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MEMS Reliability

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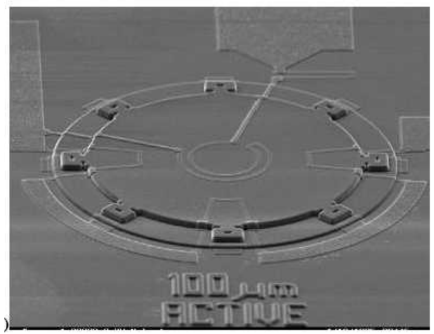
Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94-AL85000.

MEMS Taxonomy classifies reliability concerns – most commercial products (blue text) at lower classes

Class I
No Moving parts



Pressure Sensors
Inkjet Print Heads
Strain Gauge
Microphones

Class II
Moving Parts, No Rubbing or Impacting Surfaces

Image courtesy of SI Time

Gyros
Accelerometers
FBAR
(Film Bulk Acoustic Resonator)
RF Oscillators

Class III
Moving Parts, Impacting Surfaces

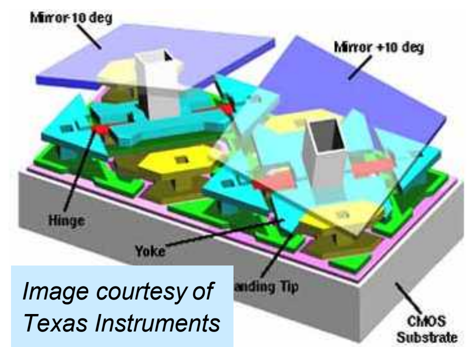
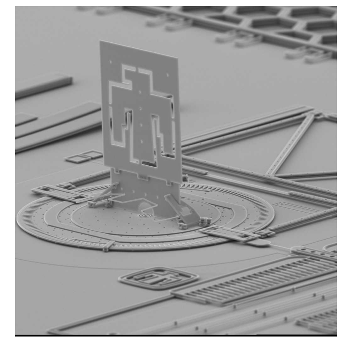


Image courtesy of Texas Instruments

Texas Inst. DLP
Accel. with stops
RF Switch
Adaptive Optics
Optical Switch

Class IV
Moving Parts, Impacting and Rubbing Surfaces



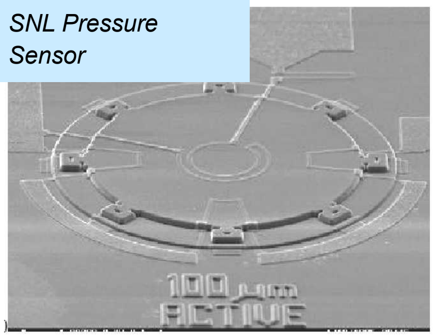
Optical Switches
Shutters
Scanners
Locks
Discriminators

Billions of inkjet print cartridges produced using HP technology!
Analog Devices ships 1 million MEMS accelerometers a week! - over 200 million
Texas Instruments has shipped over 10 million DLP subsystems!

Taxonomy of MEMS devices classifies reliability concerns –

Class I
No Moving parts

SNL Pressure Sensor



Stiction
Contamination

Class II
Moving Parts, No Rubbing or Impacting Surfaces

RF Oscillator

Image courtesy of SI Time

Stiction
Contamination – changes f_o
Fracture
Fatigue
Creep

Class III
Moving Parts, Impacting Surfaces

TI DMD Pixels

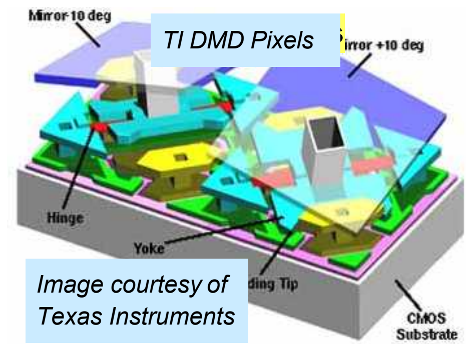
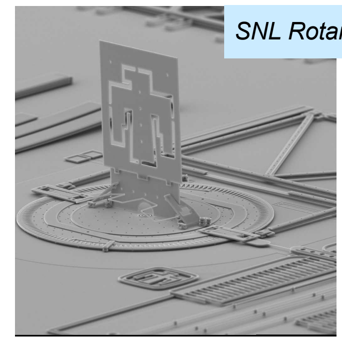


Image courtesy of Texas Instruments

Stiction
Contamination
Fracture
Fatigue
Creep
Temperature
Shock/Vib
Impact Wear

Class IV
Moving Parts, Impacting and Rubbing Surfaces

SNL Rotary Mirror



Stiction
Contamination
Fracture
Fatigue
Creep
Shock/vib
Temperature
Friction
Wear
Wear-induced Adhesion

Failure mechanisms relate to the mode of operation

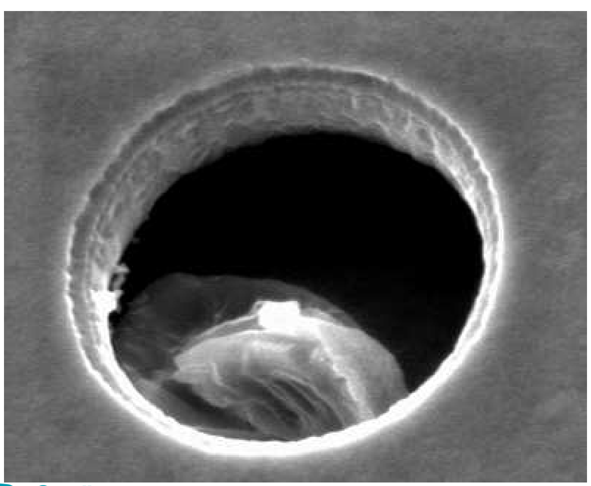
These mechanisms can be accelerated by increasing operational stresses

- Wear
- Fatigue
- Fracture
- Force induced stiction

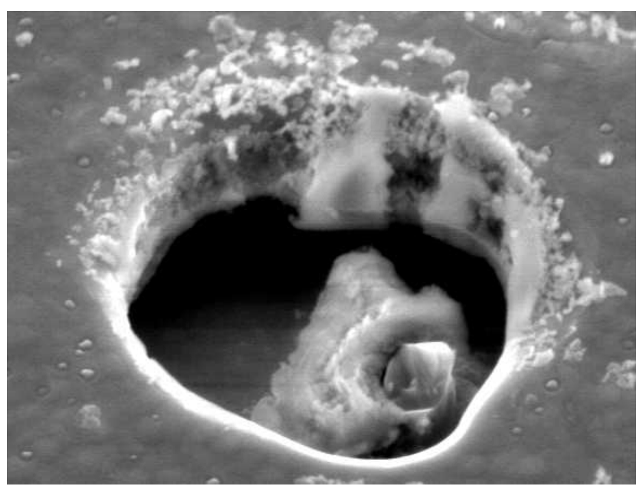
Accelerated by

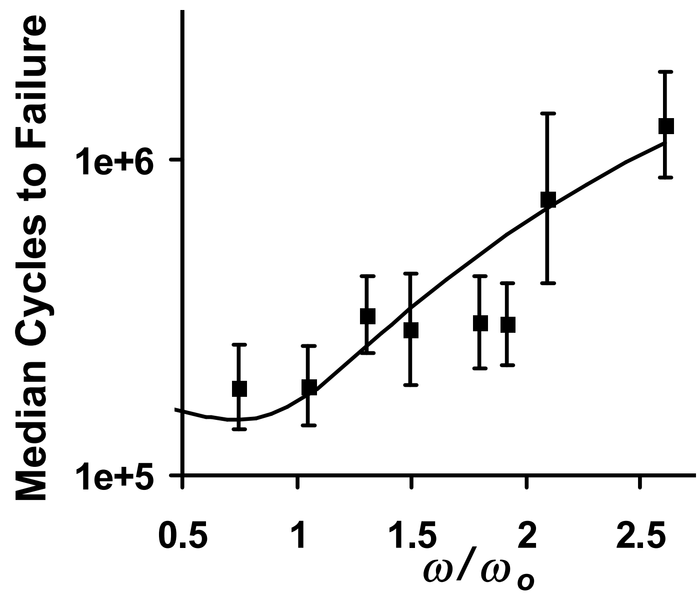
- Voltage - Force
- Operating frequency
- Drive waveforms

Unstressed



Stressed





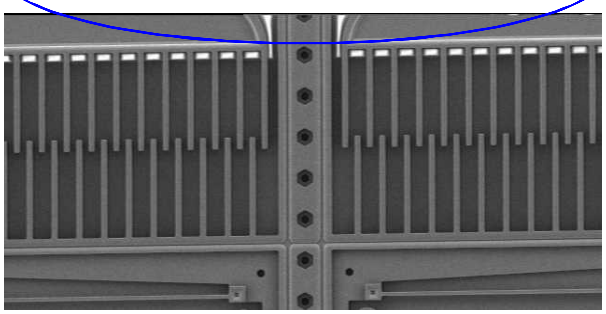
Failure mechanisms relate to environmental stresses

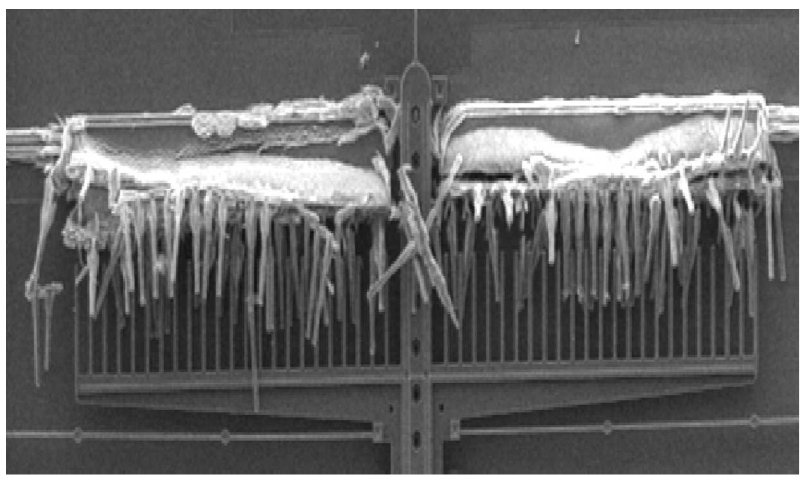
These mechanisms are accelerated by internal or external environment factors

- Surface chemistry
- Materials change
- Contamination
- Moisture ingress or desorption
- Anti-stiction coatings
- Anodic oxidation

Accelerated by

- Temperature
- Moisture
- Hydrocarbons
- Voltage
- Light





Anodic oxidation
100V + 65% RH
25°C, 10 days

Plass et al., SPIE Vol. 4980, 2003, pp 81-86.

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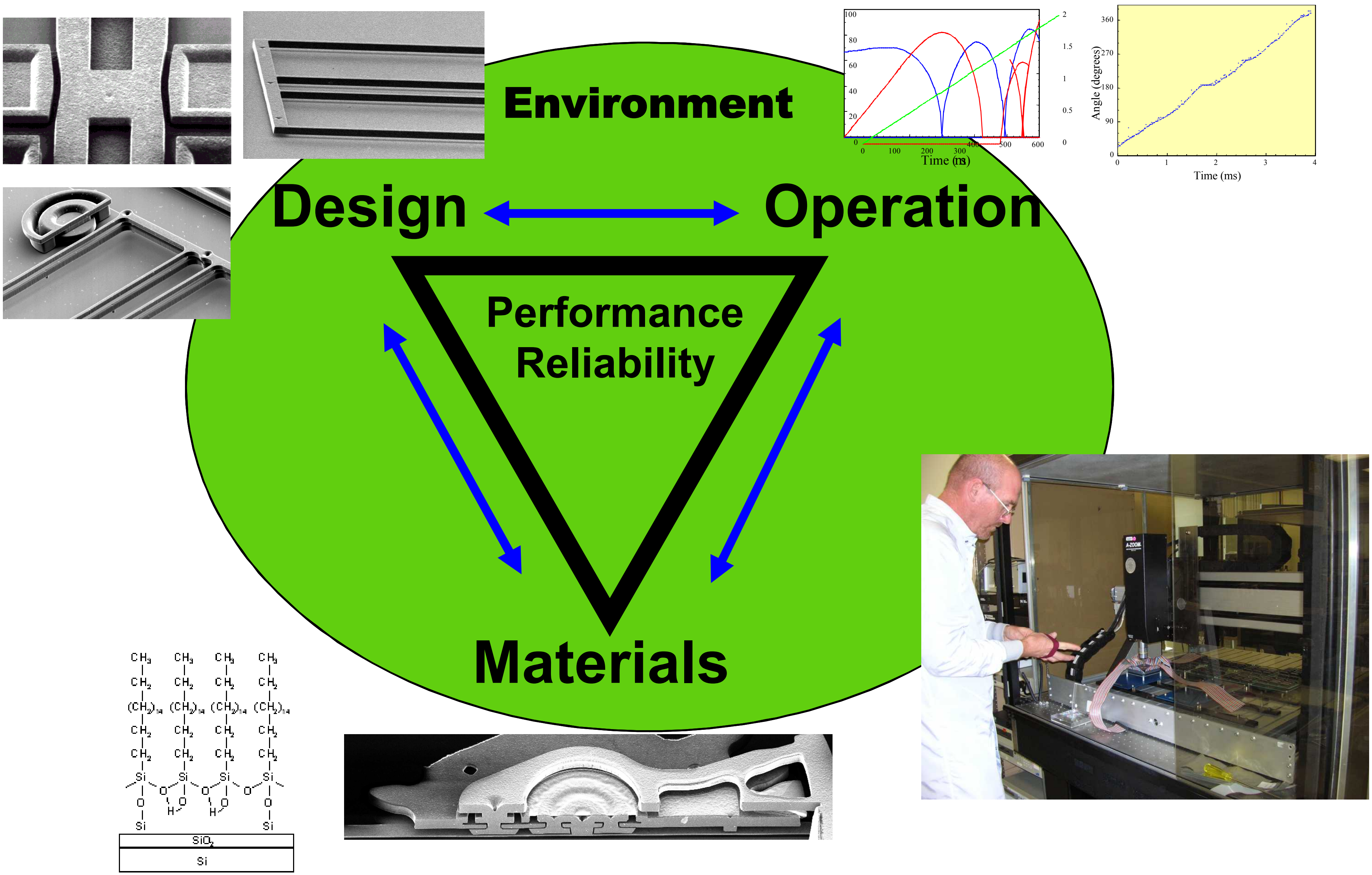
Changes in design, operation, or materials can minimize or eliminate the failure mode



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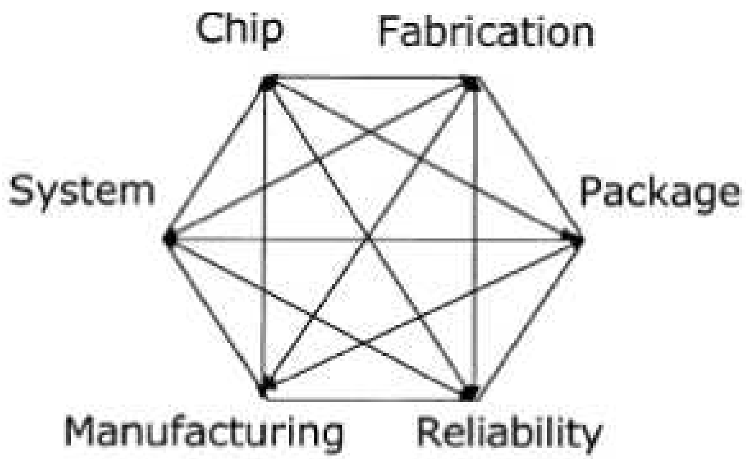
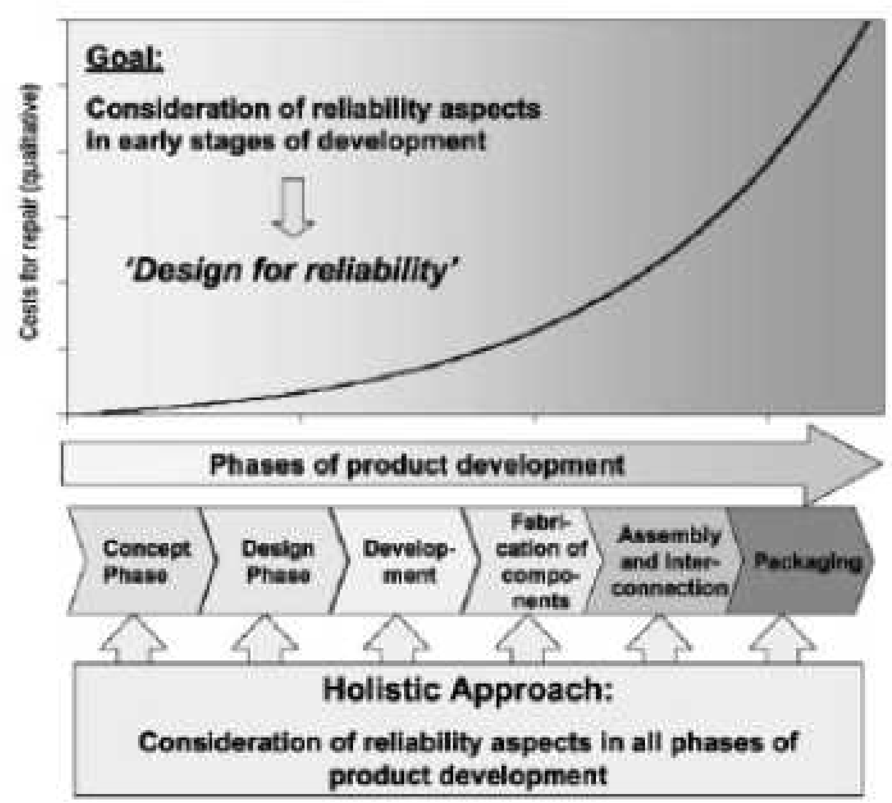
There are many different approaches to MEMS reliability …..



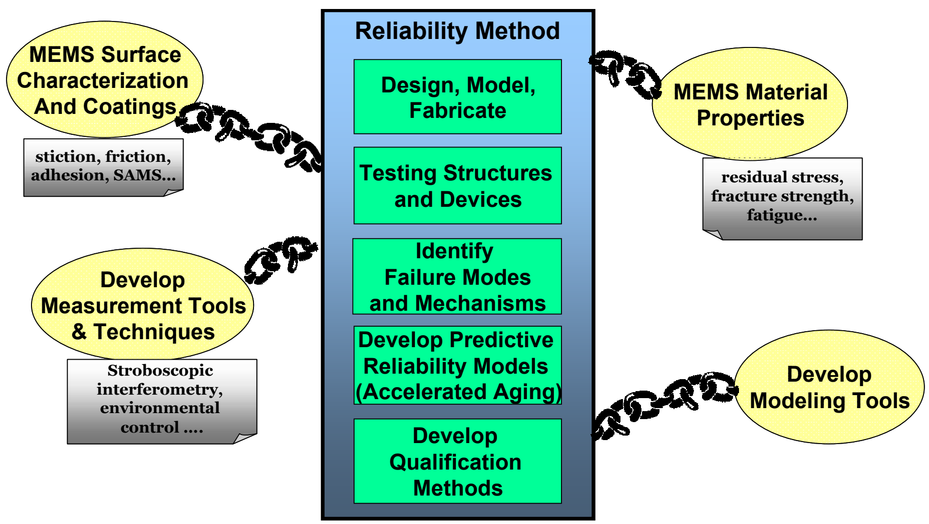
Arney, MRS Bulletin/April 2001, p 296-299

Dr. Susanne Arney
Alcatel-Lucent



R. M€uuller-Fiedler, V. Knoblauch / Microelectronics Reliability 43 (2003) 1085–1097

Dr. Roland Müller-Fiedler
Robert Bosch GmbH



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… but all include these essentials

- Need assessment and test throughout the design, fabrication, and packaging process
- Need materials properties understanding and materials interactions understanding
- Need inter-disciplinary team committed to reliability
- Failure Mode and Effects Analysis helps to assess all stages of development
  - brainstorm potential failure modes
  - identify suspected root causes
  - assign levels of risk
  - follow through with corrective action

MEMS Reliability method identical to microelectronics, but failure mechanisms are not as well quantified

Reliability Method

- Design, Model, Fabricate
- Test Structures and Devices
- Identify Failure Mechanisms
- Develop Predictive Reliability Models
- Develop Qualification Methods

MEMS Surface Characterization And Coatings

stiction, friction, adhesion, SAMS…

Develop Measurement Tools & Techniques

Stroboscopic interferometry, environmental control ….

MEMS Material Properties

residual stress, fracture strength, fatigue…

Develop Modeling Tools

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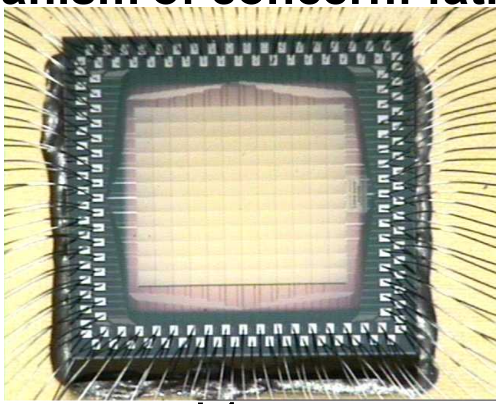
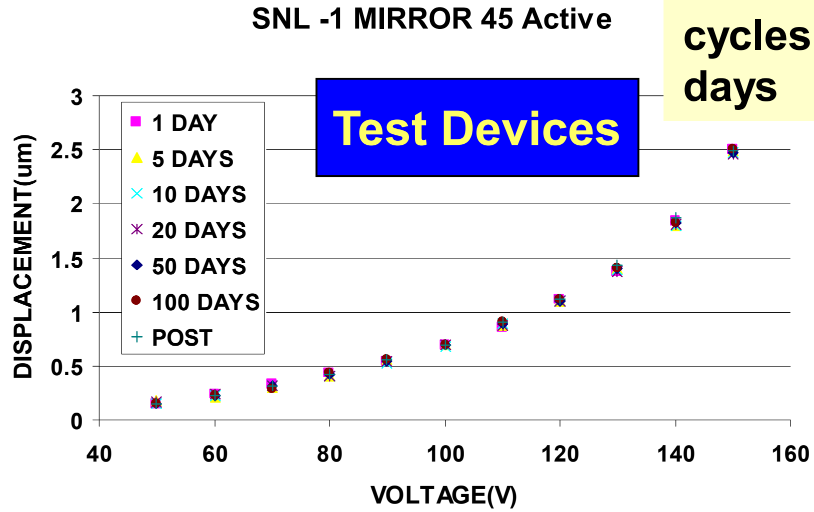
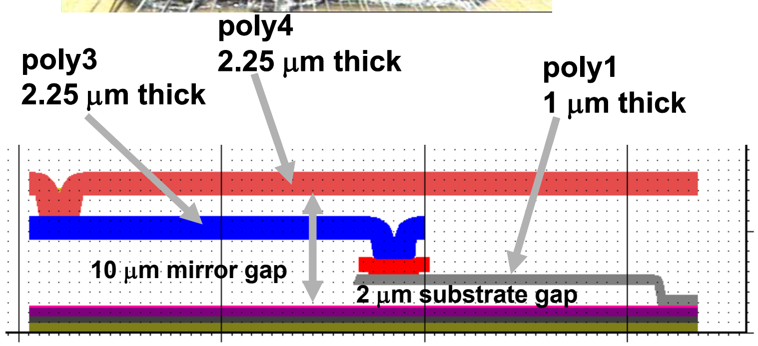
Example: Apply reliability method to a 12x12 mirror array

300 μm x 300 μm pixels, 2.5 μm stroke
Mechanism of concern: fatigue

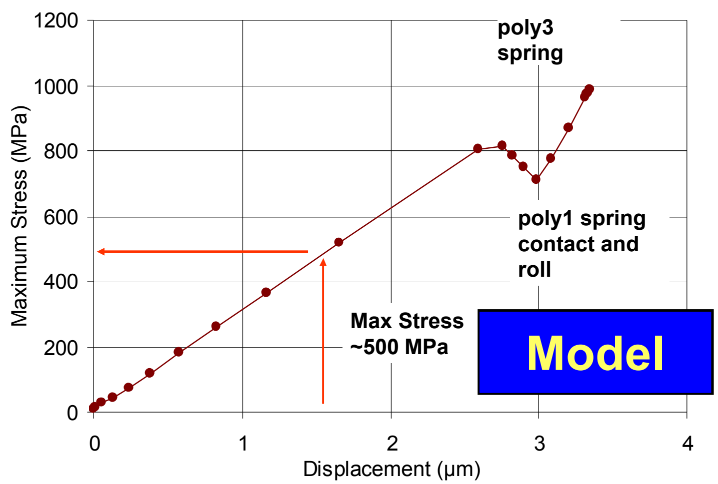


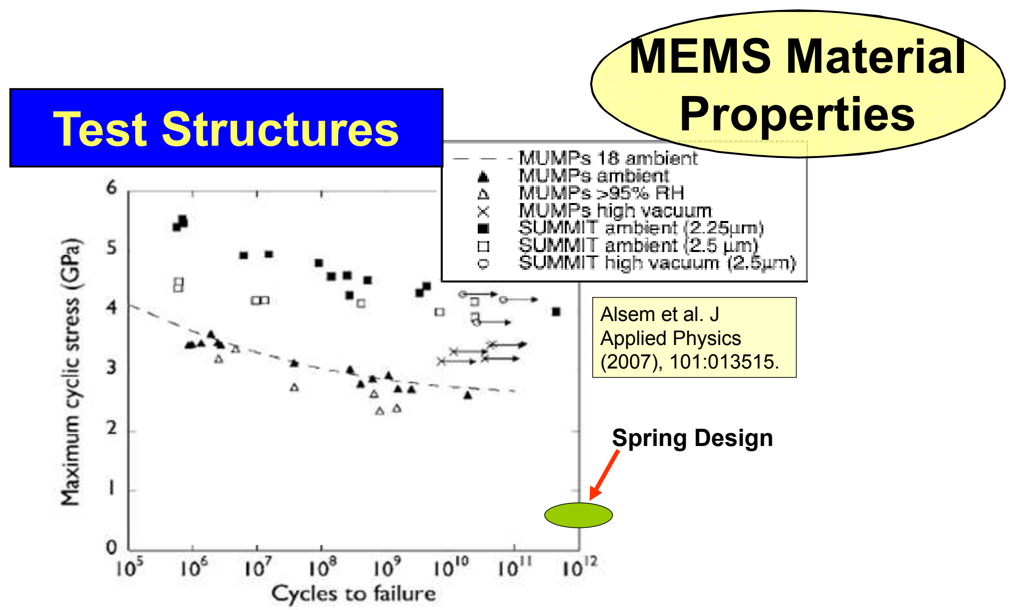


26 billion cycles in 100 days



NO failures and NO observed change in displacement – voltage profile





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Tanner DM et al., "Science-based MEMS reliability methodology", Microelectron Reliab (2007), doi:10.1016/j.microrel.2007.07.061

Develop Predictive Reliability Models

No wear out mechanism – analyze with exponential distribution

$$\lambda_{100(1-\alpha)} = \frac{\ln(\alpha)}{nT}$$

Failure rate prediction

"ASSUMES NO WEAROUT"

nT = 140 mirrors * 100 days = 38.3 mirror years

- Operating frequency is 3 KHz, unit operates continuously 24/7
- PRODUCT: 1000 mirror system with 5 year lifetime

Confidence Level	Lambda (%/yr)	Predicted Defects
50%	1.8%	90
90%	6.0%	300
95%	7.8%	391

(1- α)

Predicted maximum number of defects for product with 1000 mirrors and 5 year lifetime

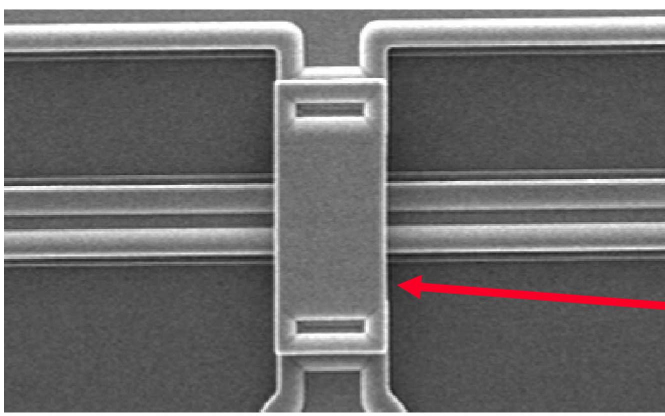
- Demonstrated a step by step method of assessing the reliability of a micro-mirror array
- Showed that the science base of modeling, test structure evaluation, and materials properties characterization lead to elimination of fatigue of polysilicon as a mechanism of concern
- Can confidently use the exponential distribution to describe the data (NO wearout mechanism)

But …… Issue: Humidity + Voltage + Si = Anodic Oxidation

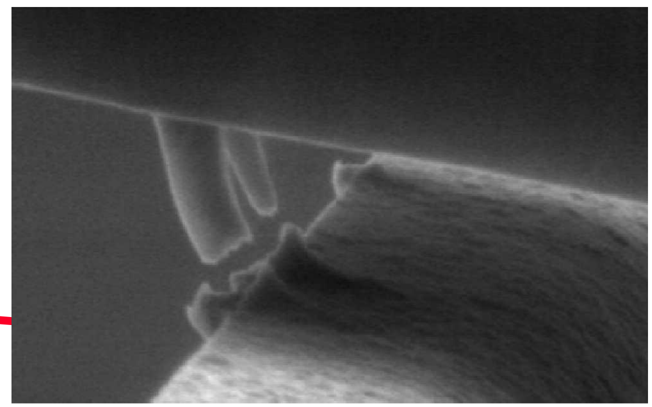
- **Where is this a concern: High humidity, continuous operation**
- **Can this be avoided: DESIGN: avoid gaps < 2 μm**

MATERIALS: surface coating helps

OPERATION: use lower voltage, humidity

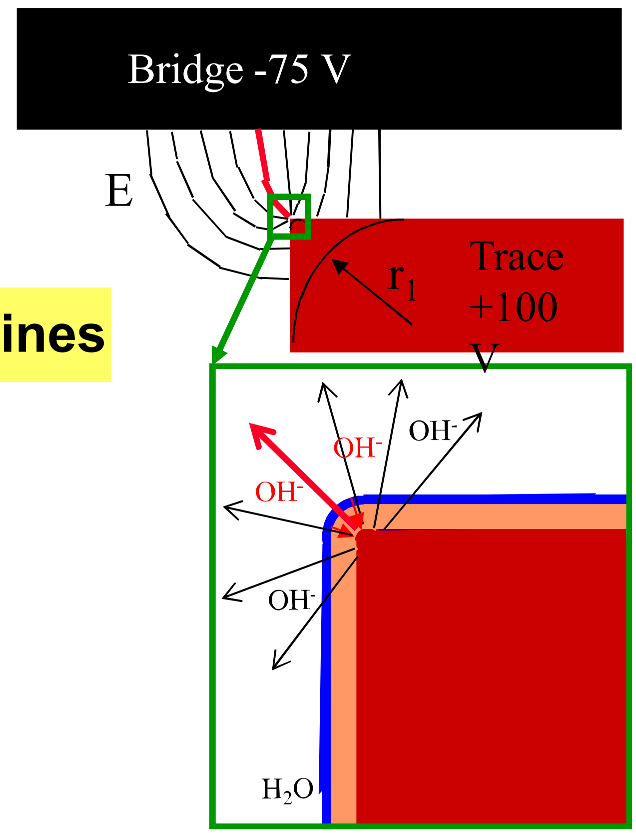


VSAM Coated 50% RH, 45 C, 10 days



Oxide growth follows field lines

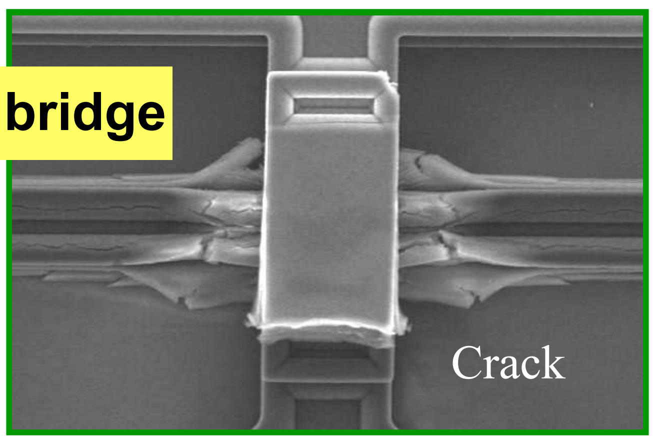
Schematic Electric Field Lines



Will crack power line bridge

Plass et al., SPIE Vol. 4980, 2003, pp 81-86.

No VSAM, 65% RH, 45 C, 5 days



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