MEMS and Reliability

18-849b Dependable Embedded Systems

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Mar 30, 1999

Required Reading: Reliability and Long Term Stability of MEMS, S.B.Brown et. al. 1996

Materials Reliability in MEMS Devices, S.B. Brown et.al. 1997

Best Tutorial: Microelectromechanical Systems(MEMS) Tutorial, Kaigham J. Gabriel

http://mems.isi.edu/archives/otherWWWsites_tutorial.html

Authoritative Books: **???**

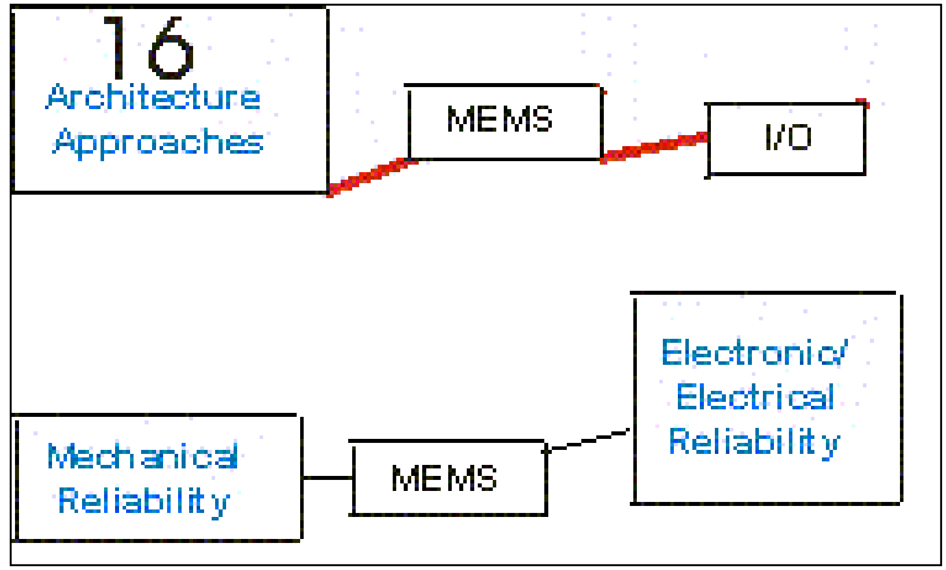
Movie Gallery: http://www.mdl.sandia.gov/Micromachine/movies.html

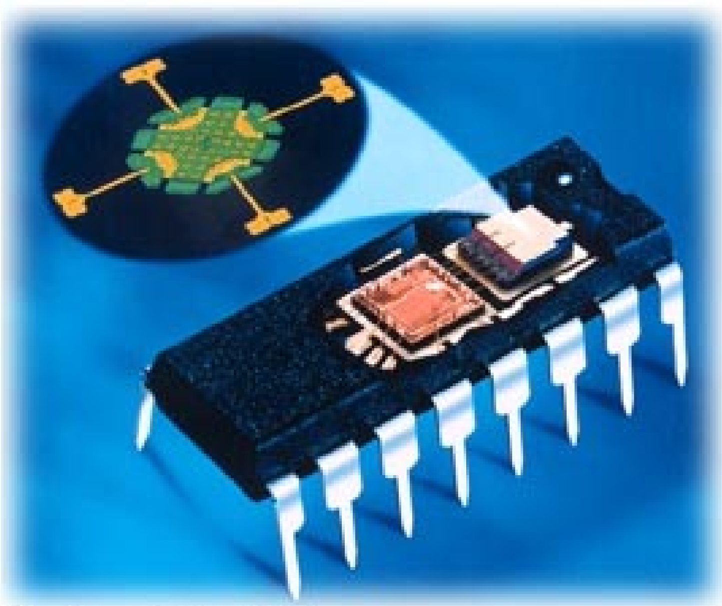
Carnegie Mellon

You Are Here

Our Idea:

Phil's Idea:





Courtesy of Motorola Corp.

Introduction

- **What is MEMS(MicroElectroMechanical Systems)**
  - Microelectromechanical systems (MEMS):
    - are integrated micro devices or systems
    - combine electrical and mechanical components
    - are fabricated using integrated circuit (IC) compatible batch-processing techniques
    - range in size from micrometers to millimeters.
    - can sense, control, and actuate on the micro scale
    - can function individually or in arrays to generate effects on the macro scale.
  - Revolutionizing "traditional" mechanical and materials engineering into "high-tech".
  - The next logical step in the silicon revolution.
  - $10 Billion market today, $34 Billion market in 2002
  - Fascinating, amazing, …
- **DARPA MEMS program Goal:**
  - co-located perception, processing and control

Applications:Size DOES Matter

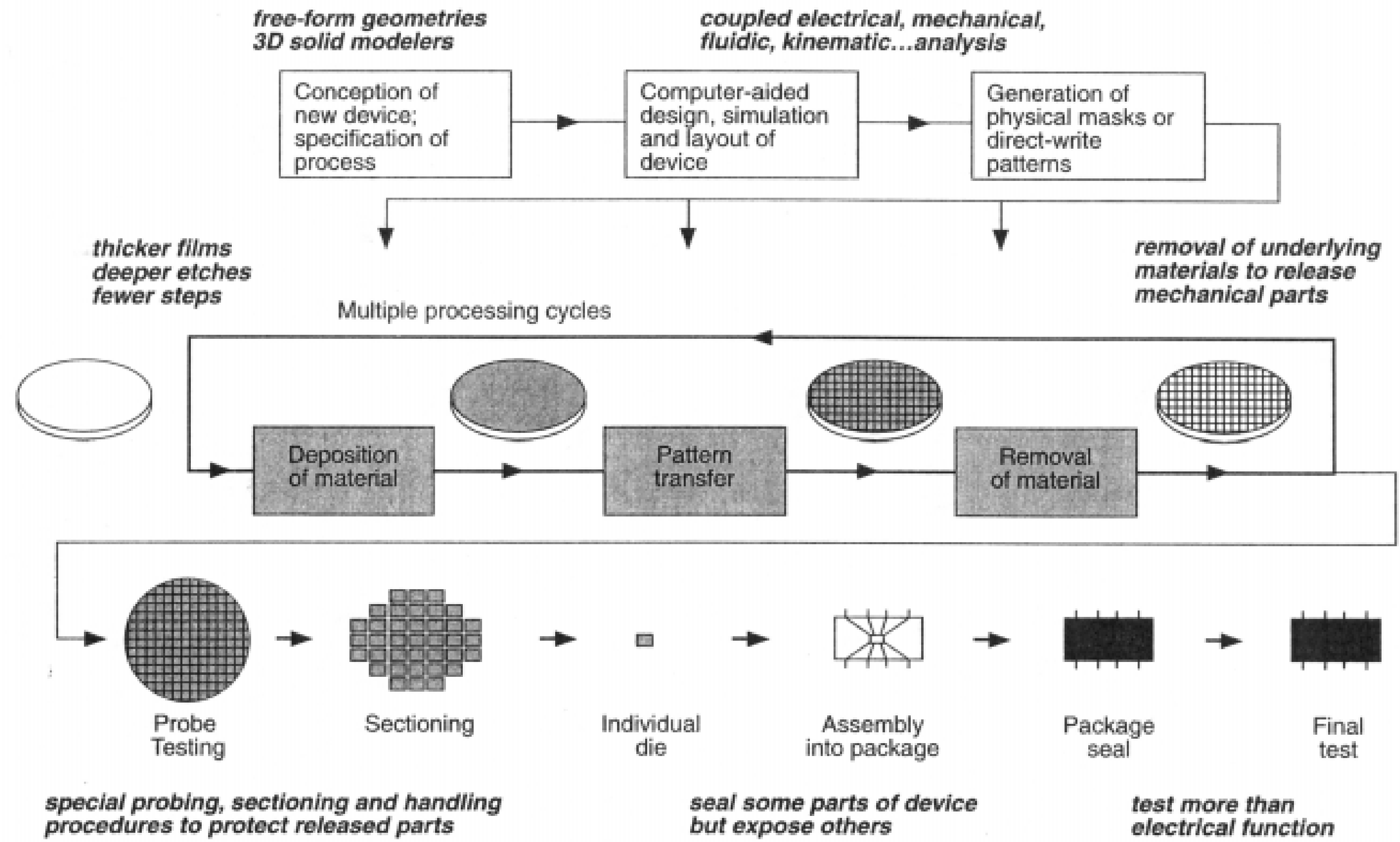
- **Optical switching:**
  - Integrated Optics, Micro-optics
- **Embedded sensors & actuators**
  - Inertial: accelerometers that deploy car airbags
  - Pressure
- **Biomedical devices**
  - Non-invasive biomedical sensors
- **Microfluidics**
  - Inkjet-printer cartridges
  - Miniature analytical instruments
  - Chip-based DNA processing & sequencing
  - Propellant and combustion control
  - Chemical factories on chip
- **Mass data storage**
  - Terabytes per square centimeter
- **Low-power, high-resolution small displays**
- **Microinstruments & Micromachines**
  - Micropumps
- **Microrobots**

MEMS Fabrication

- **"System on a chip": a miniature embedded system itself**
  - Including computing, sensing and actuating parts
  - Similar to IC manufacturing process
  - Usually fabricated completely assembled -- no piece parts
- **Characteristics of Fabrication**
  - Miniaturization
  - Multiplicity
  - Microelectronics
- **Fabrication methods and materials**
  - Bulk micromachining
  - Wafer-to-wafer bonding
  - High-aspect ratio micromachining
  - Surface micromachining

Fabrication Procedures

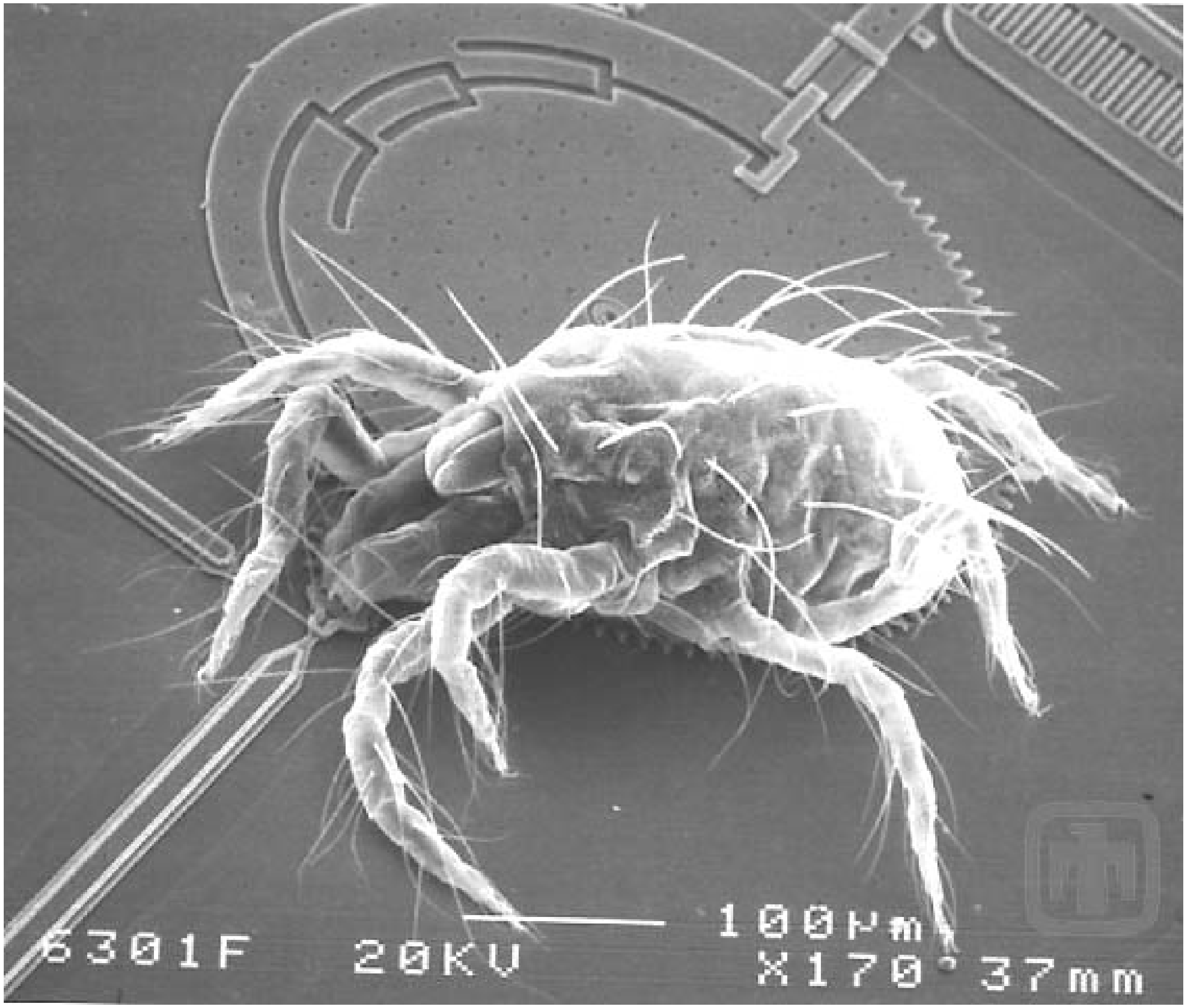
- **Significant distinctions between MEMS and ICs are noted in bold italics. Source: Electronics Technology Office, DARPA**



Typical Size

- **"The technologies and applications of three-dimensional devices with sizes in the micrometer ranges."**

- **Spider mite raids microlock**
  - This is not Godzilla. This is a spider mite (a miniscule, white fleck to the human eye) hanging out on a microlock mechanism. Note the scale key in the lower right corner.



Reliability of MEMS

- **More than just Electro+Mechanical failures**
  - Mechanical reliability
  - Electrical reliability
  - Material reliability
  - Interactions of mechanical and electrical part
- **Macro failure modes not applicable**
- **Unique failure modes at microscopic level**
  - Static overload
  - Delamination
  - Creep
  - Environmental attack
  - Fatigue

Root Causes

- **Capillary forces**
  - Liquid-air interface induced in etching
  - Stiction happens even without liquid; aggravated by moisture
- **Operational Methods**
  - Drive signals not comply to mechanical model
    - e.g. MEMS actuators driven by model based drive signals have 5 orders of magnitude longer life than square wave signals in experiment.
  - Noise in drive signals
- **Mechanical Instabilities**
  - Gear position, spring shape, alignment, etc
  - Buckling
- **Electrical Instabilities**
  - Linear clamping caused by static electricity

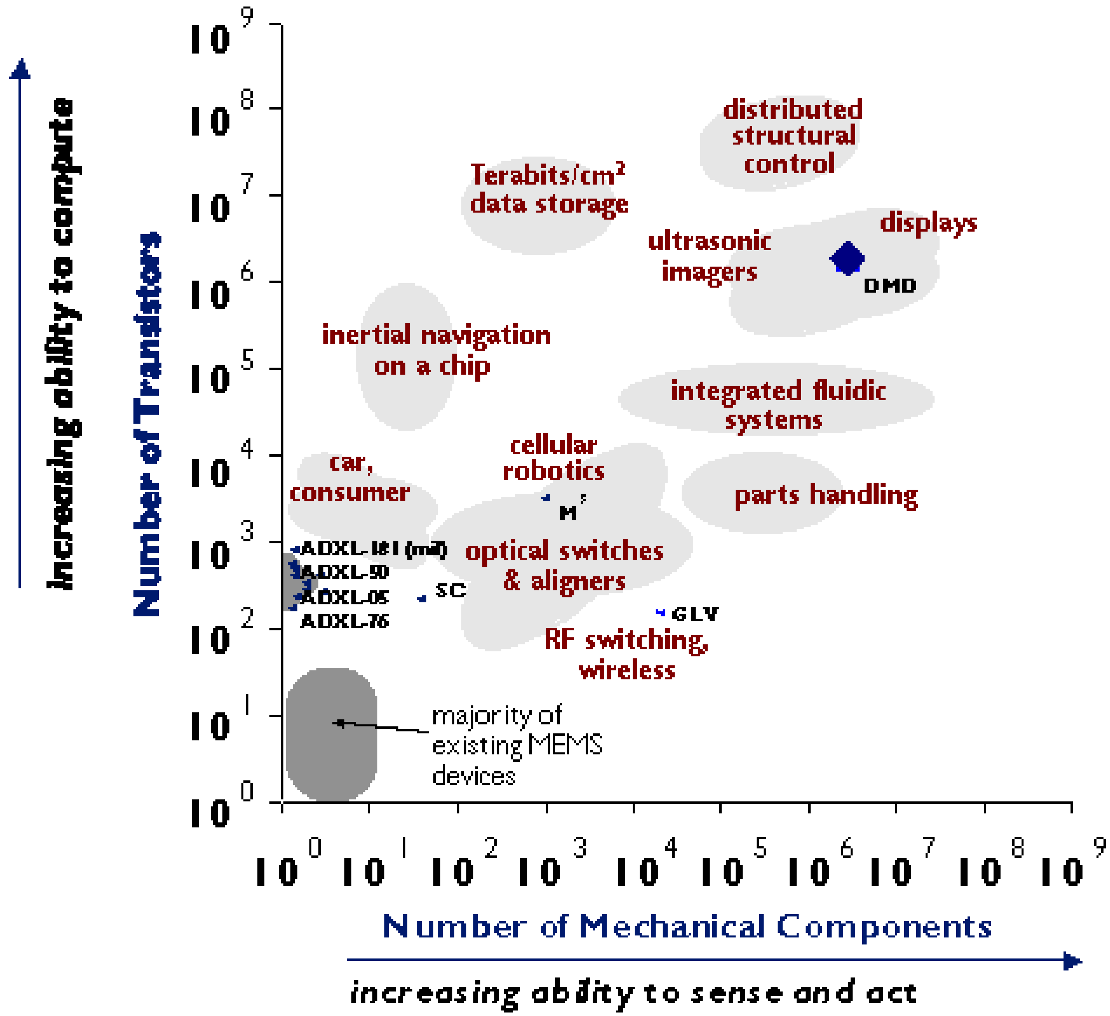
Techniques for Higher Reliability

- **Chemical surface treatments**
  - Super-critical drying method
  - Hydrophobic coating
- **Model-based operational methods**
  - Optimized electrical drive signals
  - Minimized constraint forces
- **Clever design modifications**
  - Improved thickness, stiffness, endurance, shape, etc

Conclusions

- **Revolutionary, fast growing new technology**
- **Still in its infancy**
  - Like IC technology 30 years ago
- **Reliability: How MEMS fail is not well understood**
  - Study shows material strength is NOT a key factor
    - failures induced by deficiencies in material/mechanical properties not majority, such as fracture strength or fatigue-related fracture
  - Failures causes typically related to contacting or rubbing surfaces: Stiction and friction-related wear
  - Unique failure modes at microscopic level
    - Static overload, Delamination, Creep, Environmental attack, Fatigue
  - Reliability can be enhanced by optimized designs and better techniques

Future Direction



Trends in electromechanical integration

Log-log plot of number of transistors merged with number of mechanical components for existing and future MEMS devices and systems.

On the Reading Papers

- ***Reliability and Long-Term Stability of MEMS***
  - High-level generalization of MEMS failure modes
  - Different failure modes in microscope v.s. macroscope

- ***Materials Reliability in MEMS Devices***
  - An accelerated testing technique on stress/fatigue testing
  - Found fatigue life of poly is a function of stress
  - Previous work found crack growth dependent on moisture