SiTime

A New Age for MEMS

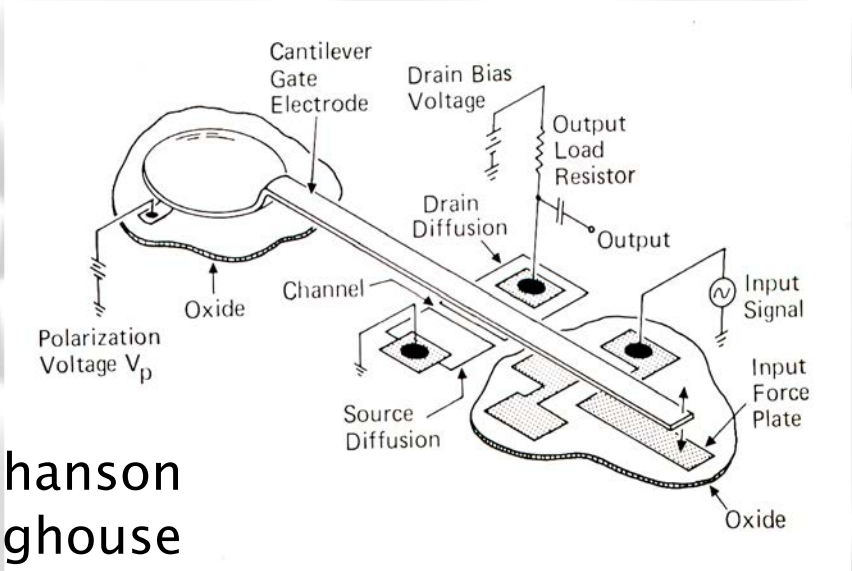
Kurt Petersen, PhD
CEO, SiTime

Outline

- Brief History of MEMS
- Current Status of IC Industry
- Some Opportunities for MEMS
- A New Age for MEMS

Pre-1970

- R&D
  - Anisotropic Silicon Etching
  - Silicon/Glass Bonding
  - Resonant-gate-transistor at Westinghouse
  - Neural probes
- Production
  - Bonded silicon strain-gage pressure sensors and accelerometers

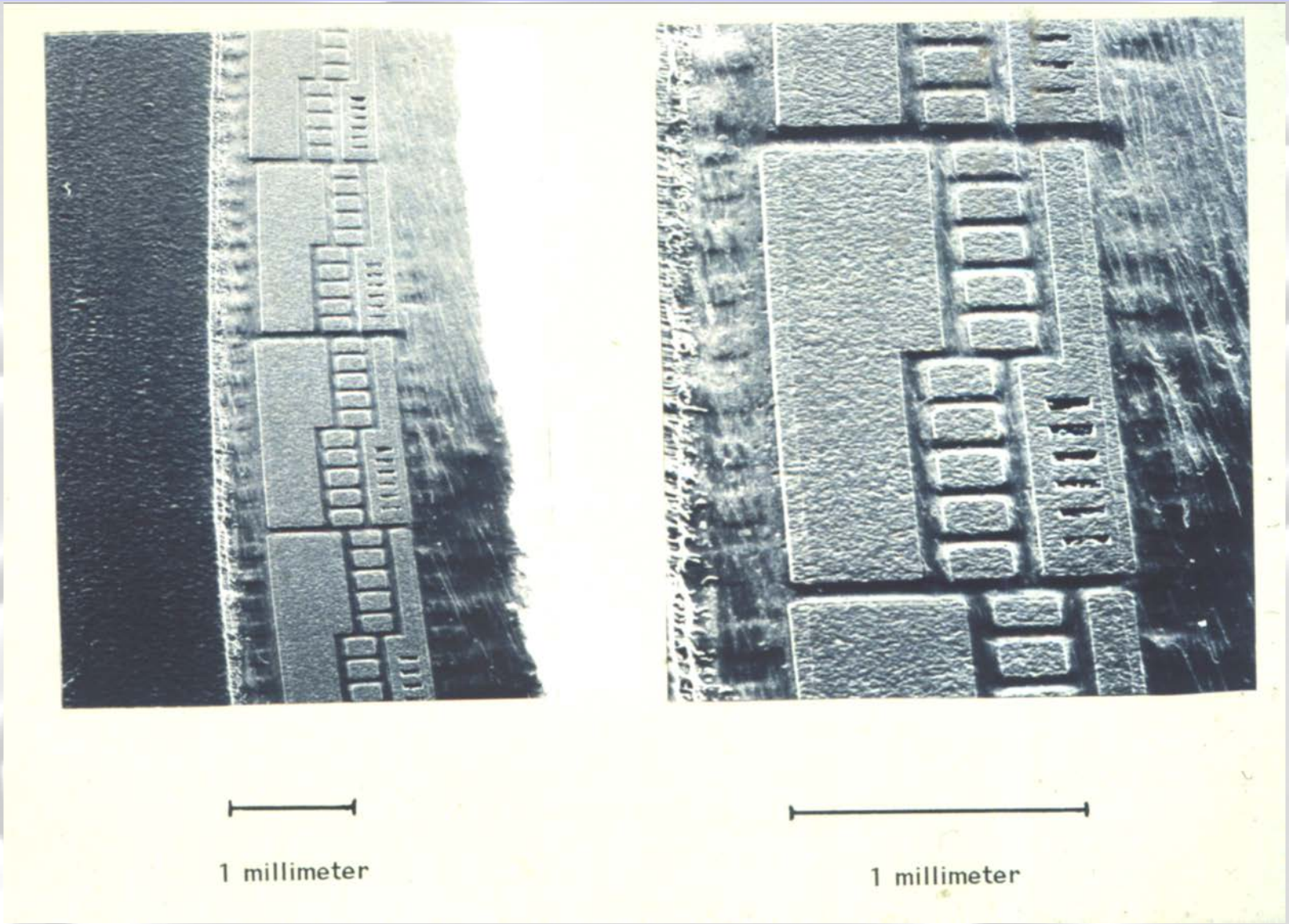


Harvey Nathanson
Westinghouse

1970-1975

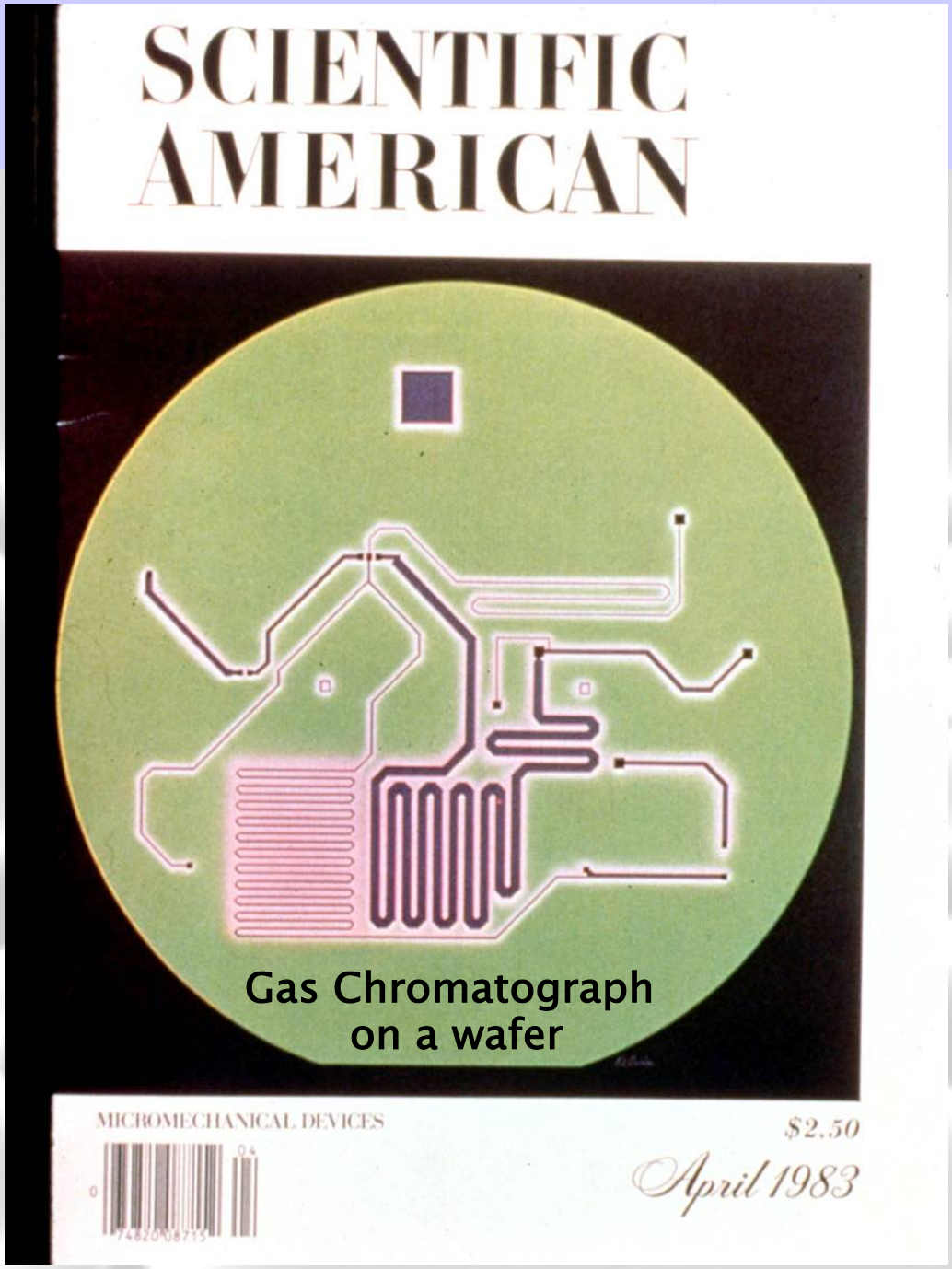
- R&D
  - Silicon ink jet nozzle
  - E-beam deflected optical modulator arrays
  - Early membrane arrays for optical mod
  - More anisotropic etching
  - Electrochemical etching
- Production
  - Etched silicon diaphragm pressure sensor
  - Thermally activated print-heads

TI Thermal Printhead – 1972

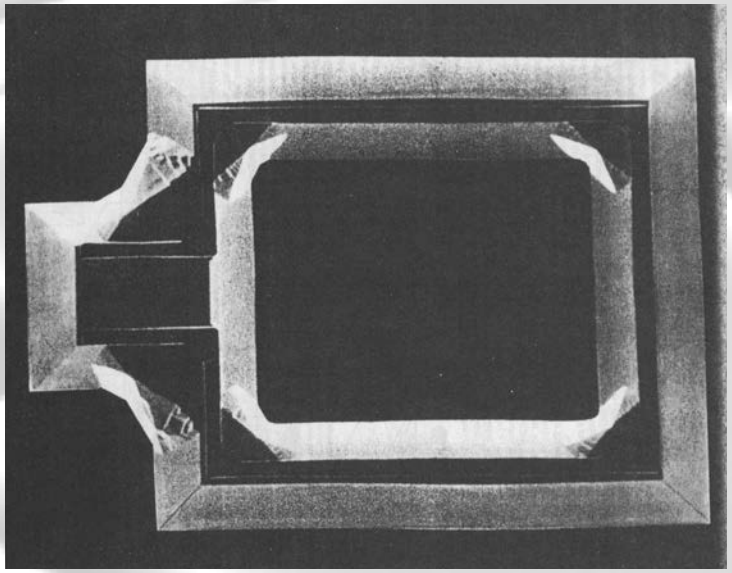


1975-1980

- R&D
  - Stanford Accelerometer
  - Gas Chromatograph on a chip
  - Miniaturized cryogenic-coolers
  - Torsional scanning mirrors
  - Electrical switches
  - Thin membranes for x-ray, e-beam lithography
  - Voltage-controlled optical modulator arrays
  - Pressure sensors with circuit on board
  - Thermally isolated devices for infrared sensors
- Production
  - High band-width thermal rms voltage detector



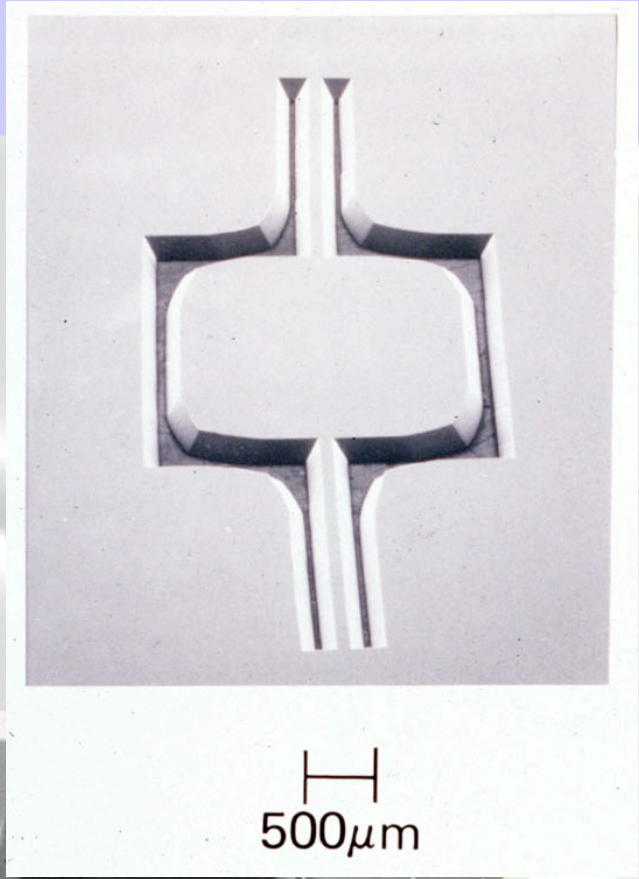
Professor Jim Angell at Stanford started much of the early MEMS research.

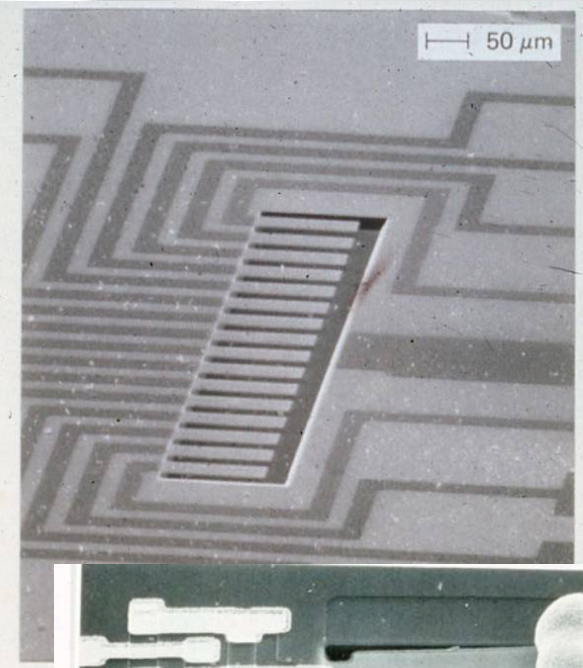


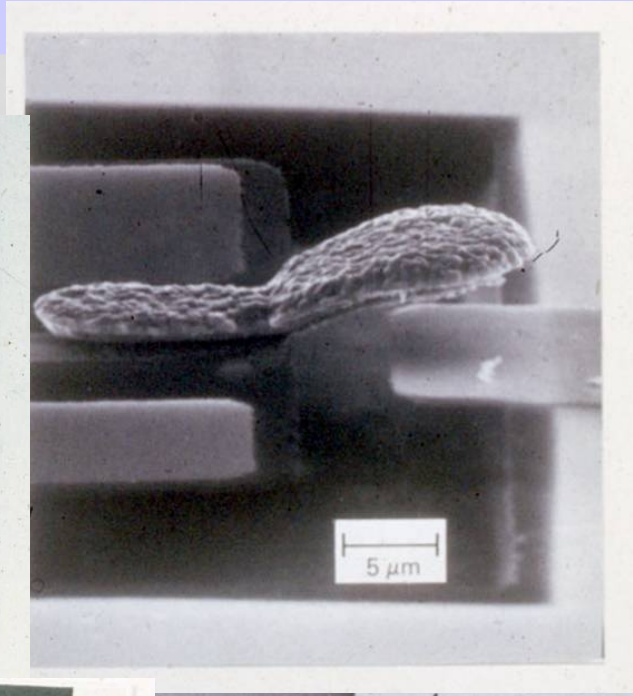
First MEMS Accelerometer

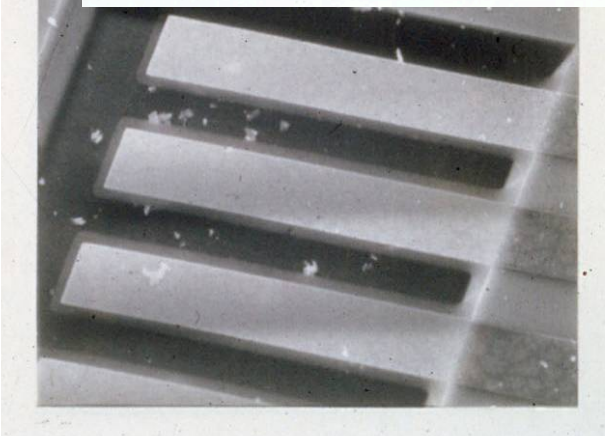
SiTime

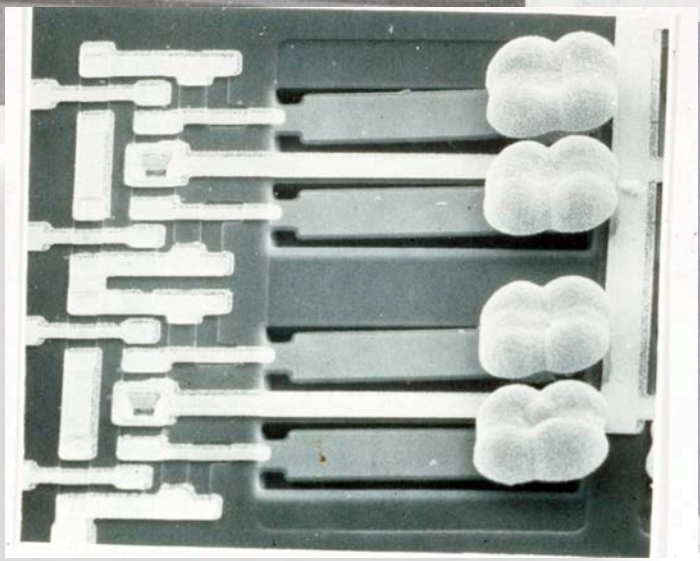
IBM Research

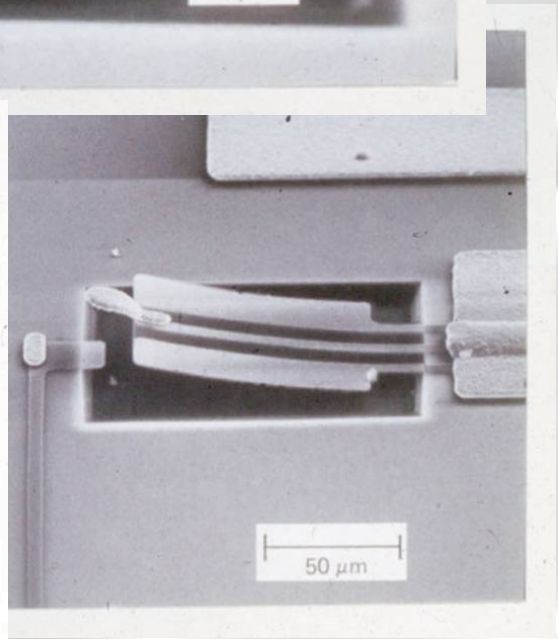








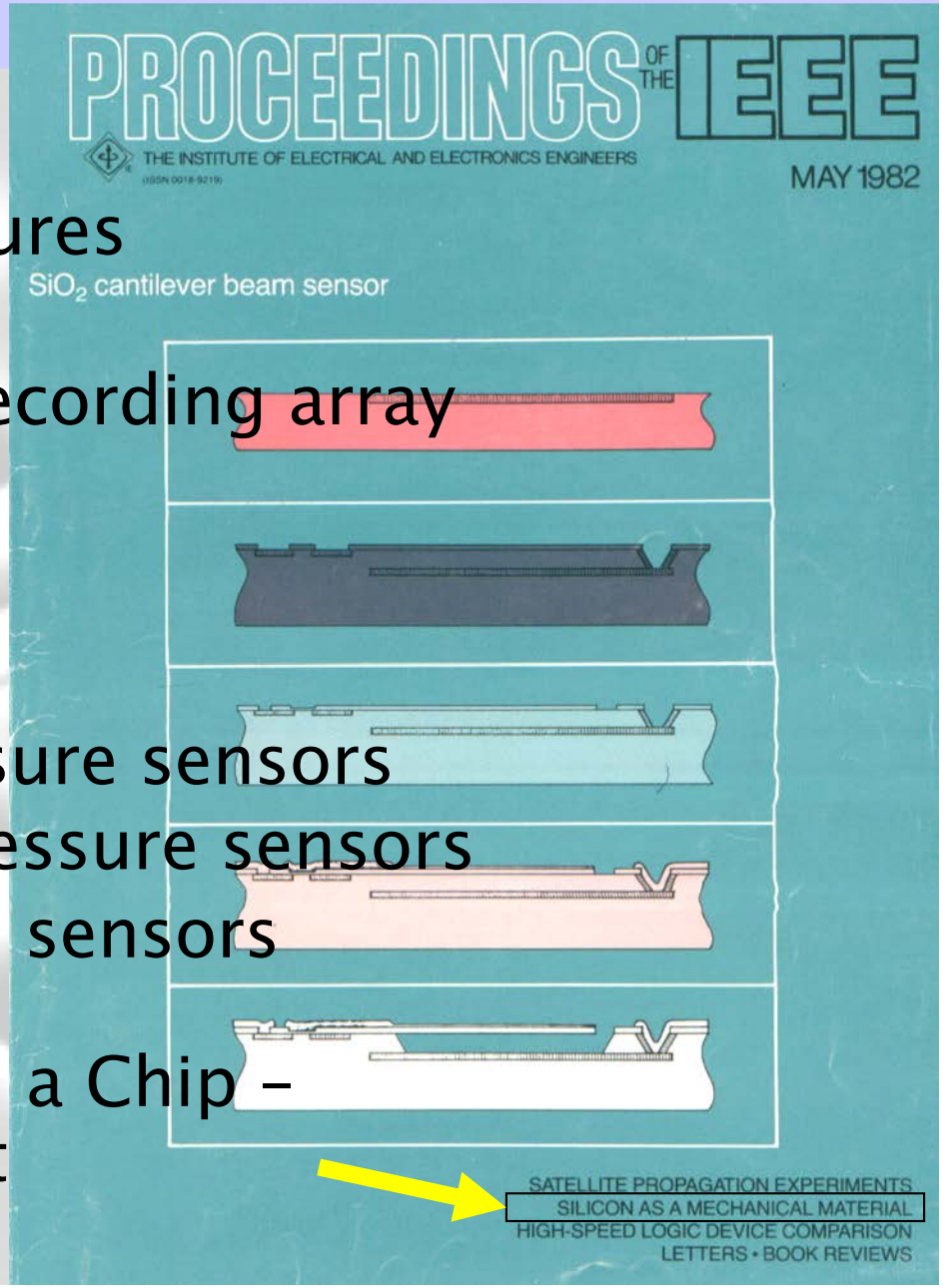




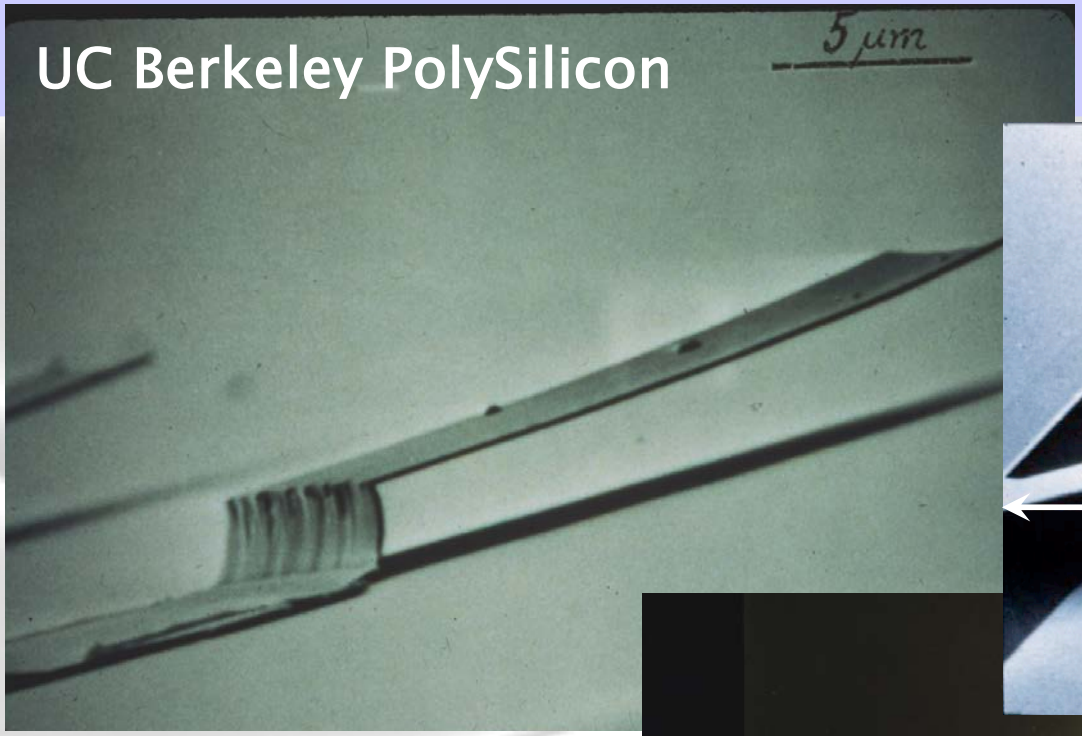
SiTime

1980–1985

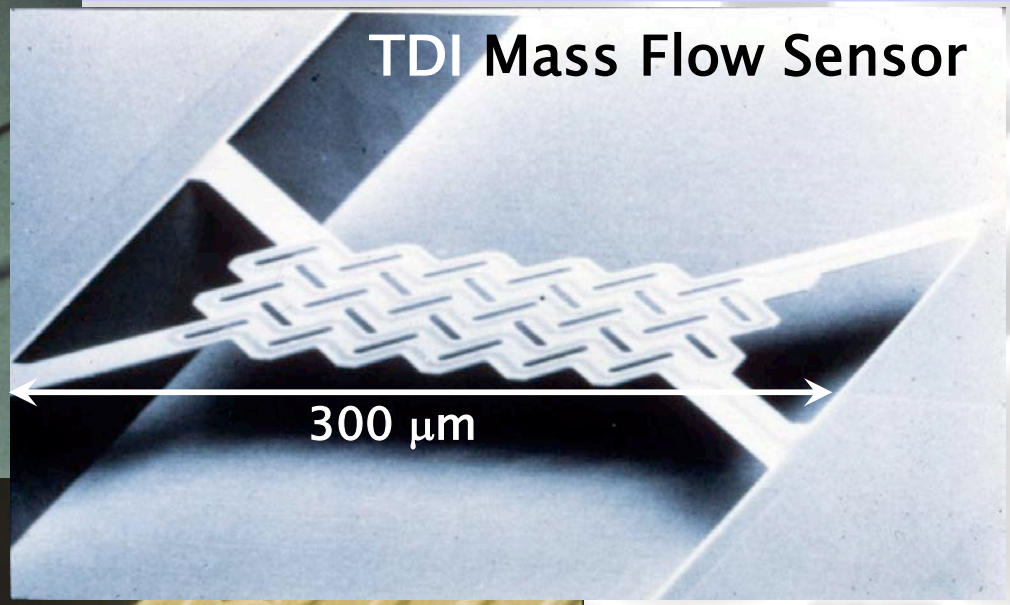
- R&D
  - Polysilicon microstructures
  - IC Chip cooling
  - Multi-channel neural recording array
  - Mass-flow sensor
  - Vapor/gas sensors
- Production
  - First high volume pressure sensors
    - disposable blood pressure sensors
    - automotive pressure sensors
      - emissions control
  - Gas Chromatograph on a Chip – now an Agilent product



SiTime



UC Berkeley PolySilicon

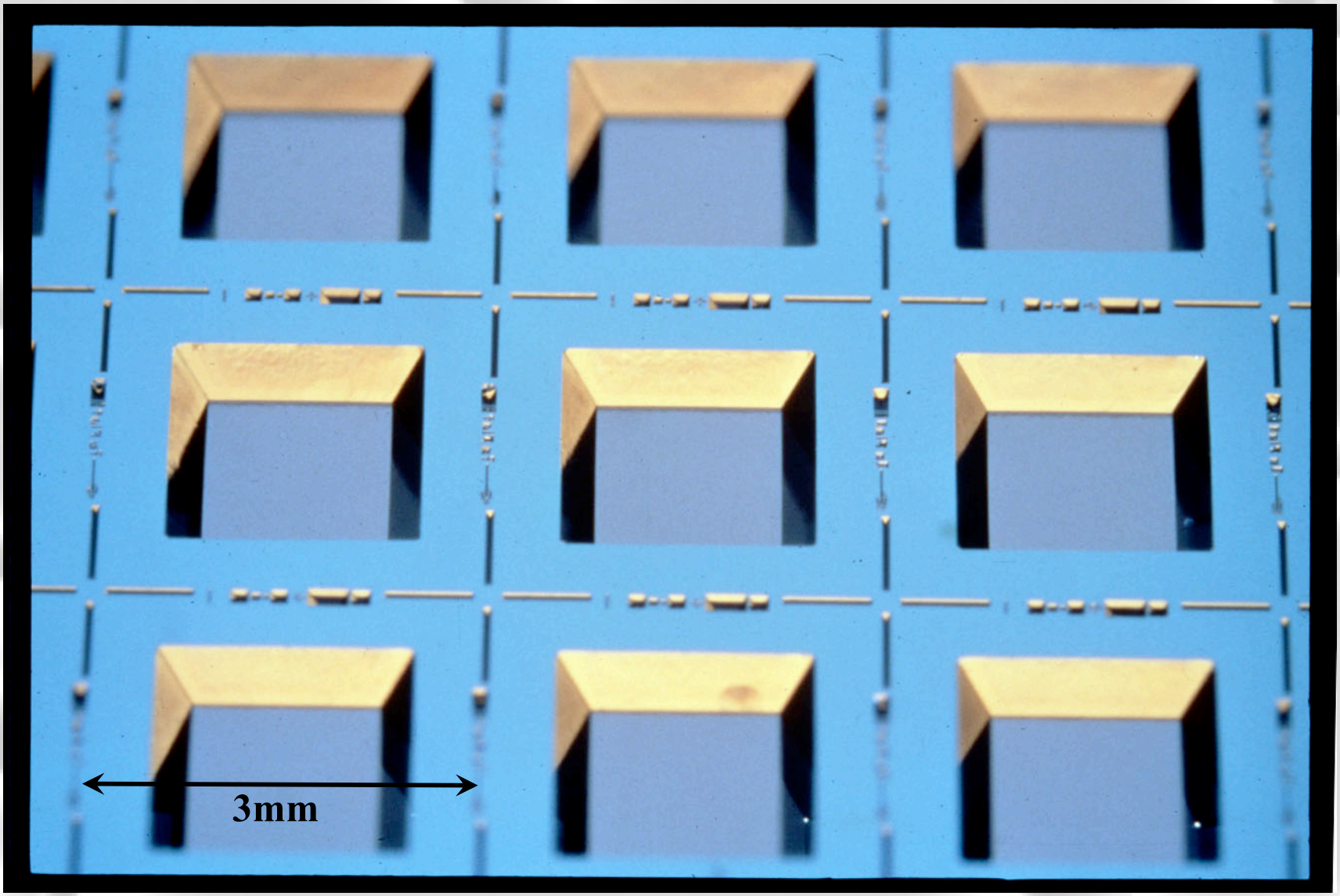


TDI Mass Flow Sensor

U Mich Neural Probes

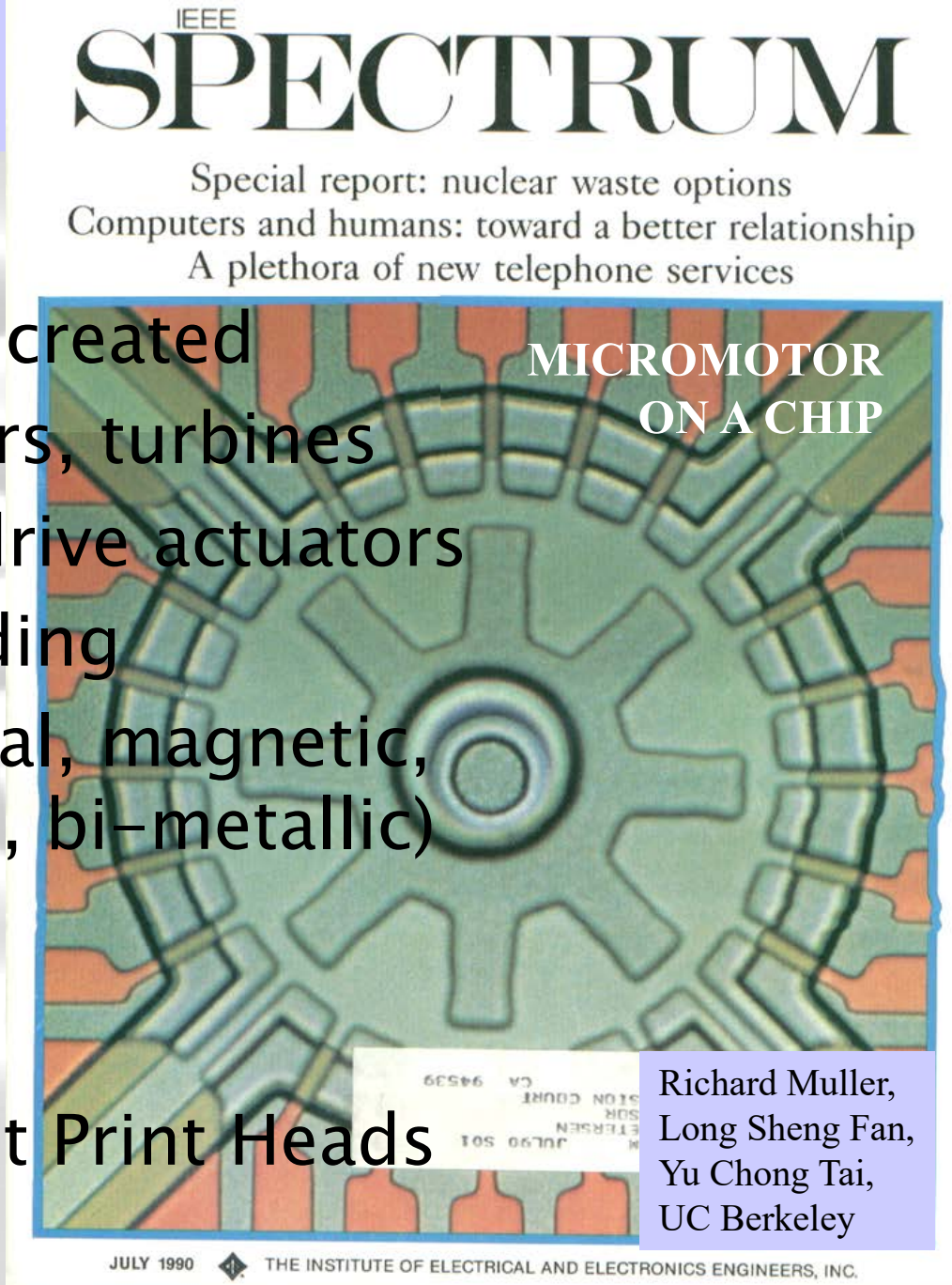
SiTime

Micromachined Pressure Sensors



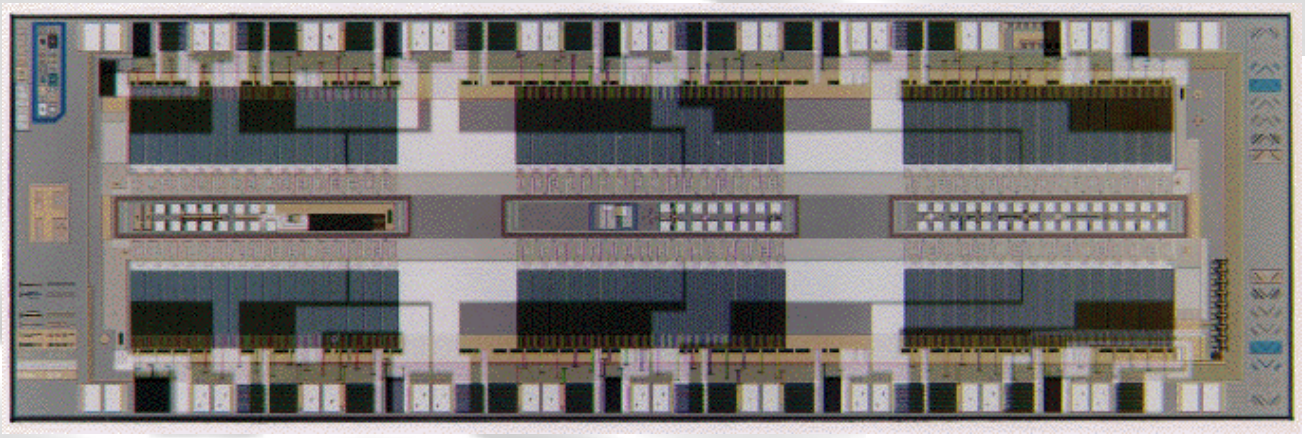
1985–1990

- R&D
  - MEMS terminology created
  - Micro-motors, gears, turbines
  - Polysilicon comb-drive actuators
  - Silicon Fusion Bonding
  - Microvalves (thermal, magnetic, electrostatic, piezo, bi-metallic)
  - Fluidic amplifier
- Production
  - High Volume Ink Jet Print Heads



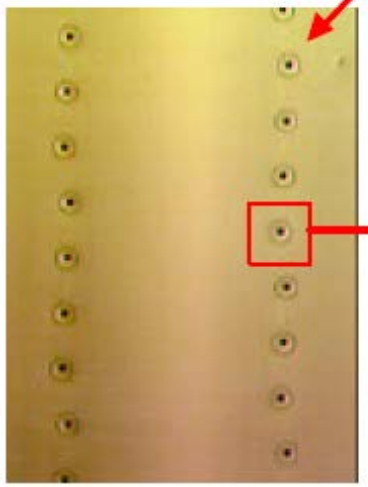
Richard Muller, Long Sheng Fan, Yu Chong Tai, UC Berkeley

Ink Jet Print-heads



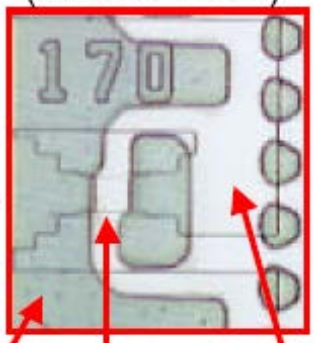
1 cm

orifice plate detail



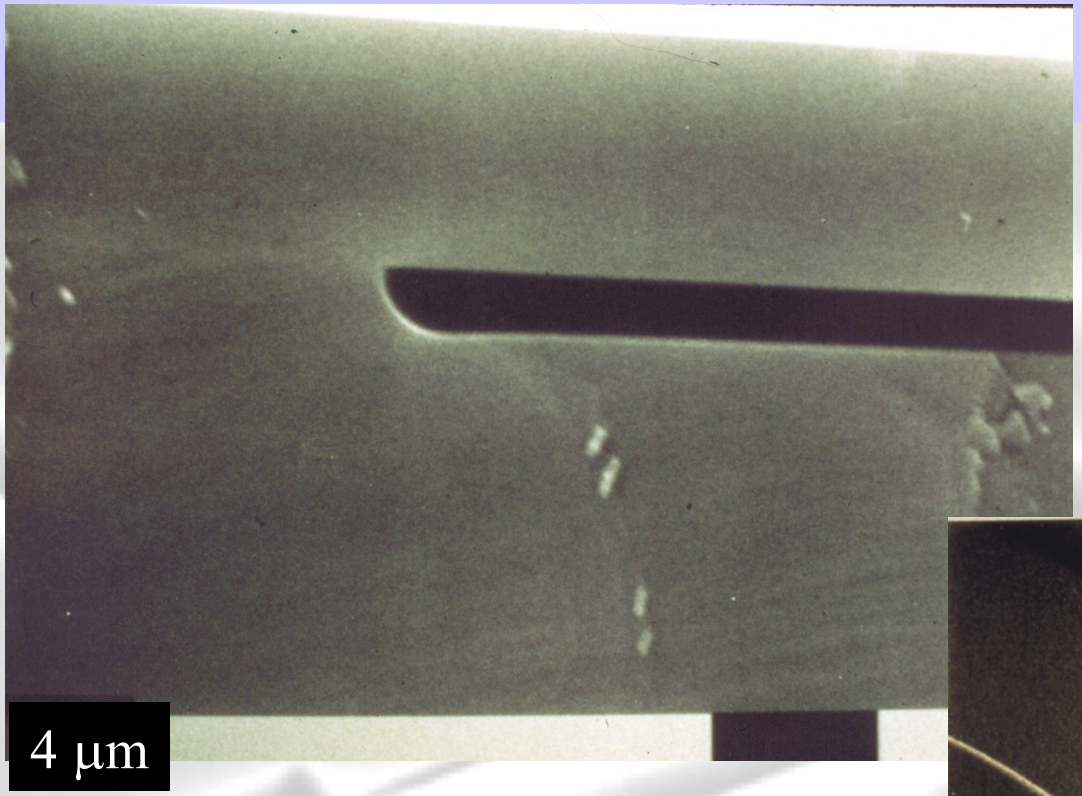
25 μm holes

substrate detail (DeskJet 895C)

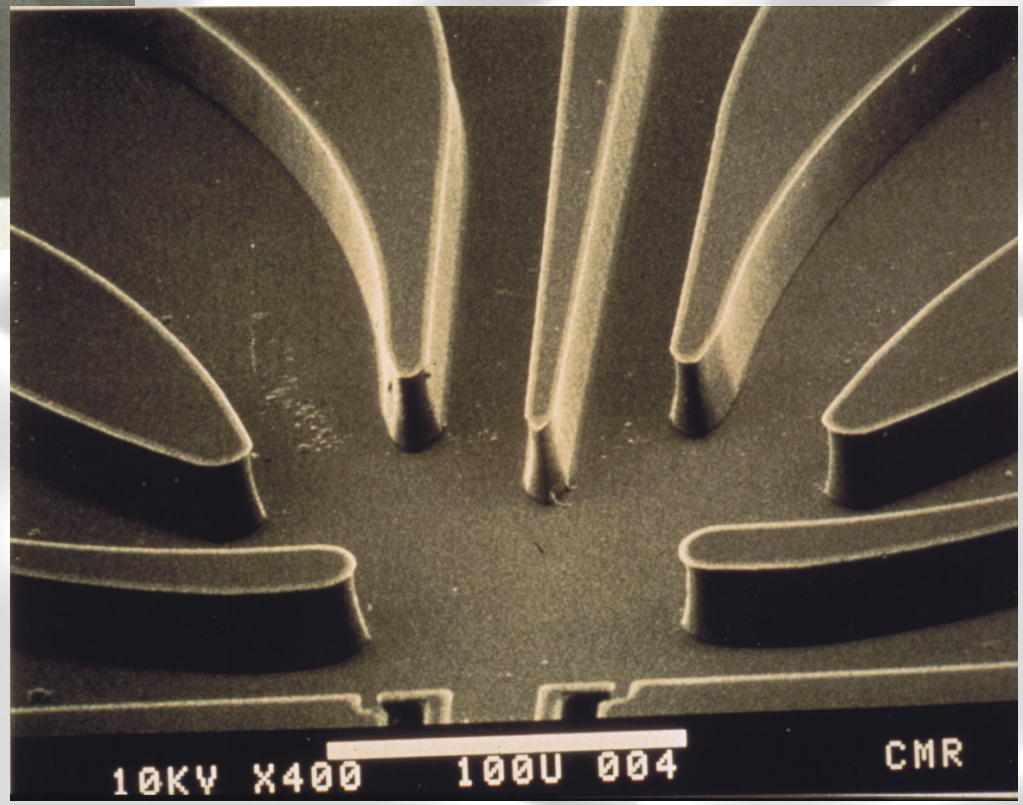


barrier heater ink channel

SiTime



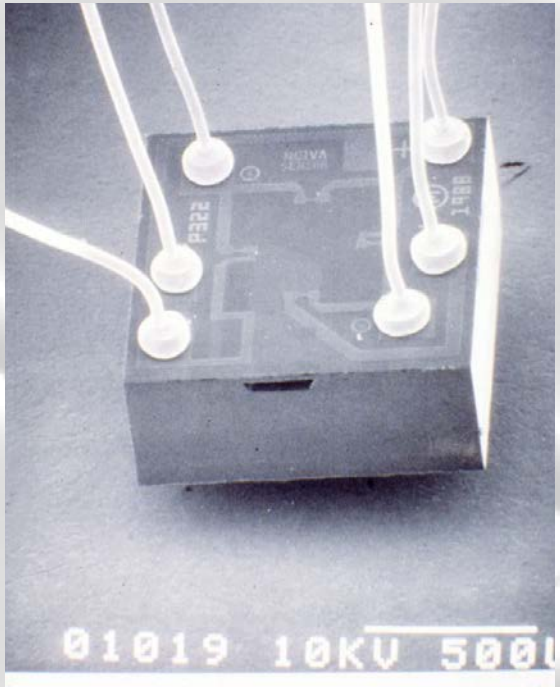
Silicon
Fusion Bonding

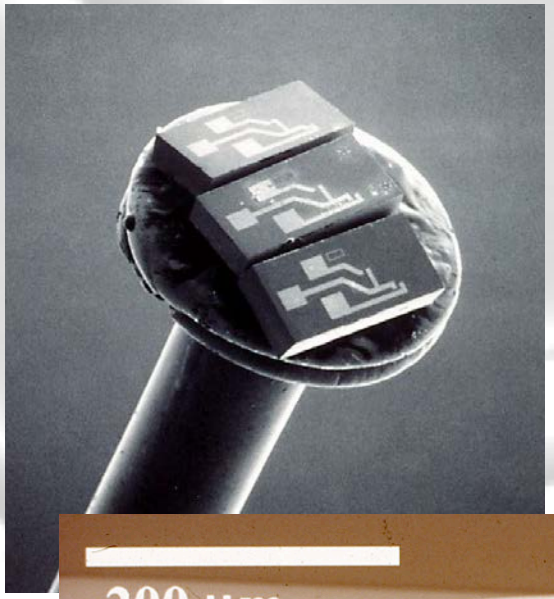


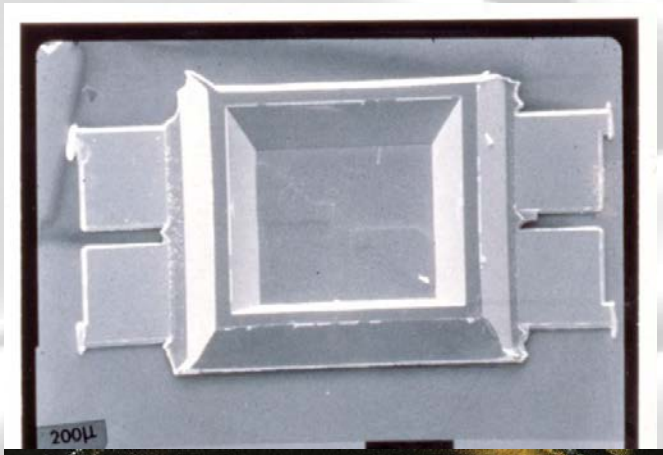
Deep
Reactive Ion
Etching

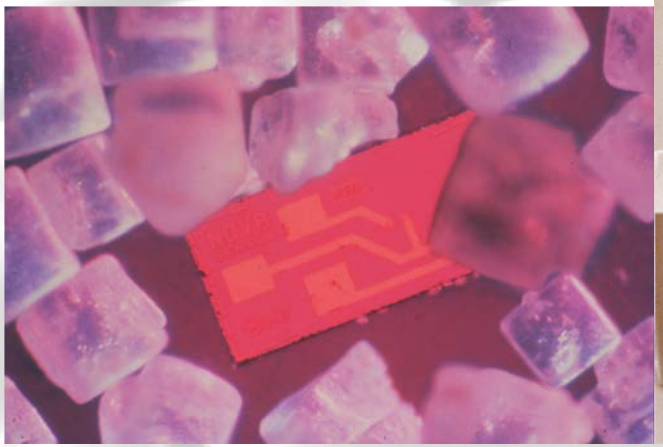
SiTime

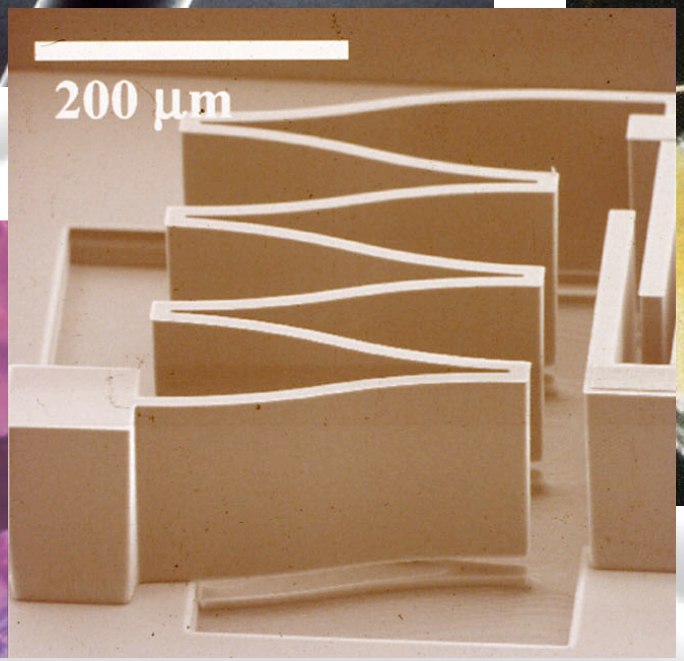
NovaSensor

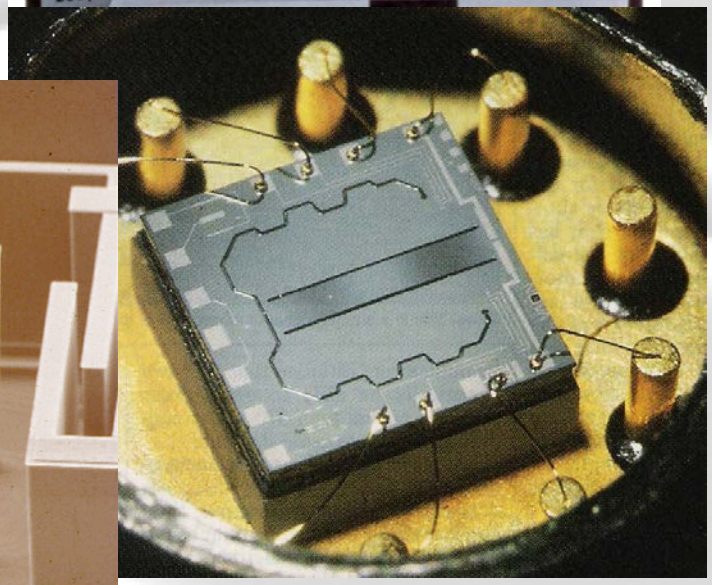


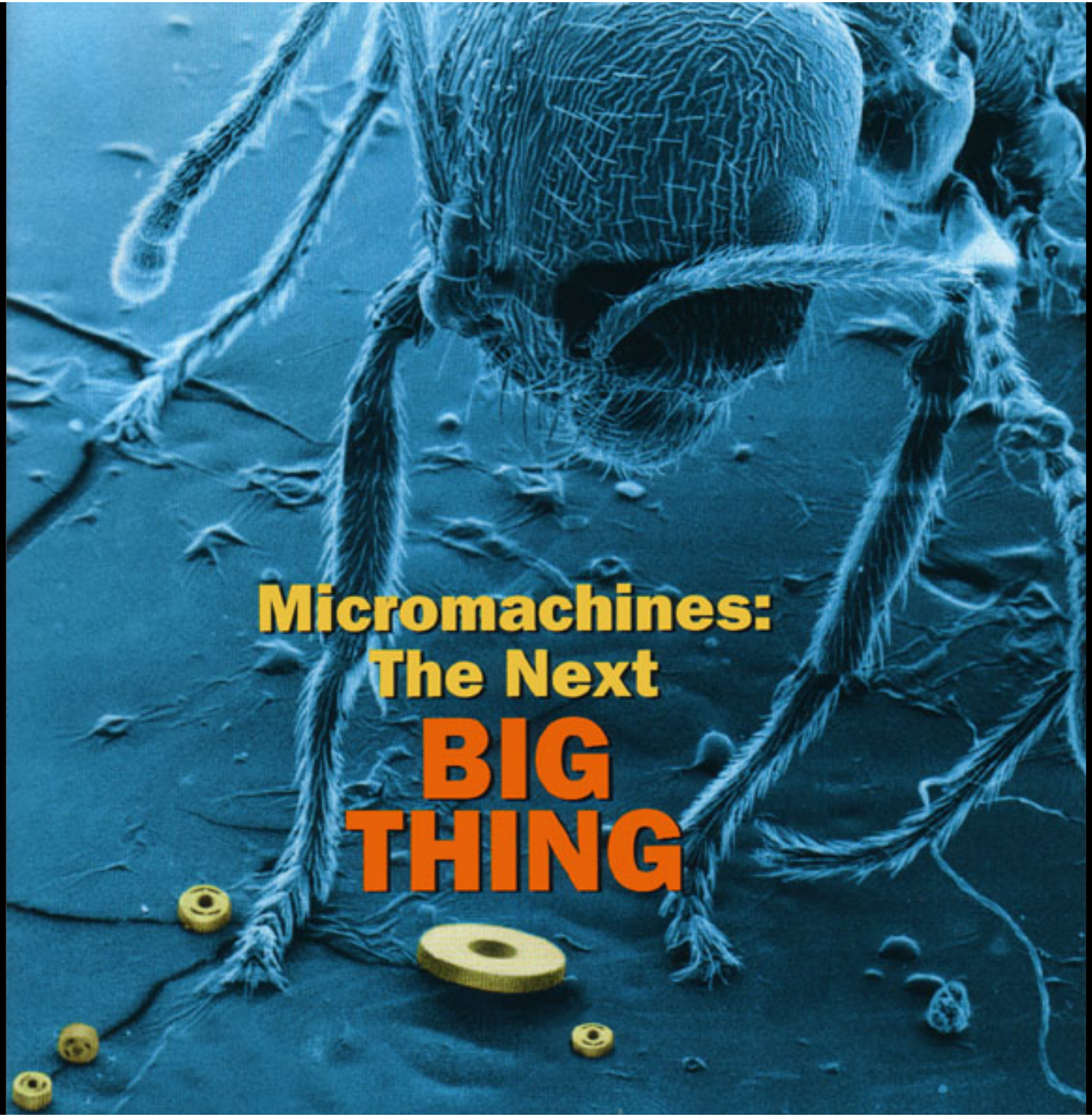






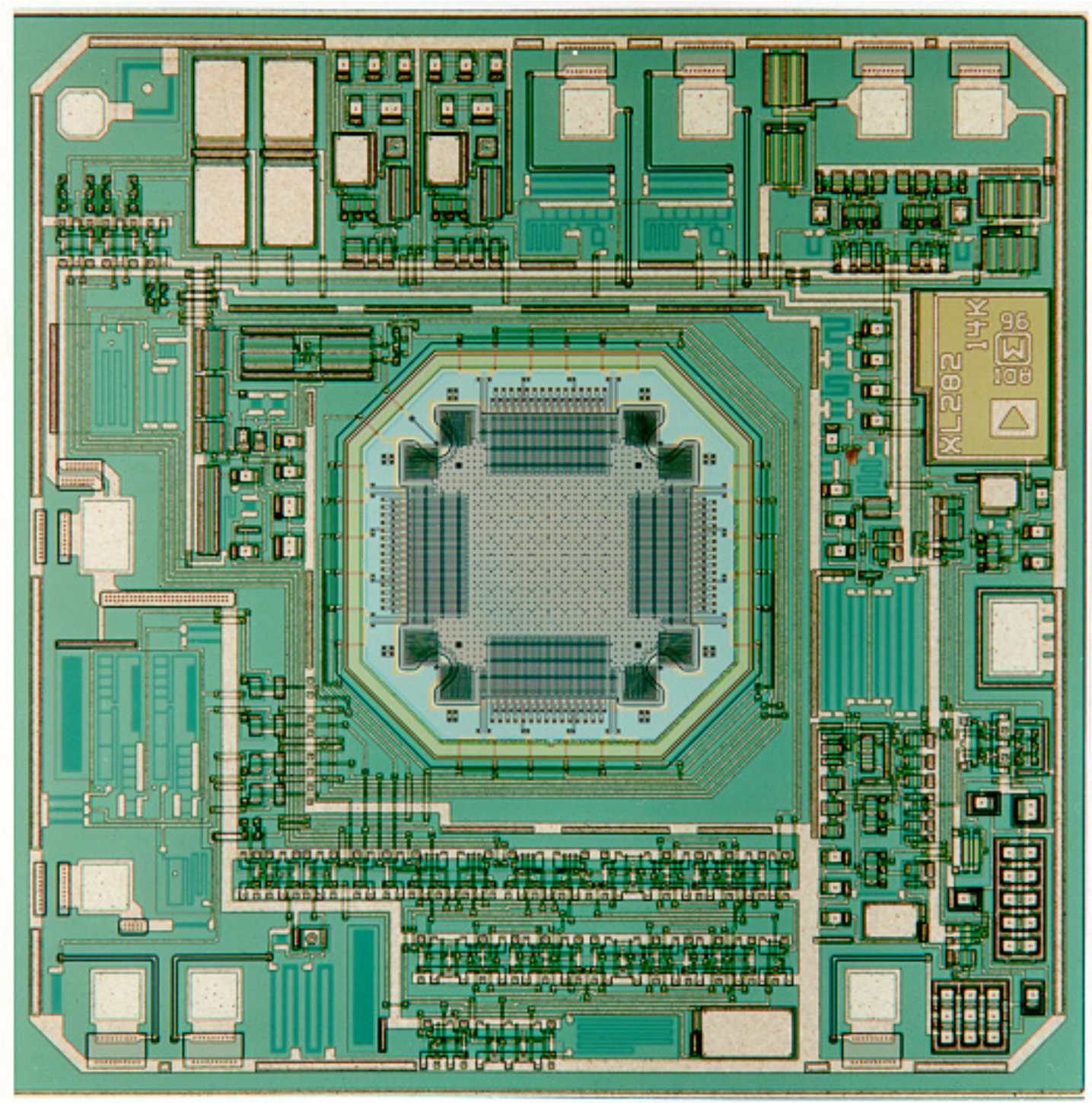





Micromachines:
The Next
BIG
THING

1995-2000

- R&D
  - Highly complex actuators
  - Deep reactive ion etching (DRIE)
  - Start-up companies in micro-fluidics
  - Start-up companies in optical switching
- Production
  - High volume production of accelerometers as automobile crash sensors
  - High Volume production of digital light processor chips



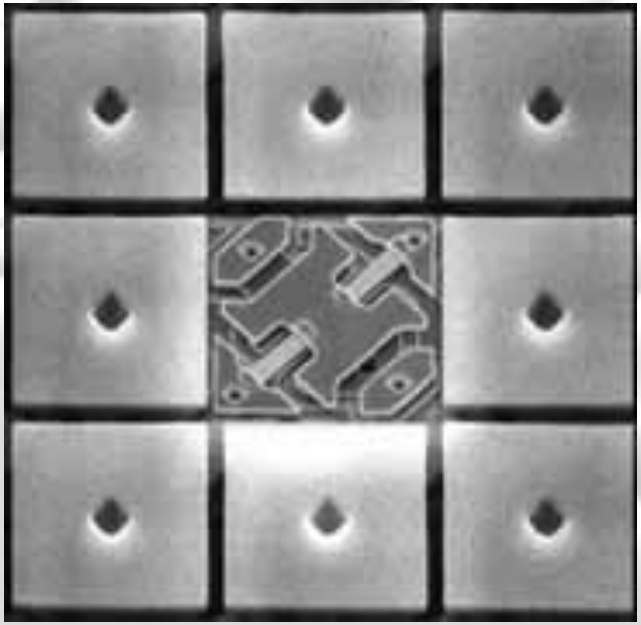
ANALOG DEVICES

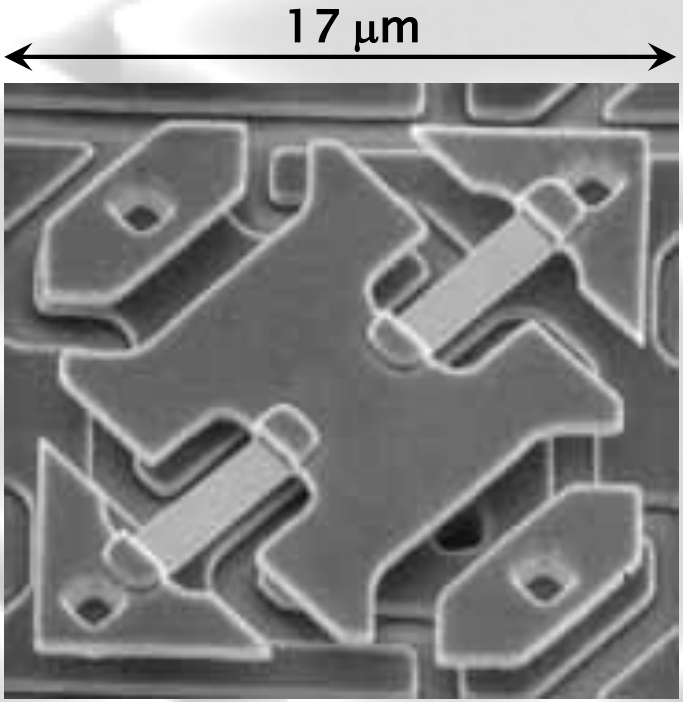
~2 mm chip

Texas Instruments Digital Mirror Display

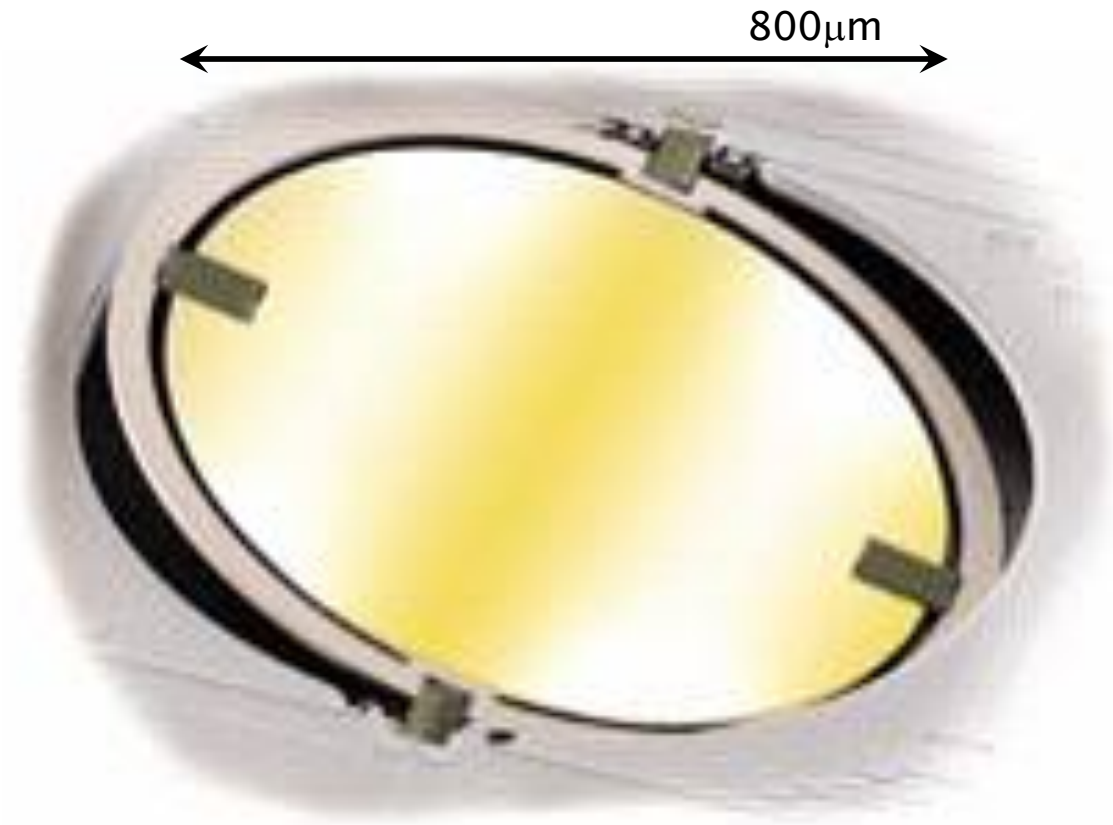
- Research by Larry Hornbeck began in 1976
- Full-scale production over 20 years later
- Extremely successful MEMS product
- (-competitors gearing up-)

→ Today: ~$1B/yr business for TI

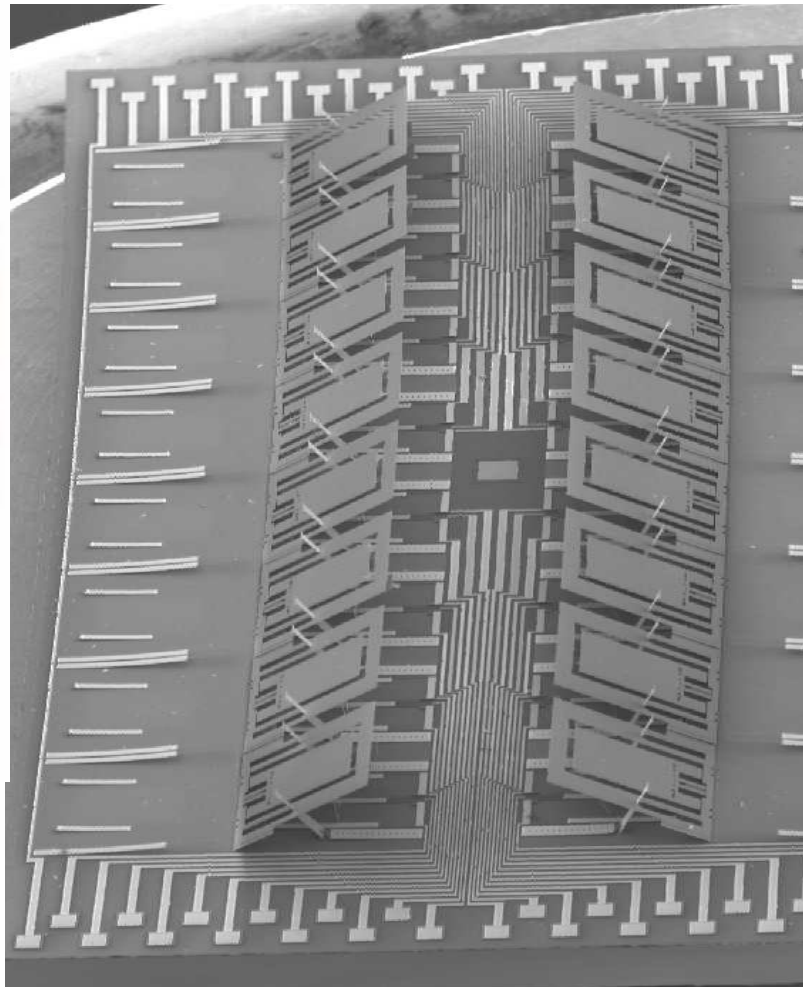




C Speed Corporation:
Ultra-High Scalability Optical Switches



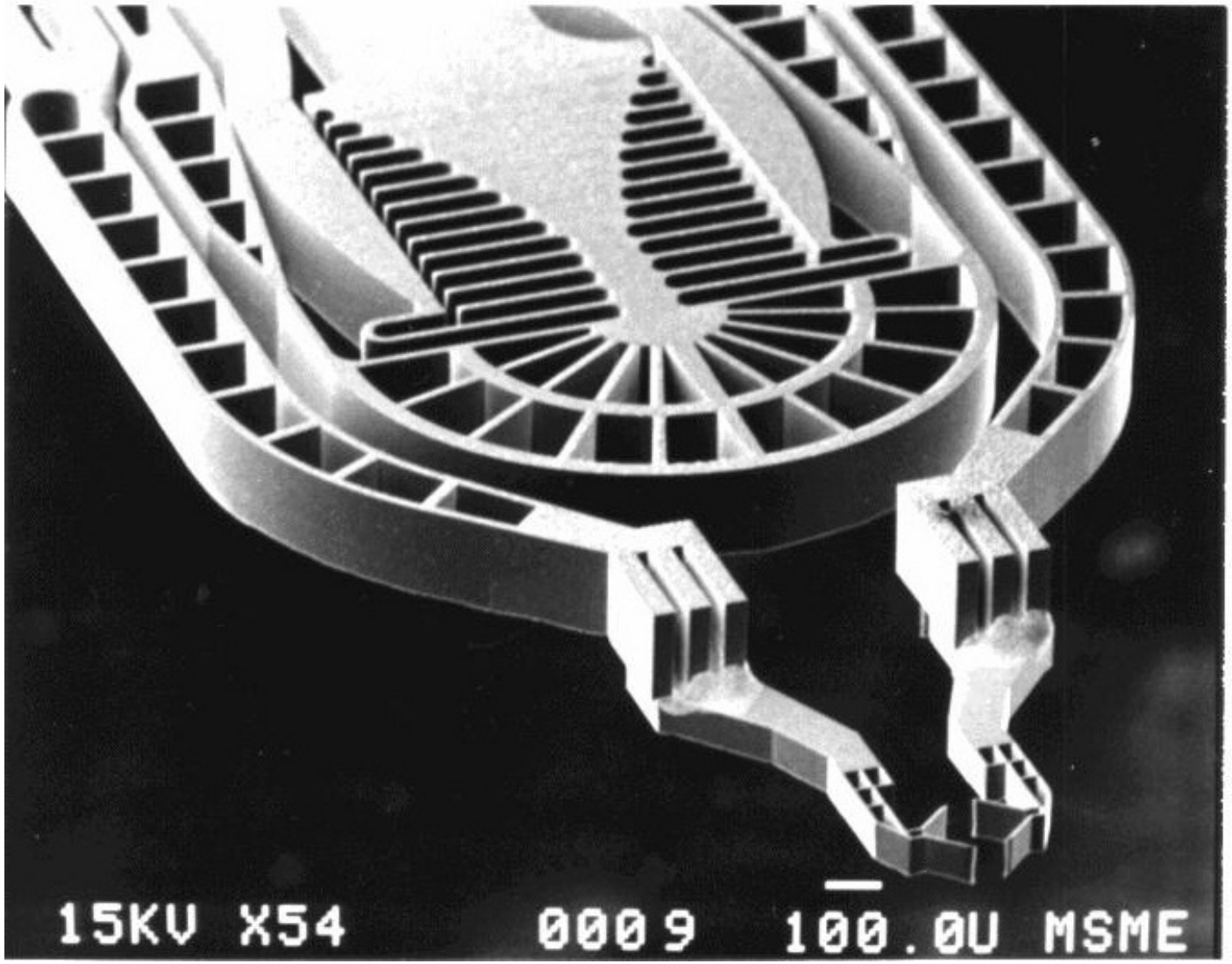
Lucent Micro-Mirror



cspeed

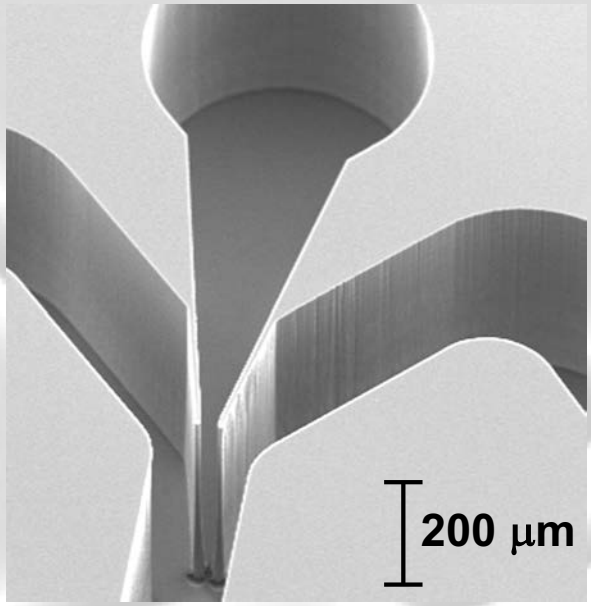
www.cspeed.com

MEMS Precision Instruments

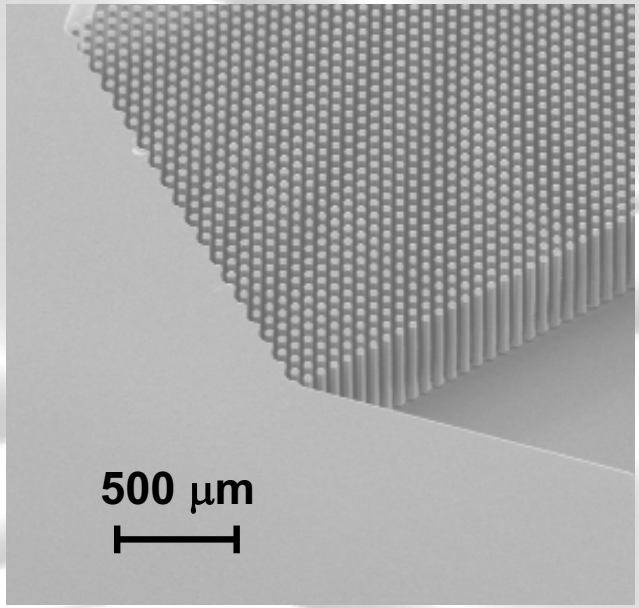


from Chris Keller

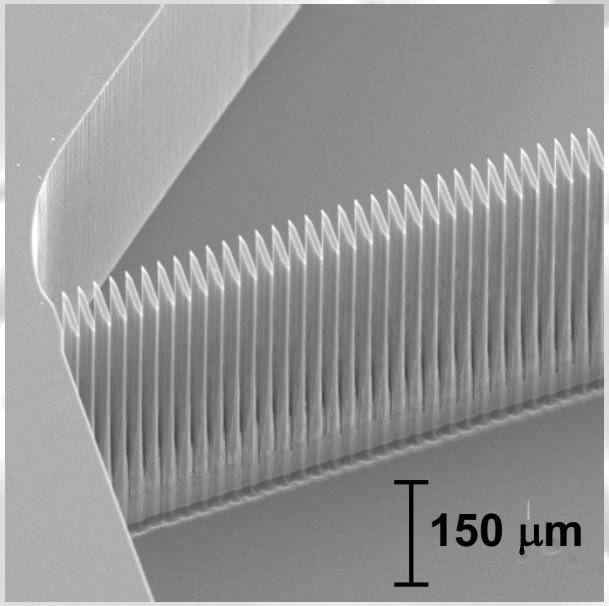
Cepheid Microfluidics; 1998



Flow Cytometry



DNA concentration



Weir or Filter

fabricated with DRIE (Deep Reactive Ion Etching)

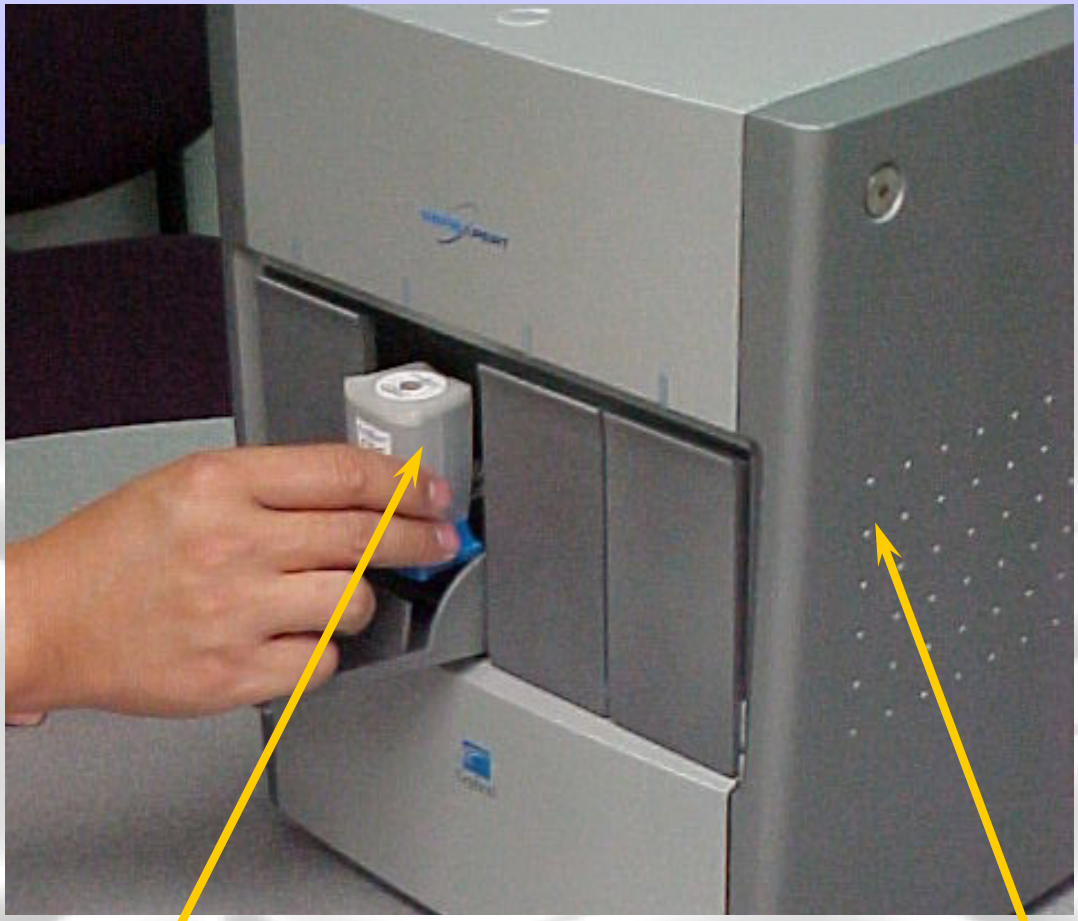
2000-2005

- R&D
  - Collapse of most fiber optic companies
  - Consolidation of micro-fluidic companies
    - Aclara out of fluidics
    - Luminex . . . .
    - Caliper . . . .
  - Start-up companies in RF devices
    - Discera
    - SiTime
- Production
  - Rapid, automated DNA analysis

SiTime

Next step for rapid DNA analysis:

fully automated DNA sequence detection at the point of need using PCR



SAMPLE PREP

AMPLICATION AND DETECTION - PCR

< 5 minutes

< 25 minutes

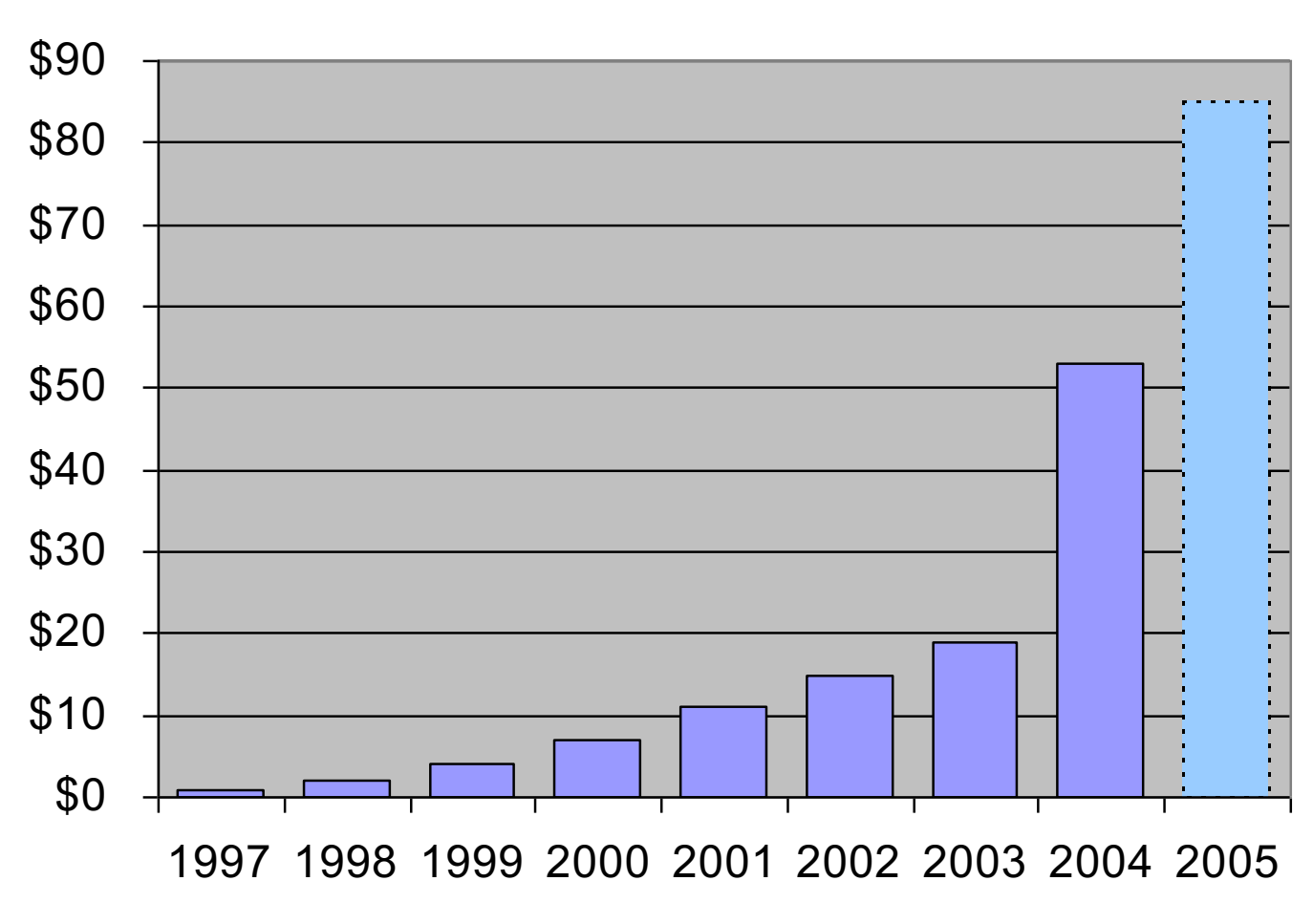
SiTime

Mail Sorting Environment

1728 mail sorting machines in the US Postal Service. Each will perform one Anthrax test/hour.

SiTime

Cepheid Yearly Revenues ($M)



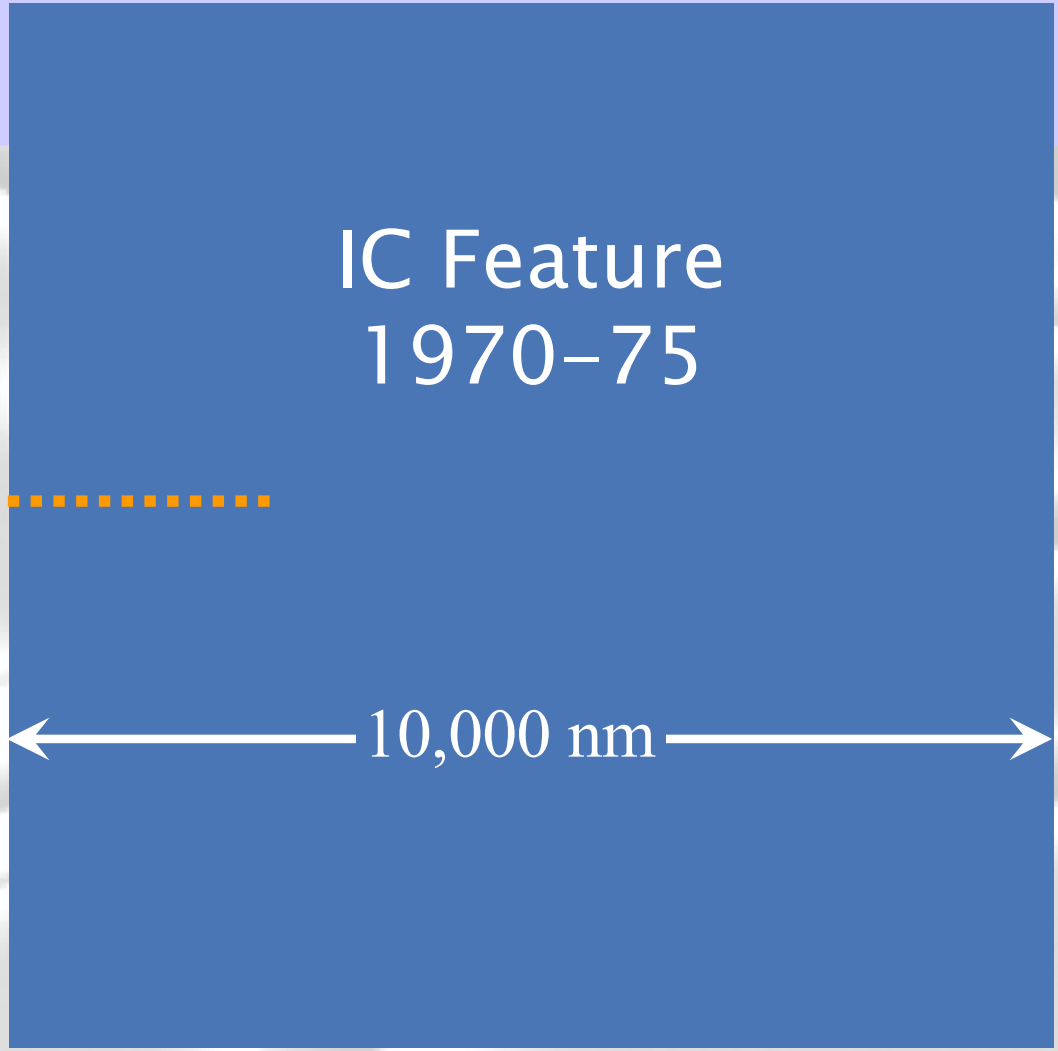
Post 2005

First, understand the present:

- Nearly 40 years of "Moore's law" . . .
  - not only for ICs, >100M transistors/chip
  - also for data storage, >200Gb hard-drives
- Common-place wireless communication
- THE INTERNET ! – instant information
- Flat color displays of all sizes
- Bio-tech researchers routinely analyze 100K DNA base-pairs on a single bio-chip; are proteins next?

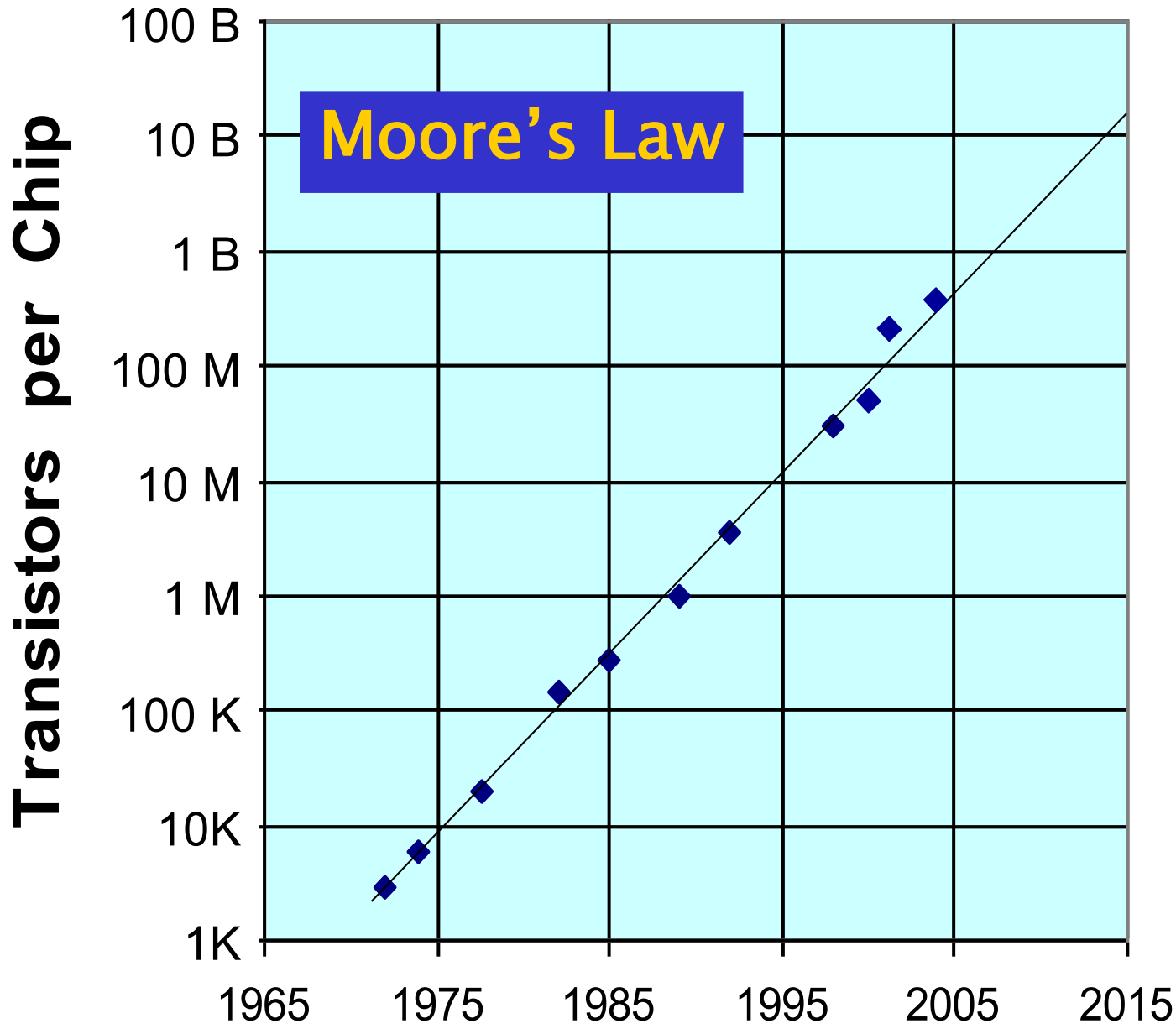
SiTime

IC Feature
2004



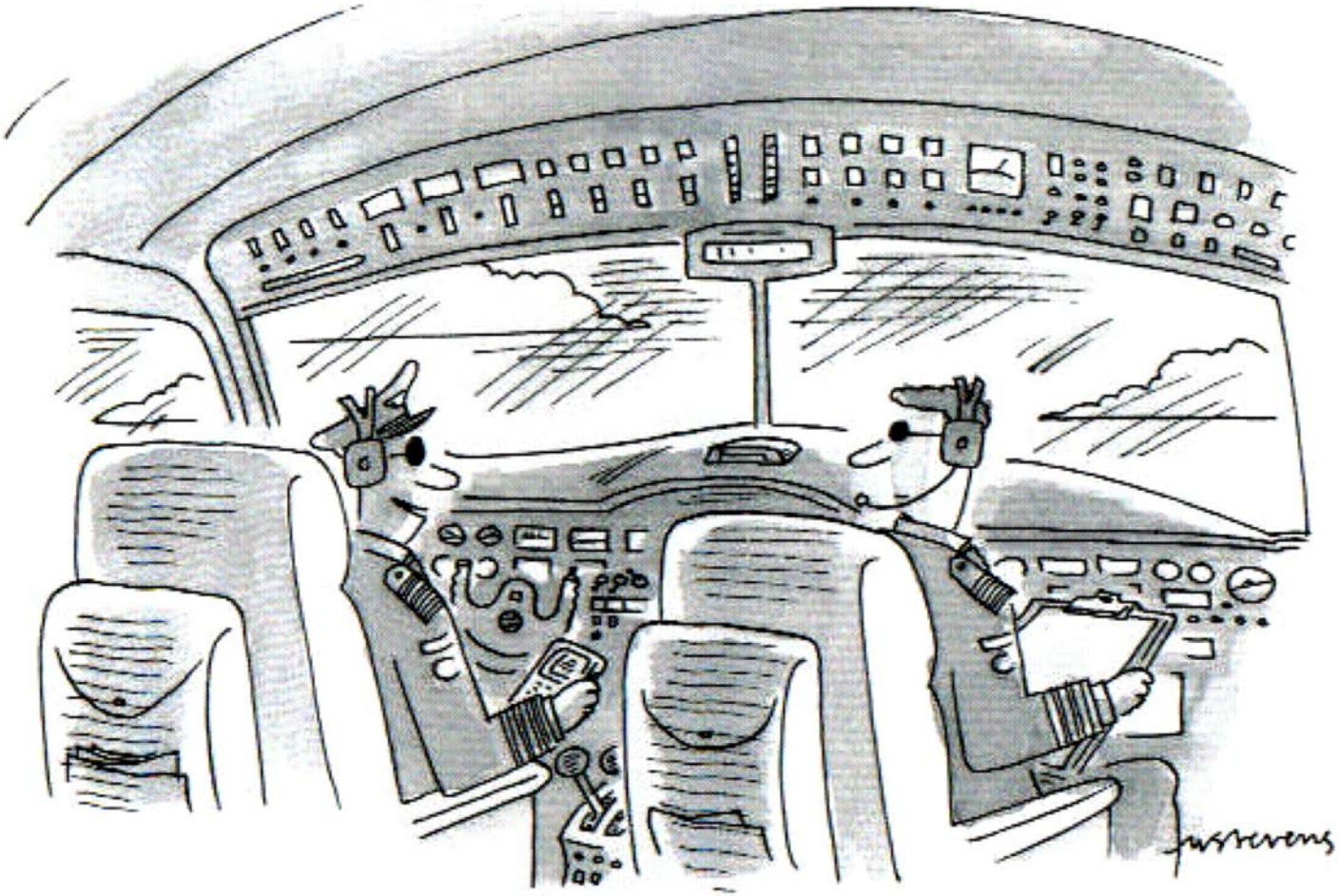
'Road-Map'

2004 90nm
2007 65nm
2010 45nm
2013 32nm
2016 22nm = 18X area improvement during next 11 years


Moore's Law
Transistors per Chip
100 B
10 B
1 B
100 M
10 M
1 M
100 K
10K
1K
1965
1975
1985
1995
2005
2015

Universal, Ubiquitous, Electronic Intelligence

- 90 nm chips in production; 65 nm in 2007
- ~1 billion transistors/chip before 2010
- What will we do with all that power?
- Wireless PDA μP running at 20GHz with a terabyte of storage . . talking to your watch, car, office, home . . . recording continuous audio/video
- Smart, smart cards
- Intelligence everywhere and inside everything
- Novel packaging and deployment
  - clothes, jewelry, books, furniture, wallets,……



"This is so cool! I'm flying this thing completely on my Palm pilot!"

IC Industry is Changing

- Enormous Capacity
  - Shrinking Lithography
  - Increasing Wafer Size
  - The China/Far-East Effect
  - 10^{18} transistors manufactured per year
    - 200M/year/person on the planet
- Increased Integration and Sophistication
  - Mixed signal CMOS
  - RF front-end integration (radio on a chip)

IC Industry is Changing

- TODAY:
  >240 existing 8" fabs, 0.18μm litho
  - These are becoming obsolete !
- Increasingly cheaper to build high performance, intelligent chips
- Foundries are more receptive to MEMS
  - Semi companies now say – "we do MEMS"
- Manufacturers are making specialty MEMS equipment – Suss, EV, Xactix, STS, others
- Ink-jet printed electronics on horizon
- Mask-less lithography on the horizon?

Packaging Houses Embrace MEMS

- High Volume packaging manufacturers also “do MEMS”
- Bring MEMS packaging specialists to meetings (accels, display chips, gyros)
- Special package configurations are customized for MEMS

China/Far-east Effect

- 60% of 8” wafer fabs are in Asia
- TSMC has perfected wafer foundry model
  - first class production services in Taiwan
- >240 8” fabs in production worldwide
  - Each manufacturing ~2 acres of silicon/year
- Numerous 12” fabs in planning/building
  - Each manufacturing ~6 acres of silicon/year
- Gradual transfer of IP from west to east
- Commoditization of high-end IC wafer processing and production

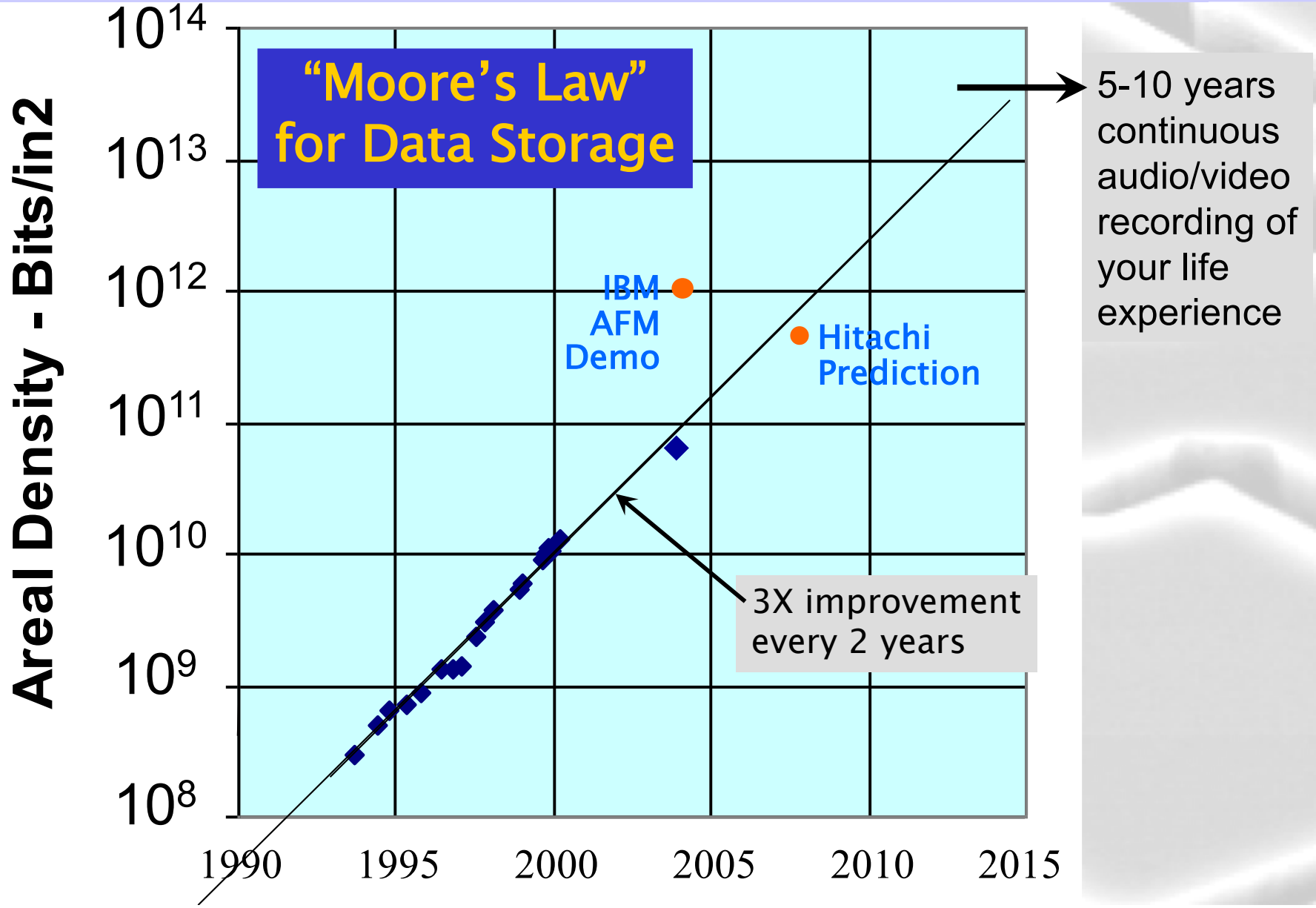
→ Enormous cost pressure

What does this mean for MEMS?

- Fabs becoming desperate for business
  - and more capable of "unusual" processes
- Fabs today enjoy enhanced thin-film processing abilities;
  - new materials (metals, dielectrics)
  - new processes (DRIE, CMP)
- Easier to attract high-end foundries for "promising" MEMS applications
  - although they still prefer high silicon "acreage"

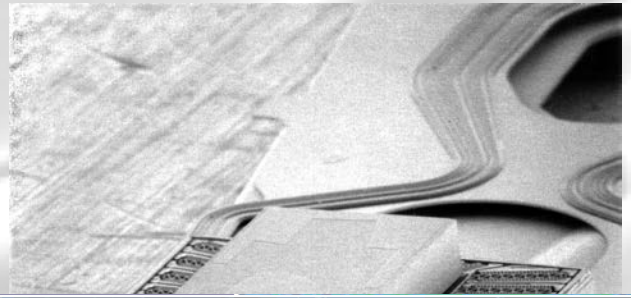
→This translates into opportunities for MEMS !

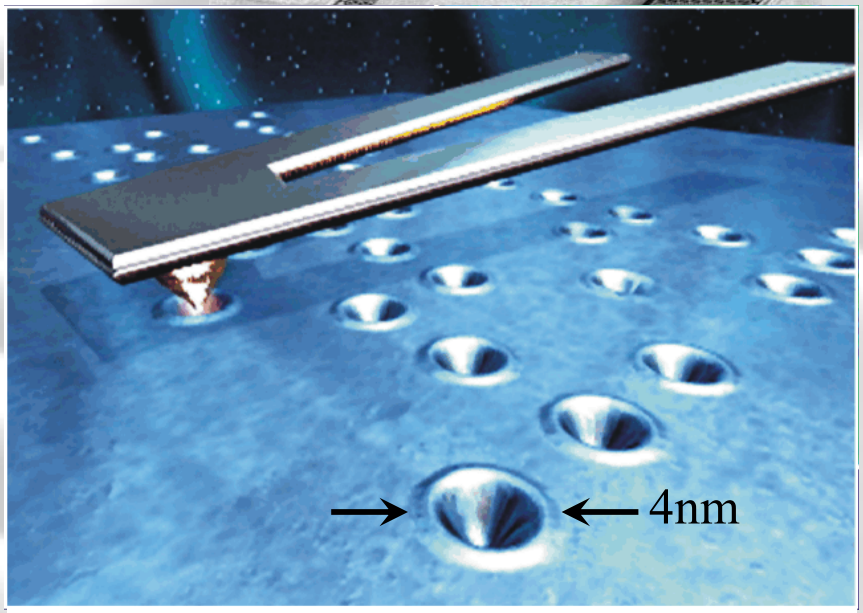
MEMS Opportunity – Storage



MEMS Opportunity – Storage

- Highly miniaturized and complex mechanical systems
- Record video and audio
  - favorite movies *always* with you → like music today
  - record *everything*
  - record entire personal life experience
- Complete reference information sources
- When will MEMS impact magnetic hard drives?
- When will Atomic Force memories become available?





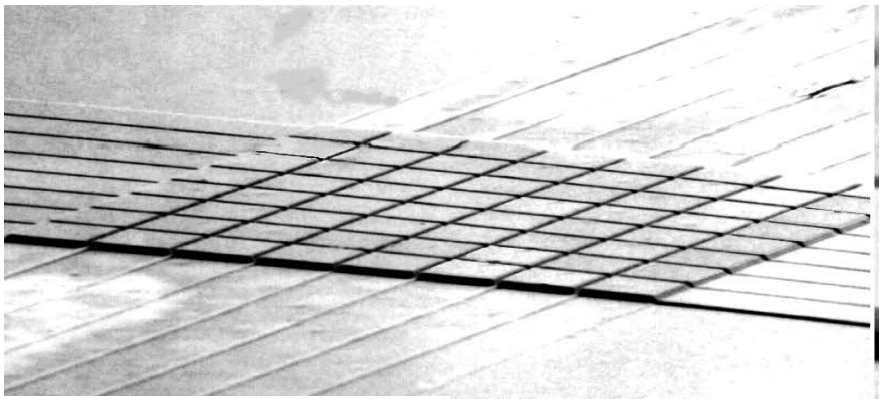
IBM millipede AFM Memory

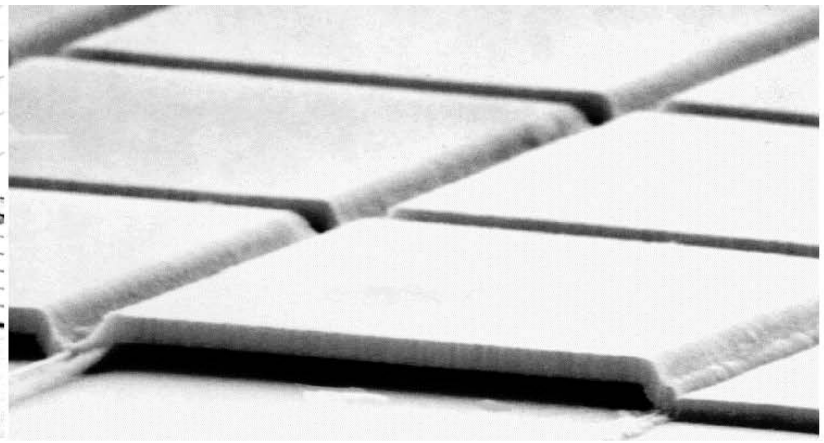
MEMS Opportunity – Displays

Digital Paper

- **IMod**: Interferometric Modulator
- Driven = absorbing **(black)**
- Undriven = optically resonant reflector **(reflected color peak)**
- Made using existing LCD processes and components

Sold to Qualcomm in 2004 for $200M

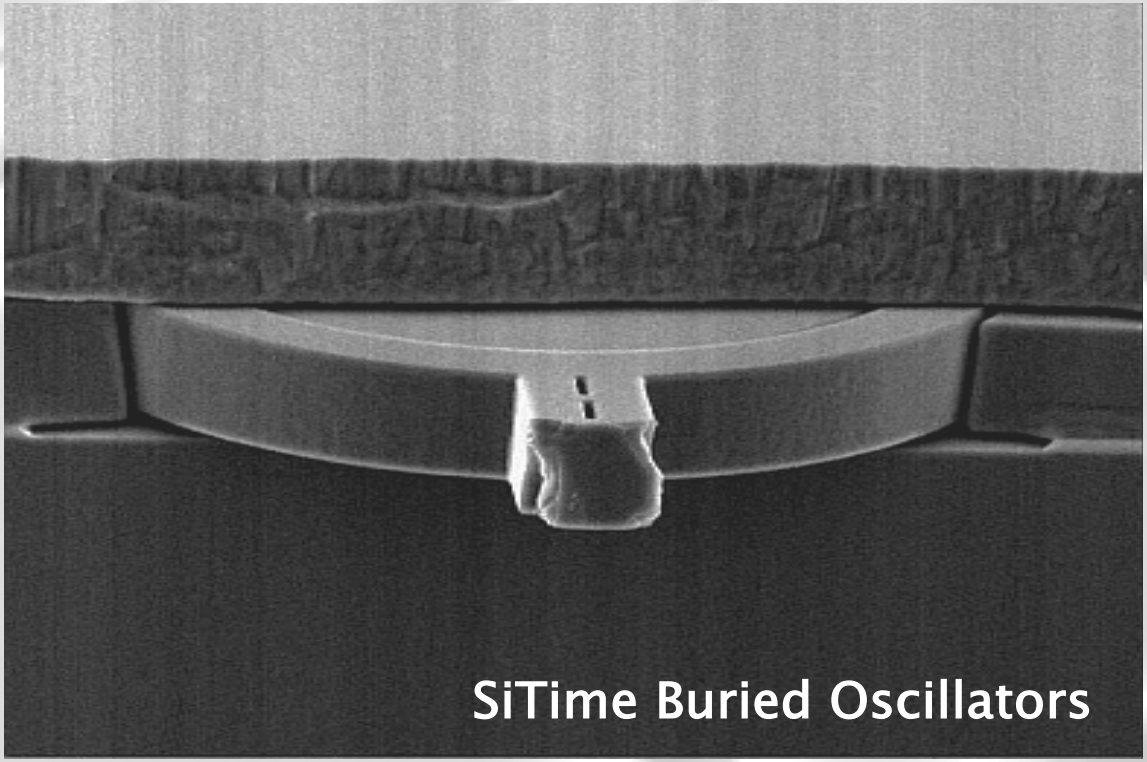




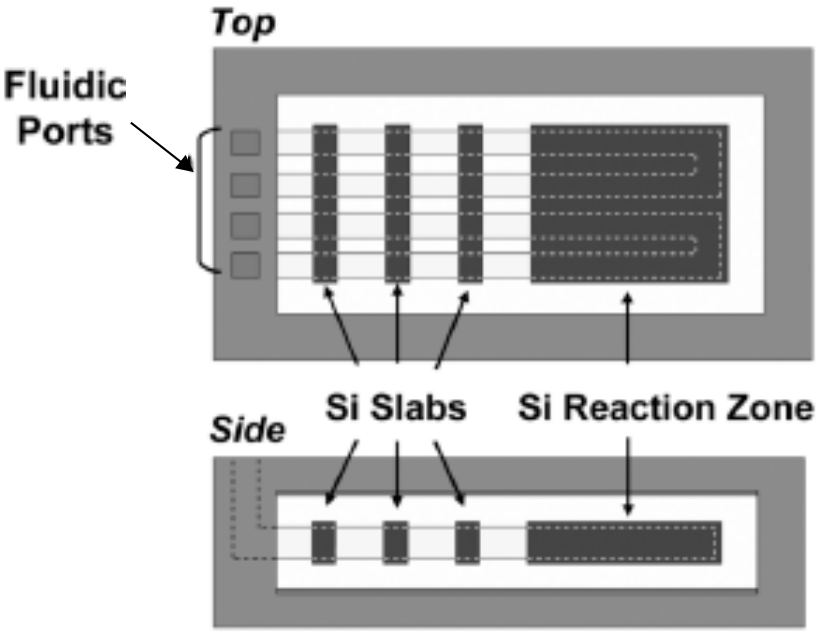
from Mark Miles

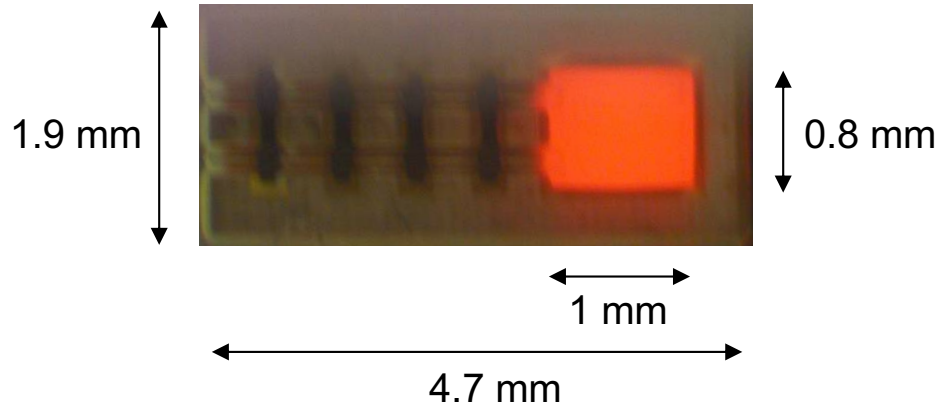
MEMS Opportunity – RF

- Everything will talk to everything else
- Laptops and phones are only the beginning
- AOL – everyone, always on line!
- Wireless sensor networks
- Wireless keys
- RFID tags on everything
- → Future MEMS RF components
  - Oscillators
  - Switches
  - Filters



MEMS Opportunity – Power





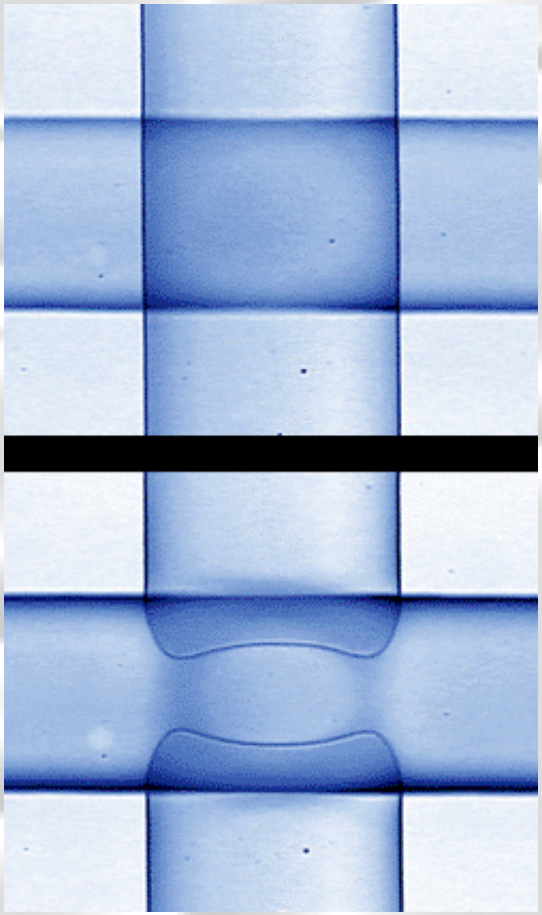
Full test chips are 10 x 8 mm

- Thermally efficient and very small ~2mm^2
- Over 90% conversion of butane demonstrated on-chip at flow rates sufficient for a 1 W power supply
- Over 70% yield of hydrogen and carbon monoxide
- Operating using commercial catalyst

Lilliputian Microsystems

MEMS Opportunity – Fluidics

Fluidigm
Micro-Valve Array



Valve Open

Valve Closed

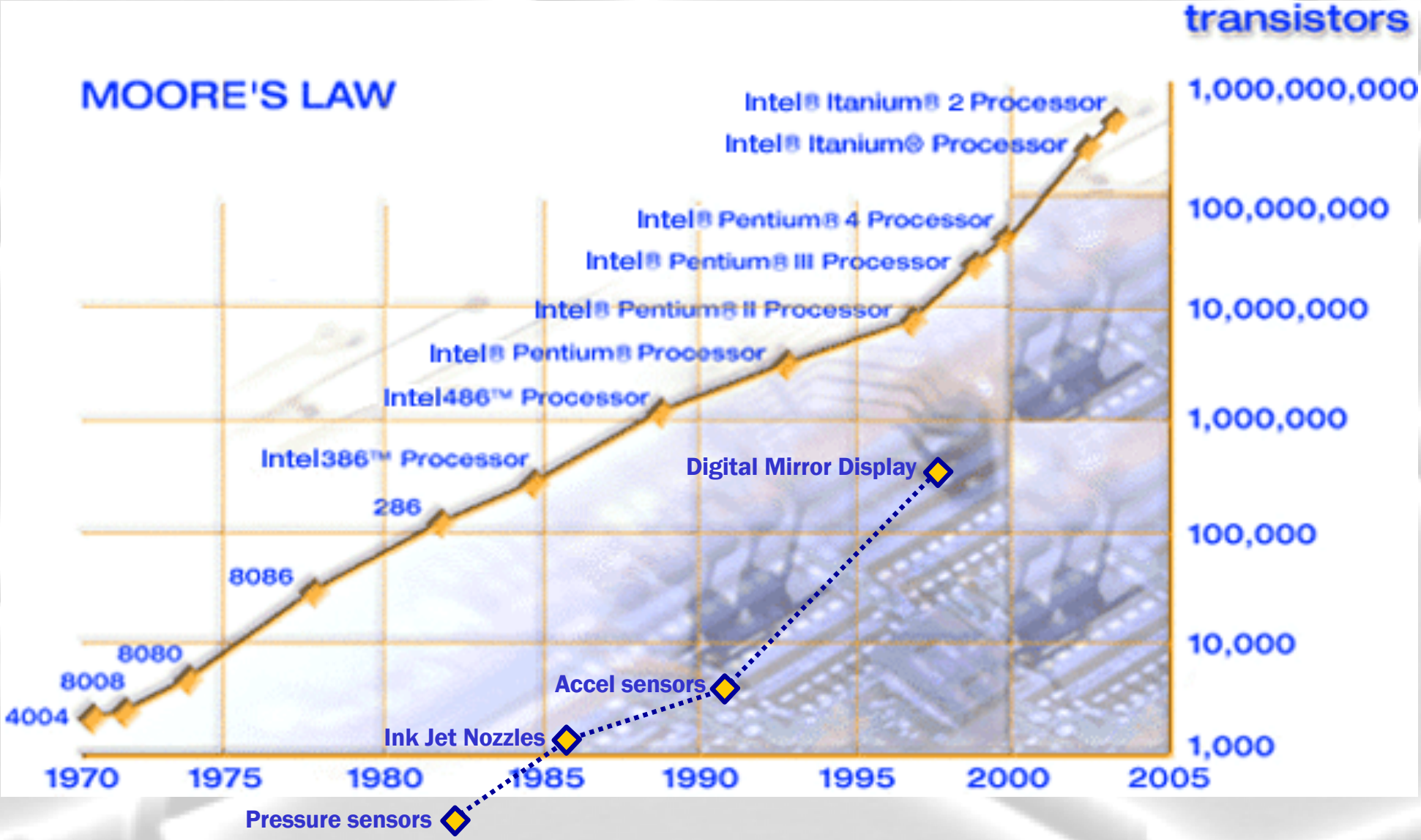
MEMS as an Underlying Technology – e.g . . . . .

- Miniaturized Instruments :
- Miniaturized Sensing networks :
- Miniaturized Display/Optical systems :
- Miniaturized Biological systems :
- Miniaturized RF systems :
- Miniaturized Chemical systems :
- Miniaturized Data storage :
- Miniaturized Power systems :

- All using MEMS as the preferred technology for implementation.

SiTime

can't compare ICs to MEMS, but……



A New Age for MEMS

- MEMS is 15-20 yrs behind IC technology
  - think: pre-Internet
  - think: 386 vintage, pre-Pentium technology
- MEMS has only four high volume products
  - Ink Jet heads (HP)
  - DLP (TI)
  - Pressure sensors
  - Acceleration sensors

  $5B in 2003 (In-Stat)
- ICs are world-wide commodity products
- Foundries are hungry for silicon acreage
- Foundries are unafraid of new technologies
  - copper metallization !
  - 2nm gate oxides !

A New Age for MEMS

- MEMS has commercial success stories under its belt to the tune of >$5B/yr
- MEMS progress toward commercialization is still immature, but growing
- also, much of the basic research is done
- and major opportunities abound
- MEMS is coming of age just when the IC industry needs, and is economically ready for, advanced, novel products.

→ Stayed tuned –

to the future of miniaturization

MEMS

MEMS Success Stories . . .