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MEMS Product Cycle and It's Connection to Reliability

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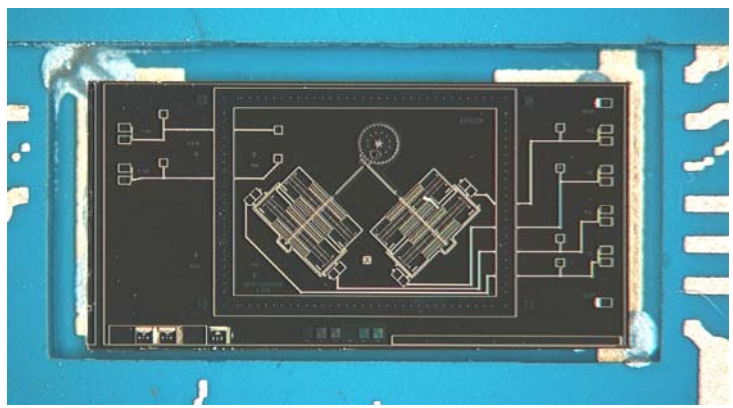
Topics

- Questions, Sandia Interests and Background
- Reliability Connections
- Elements of a Product Realization Sequence
- Why do things go wrong?
- Estimation and Planning
- Reliability Status
- X-based Engineering
- Where to from here

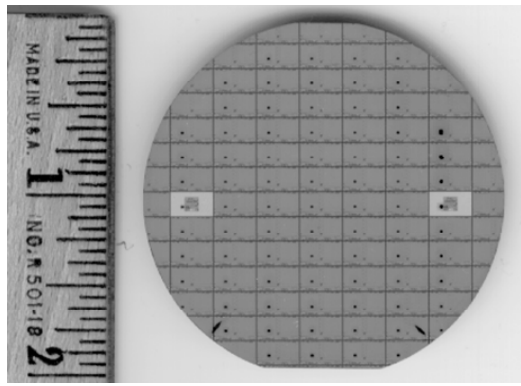


Questions

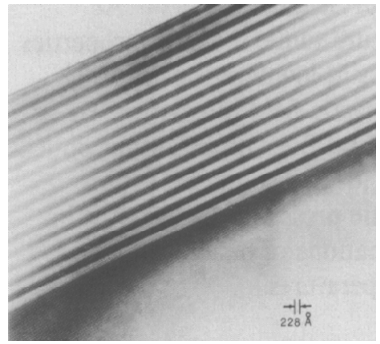
- How reliably will MNT-based systems operate in their actual environments?
- How do we determine reliability?
- How does the product realization cycle or process affect or permit us to obtain a certain level of reliability?
  - In fact many seemingly unrelated activities within the product realization process have a *profound effect* on the resulting product's reliability characteristics

Sandia Has Been Developing Innovative Microtechnologies for Over 40 Years

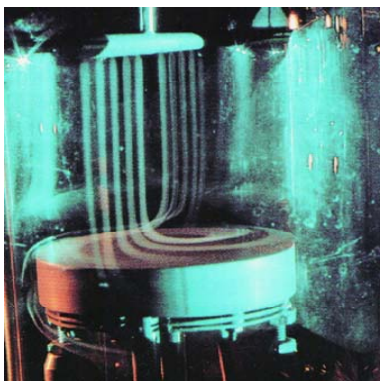
Laminar Flow Cleanroom, 1960



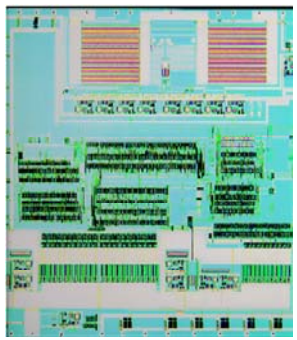
Radiation-hardened CMOS, 1975



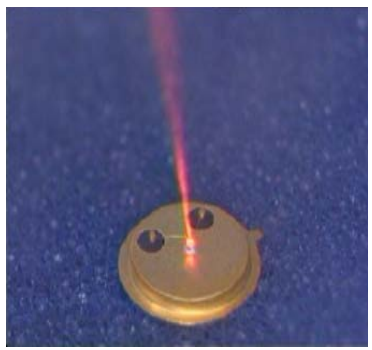
Strained-layer Semiconductors, 1981



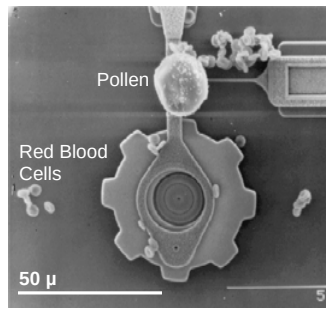
Semiconductor equipment partnerships, 1989



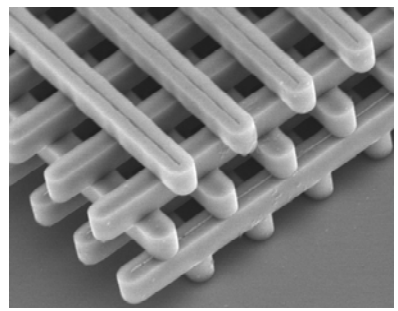
Integrated sensor, 1993



High-efficiency VCSELs, 1995



Silicon surface micromachine, 1995



Photonic Lattice, 1998

Microsystems & Engineering Sciences Applications

12.000 m^2

Microsystems Laboratory Building

15.000 m^2

Work Integration Facility

Microsystems Fabrication Facility

9.000 m^2

The MESA Project provides essential facilities and equipment to enable the RAPID design, integration, and qualification of microsystem-based components for the future.

MESA

Microsystems and Engineering Sciences Applications

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85

NNSA

Sandia National Laboratories

Center for Integrated Nanotechnologies (CINT)

http://cint.lanl.gov/

Inauguration held on 23 August 2006

National User Facility
(8400 m²)

Microelectronics Development Lab

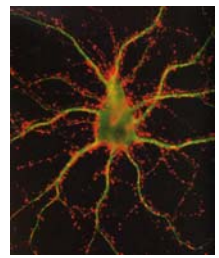
Collaborators
Users
University
Industry

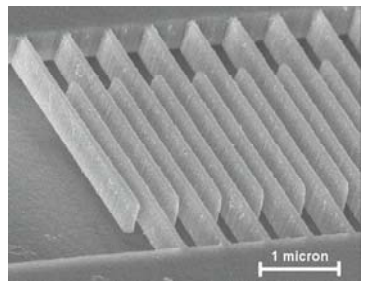
CINT
Core Facility

Gateway to SNL

Gateway to LANL

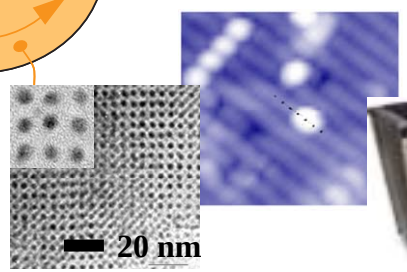
Biosciences





National High Magnetic Field Lab

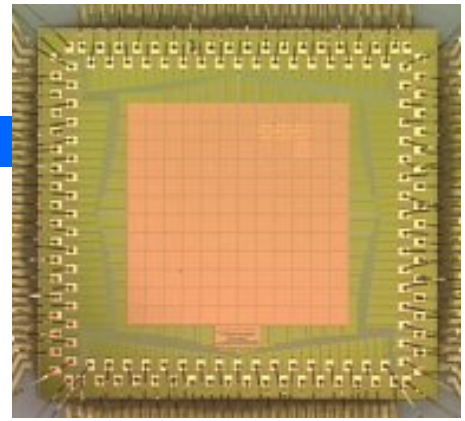
Compound Semiconductor Research Lab



Synthesis, Characterization, & Theory

Los Alamos Neutron Science Center

Clearly We're Interested in Reliability



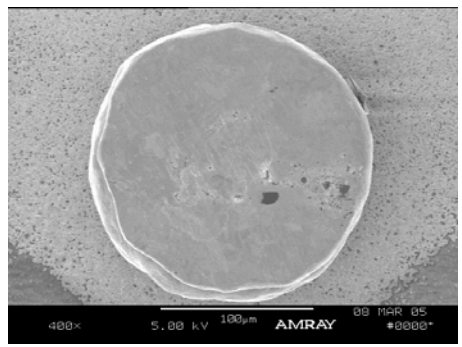
- What is it?
- Different definitions
  - The quality or state of being reliable (Webster's)
  - Reliable- Fit to be relied on ! (Webster's)

Dependability, Consistency, Steadfastness, Trustworthiness

Connections →

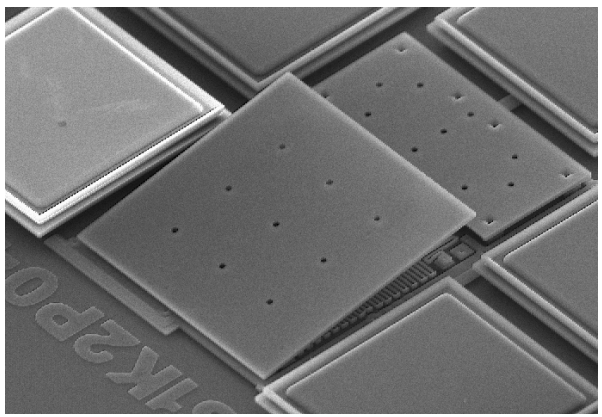
Reliability Connections

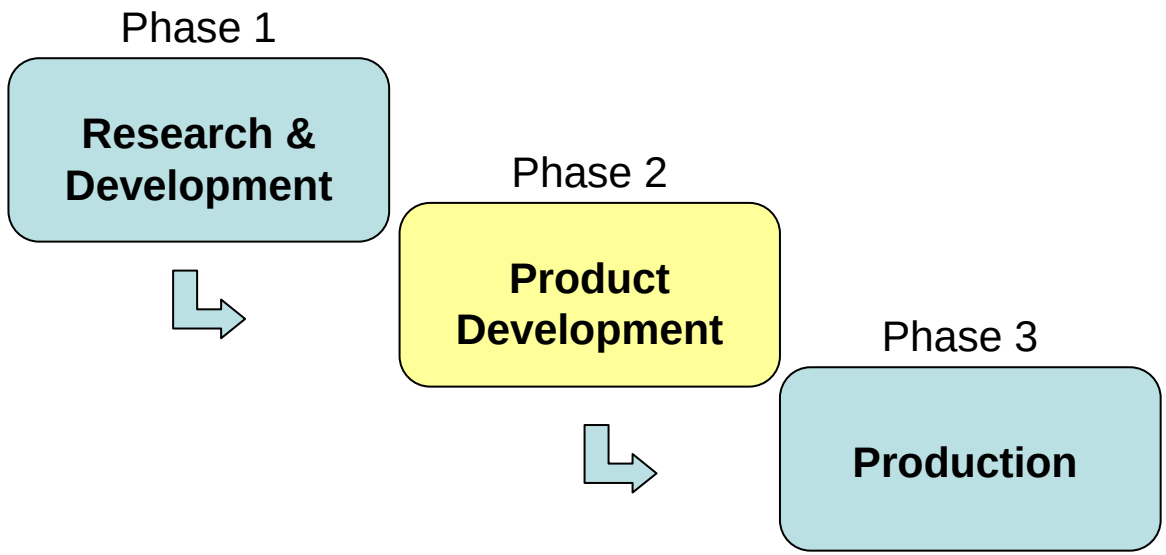
- The ability to determine reliability is one of the most critical elements in product development
- Some obvious and non obvious connections to reliability
  - How we operate within the product realization process
  - Why do things go wrong?
  - Estimation and project planning



Elements of a Product Realization Sequence

- Basic Elements
  - Research Phase
  - Productization or Product Development Phase (Thomas George-"Crossing the Valley of Death")
  - Production Phase



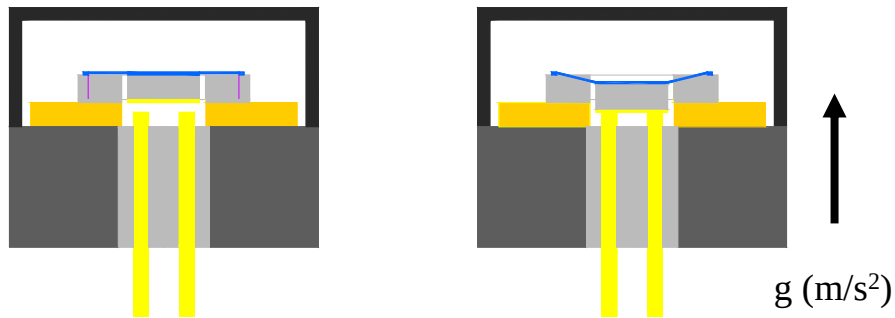


Fundamental Product Cycle (R&D)

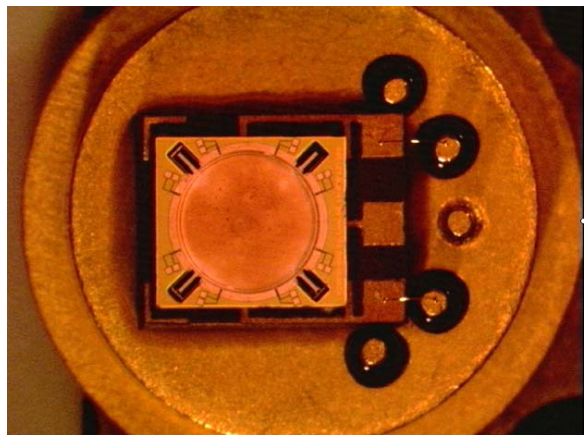
Phase 1

Research & Development

MEMS Acceleration Switch



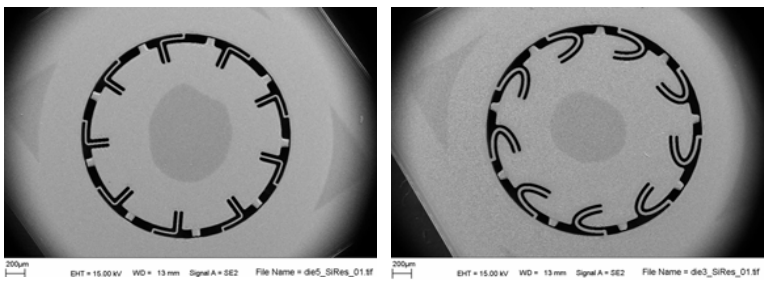
- **<u>Synthesize Concept</u>**
- Develop Fabrication Processes
- Fabricate Conceptual Design
- Integrate Design into Package
- Prototype Testing

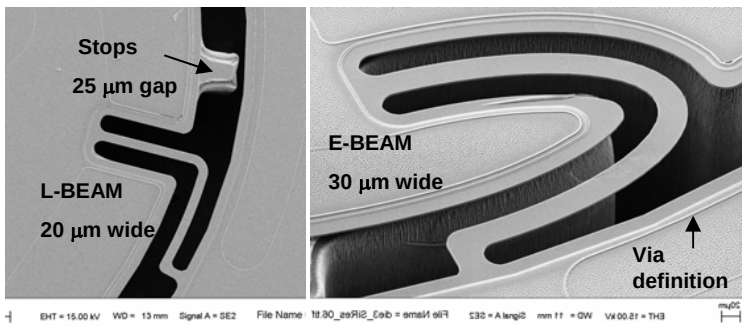


Fundamental Product Cycle (Product Dev.)

Phase 2

Product Development



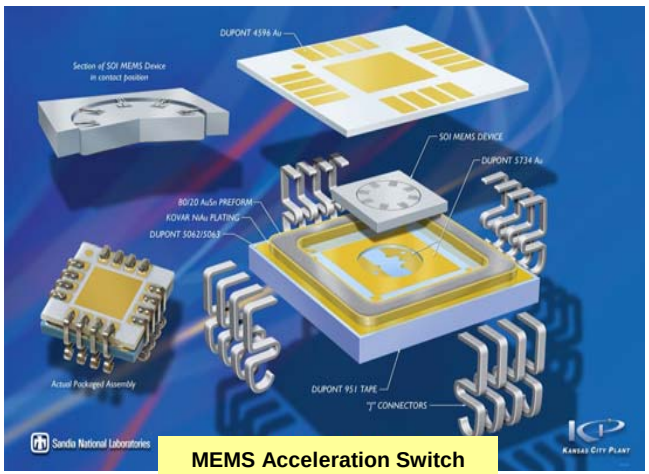


- Negotiate Requirements
- Establish Team
- **<u>Mature Design & Fabrication Processes</u>**
- Develop Process Controls
- Develop Tooling / Gages / Fixtures / Testers
- Verify Design Meets Requirements
- Qualify Manufacturing Processes

Fundamental Product Cycle (Production)

Phase 3

Production



MEMS Acceleration Switch

- Fabricate Product
- Maintain Process Controls
- Manage Production Schedules
- Lot Sample Testing
- Ship Finished Product

Fundamental Product Cycle

- So what is the issue here?
  - The *manner* in which we operate in each phase is confused
    - In the R&D Phase for example we should
      - Think out of the box
      - Look at revolutionary methods to solve problem, etc.
    - In the Product Development Phase we need to change our orientation and become more *disciplined*
      - We cannot continue to operate in the R&D mode; we set ourselves up for failure!
    - In both the Product Dev. & Production Phase absolute attention to non-glamorous details is mandated

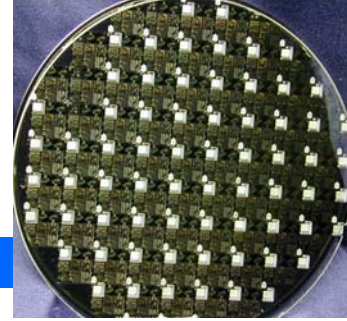
Why do things go wrong?

- Failure to learn from history
  - This happens regularly----- **Learning without thought is labor lost** -**Confucius**
  - Many times there was a lesson that was learned in the past → But Completely Forgotten !!!
- Naive or Over Optimistic at the Start
  - This will be easy, it looks simple, …
  - Need the right mix of confidence and humility
- Inability to estimate and plan

Why do things go wrong?

- Poorly defined requirements
  - Lack of knowledge of true environments
  - Design lifetime naiveté
  - Minimal effort is usually devoted to requirements determination
    - "The customer is supposed to know what he wants"
    - "That is for them to tell us"
    - It is **our job** to determine the requirements
      - Why do you think the requirements always end up changing? → We didn't do our job!

More wrong!



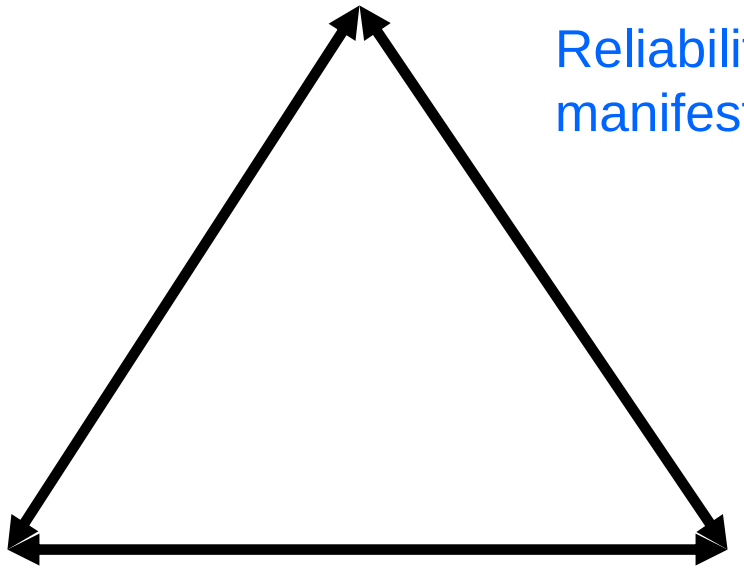
- We very often unconsciously set ourselves up to fail right from the start!
  - First we begin with a wrong or misstated goal
    - Again this is related to knowledge of requirements
  - We really fail to **plan** properly
    - Usually it's a marginal plan created in haste
    - Do we really know how to do a real plan?
    - We proceed, with an Inadequate PLAN!!
    - We've now done a great job settings ourselves up!

What Else?

- How about a feasibility assessment plan?
  - It could be the project is impossible by one or more elements of the triple constraint and we simply are unaware!
  - We usually don't have a plan to determine feasibility given real requirements
    - Again we've done an excellent job setting ourselves up for failure!
  - Important connection between
    - Requirements ←→ Feasibility

The Triple Constraint

Performance

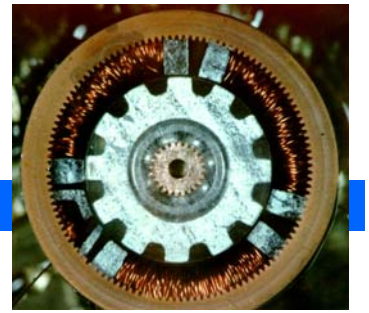


Reliability is essentially a manifestation of performance.

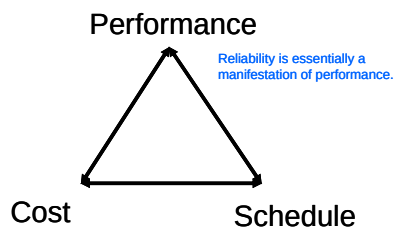
Cost

Schedule

Estimation and Project Planning

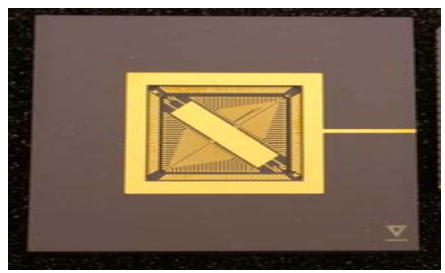


- To start
  - Most of us were never trained to plan and estimate (it's not easy)
    - This type of capability is a serious undertaking and not satisfied by a few "short courses"
    - True planning professionals already know this
      - We need their help and usually they're brought in as an afterthought
- What is it that we can't plan and estimate?
  - Cost, Schedule and Performance



Estimation and Project Planning

- But what is the real problem?
- Answer → We don't invest sufficiently in project planning and estimation
  - Again the real planning professionals say an investment of 25% of the budget is required!!
    - And we don't believe this (at first)
- Project planning and estimation is the single most important element of a successful product development



Other Elements of Project Planning

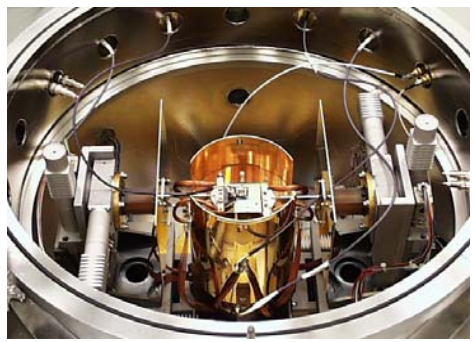
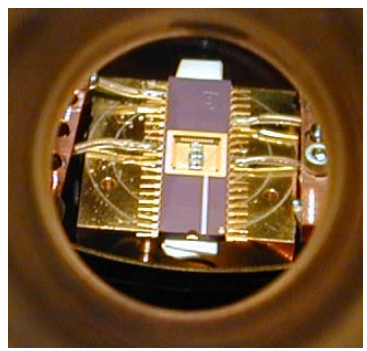
- A well thought out project plan also contains a Risk Management Plan
  - Lack of a formal risk management plan should be considered a red flag to a customer
- Does your project plan have provisions for Independent Peer Review?
  - Surprisingly many extremely large projects have no formal provision for true independent peer reviewing

Where are we now?

- Progress has slowed
- We should be farther along in the MEMS product development arena
  - Lots of reasons including:
    - Extremely poor product realization planning or lack of it
    - Modeling and simulation capabilities and tools that are insufficient (Our underestimation of the nonlinearity of physical systems and their interactions)
    - Misunderstandings about how we proceed in the various phases of the product cycle

Reliability Significance

- Reliability is effectively one of the key elements of the triple constraint
  - Reliability is a keystone characteristic of the performance and quality of a product
  - At present the only effective method to determine reliability is through experiment

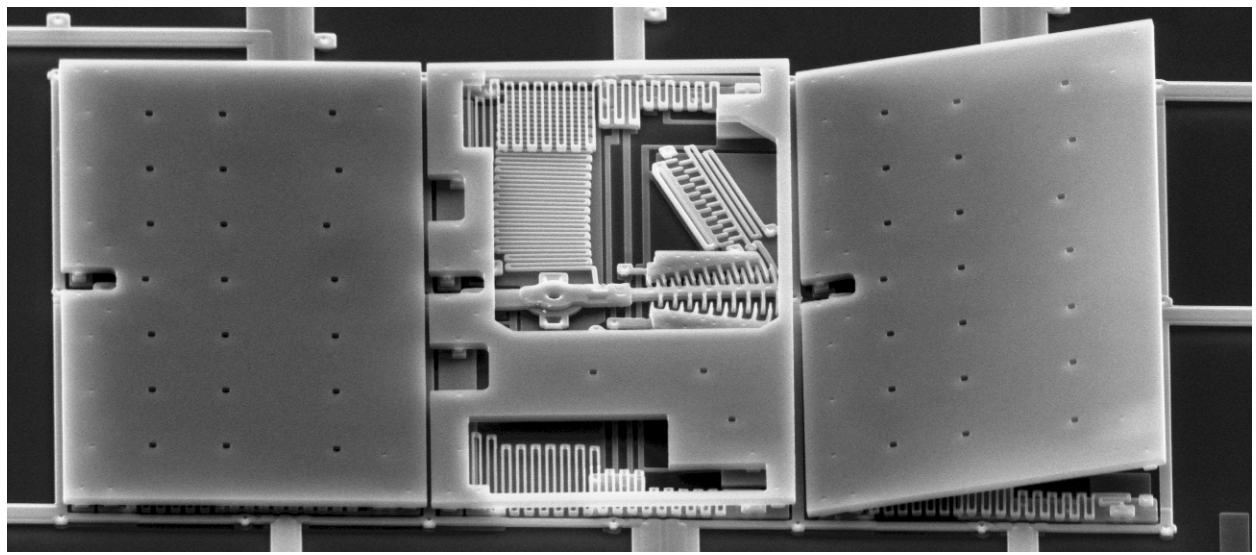




Micromirrors (reliably?) operating at 12° K

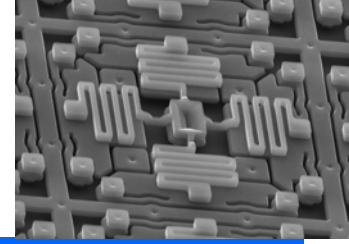
Reliability Status

- However, complex system configurations have now evolved such that our ability to determine reliability, based on experiment, is quickly becoming obsolete and cost prohibitive

Latching Micromirror Design



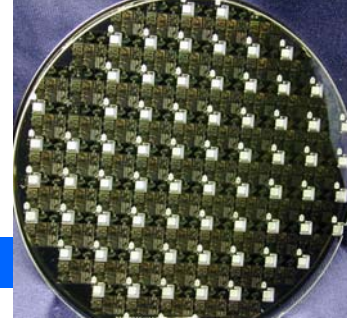
Are We Arriving at an Impasse?



- We need to reexamine our design and development processes
  - Especially for MNT with it's scaling spectrum
  - Engineering development has stagnated as systems have become more complex
  - Recognize our existence in the empirical world
    - Product validation requires empirical evidence

The problem→ We still live in the empirical world!!!

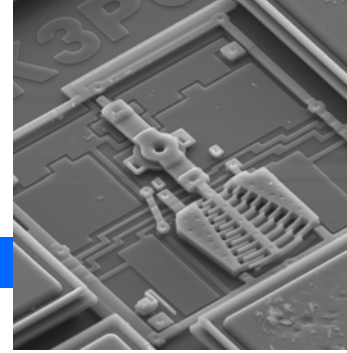
Where to from here?



- At present we're on an incremental path
- Is there a path to revolutionary advances?
  - How? → Computational advancements **coupled** with a true understanding of engineering physics can revolutionize our capabilities
- It's called **Science-Based Engineering**

This idea has been around for a long time

Science-Based Engineering



- Science-Based Engineering integrates scientific understanding with experiment and validated modeling to create a responsive *product realization process*

  – Emphasis is toward predictive capabilities to design and insure reliability requirements are satisfied over product environments and lifetimes

Science-Based Engineering

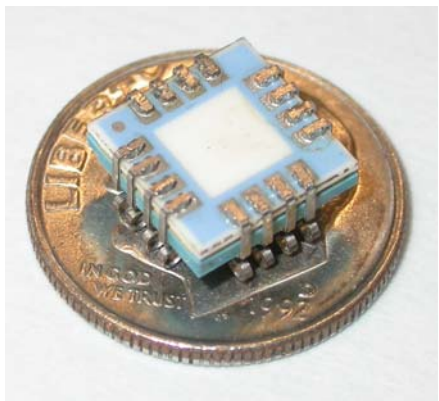
- Moves to take our empirically-based development methodologies to a science-based approach that relies on validated modeling and simulation

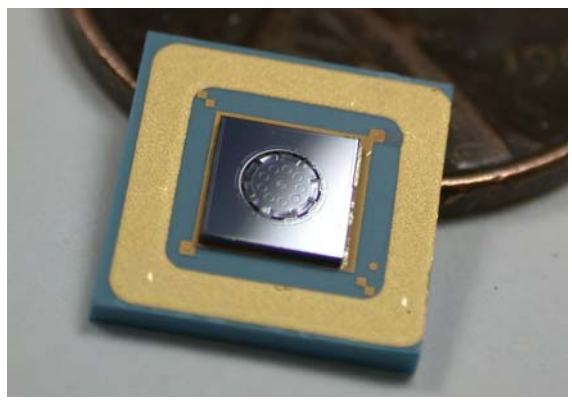
  – Our Laboratory goal is to enable reliability assessments from an a priori knowledge of the system physics

-It's not going to be easy-

Where to from here?

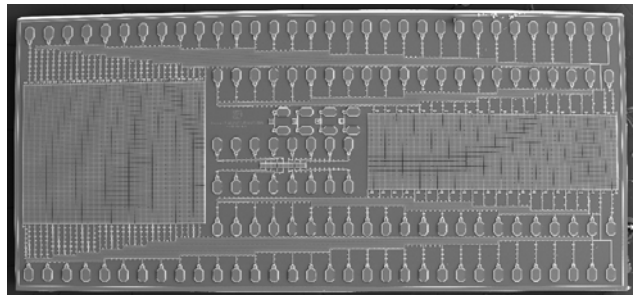
- Start on the road to Science-Based Engineering now
  - Investments to achieve capability are required
  - Recognize this is the path to competitiveness
- Re-Reinvent our *product realization process*
  - Such reinvention will require resolve





What can we do right now?

(To Build a Reliable System)



- A brief recipe:

-Decide on your priorities

-Allocate sufficient resources: staff, time, budget, PLANNING

-The design, build, test, ….., etc., process must be subject to strict discipline

-Ultimate goal: Develop an intrinsic and profound understanding of your system

Extensive testing is the only path today

In Our Laboratory Future

- We are pursuing a methodology to create
  - A predictive science-based engineering process to:
    - Produce believable characterizations (including reliability) of a product's behavior before the product is built and system tests are conducted.
- This methodology will be enabled by
  - Scientific Research
  - Modeling using high-performance computational capabilities
  - Advanced experimental and testing capabilities for phenomenological discovery and code validation

Acknowledgements

- Thanks to:
  - CANEUS Organizers: Milind Pimprikar and Thomas George
  - Many colleagues at Sandia especially
    - Mark Polosky, Gregory Bogart, Randy Shul, Andrew Oliver, Jeremy Walraven, Danelle Tanner, Ken Petersen, Steve Lott, Thomas Swiler

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Micro-Nano-Technologies?

Choose a job you love, and you will never have to work a day in your life.

Confucius