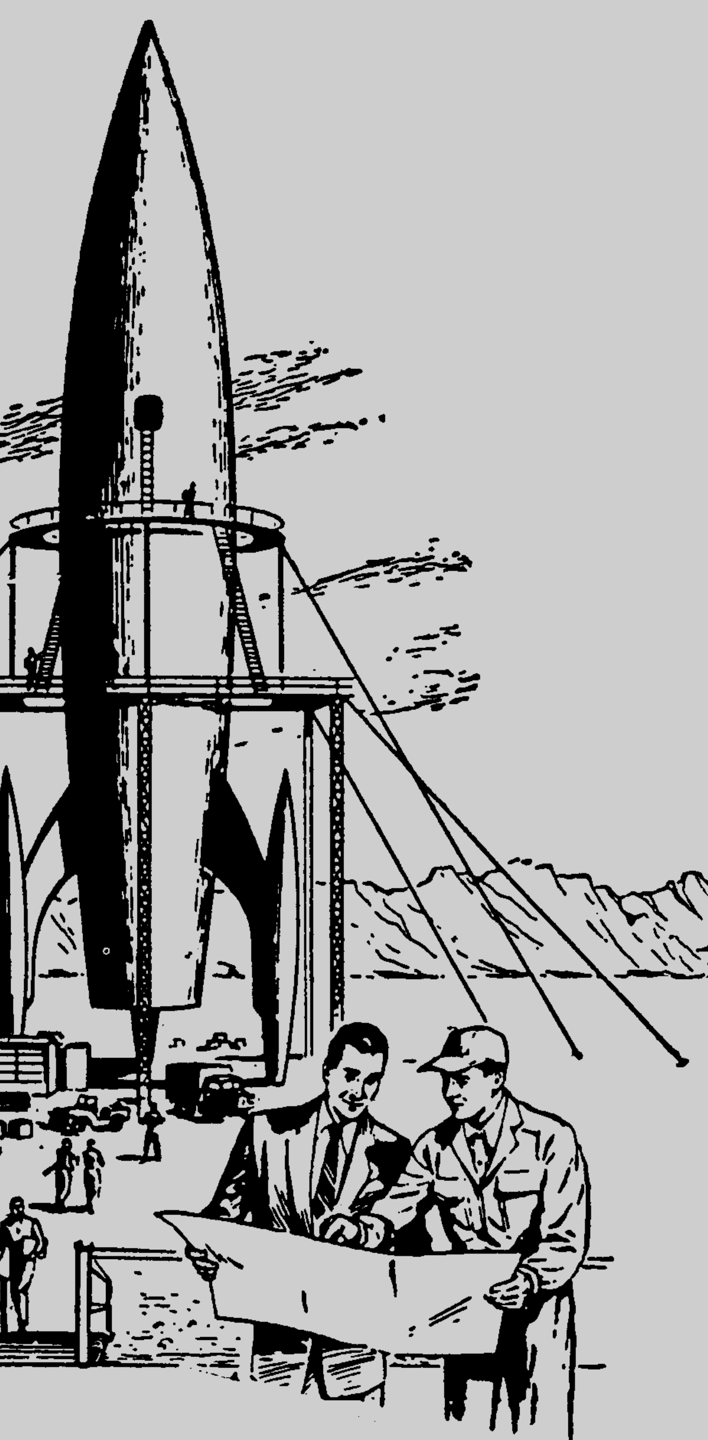

The Past, Present, and Potential Future of Miniaturization Technologies

Gregory T. A. Kovacs, M.D., Ph.D.

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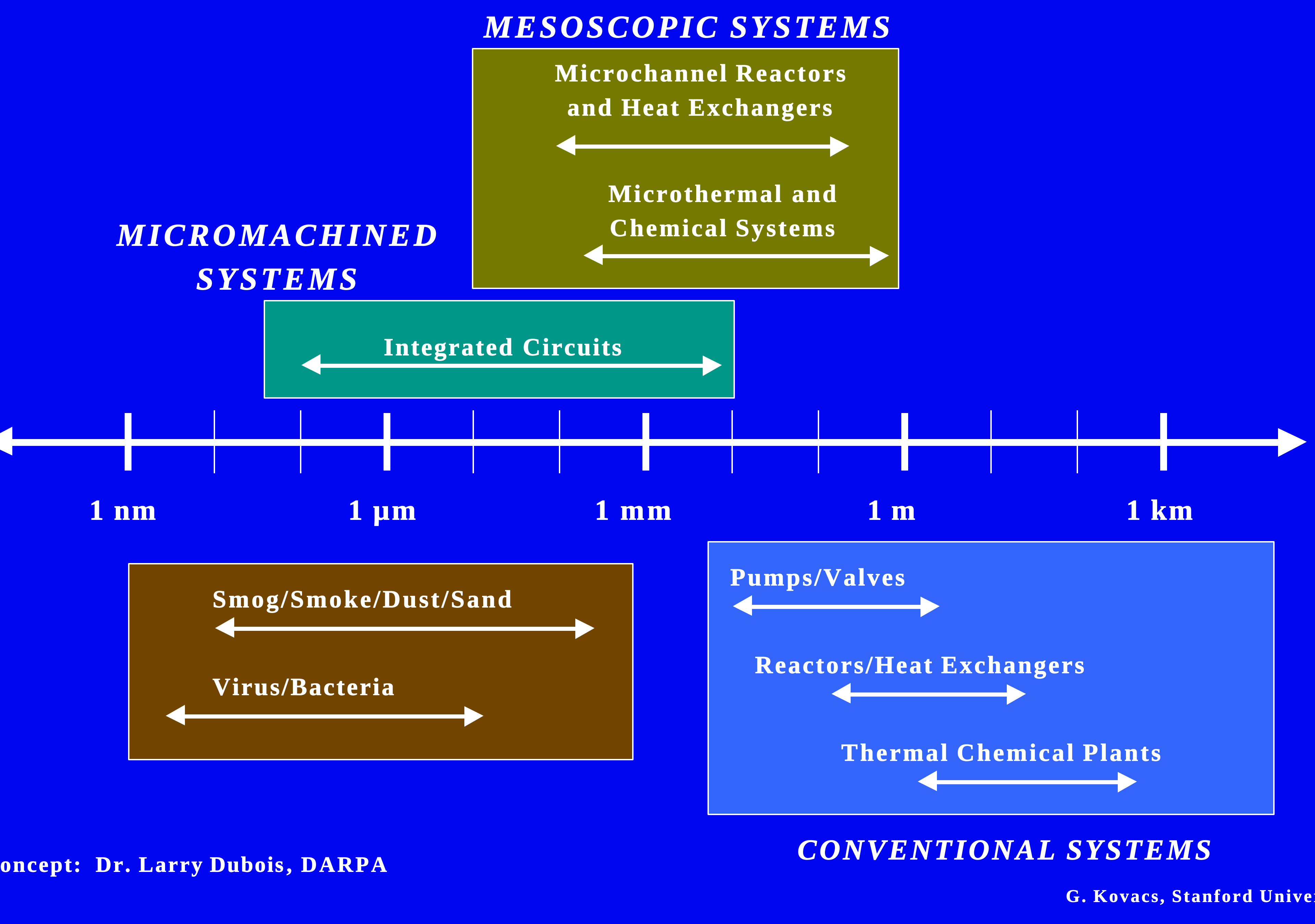

MESOSCOPIC SYSTEMS
Microchannel Reactors
and Heat Exchangers
Microthermal and
Chemical Systems
MICROMACHINED
SYSTEMS
Integrated Circuits
1 nm
1 µm
1 mm
1 m
1 km
Smog/Smoke/Dust/Sand
Virus/Bacteria
Pumps/Valves
Reactors/Heat Exchangers
Thermal Chemical Plants
CONVENTIONAL SYSTEMS
oncept: Dr. Larry Dubois, DARPA
G. Kovacs, Stanford Unive

Origins of Miniaturization Techniques

Prior to the advent of electronics, most miniaturization was of mechanisms, and was serially executed (e.g., watchmaker).

With the dawn of computation, the push to reduce the bulk of computing elements (tubes/relays) and interconnects led in part to the development of modern integrated circuits.

Early History - Electronics

Cat hair, amber, lightning, phlogiston, ether.

1906 Lee De Forest invents the "audion" (triode).

1943 Paul Eisler invents printed circuit boards.

1945 Eniac computer becomes operational.

1947 John Bardeen and Walter Brattain invent the point-contact transistor.

1949 William Shockley proposes junction transistor.

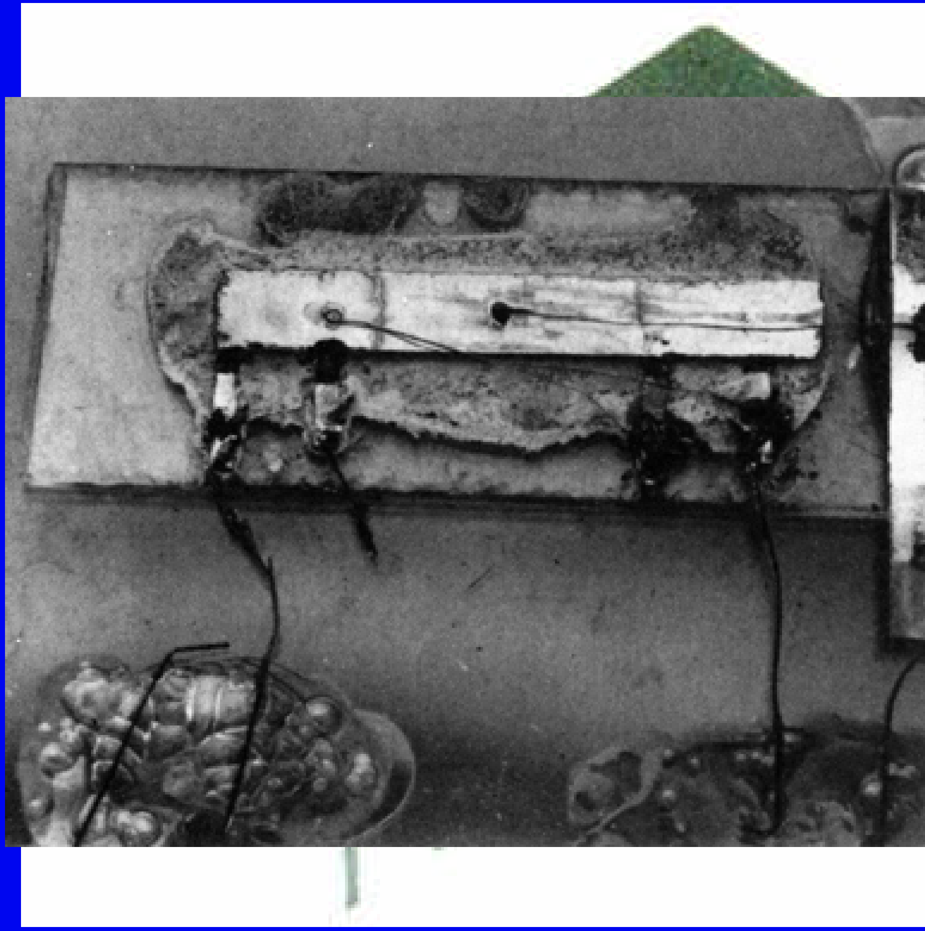
Recent History - Electronics

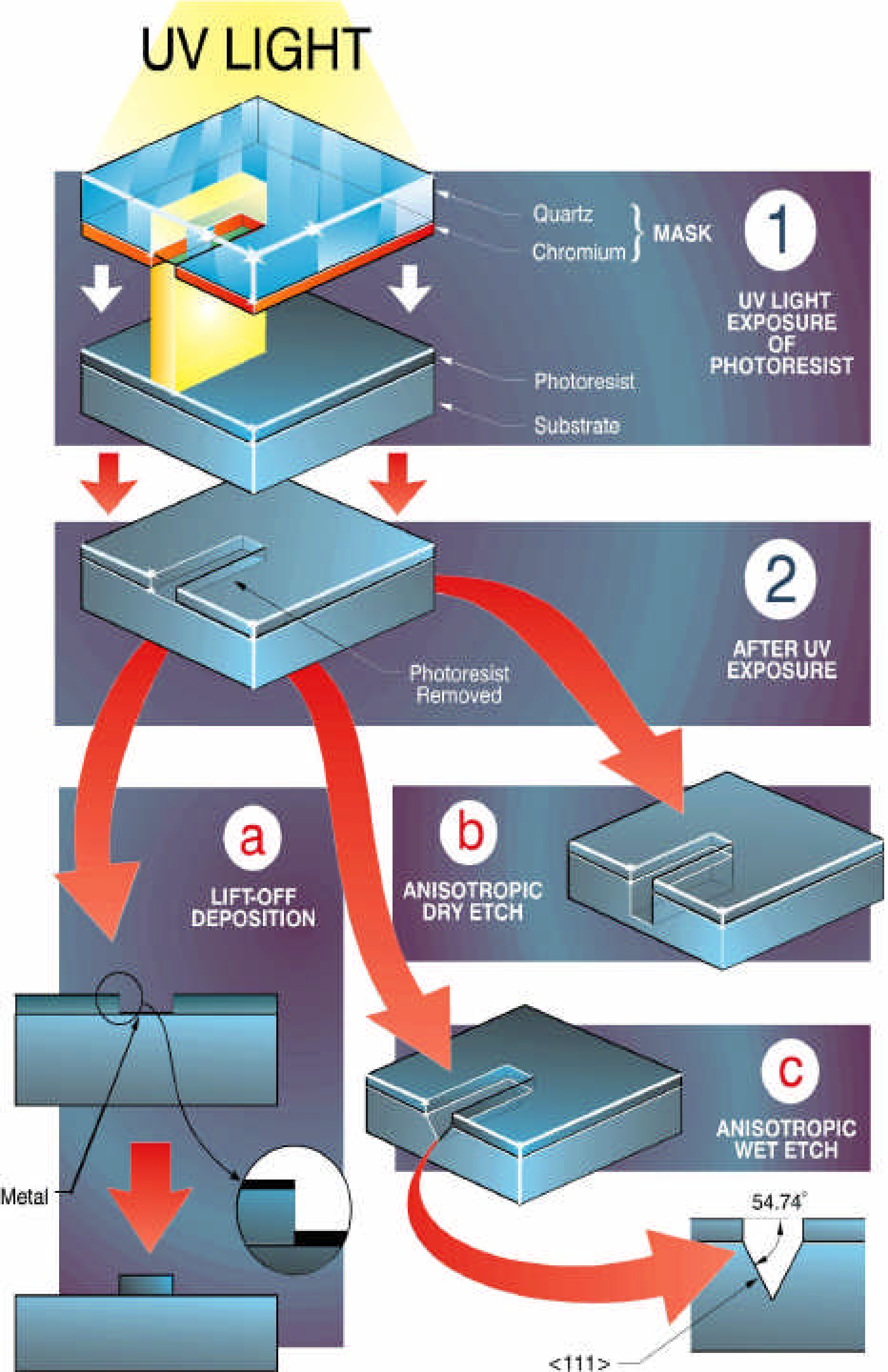
1958 Jack Kilby (TI) invents the integrated circuit.

1962 Steven Holstein and Frederick Heiman (RCA) demonstrate the MOS integrated circuit.

1965 PDP-8 computer introduced - first to use IC's.

1971 Marcian ("Ted") Hoff develops Intel 4004 - the first IC microprocessor.





MICRO-LITHOGRAPHY

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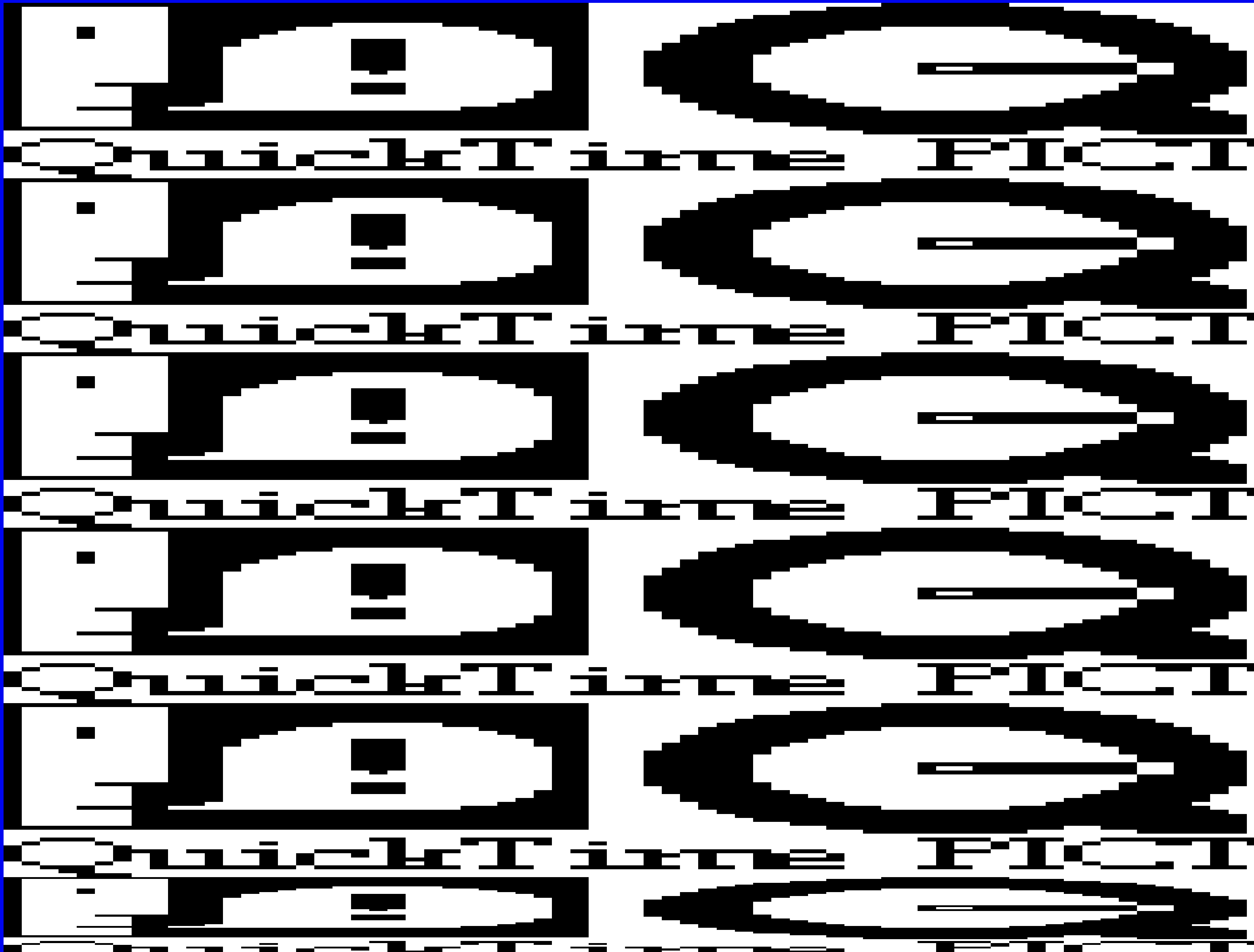
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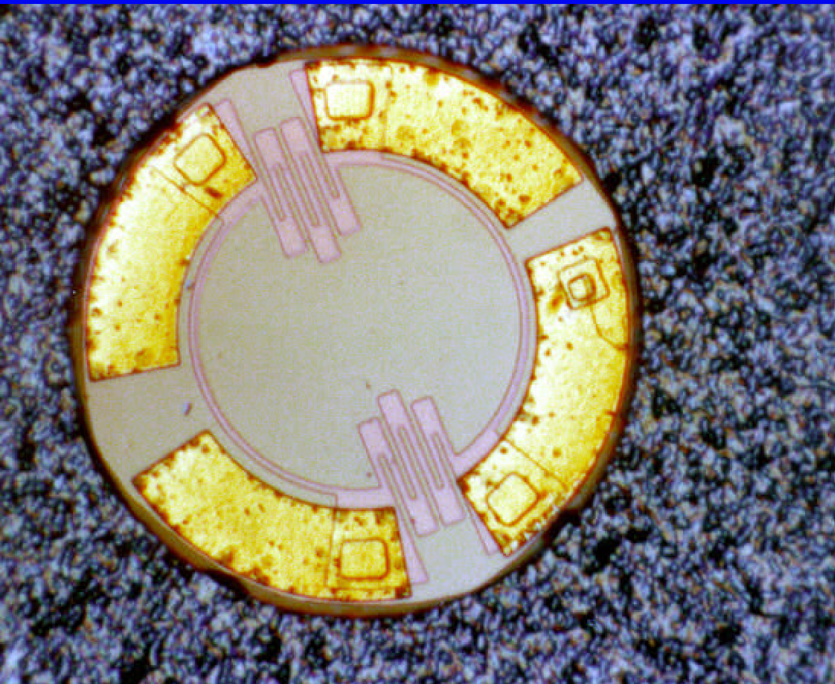
Samaun Relative Pressure Sensor - 1969



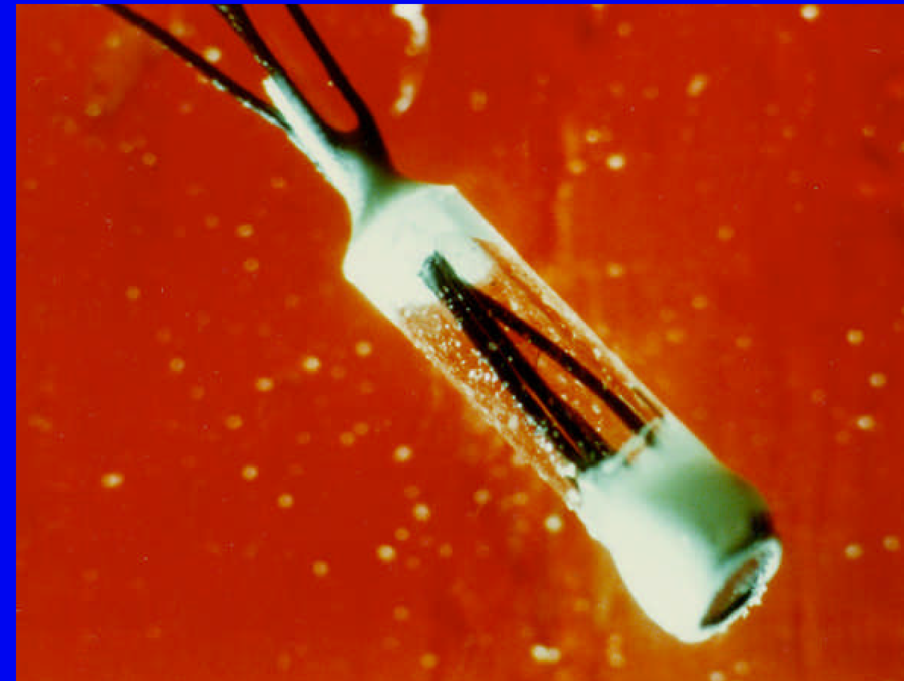
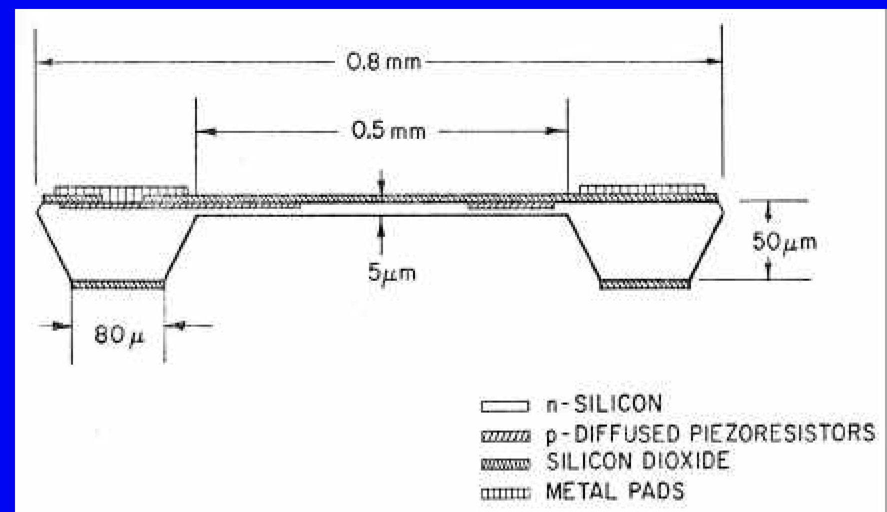
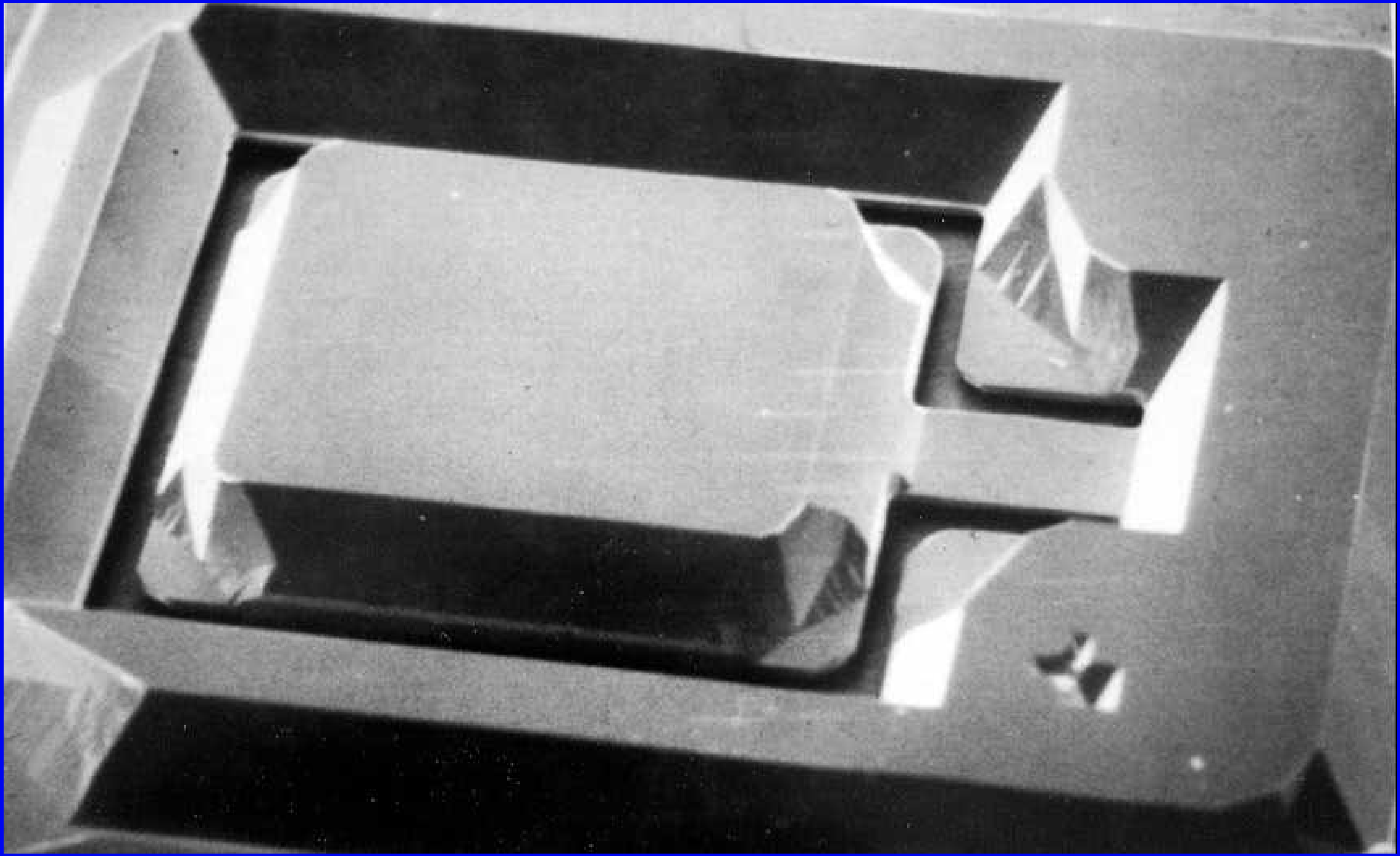


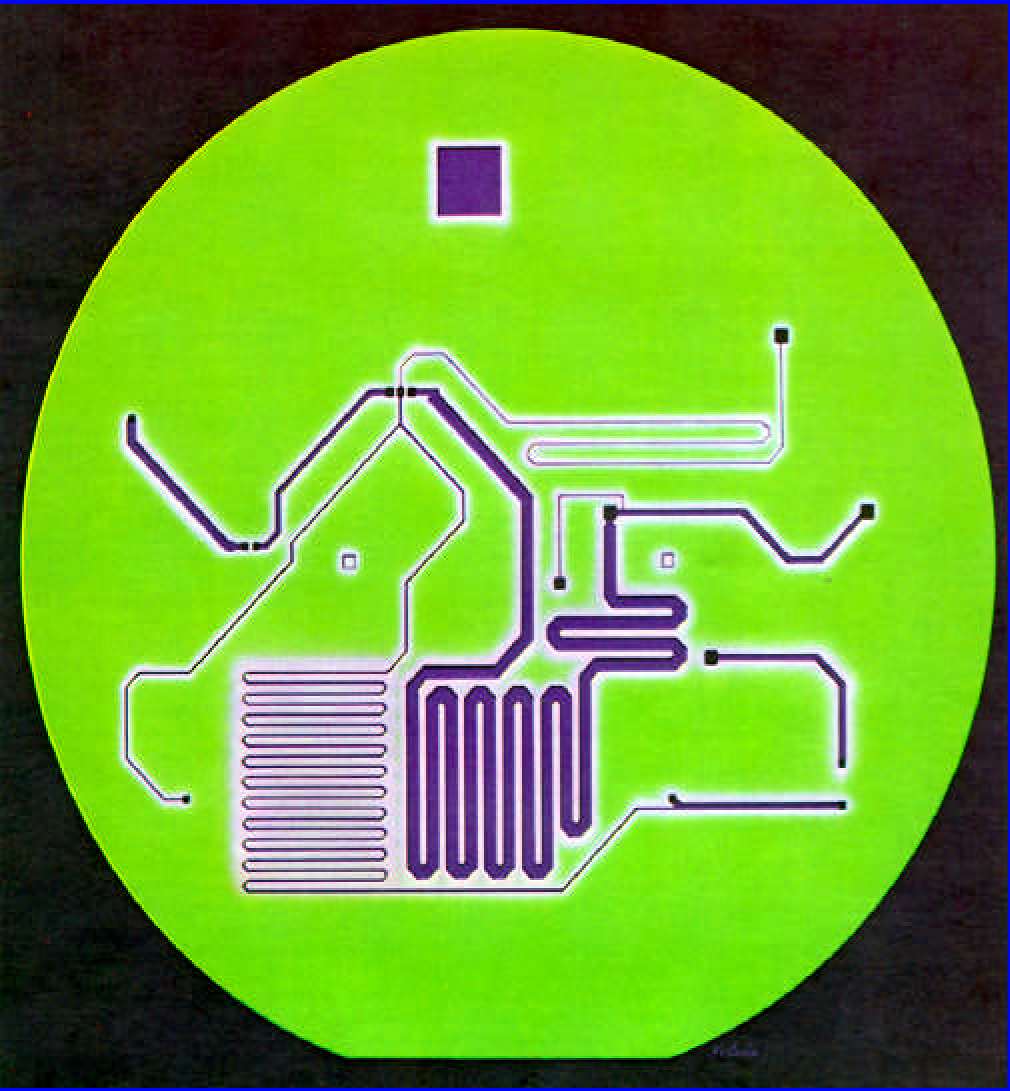
Fig. 5.2. Recording of the blood pressure in the left ventricle of a dog.

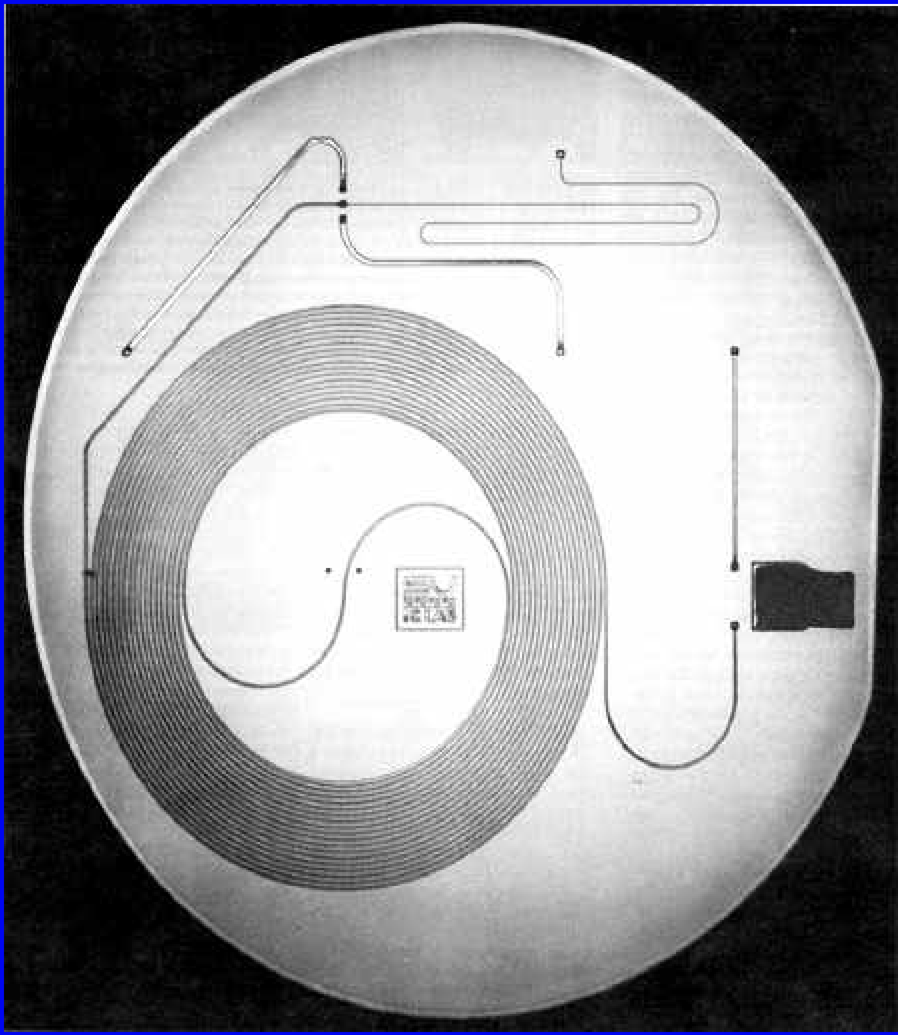


Roylance - Micromachined Accelerometer - 1974

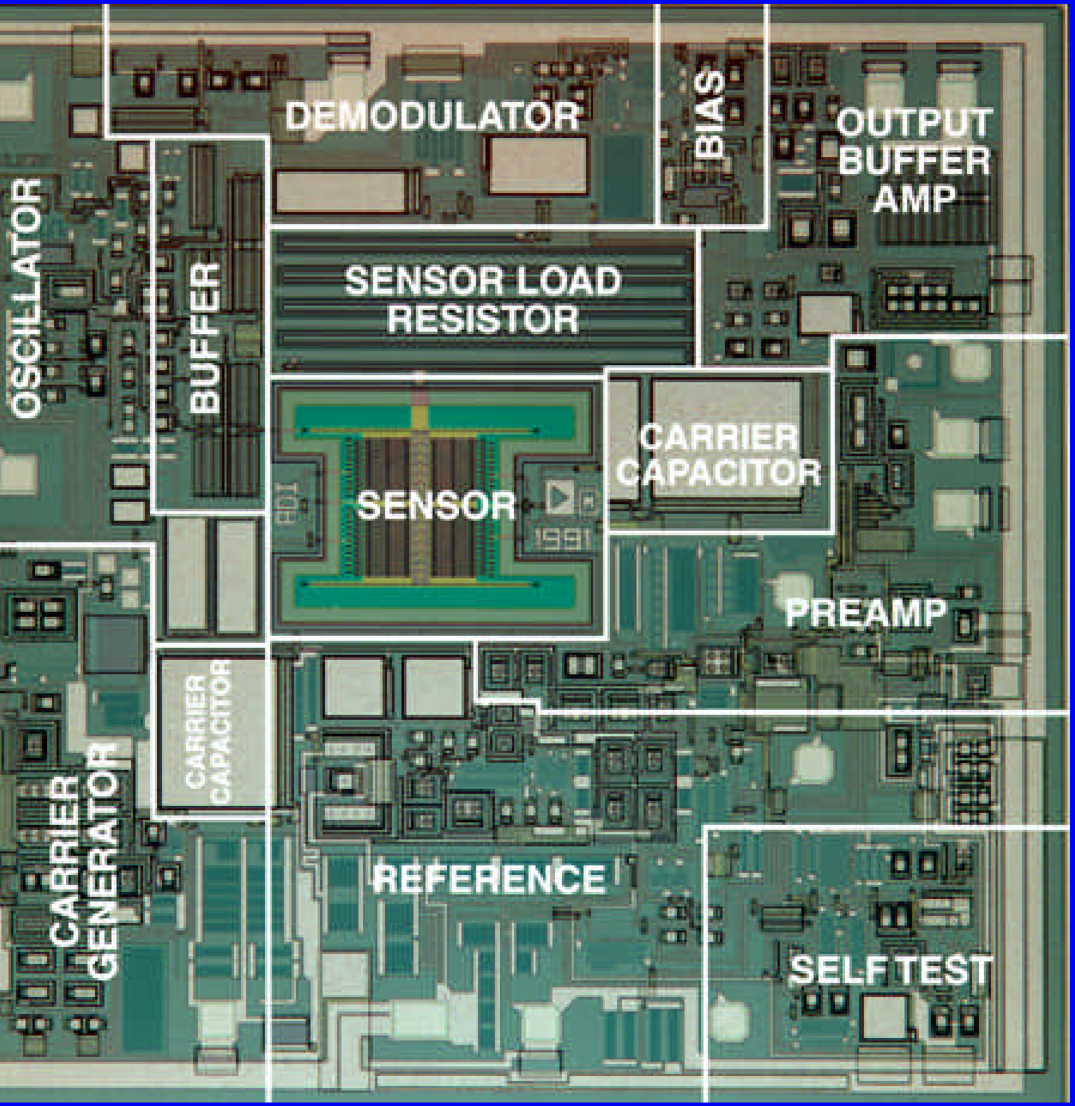


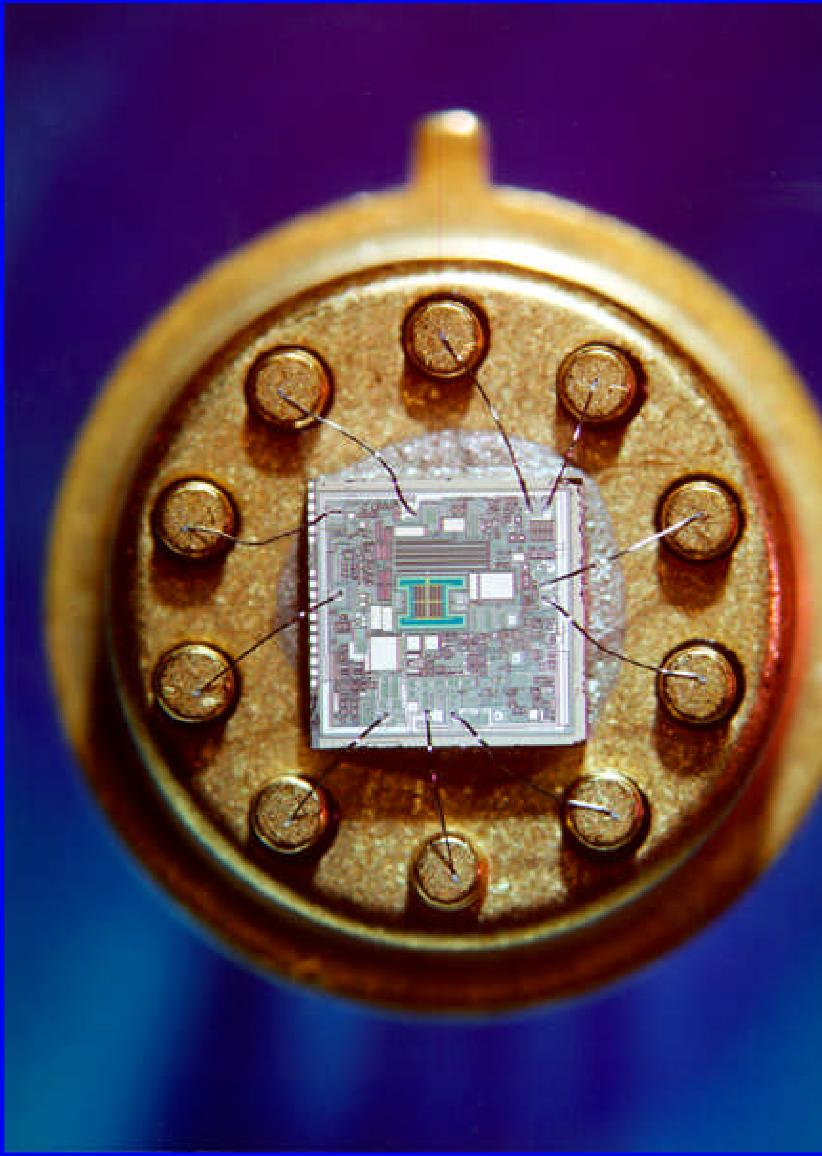
Terry - Integrated Gas Chromatography System - 1975





ANALOG DEVICES ADXL-50





ages courtesy Dr. R. Payne, Analog Devices, Inc.

Miniaturized POC Diagnostic

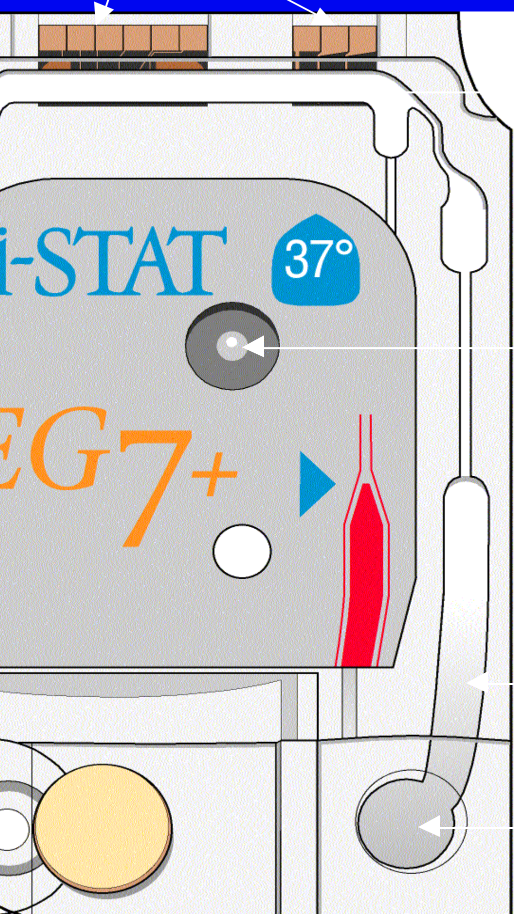
Sensor Chips

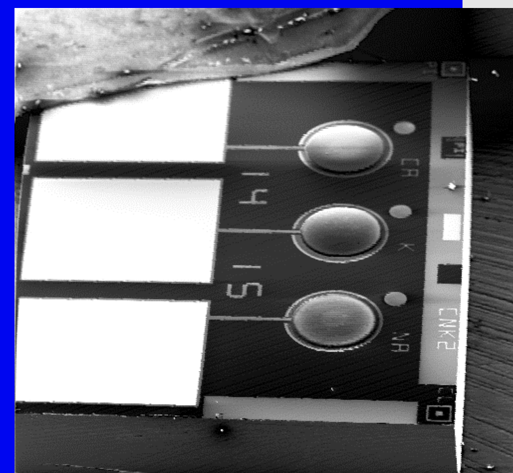
Flow Channel

Calibrant Pouch

Sample Holding Chamber

Sample Entry Port





rtesy Dr. Anca Varlan, I-Stat.

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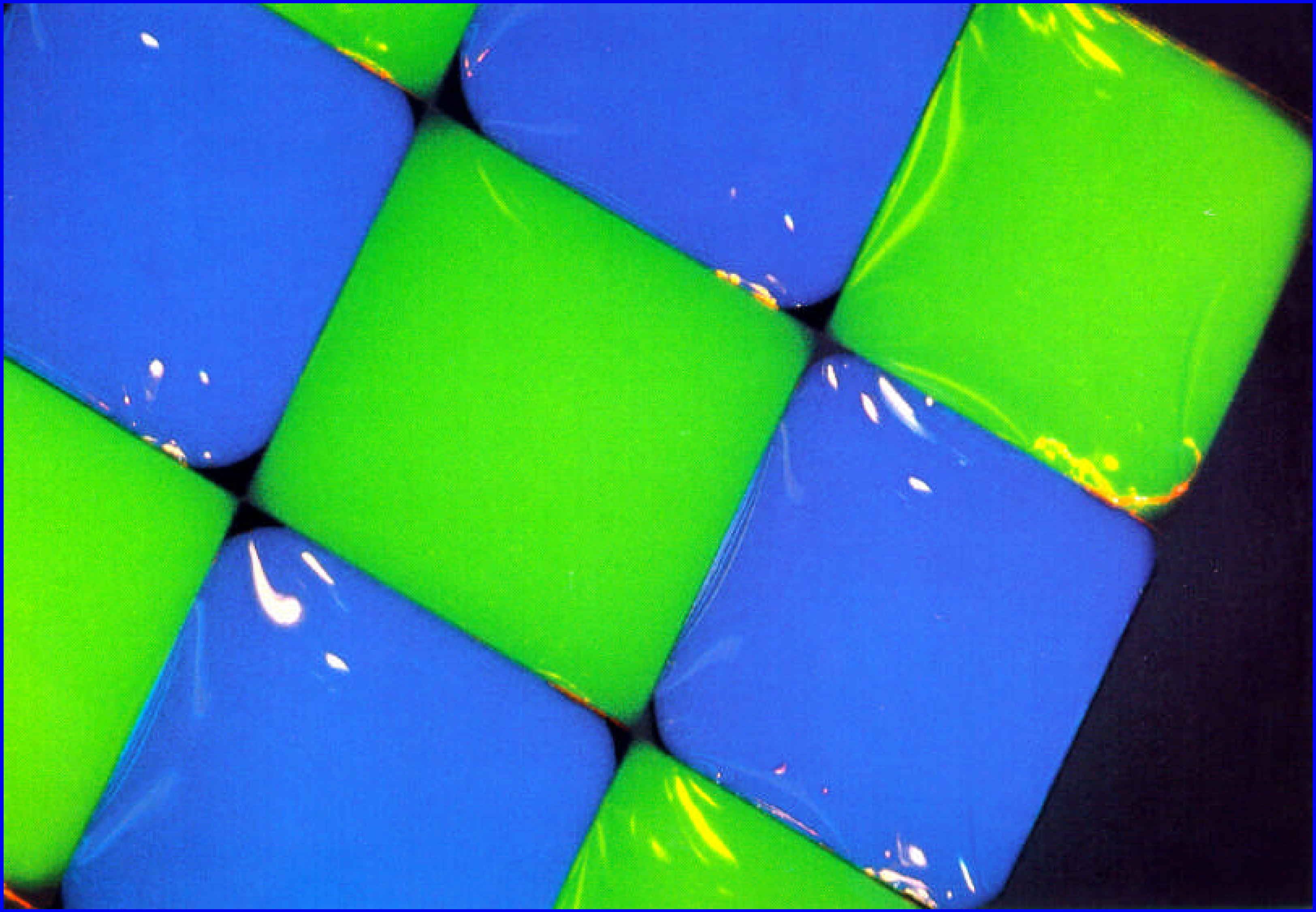
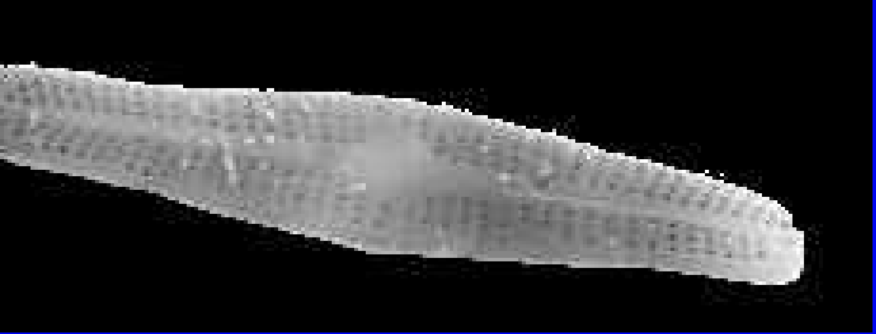
SOFT LITHOGRAPHY

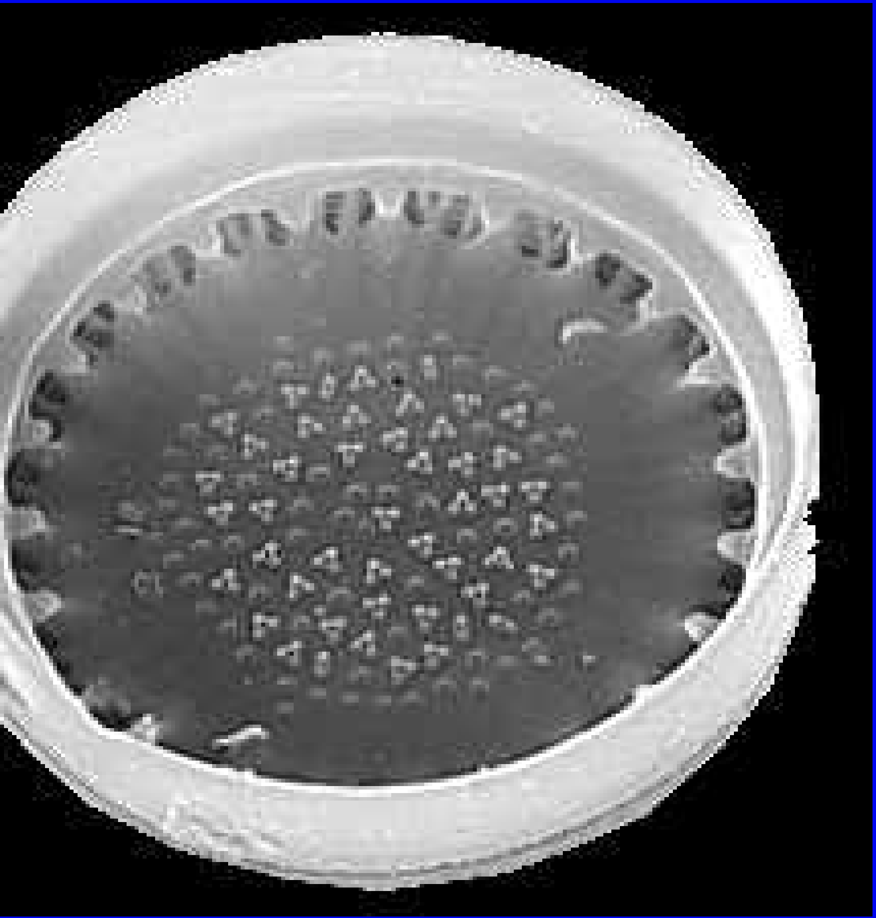
rtesy Prof. G. Whitesides. Reference: Kim, E., Xia, Y., and Whitesides, G. M., "Polymer Microstructures Formed by Moulding in llaries," Nature, vol. 376, 1995, pp. 581 - 584.

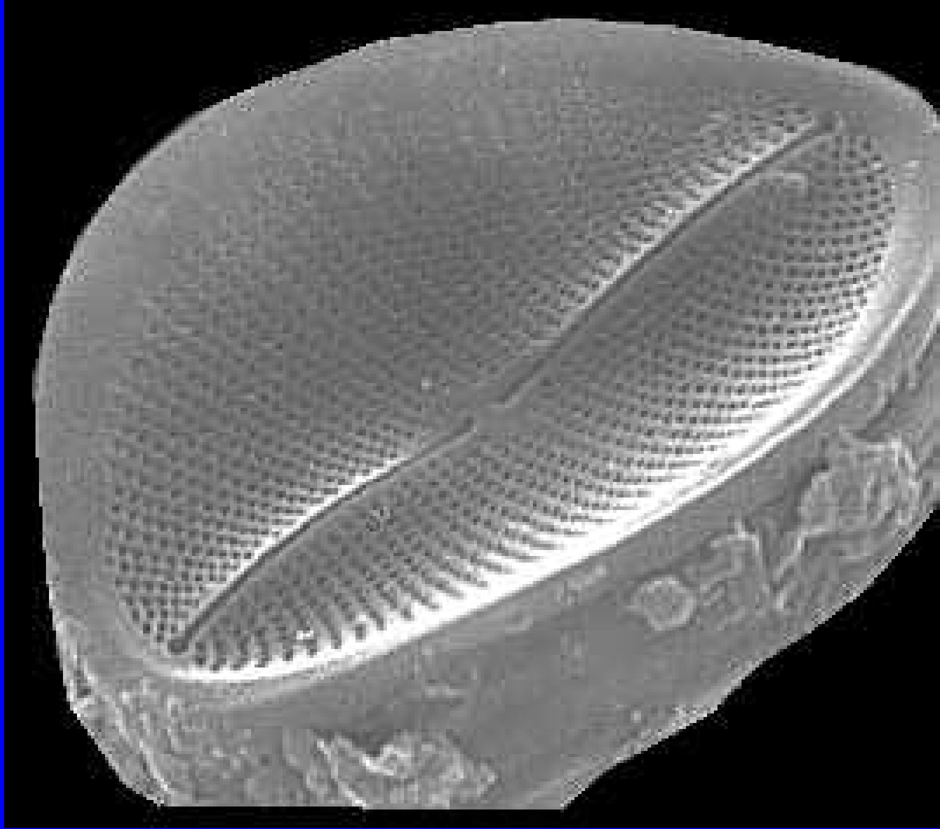
SURFACE MODIFICATION

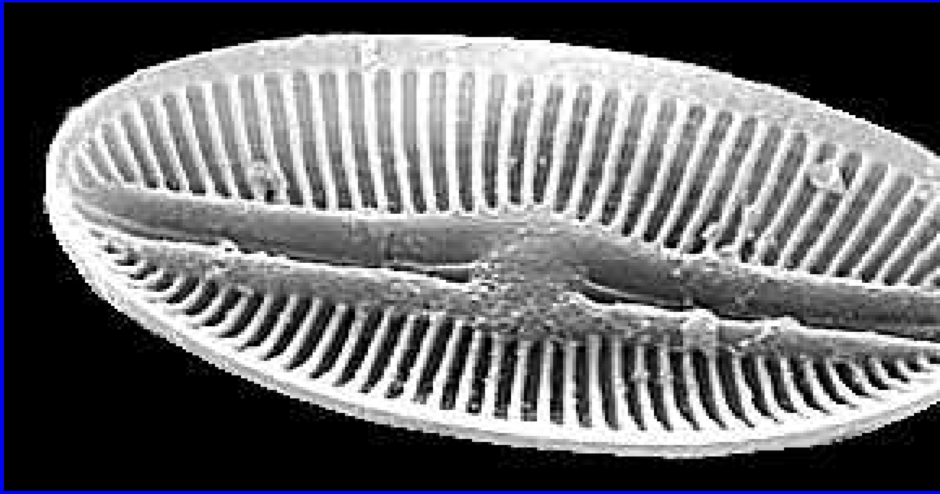


rtesy Prof. G. Whitesides. Reference: Abbott, N. L, Folkers, J. P., and Whitesides, G. M., “Manipulation of the Wettability of aces on the 0.1 - 1 Micrometer Scale Through Micromachining and Molecular Self-Assembly,” Science, vol. 257, 1992, pp. 1380 - 1382.









ce: Bowling Green University Center for Algal
oscopy and Image Digitization

//www.bgsu.edu/departments/biology/algae/index.html

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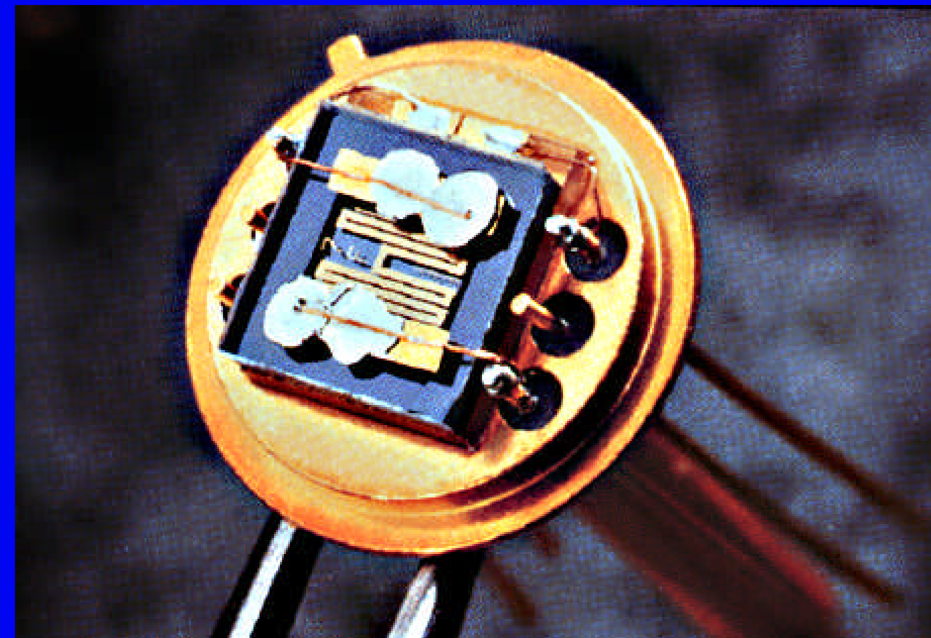
ACTUATOR AND ENERGY SCALING

Actuation schemes generally do not scale well.

Thermal actuation generally used (high power).

Current alternatives have significant drawbacks.



Courtesy Dr. Mark Zdeblick, Redwood Microsystems, In

- Power source scaling is even worse.
- Many portable or implantable systems are dominated by battery volume/mass.
- Need more efficient actuators and better power sources.

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MICROTUBULES & KINESIN

QuickTime™ and a
Cinepak decompressor
are needed to see this picture.

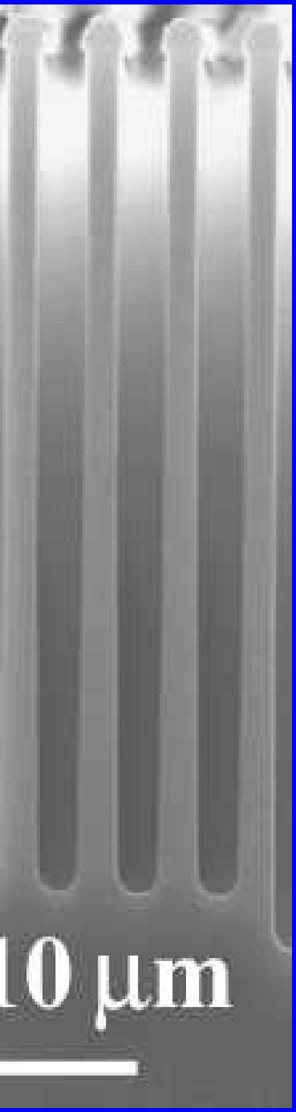
QuickTime™ and a
Cinepak decompressor
are needed to see this picture.

QuickTime™ and a
Cinepak decompressor
are needed to see this picture.

es courtesy Prof. H. C. Heller,
ford University.

ce: Purves, Orians, Heller, and
va, "Life: The Science of Biology,"
uer Associates/W.H. Freeman & Co.,
York, 1999.

THERMAL TRANSPORT SCALING



- **Thermal transport (and isolation) achievable with microstructures far exceeds what can be done with larger-scale devices.**
- **Radically improved heat exchangers.**
- **Unprecedented thermal isolation.**
- **Potential for localized chemical reactions + stable operation of reactions not feasible at macro-scale.**

Klaassen, E. H., Reay, R. J., Storment, C. W., and Kovacs, G
“Micromachined Thermally Isolated Circuits,” Sensors and Ac
A, vol. 58, no. 1, Jan. 1997, pp. 43 - 50.

MASS TRANSPORT SCALING

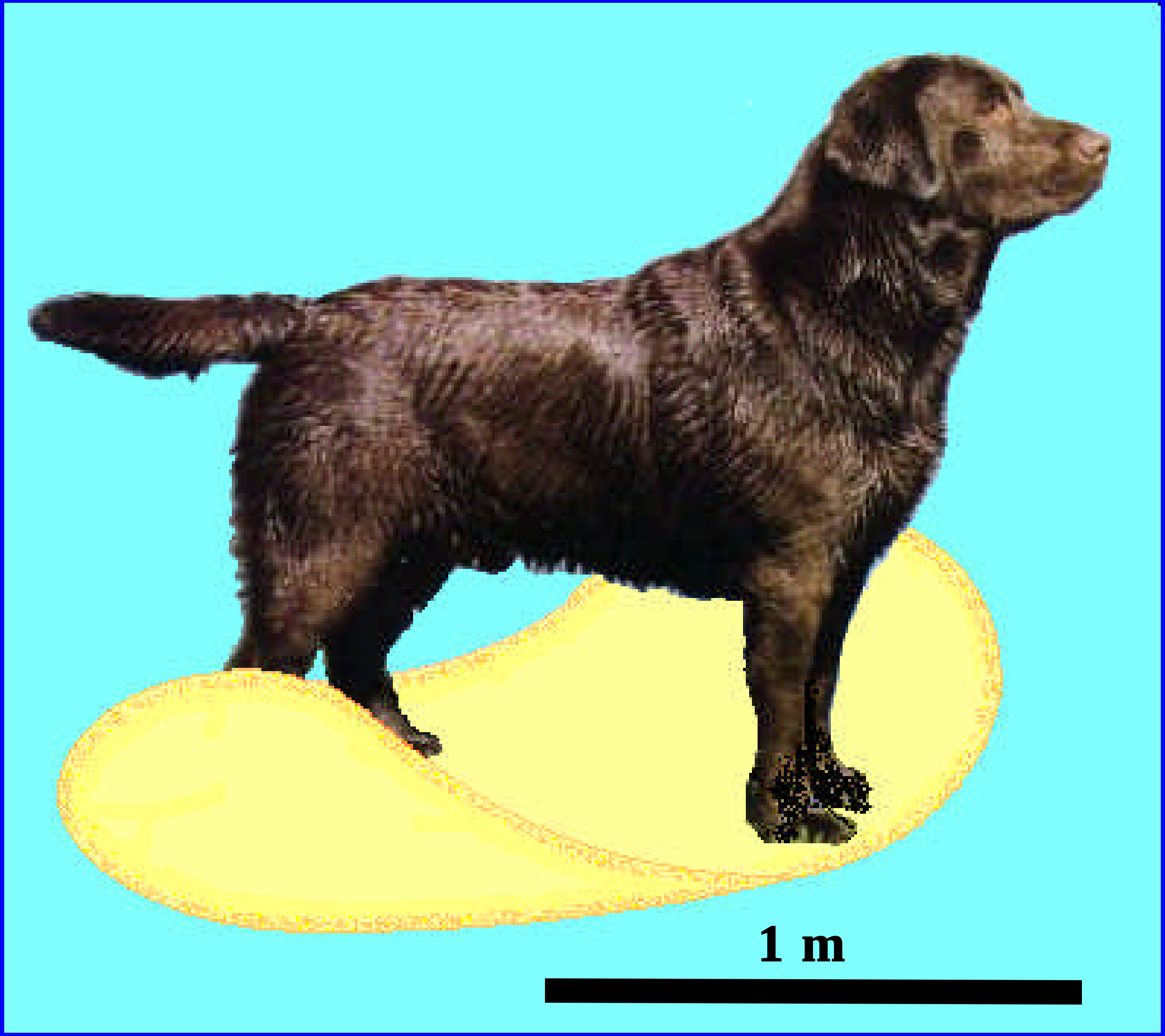
- **Fluid flows at the micro-scale are almost certainly laminar.**
- **Separations are enhanced by surface-area-to-volume ratio increases as channels are scaled down.**
- **As described by Manz, for an ideal (single molecule) sensor, the volume containing a molecule is given by,**

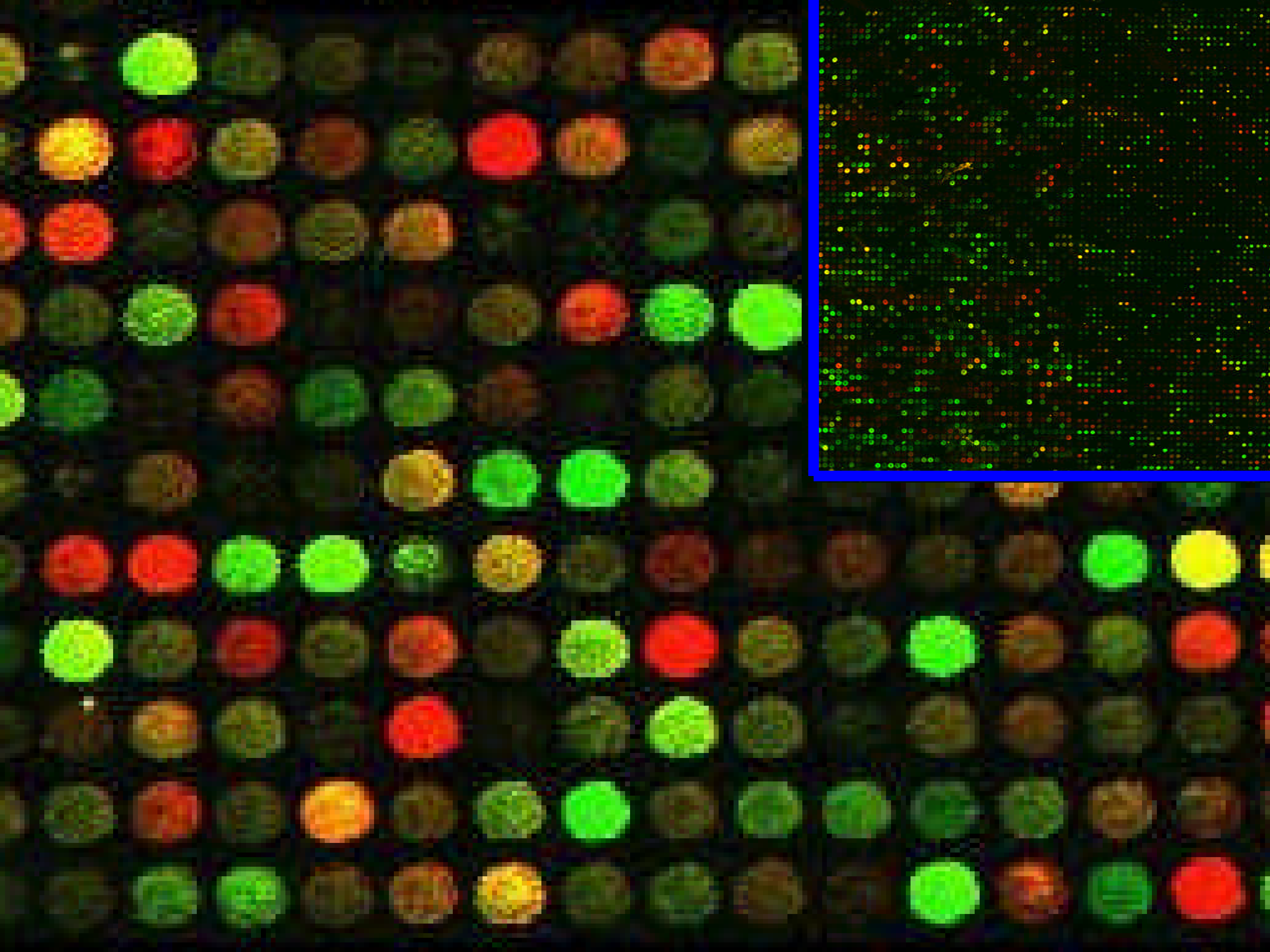
$$V_{sm} = \frac{1}{C\,N_A}$$

(C = concentration, N_A = Avogadro's number)

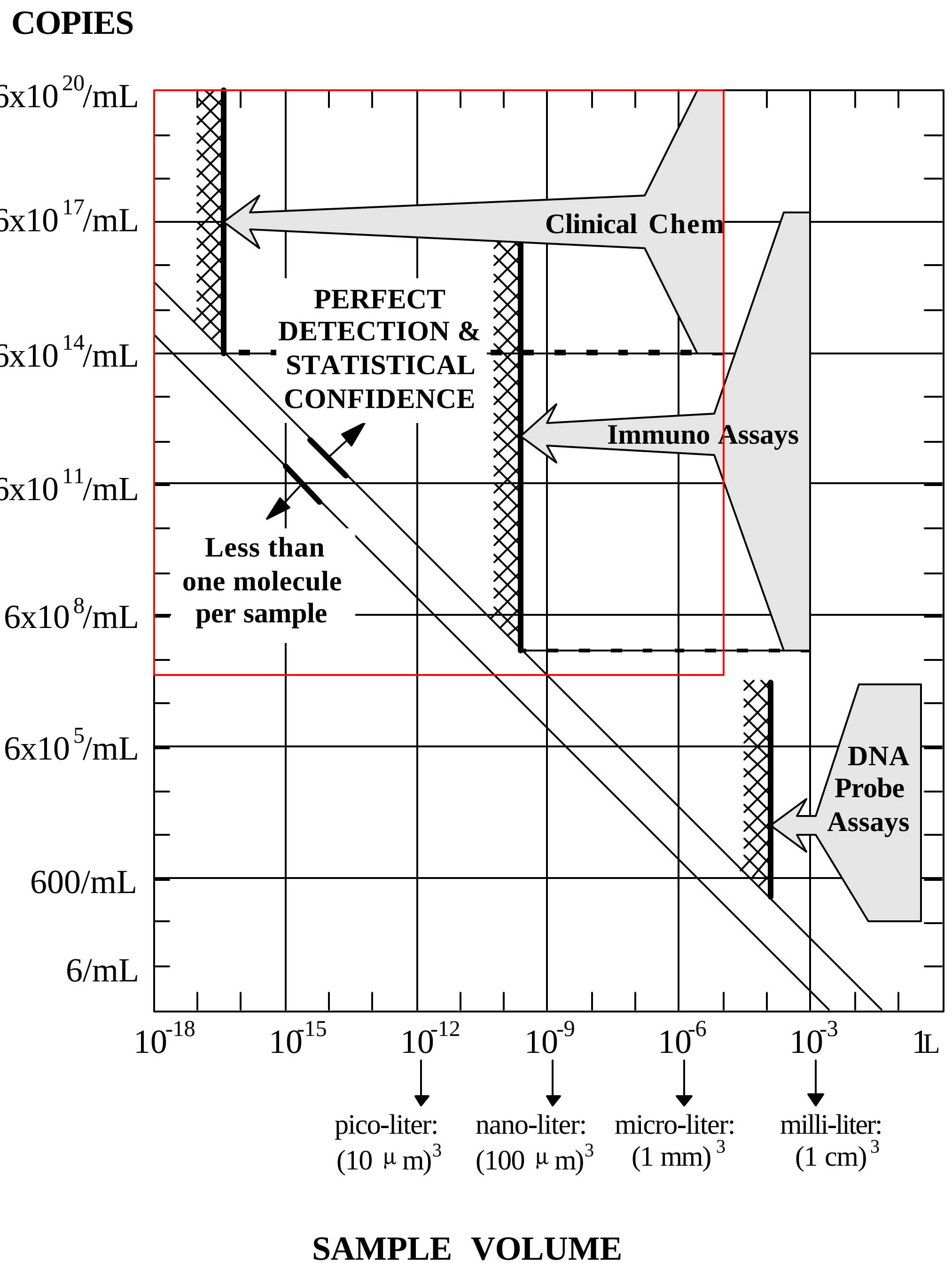
- ***Affinity*** **techniques are often needed.**
- ***Amplification*** **techniques may also be applicable if they have sufficient signal-to-noise ratio (key metric!).**

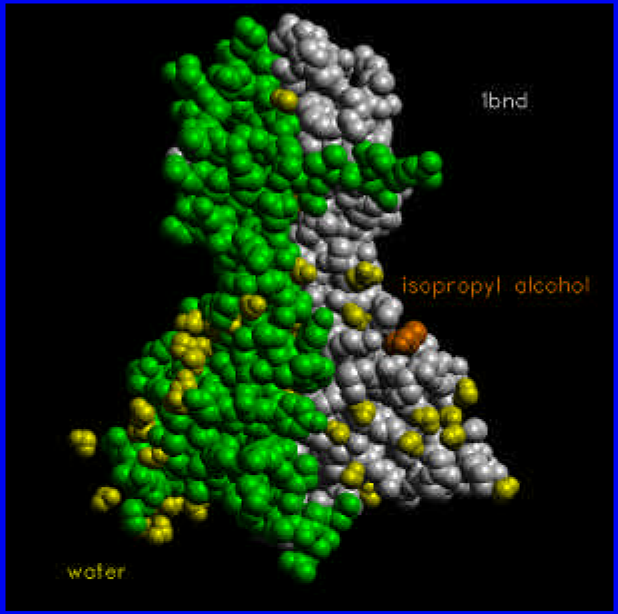
"LAB-ON-A-CHIP"





DETECTION LIMITS OF MICROFLUIDIC ASSAYS





Courtesy Dr. Kurt Petersen, Cepheid,

FLOWS AT LOW REYNOLDS NUMBER

Q = 10 µl/min

v = 67 mm/s

R_e = 4.4

100 µm

50 µm

QuickTime™ and a
Component Video decompressor
are needed to see this picture.

Two parallel streams of dyed water showing mixing by diffusion only.

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"Micro" Breakthroughs in the Next 50 Years?

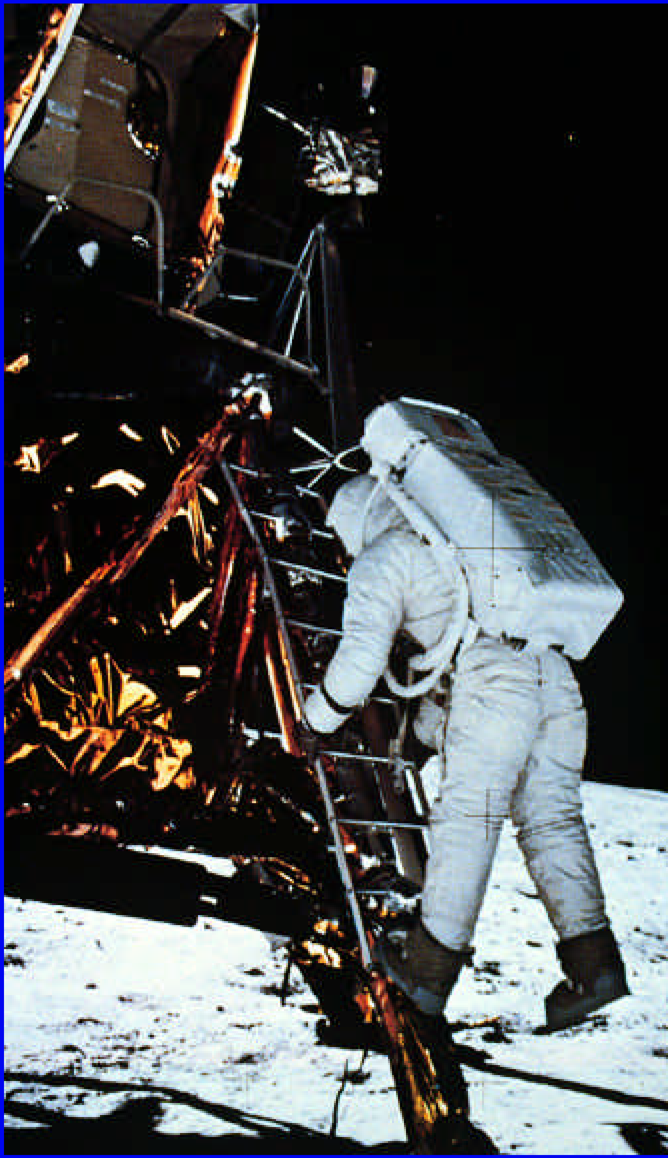
- Integrated circuits will reach billion transistor level
- Lithography will take us down to tens of nanometer features.
- Quantum devices or other "alternate" computation schemes will emerge.
- Sensor fusion approaches will be invented that work across size domains.
- High-performance biosensors will emerge that allow the target biological signals to be monitored rather than inferred.

“Micro” Breakthroughs in the Next 50 Years? - Cont’d.

- Nanotechnology will actually become a technology instead of a science fair.
- Techniques will emerge for seamless integration of various technologies, materials, etc., into systems.
- Multi-mode integrated systems (e.g., fluidic, thermal, electronic, etc.) will emerge in some applications.
- Miniaturized implants will be commonplace for treating disorders, predicting/preventing disease, and potentially for enhancing human capabilities.

WHAT HAPPENED TO GOALS?

- What about the “grand” projects like predictive protein design, curing cancer, curing cardiovascular disease, or even curing aging?
- The last grand-scale national science push worked because it had a clear goal, was adequately funded, and because it was led by applied scientists (engineers, doctors, physicists). Genome project?
- If government agencies want to push the frontiers at a basic science level, the cultures of the scientists must be considered (modified?).



Do not confuse the complexity of the system under study with the complexity of the project to study it.

CROSSING DISCIPLINARY BOUNDARIES

- Interdisciplinary centers - with clear goals.
- Interdisciplinary education!
- Interdisciplinary design and modeling tools (software and hardware).

Technology push or need pull?

Does adding funding add breakthroughs?

CONCLUSIONS

- **The thoughtful application of miniaturization technologies will have broad impact when applied to the bio:info domains. Examples: diagnostic, pharmaceutical discovery, therapeutic, and basic science instrumentation.**
- **Clear understanding of scaling laws and system-level issues across disciplines is vital for successful miniaturization.**
- **Interdisciplinary teams are critical, but interdisciplinary people are even better.**