Introduction to MEMS Design and Fabrication

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A brief history of MEMS

- 1750s first electrostatic motors (Benjamin Franklin, Andrew Gordon)
- 1824 Silicon discovered (Berzelius)
- 1927 Field effect transistor patented (Lilienfield)
- 1947 invention of the transistor (made from germanium)
- 1954 Smith, C.S., "Piezoresistive effect in Germanium and Silicon, Physical Review, 94.1, April 1954.
- 1958 silicon strain gauges commercially available
- 1961 first silicon pressure sensor demonstrated (Kulite)
- 1967 Invention of surface micromachining (Nathanson, Resonant Gate Transistor)
- 1970 first silicon accelerometer demonstrated (Kulite)
- 1977 first capacitive pressure sensor (Stanford)
- 1980 Petersen, K.E., "Silicon Torsional Scanning Mirror", IBM J. R&D, v24, p631, 1980.
- 1982 disposable blood pressure transducer (Foxboro/ICT, Honeywell, $40)
- 1982 active on-chip signal conditioning
- 1984? First polysilicon MEMS device (Howe, Muller)
- 1988 Rotary electrostatic side drive motors (Fan, Tai, Muller)
- 1989 Lateral comb drive (Tang, Nguyen, Howe)
- 1991 polysilicon hinge (Pister, Judy, Burgett, Fearing)
- 1992 Grating light modulator (Solgaard, Sandejas, Bloom)
- 1992 MCNC starts MUMPS
- 1993? first surface micromachined accelerometer sold (Analog Devices, ADXL50)
- 1994 XeF2 used for MEMS (OK, so this one isn't as important as the others)

References

- Books
  - Elwenspoek and Jansen, Silicon Micromachining, Cambridge
  - Keller, Microfabricated High Aspect Ratio Silicon Flexures, MEMS Precision Instruments
  - Kovacs, Micromachined Transducers Sourcebook, McGraw-Hill
  - Madou, Fundamentals of Microfabrication, CRC
  - Maluf, An Introduction to Microelectromechanical Systems Engineering, Artech House
  - Ristic, Sensor Technology and Devices, Artec House
  - Senturia, Microsystem Design, Kluwer
  - Sze, Semiconductor Sensors, Wiley

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References

- Conferences
  - Sensors and Actuators Workshop (Hilton Head), even years, Hilton Head Island, SC. N. America only
  - IEEE MEMS workshop, annual, 00 Japan, 01 Europe, 02 U.S.
  - Intl. Conf. Solid State Sensors and Actuators (Transducers), odd years, 99 Japan, 01 Europe, 03 U.S.
  - MOEMS, 97 Japan, 98 U.S. (LEOS), 99 Germany
  - SPIE, annual, San Jose, CA. (formerly Austin, TX)
  - LEOS, OSA, CLEO
  - ASME
  - …

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References

- Periodicals
  - IEEE/ASME, JMEMS
  - Sensors and Actuators A/B
  - J. Micromechanics and Microengineering
  - Sensors and Materials
- Articles
  - Petersen, *Silicon as a Mechanical Material*, Proc. IEEE, V70 pp.420-457, 1982.
  - Proc. IEEE V86N8, 1998 Special issue on MEMS
  - Wu, Micromachining for Optical and Optoelectronic Systems, Proc. IEEE V85N11 pp.1833-1856, 1997.

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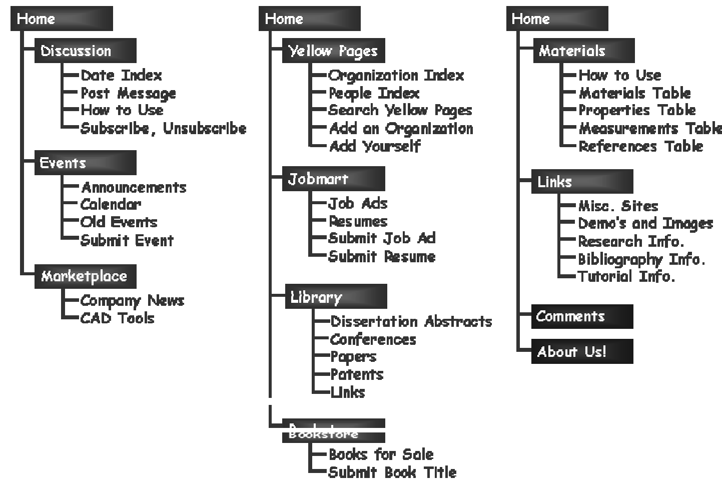
References



Http://mems.isi.edu - probably the best overall MEMS site on the web. Materials database, bibliography are great.

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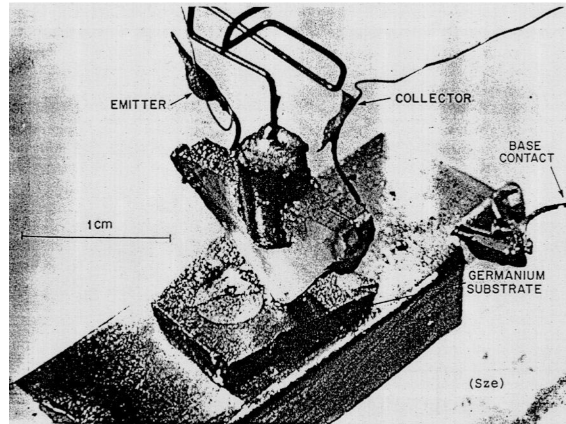
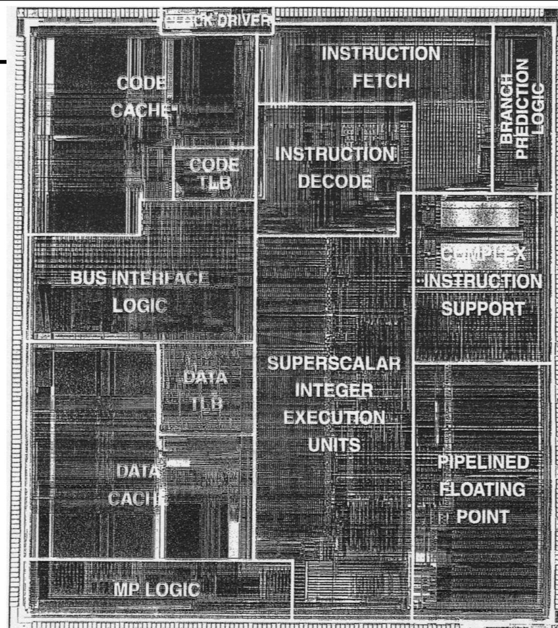
Early Semiconductor Fabrication



J. Bardeen, W.H. Brattain, "*The first transistor, a semiconductor triode*", Phys. Rev., 74, 230 (1948).

Intel 133 MHz Pentium Processor

3.3 million transistors
0.35 micron lithography
4 layer metalization
First silicon: May 1995



Fabrication

- IC Fabrication
  - Deposition
  - Lithography
  - Removal
- Bulk micromachining
  - Crystal planes
  - Anisotropic etching
  - Deep Reactive Ion Etching
- Surface micromachining
  - Sacrificial etching
  - Molding
  - Bonding

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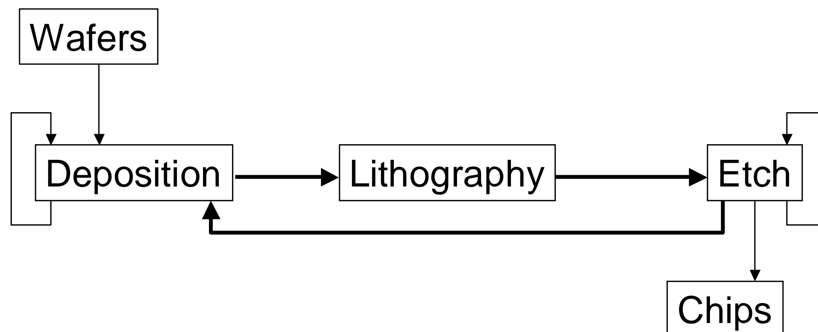
Process Flow

- Integrated Circuits and MEMS identical
- Process comlexity/yield related to # trips through central loop



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Materials

- Metals
  - Al, Au, Cu, W, Ni, TiNi, NiFe,
- Insulators
  - SiO_2 - thermally grown or vapor deposited (CVD)
  - Si_3N_4 - CVD
- Polymers
- The King of Semiconductors: Silicon
  - stronger than steel, lighter than aluminum
  - single crystal or polycrystalline
  - 10nm to 10mm

Applications

- Pressure sensors
  - Automotive, Medical, Industrial, …
- Accelerometers
  - Automotive, Medical, Industrial
- Gyros
  - Automotive
- Displays
  - TI DMD, SLM GLV
- Fiber optics
  - Switches, attenuators, alignment
- RF components
  - Relays, tunable passives elements
- Biomedicine
  - Drug delivery, DNA sequencing, chemical analysis

Course content

- Fabrication
  - Materials, geometry
  - Compatibility, integration
- Physics
  - Beam theory, electrostatics, thermal, fluidic, …
- Design
  - Combs, springs, hinges
  - Resonators, accelerometers, gyros
  - Scanning mirrors

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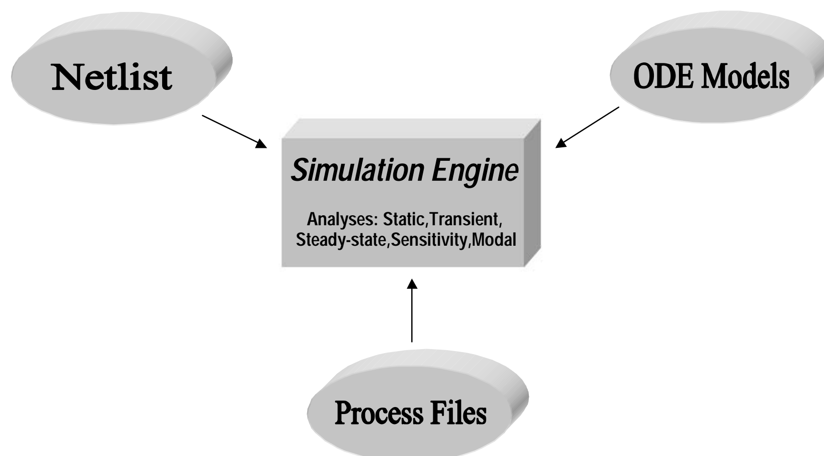
SUGAR: Spice-like environment



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