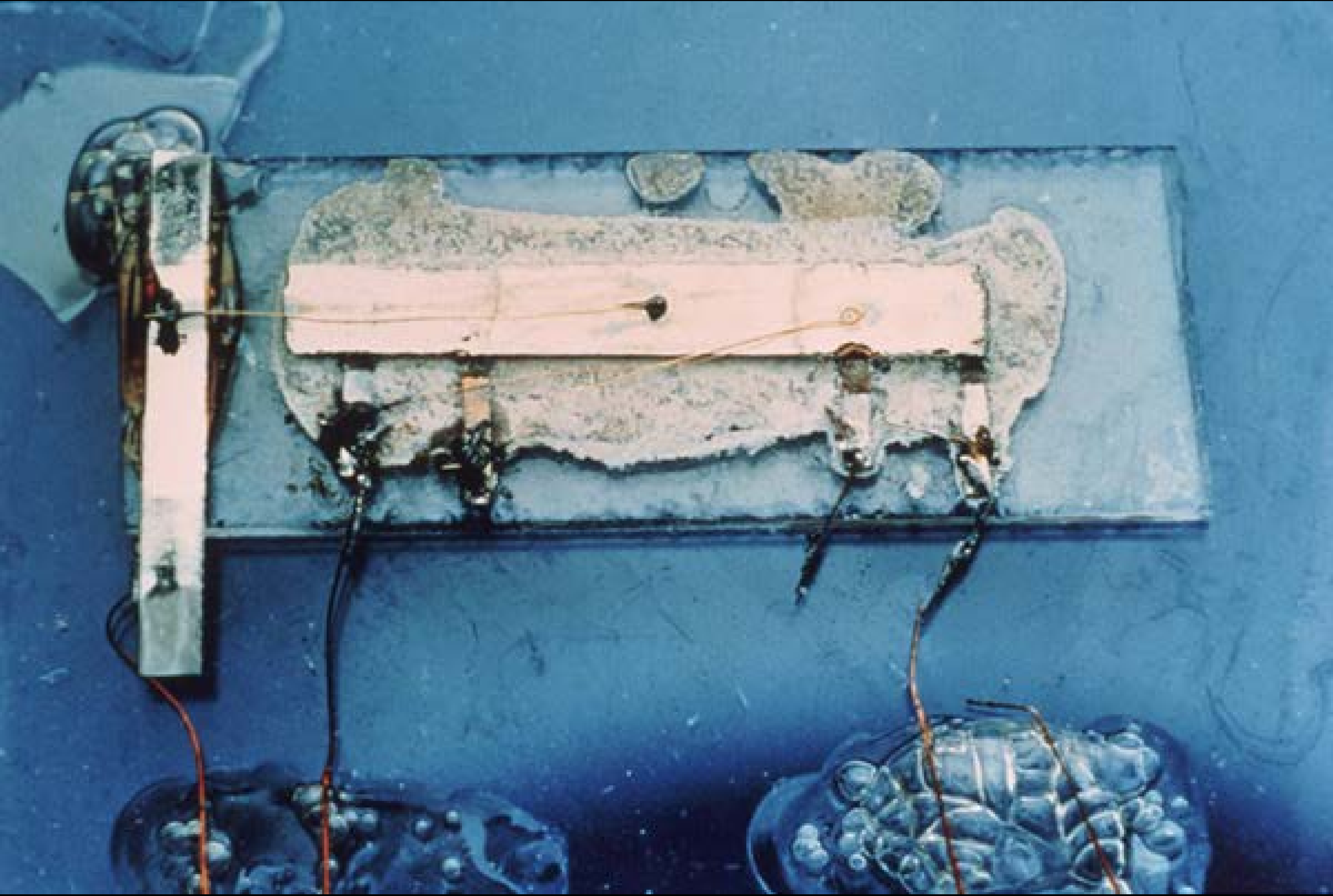
Microelectronics and Micromechanics

Harald Plank and Peter Hadley



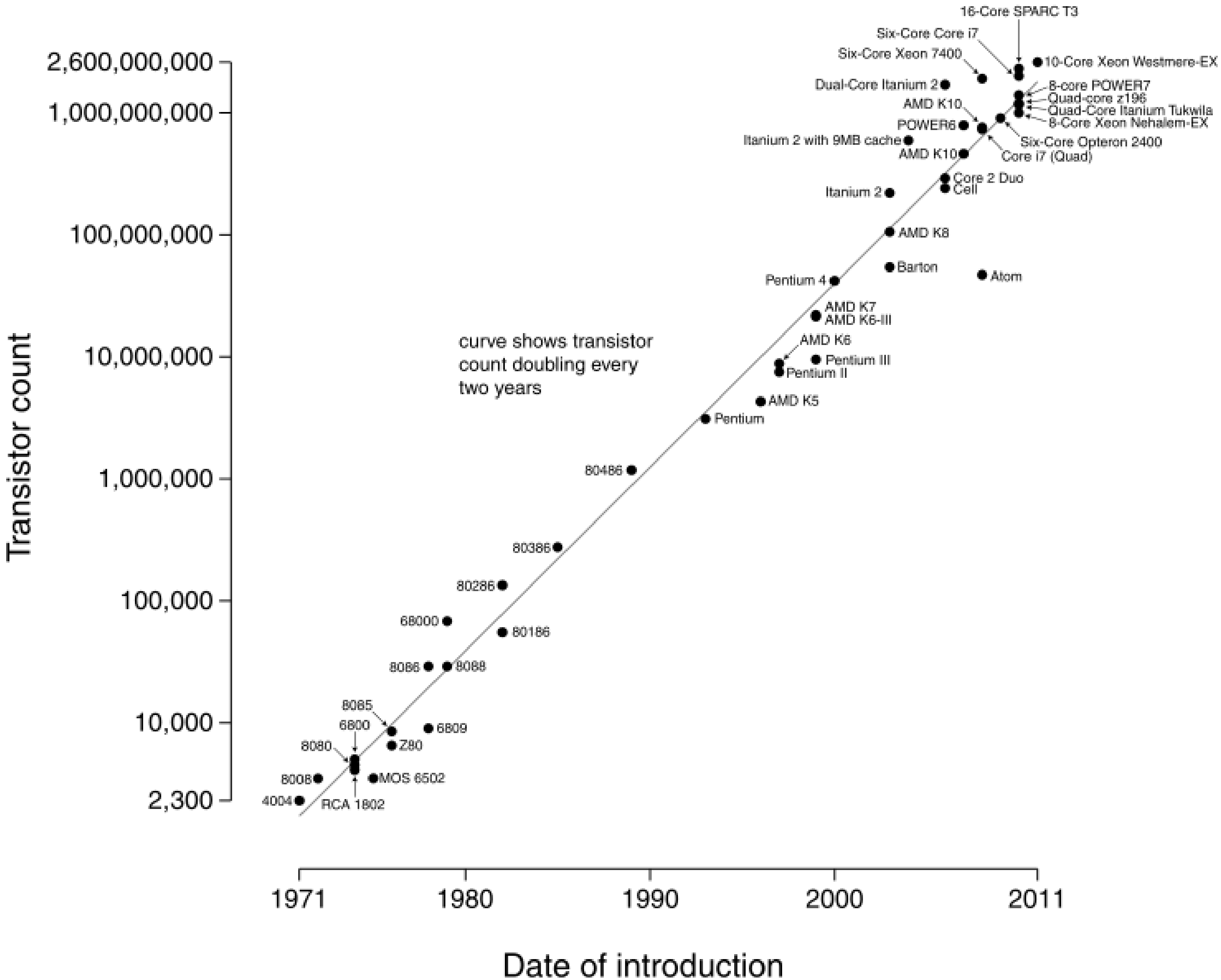
Jack Kilby's first integrated circuit 1958

Moore's law

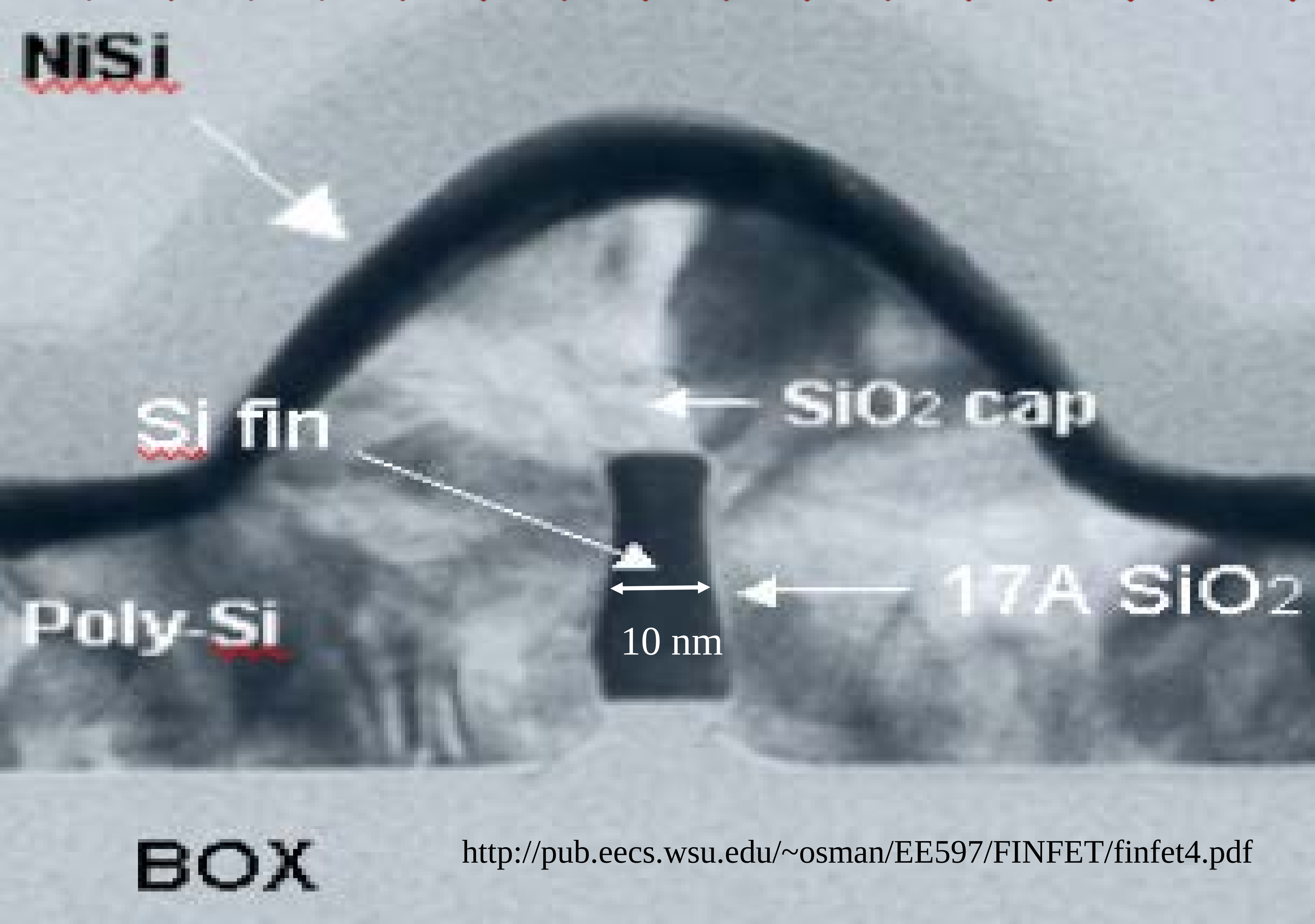
The complexity for minimum component costs has increased at a rate of *roughly a factor of two per year*. Certainly over the short term this rate can be expected to continue, if not to increase. Over the longer term, the rate of increase is a bit more uncertain, although there is no reason to believe it will not remain nearly constant for at least 10 years.

G. Moore, 1965

Microprocessor Transistor Counts 1971-2011 & Moore's Law

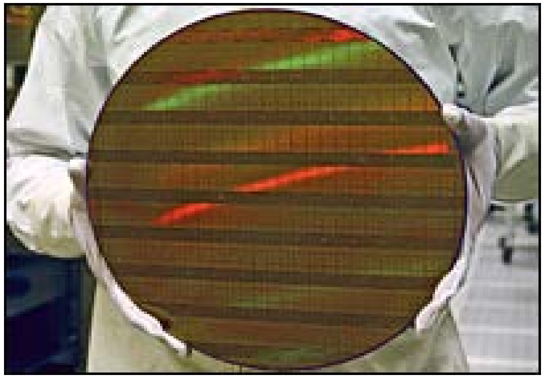


http://en.wikipedia.org/wiki/Moore%27s_law#mediaviewer/File:Transistor_Count_and_Moore%27s_Law_-_2011.svg



http://pub.eecs.wsu.edu/~osman/EE597/FINFET/finfet4.pdf

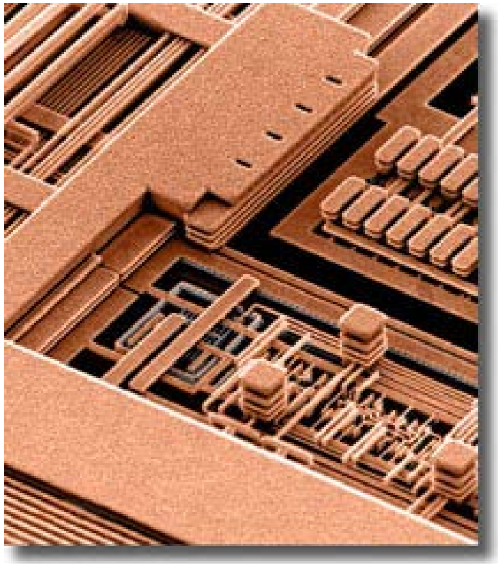
Microelectronics



Silicon chips are used in computers, mobile telephones, and microcontrollers.

1 trillion transistors are produced simultaneously on a wafer.

Gate length ~ 15 nm



1 μprocessor ~ 1 billion transistors ~ 100 Euros
1 transistor for 10^{-5} cents.

10^5 transistors ~ 1 cent $\rightarrow$ packaging is the major cost for simple circuits

100 euro/cm^2

MIT
Technology
Review

Computing

Intel Puts the Brakes on Moore's Law

Intel will slow the pace at which it rolls out new chip-making technology, and is still searching for a successor to silicon transistors.

by Tom Simonite March 23, 2016

Chip maker Intel has signaled a slowing of Moore's Law, a technological phenomenon that has played a role in just about every major advance in engineering and technology for decades.

Micromechanics

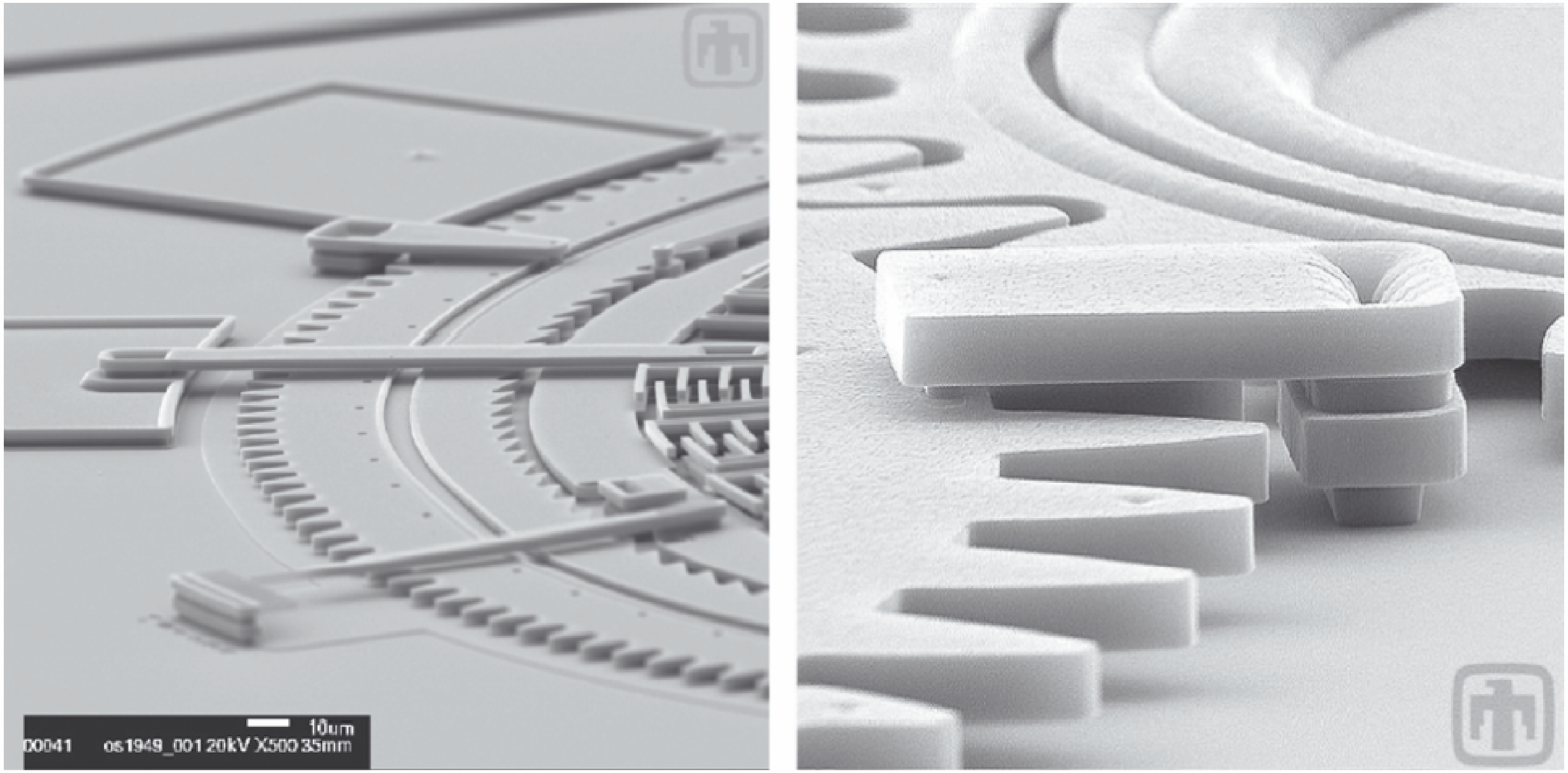
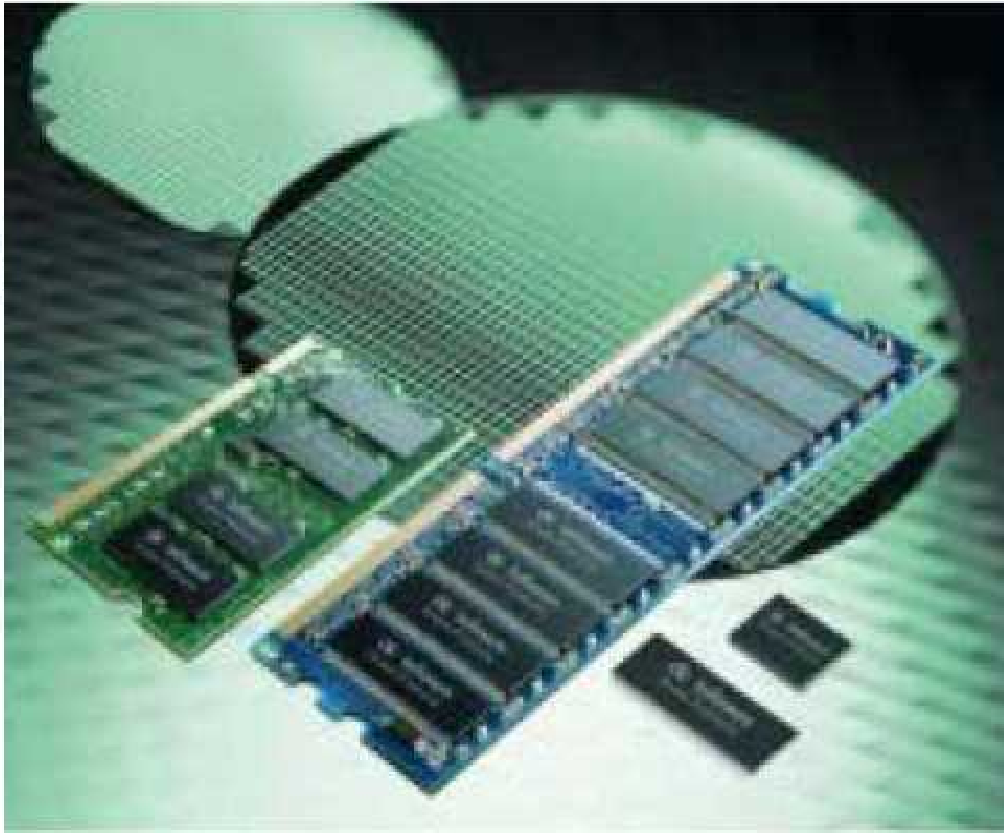


Figure 29.20 Mechanical gears made in multiple layer polysilicon process. Courtesy Sandia National Laboratories

IC-Fabrication

http://www.if.tugraz.at/memm.html

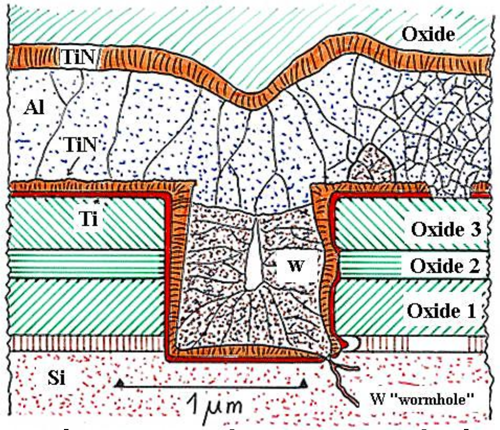
TU Graz

513.160 Microelectronics and Micromechanics

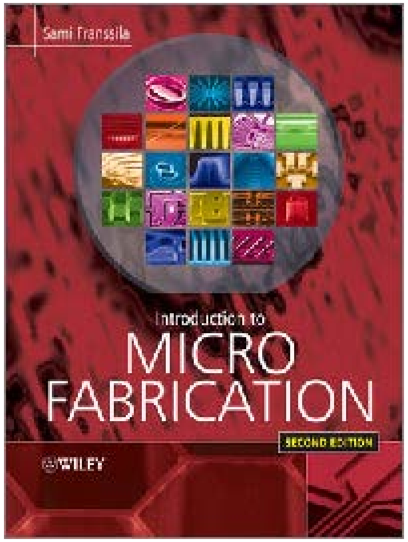
- Home
- Outline
- Books
- Lectures

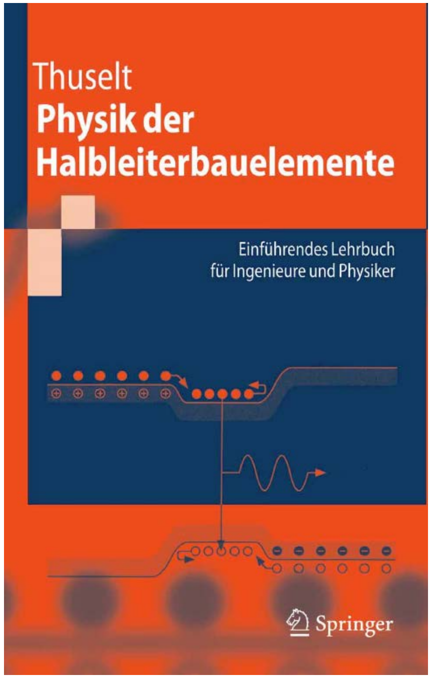
Microfabrication is a collection of production methods that are used to create very many electrical or mechanical components simultaneously. These methods have allowed us to produce microcontrollers and computers that affect virtually all aspects of our lives. Microcontrollers are found in household appliances such as coffee makers, vacuum cleaners, dishwashers, heating systems, and televisions. Mobile telephones and the internet have transformed how we communicate. Computers are essential for transportation systems, weather prediction, science, medicine, education, industrial design, banking, and retail sales. Even though computers are so important to modern life, there are relatively few people who understand how they are made.This course describes microelectronic and micromechanical devices and how they are fabricated. We will concentrate on silicon devices produced by optical lithography.

e-Books



Electronic Materials





International Technology Roadmap for Semiconductors

Principles of

Semiconductor Devices

by

Bart Van Zeghbroeck

Home
Outline
Books
Lectures
Materials
Student projects

Outline

- **Introduction** Chapter 1: Introduction
  - The evolution of microelectronics
  - Moore's law
  - Why the future doesn't need us
- **Semiconductors and semiconductor devices** Chapter 4: Silicon
  - Silicon
  - Intrinsic semiconductors
  - Extrinsic semiconductors
  - pn-junctions
  - metal-semiconductor contacts
- **Lithography** Chapter 8: Pattern generation, Chapter 9: Optical lithography
  - Pattern generation
  - Electron beam lithography
  - Optical lithography and EUV
  - Photoresist
  - Spin coating
  - Spray coating
  - Nanoimprint lithography
- **Crystal and thin film growth** Chapter 5: Thin film material and processes, Chapter 6: Epitaxy
  - Purification of silicon
  - Czochralski process
  - Float Zone process

Learning Goals

Be able to describe the processes used in microelectronics

Understand a research article about microelectronics

Given the description of a device, be able to describe how that device could be fabricated.

Examination

One contribution to improve the course

- Make notes for the exam
- Improve the website
  - Examples of fabrication processes
  - Finding better images, resources, videos,...

Oral exam (bring one page of handwritten notes)

Student Projects

- Make a study guide: For each of the sections in the outline, make a 1-2 page summary of important facts that the students should know for the exam. This project could involve more students.
- A goal of the course is to enable students to read a recent scientific paper on microelectronics or micromechanics and be able to explain it. Find some recently published fabrication process and explain it to the other students.
- Some students work at a semiconductor company and are experts on a certain device or process. It would be useful for them to write a description or video about this device or process.
- Make a cut-out foldable model like the one in Appendix A of Franssila but draw the atoms on the surfaces.
- We are making a list of materials properties. The most complete example we have is of silicon. Add some materials properties of silicon or make a similar page for SiC, GaAs, SiO_2, SiN_x, or GaN.

WIRED

On Newsstands Now
Issue 8.04 | Apr 2000

Why the future doesn't need us.

Print, email, or fax this article for free.

Our most powerful 21st-century technologies - robotics, genetic engineering, and nanotech - are threatening to make humans an endangered species.

By Bill Joy

PLUS
A Tale of Two Botanies

From the moment I became involved in the creation of new technologies, their ethical dimensions have concerned me, but it was only in the autumn of 1998 that I became anxiously aware of how great are the dangers facing us in the 21st century. I can date the onset of my unease to the day I met Ray Kurzweil, the deservedly famous inventor of the first reading machine for the blind and many other amazing things.

Ray and I were both speakers at George Gilder's Telecosm conference, and I encountered him by chance in the bar of the hotel after both our sessions were over. I was sitting with John Searle, a Berkeley philosopher who studies consciousness. While we were talking, Ray approached and a conversation began, the subject of which haunts me to this day.

DROID DUTIES

The robot that takes your job should pay taxes, says Bill Gates

International Technology Roadmap for Semiconductors

ITRS 2009 Edition

- Executive Summary
- System Drivers
- Design
- Test & Test Equipment
- Process Integration, Devices & Structures
- RF and A/MS Technologies for Wireless Communications
- Emerging Research Devices
- Emerging Research Materials
- Front End Processes
- Lithography
- Interconnect
- Factory Integration
- Assembly & Packaging
- Environment, Safety & Health
- Yield Enhancement
- Metrology
- Modeling & Simulation

2009 ERRATA-Executive Summary, list of corrections

http://www.itrs.net/reports.html

Table PIDS2a High-performance (HP) Logic Technology Requirements - TCAD																
Year of Production	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Logic Industry "Node Range" Labeling (nm) [based on 0.71x reduction per "Node Range" ("Node" = "2x Mx)	"16/14"		"11/10"		"8/7"		"6/5"		"4/3"		"3/2.5"		"2/1.5"		"1/0.75"	
MPU/ASIC Metal 1 (M1) ½ Pitch (nm) (contacted)	40	32	32	28.3	25.3	22.5	20.0	17.9	15.9	14.2	12.6	11.3	10.0	8.9	8	7.1
L_g : Physical Gate Length for HP Logic (nm)	20	18	16.7	15.2	13.9	12.7	11.6	10.6	9.7	8.8	8.0	7.3	6.7	6.1	5.6	5.1
L_{ch} : Effective Channel Length (nm) [3]	16.0	14.4	13.4	12.2	11.1	10.2	9.3	8.5	7.8	7.0	6.4	5.8	5.4	4.9	4.5	4.1
V_{dd} : Power Supply Voltage (V)																
Bulk/SOI/MG	0.86	0.85	0.83	0.81	0.80	0.78	0.77	0.75	0.74	0.72	0.71	0.69	0.68	0.66	0.65	0.64
EOT: Equivalent Oxide Thickness																
Bulk/SOI/MG (nm)	0.80	0.77	0.73	0.70	0.67	0.64	0.61	0.59	0.56	0.54	0.51	0.49	0.47	0.45	0.43	0.41
Dielectric constant (K) of gate dielectrics	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0
Physical gate oxide thickness (nm)	2.56	2.57	2.53	2.51	2.49	2.46	2.42	2.42	2.37	2.35	2.29	2.26	2.23	2.19	2.15	2.10
Channel Doping (10^{18} /cm^3) [4]																
Bulk	6.0	7.0	7.7	8.4	9.0											
SOI/MG	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Body Thickness (nm) [5]																
SOI																
MG	6.4	5.8	5.3	4.9	4.4	4.1	3.7	3.4	3.1	2.8	2.6	2.3	2.1	2.0	1.8	1.6
T_{BOX} : Buried Oxide Thickness for SOI (nm) [6]																
SOI																
CET: Capacitance Equivalent Thickness (nm) [7]																
Bulk/SOI/MG	1.10	1.07	1.03	1.00	0.97	0.94	0.91	0.89	0.86	0.84	0.81	0.79	0.77	0.75	0.73	0.71
C_{ch} intrinsic (fF/μm) [8]																
Bulk/SOI/MG	0.502	0.465	0.448	0.420	0.396	0.373	0.352	0.329	0.311	0.289	0.273	0.255	0.240	0.225	0.212	0.198
Mobility (cm^2 /V-s)																
Bulk	400	400	400	400	400											
SOI																
MG	250	250	250	250	250	250	200	200	200	200	200	150	150	150	150	150
I_{off} (nA/μm) [9]																
Bulk/SOI/MG	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
$I_{d,sat}$: NMOS Drive Current (μA/μm) [10]																
Bulk	1,348	1,355	1,340	1,295	1,267											
SOI																
MG	1670	1,680	1,700	1,660	1,660	1,610	1,600	1,480	1,450	1,350	1,330	1,170	1,100	1,030	970	900
$V_{t,lin}$ (V) [11]																
Bulk	0.306	0.327	0.334	0.357	0.378											
SOI																
MG	0.219	0.225	0.231	0.239	0.264	0.266	0.265	0.276	0.295	0.303	0.306	0.319	0.334	0.340	0.354	0.364

http://www.itrs.net/reports.html

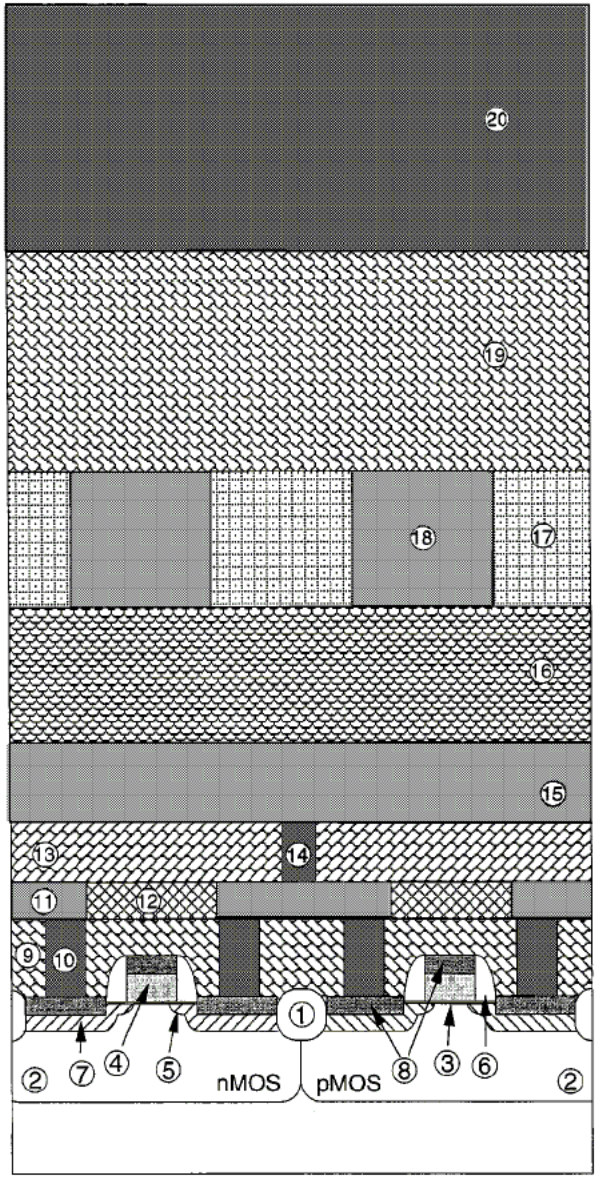
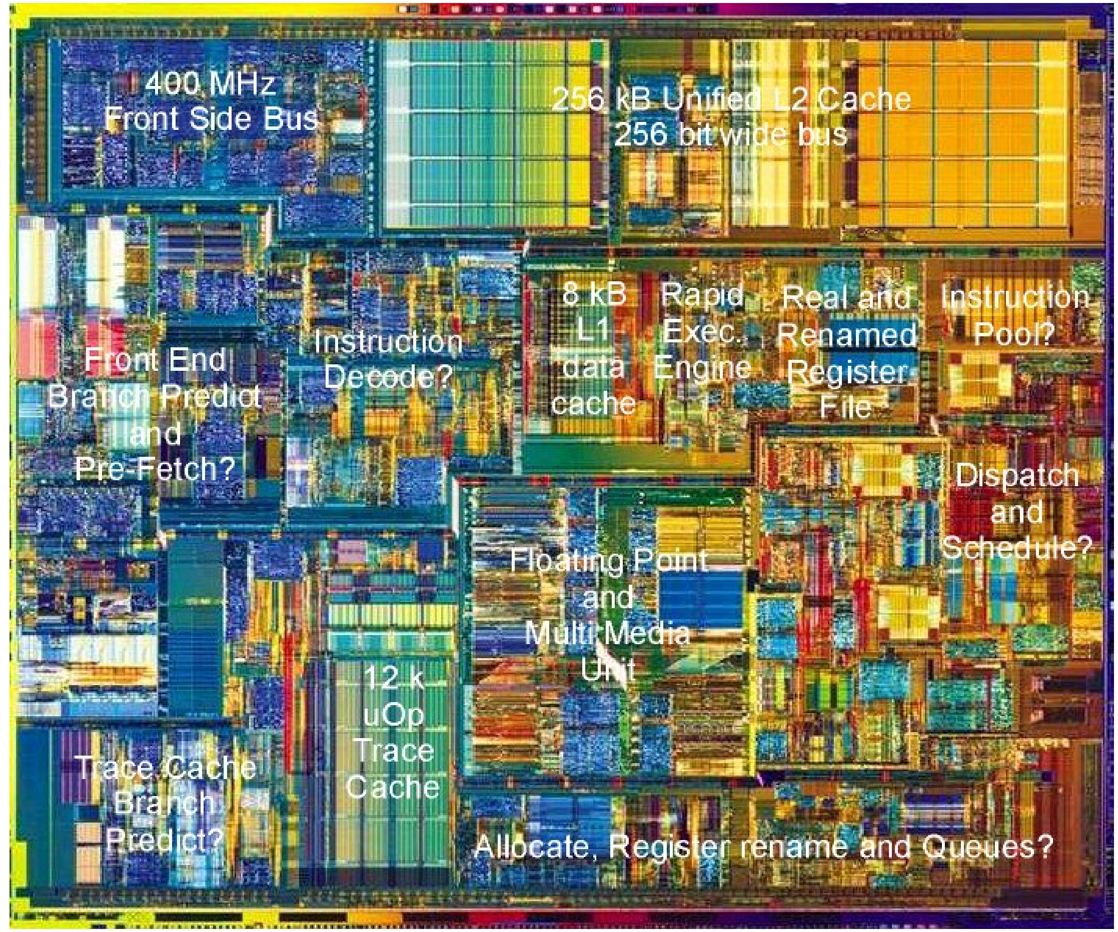
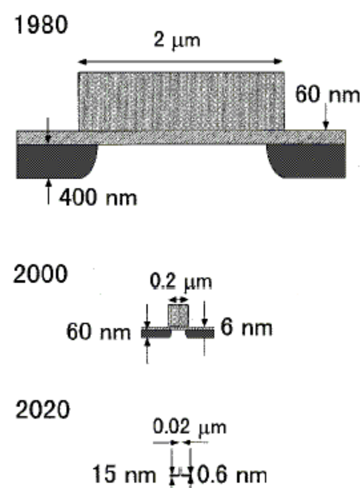


Fig. 2 Schematic cross section of present CMOS FETs with multilayered wiring.





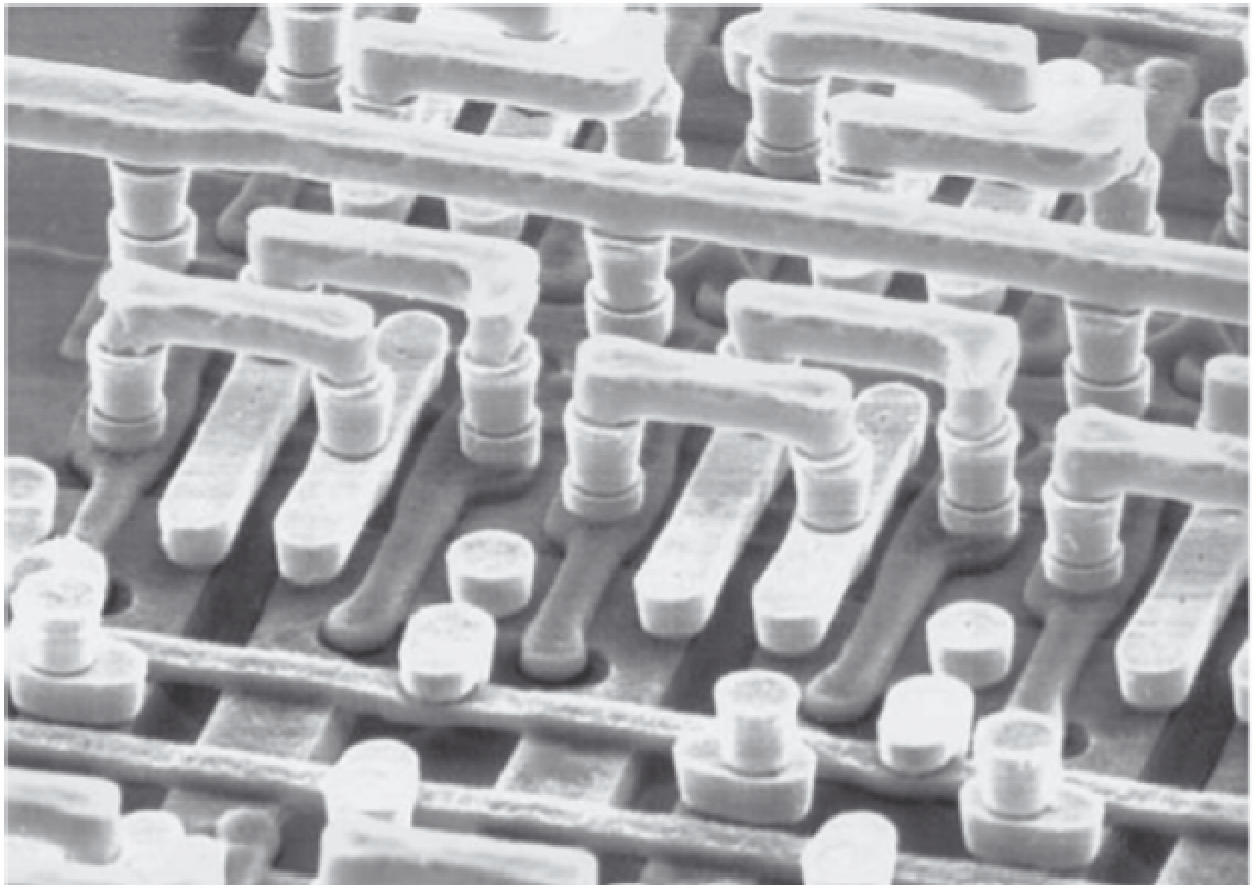
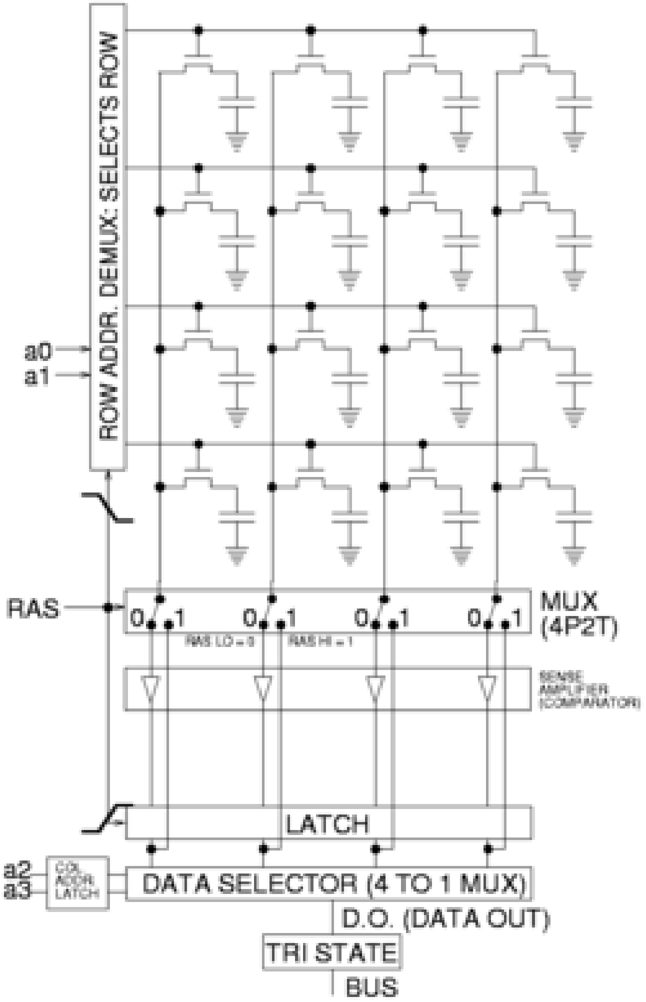


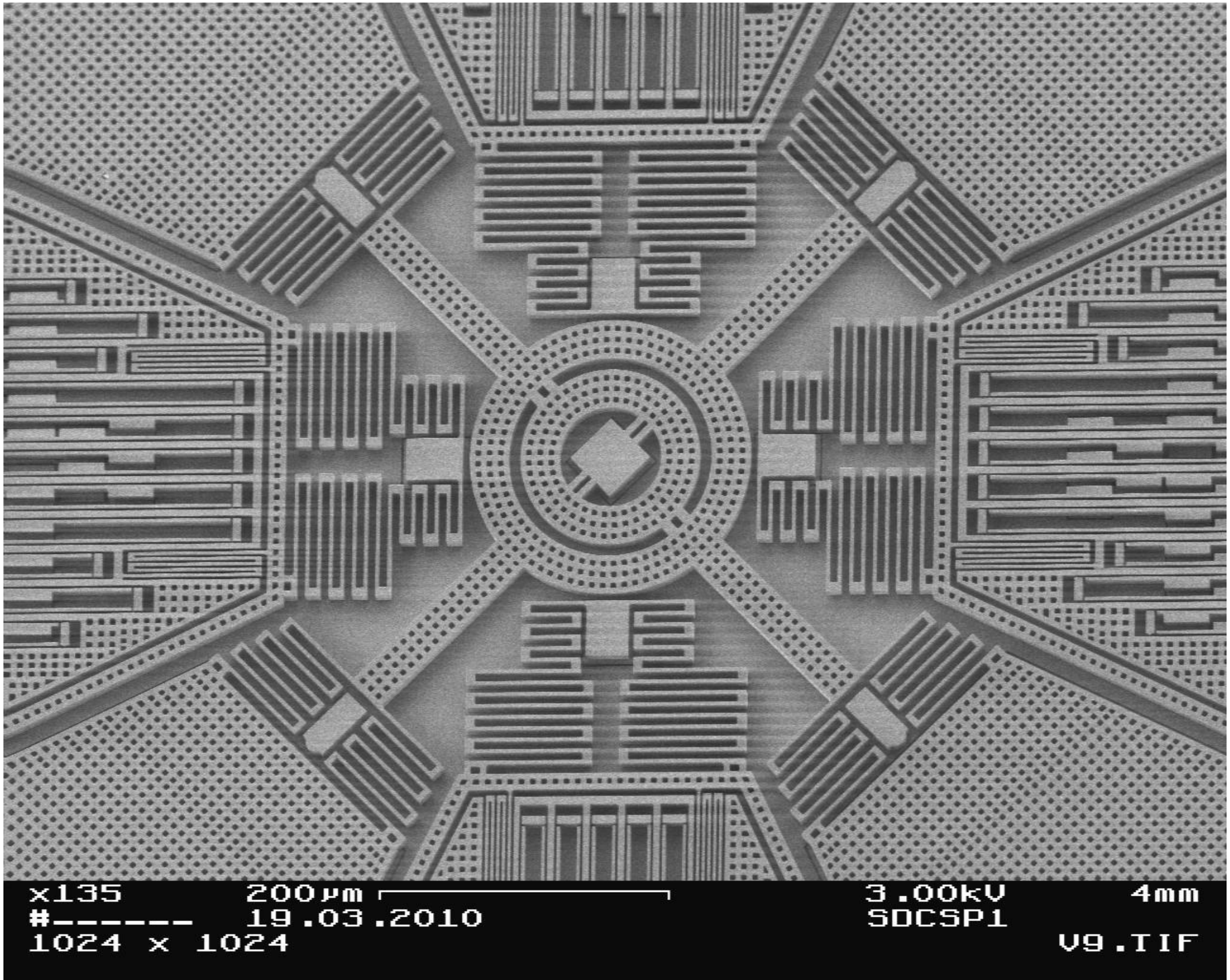
Figure 28.6 Multilevel metallization with all dielectric layers etched away. $TiSi_2$/poly gates, tungsten plugs and local wires, Al global wires. Reproduced from Mann *et al.* (1995) by permission of IBM

DRAM

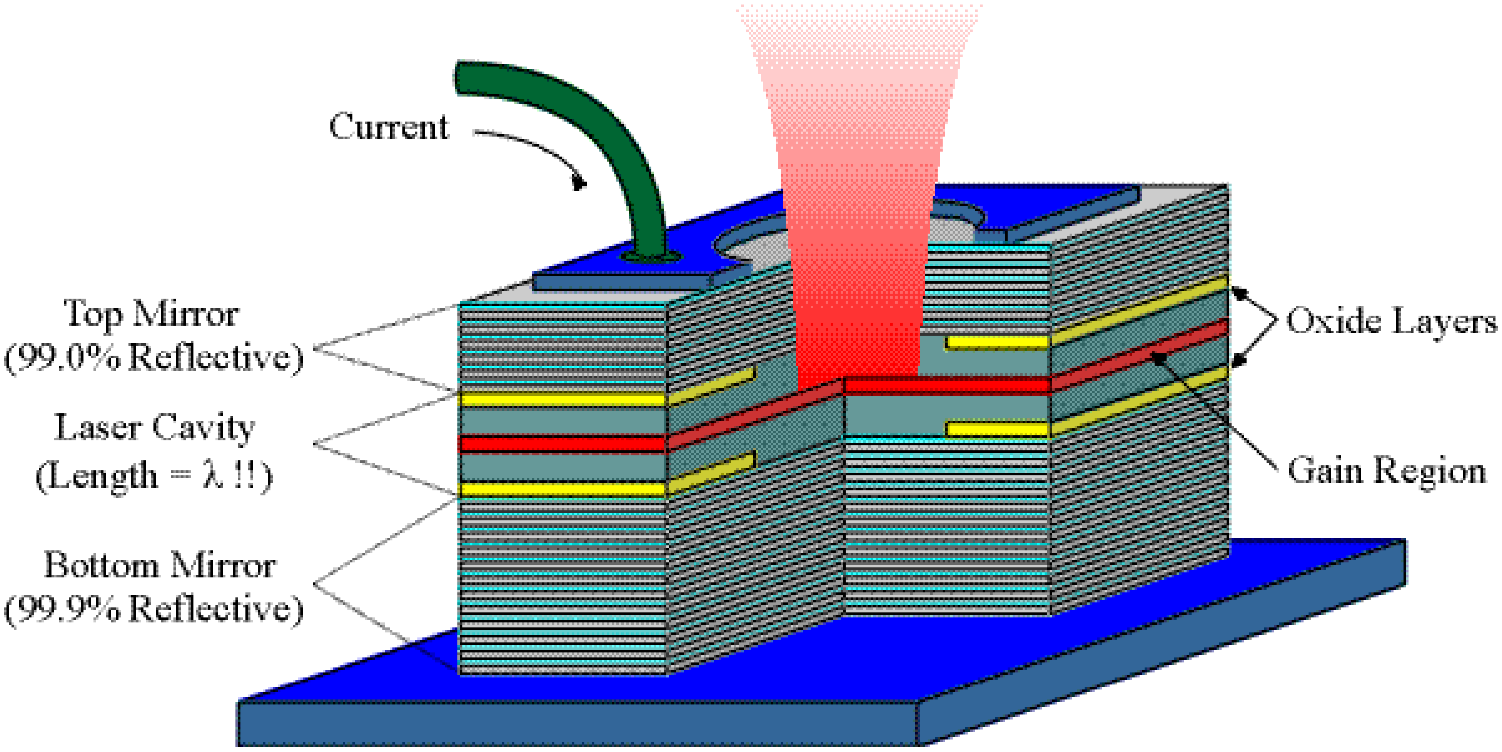
Dynamic random access memory



MEMs gyroscopes

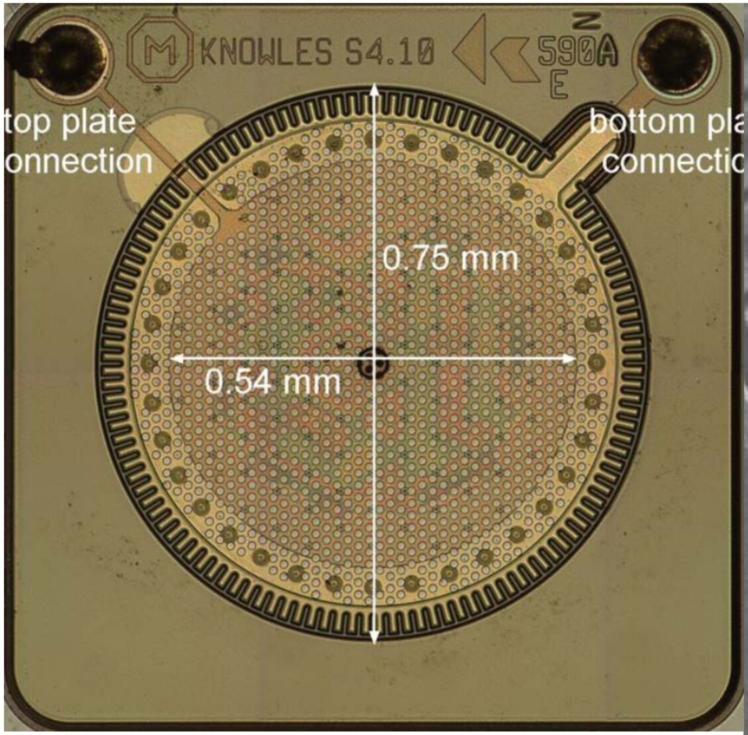


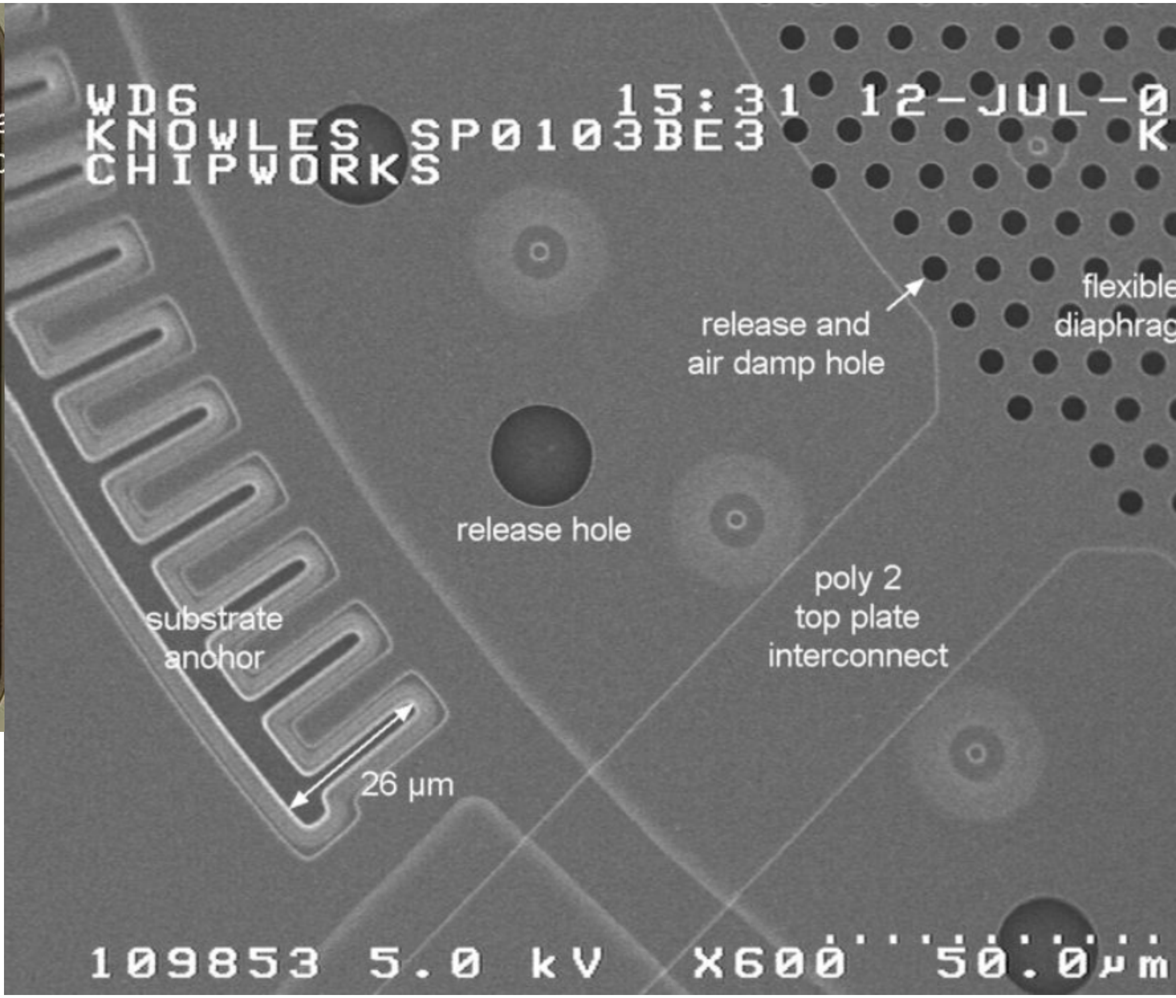
Vertical-cavity surface-emitting laser (VCSEL)



http://wwwold.fi.isc.cnr.it/users/giovanni.giacomelli/Semic/Samples/samples.html

MEMs microphones





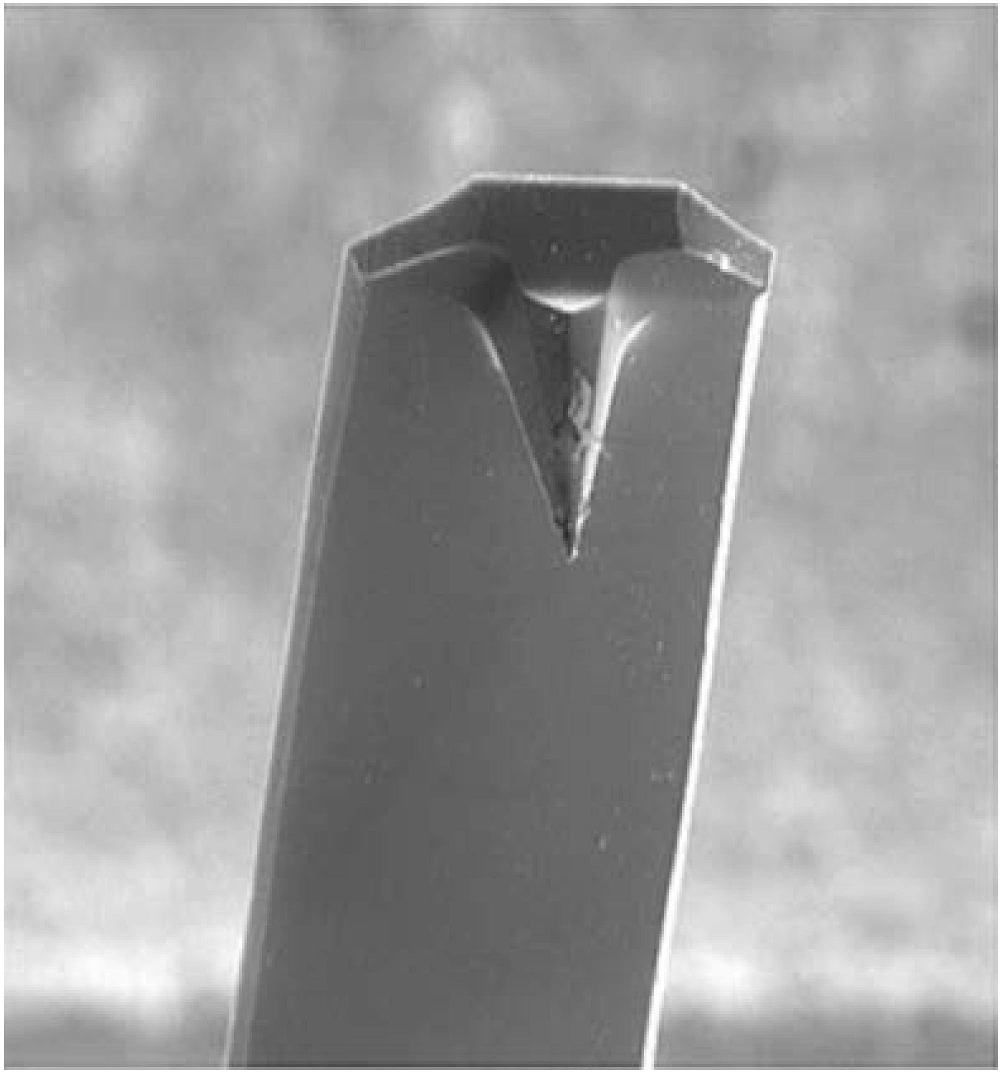
Hearing aids
Phones, Tablets
Machine health
Noise cancellation

http://www.memsjournal.com/2011/03/overview-of-mems-microphone-technologies-for-consumer-applications.html

AFM

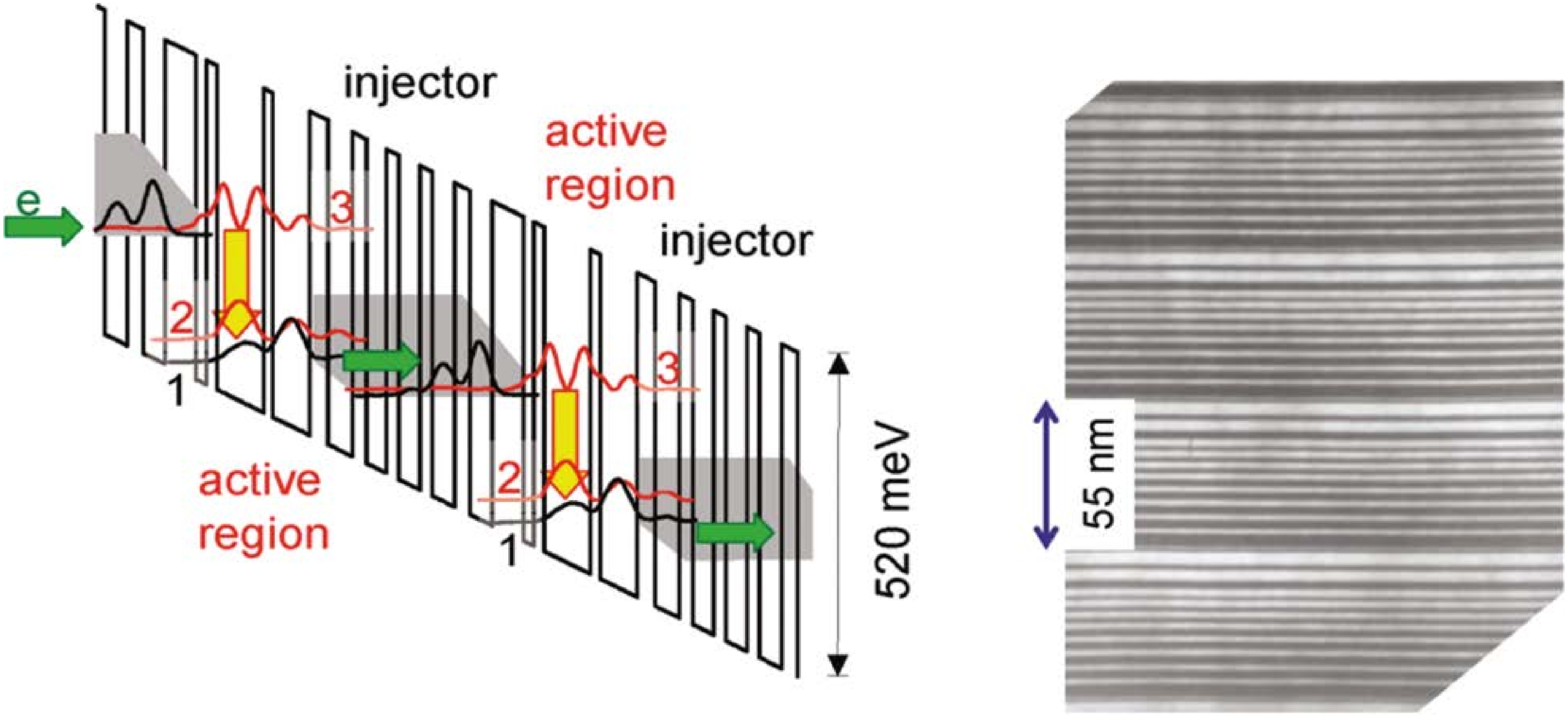
Contact model ~15 kHz
Noncontact mode ~200 kHz

Stiffer beams are used in nc-mode to avoid stiction.



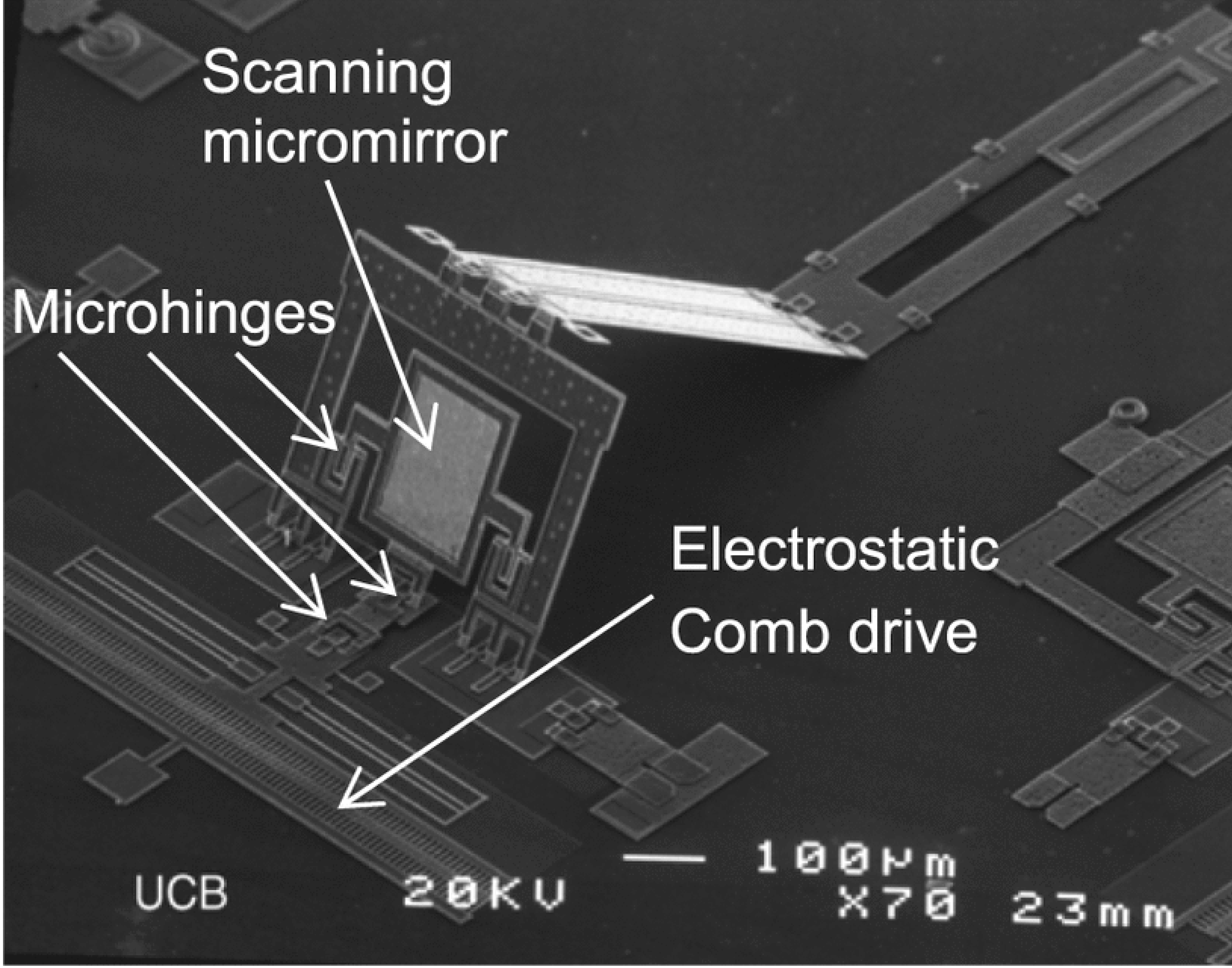
http://ieeexplore.ieee.org/xpls/icp.jsp?arnumber=6817527

Quantum cascade lasers



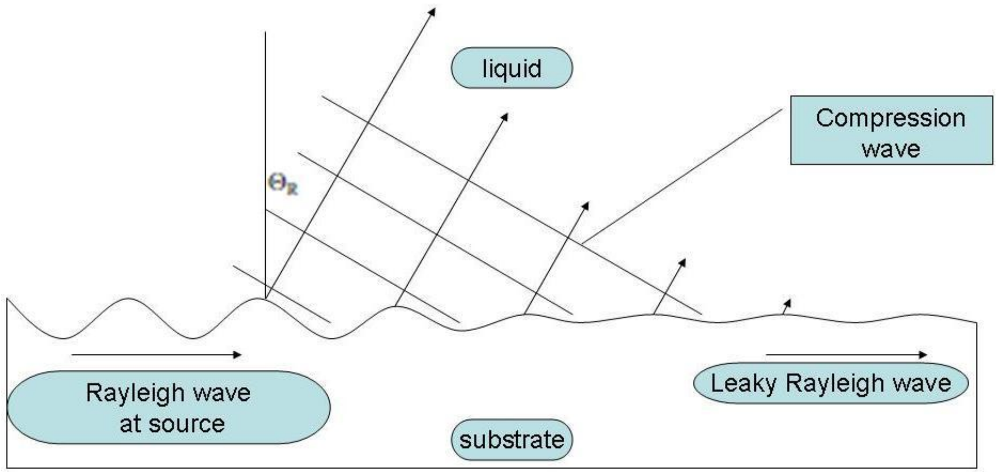
(a) (b)

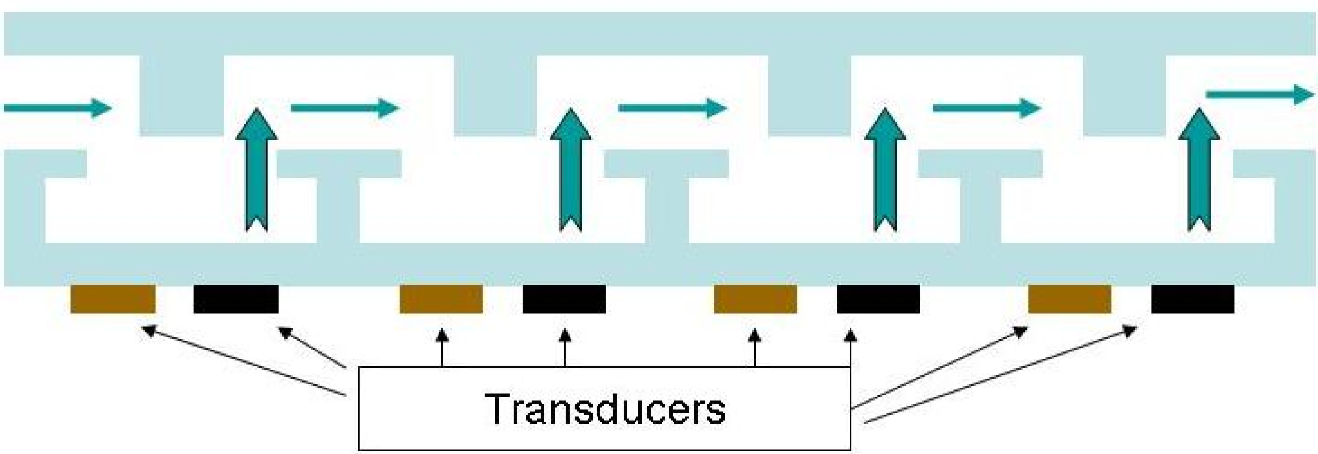
http://opticalengineering.spiedigitallibrary.org/article.aspx?articleid=1096486



http://ieeexplore.ieee.org/xpls/icp.jsp?arnumber=6817527

Microfluidic pump

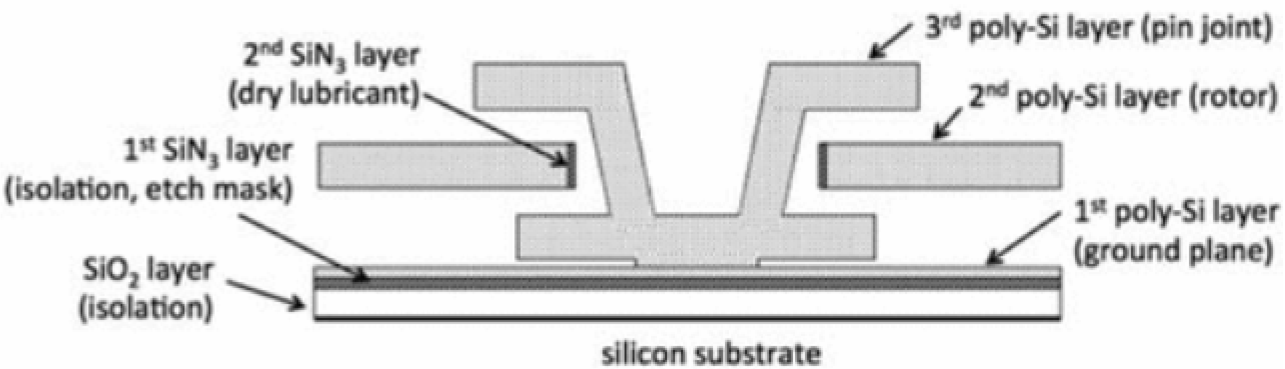




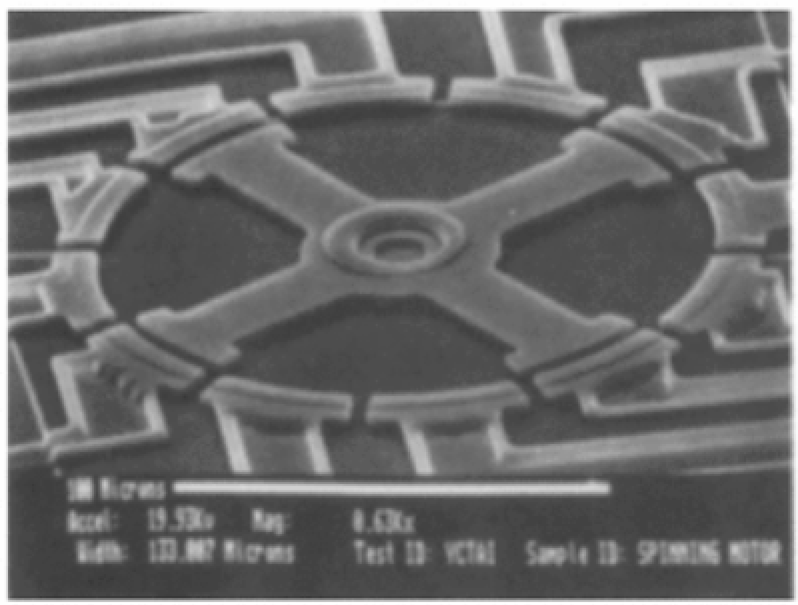
Black transducers off
Brown on
Reverses flow

https://en.wikibooks.org/wiki/Engineering_Acoustics/Acoustic_Micro_Pumps

Electromotors



(b)



http://ieeexplore.ieee.org/xpls/icp.jsp?arnumber=6817527&tag=1