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Advanced Microsystems

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- Microsystems activities started c.1991/2
  - Identified as an emerging disruptive technology
  - Silicon technology base from IC industry
- Largest Microsystems group in the UK
  - An integrated team of about 35 staff
    - Diverse range of device and system applications
    - Advanced CAD capability
  - Dedicated Microsystems fabrication facility
    - Stable processes - Design for Manufacture principles
    - MEMS materials development
    - Portfolio of MEMS based solutions

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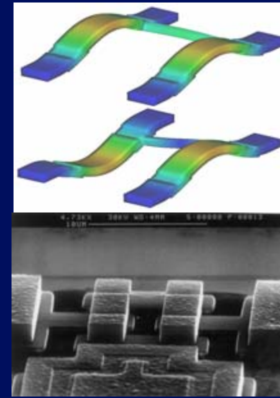
QinetiQ Microsystems Capability

- Device Physics & Modelling
- Microsystems Design
- Layout
- Fabrication
  - Prototype – low volume production
- Evaluation
- Electronics & system design
- Materials Characterisation



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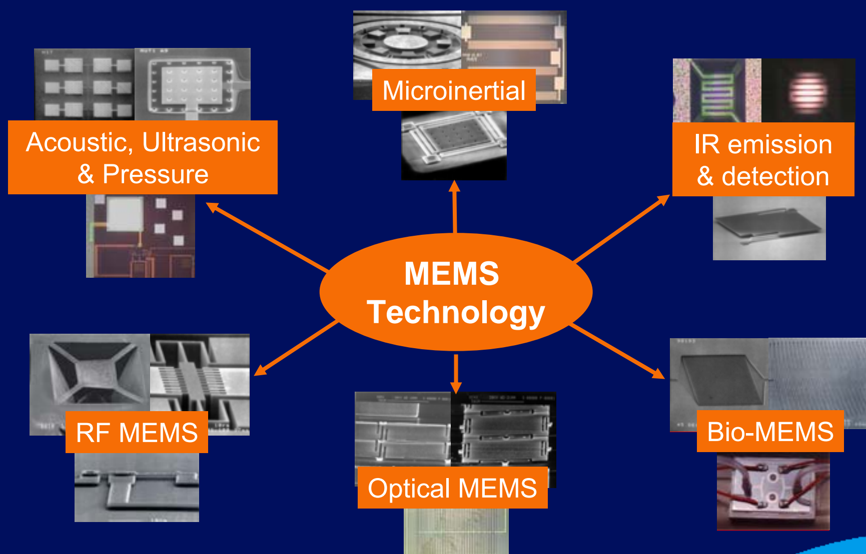
Some Microsystems Applications Areas



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Overall Metrology for Fabrication of MEMS

- 2 inter-related requirements (holistic approach):
  - **Process Development - Stabilisation**
    - Determine fundamental materials properties
    - Refine process flow
    - All techniques applicable
      - High proportion off-line
  - **Process Control**
    - Quality and reproducibility
    - In-line non-destructive techniques
    - Periodic sampling for off-line tests

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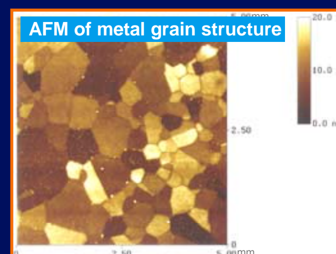
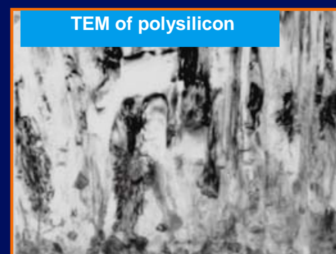
Required Materials Metrology Data

- Composition
- Microstructure
- Mechanical
  - Strain (Stress)
  - Young's Modulus
  - Density
- Electrical
  - Resistivity & dielectric constant
- Optical
  - Reflectivity & refractive index
- Thermal
  - Thermal conductivity & heat capacity





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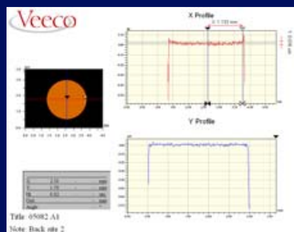
Required Dimensional Metrology Data

Parameters

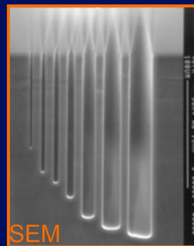
- Layer thickness
- Surface & interface roughness
- Bow of wafer & released structures
- Lateral feature sizes
- Sidewall roughness & profile

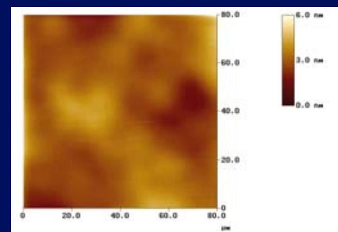
Techniques

- Optical (microscopy, interferometry, SE)
- AFM, profilometry
- SEM, TEM
- Vernier alignment scales (on-chip)



3-D micro-interferogram of MEMS membrane





AFM – surface morphology

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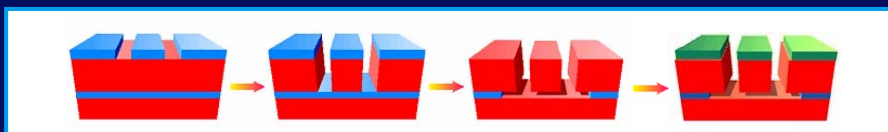
SOI High Aspect Ratio Micromachining

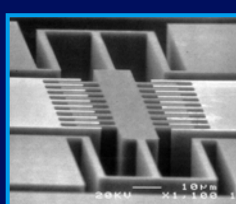
- Silicon deep dry etching



Pattern mask	Deep dry etch stop on thick buried oxide	Sacrificial etch to release structures	Evaporate aluminium to provide bonding contacts

SOI ring gyroscope

Tunable capacitor



Variable Optical Attenuator

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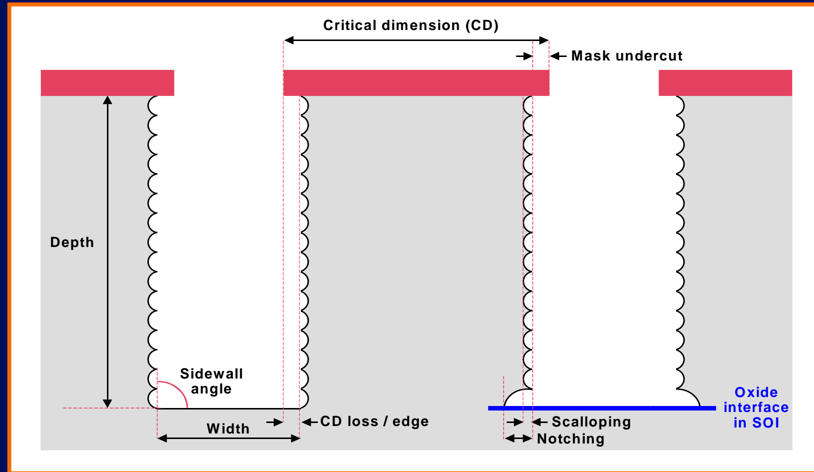
Critical Aspects of HARM



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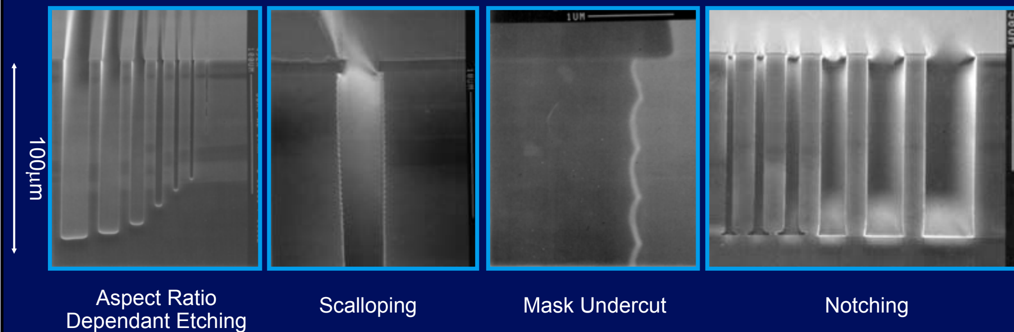
Critical Aspects of HARM



Aspect Ratio Dependant Etching | Scalloping | Mask Undercut | Notching

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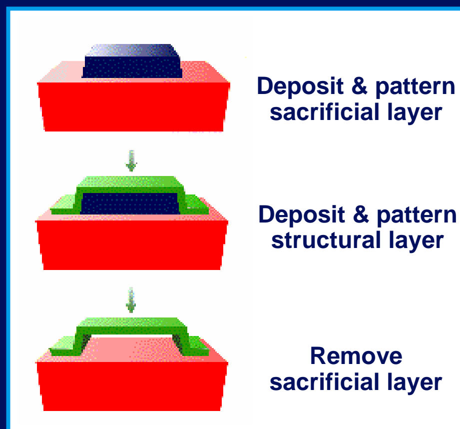
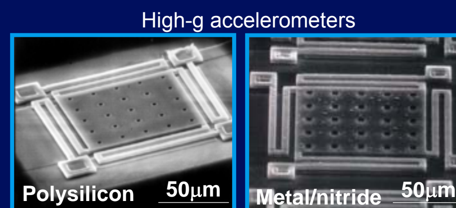
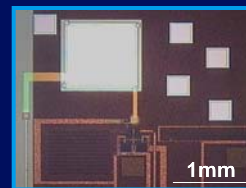
Sacrificial Surface Micromachining

- Polysilicon
- Metal/nitride (CMOS compatible)



High-g accelerometers





Microphone on CMOS

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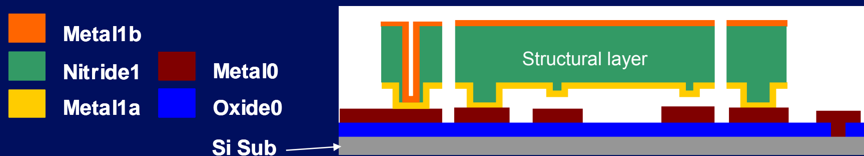
Metal-Nitride Surface Micromachining

- Optimised metal-nitride-metal mechanical layer
  - Low stress nitride as dominant structural layer (1-2µm)
    - Tailored composite residual stress (0 – 100'sMPa)
    - Low composite stress gradient (<20MPa/µm)
  - Symmetrical metallisation (0.2µm)
    - Low sheet resistance, 1 Ω/□
    - Stress balancing and reduced thermal sensitivity
  - Dry release for high yield
  - Up to 13 masks
  - Lateral or vertical monolithic integration

Metal1b
Nitride1
Metal1a
Metal0
Oxide0
Si Sub



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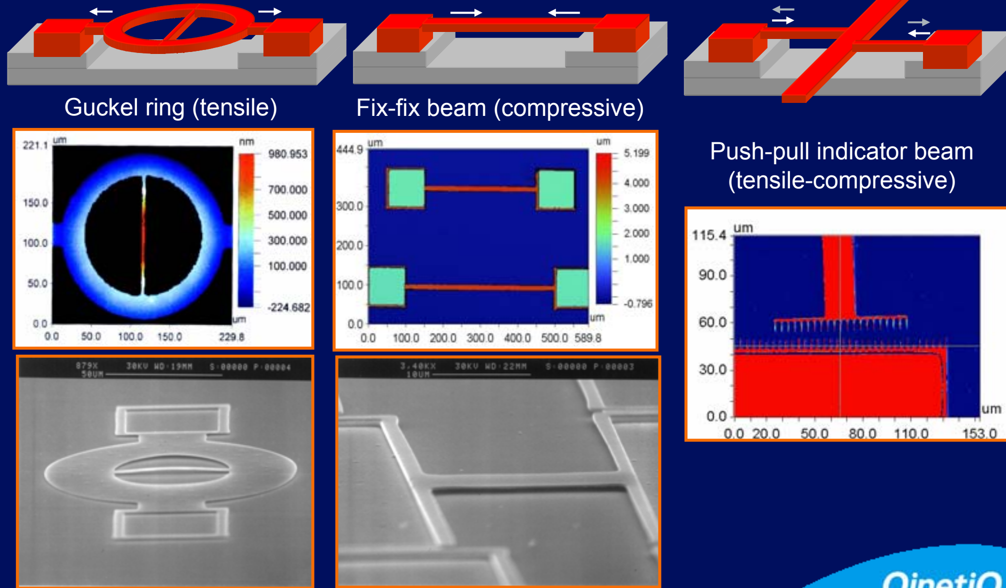
Wafer test structures: In-plane Strain (Stress)
Guckel ring (tensile)
Fix-fix beam (compressive)
Push-pull indicator beam
(tensile-compressive)
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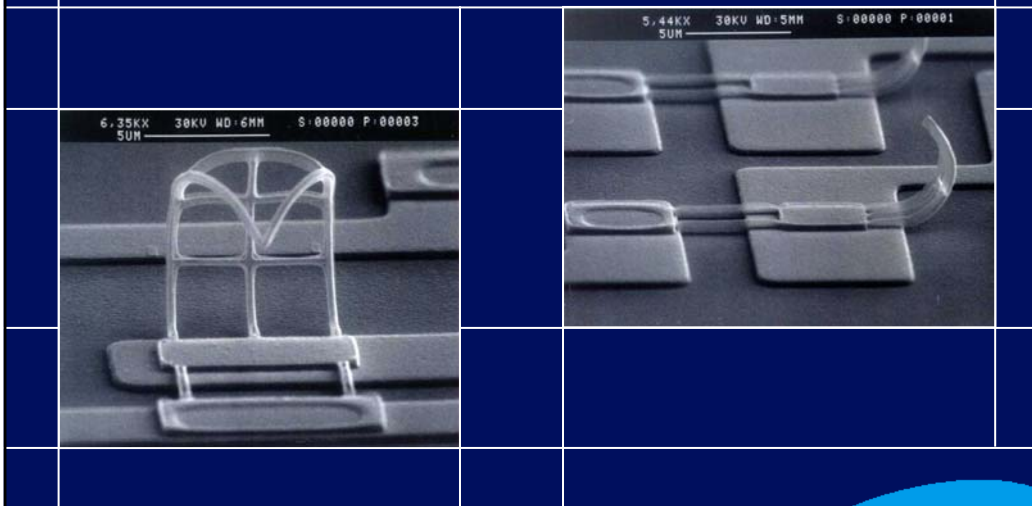
Why in-plane strain alone is not enough...
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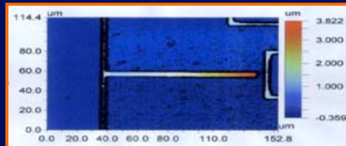
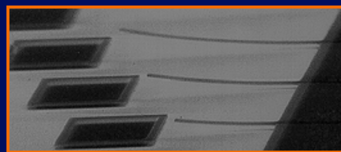
Strain (Stress) Gradient Evaluation

$$\Gamma = \frac{2 \cdot \Delta}{l^2 \cdot (1 - \nu^2)}$$

High stress gradient

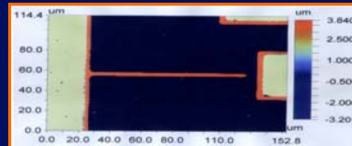


Wyko interferometric image



SEM image

Low stress gradient



Wyko interferometric image

SEM image

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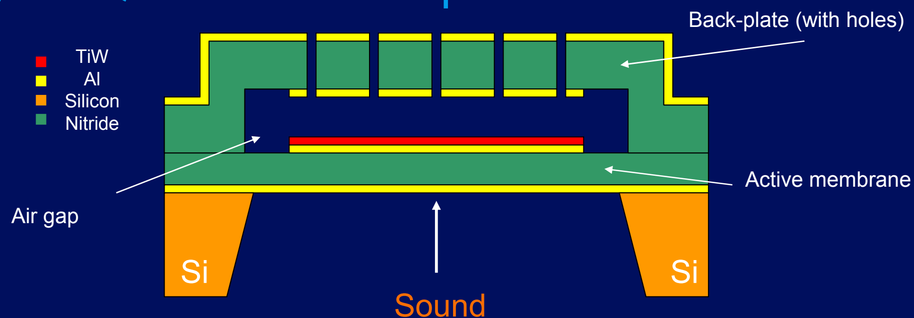
QinetiQ Generic Microphone Schematic



- Microphones fabricated using CMOS compatible Metal-Nitride surface machining process
  - Membrane: 0.2um metal / 1.0um nitride / 0.2um metal composite
  - Gap between plates: 1.2um
- Good control of layer geometry and thicknesses
  - Required for tight control over microphone sensitivity

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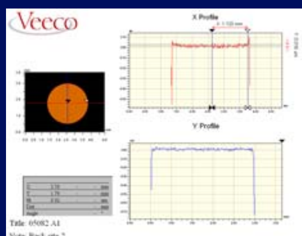
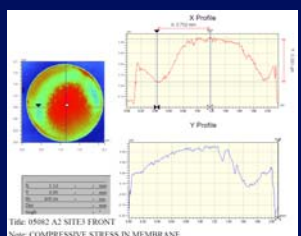
Effects of Stress on Membrane Structures

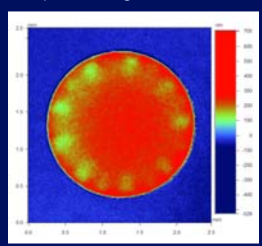


Targeted composite membrane profile



Bowed membrane due to stress control in the composite layers

Distorted membrane due to processing anomalies



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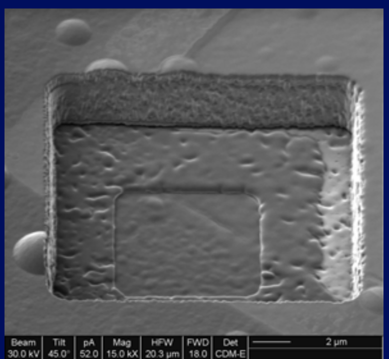
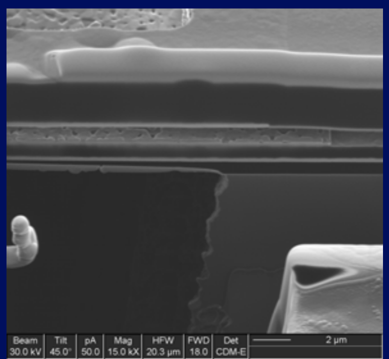
Destructive Physical Analysis to Determine Anomalies



Short circuit condition due to distorted membrane



Membrane distortion due to HARM through wafer etch

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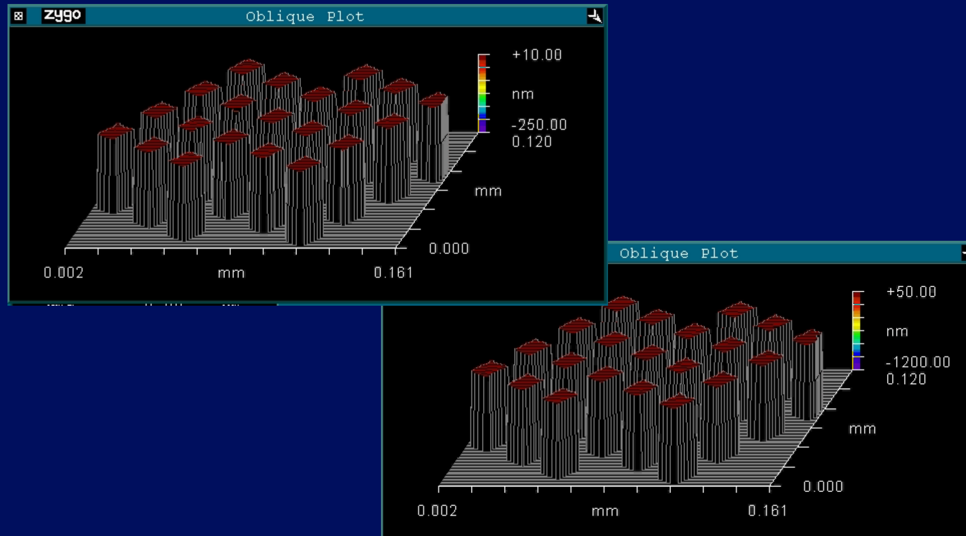
On-wafer dynamic functional test (19kHz)



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Parametric Testing

- Will require novel solutions for multi-domain testing and product qualification both wafer level and/or discrete device, for example:
  - Inertial
  - Acoustic
  - Magnetic
  - Pressure
  - Flow
  - Thermal
  - Optical
  - Electrical
  - Fluidic
  - Chemical – Biochemical
  - Etc.

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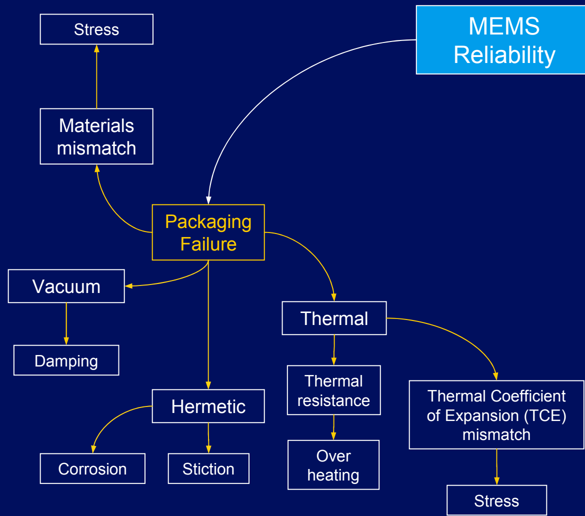
MEMS reliability issues



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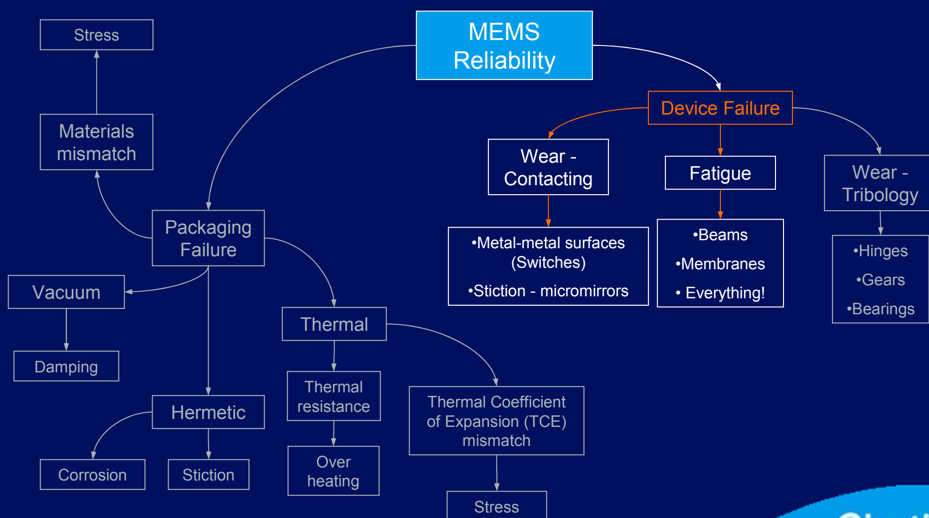
MEMS reliability issues



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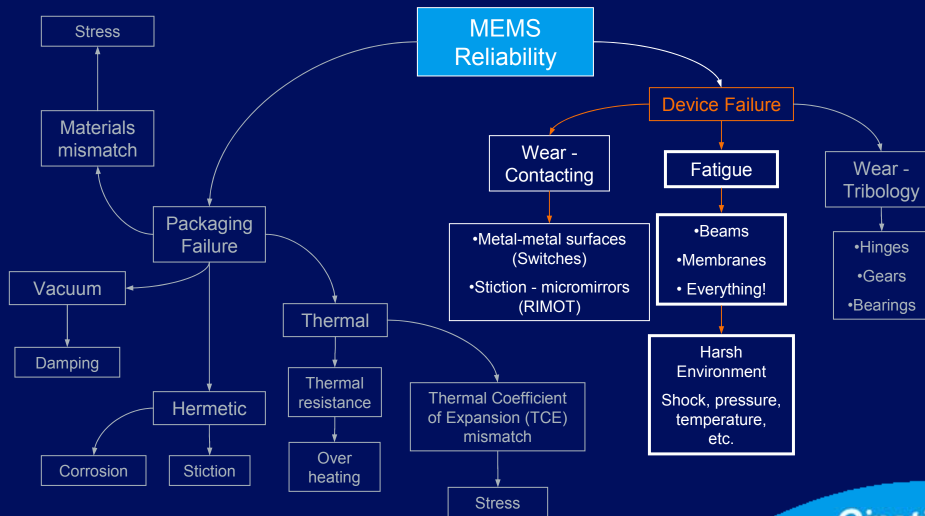

MEMS reliability issues

- Polysilicon
  - Polycrystalline
  - Relatively mature process
    - Published data from number of groups
      - Wear
      - Fatigue
  - Significant variation
    - "no two groups make the same polysilicon"
      - Depends on dopant density, microstructure, etc…….
  - Statistical nature of brittle fracture
    - Distributed nature of defects
    - Weibull analysis

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MEMS reliability issues

- SOI
  - Single crystal
    - But the surface topography can introduce defects
      - Sidewall roughness, scalloping, curtaining, etc..
      - Notching
  - Some published data but similar story
    - Need statistical approach
- Metal nitride
  - Composite amorphous brittle nitride + ductile metal
  - Little data available
    - Some on nitrides and metals

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Comments

- Off-line metrology is essential for development, determining materials properties and failure analysis of the developed process.
- Non-destructive (non-contact) in-line metrology of parameters and test structures is essential for statistic process control.
- Data fusion required to measure with <nm resolution over >mm length scales.
- Currently, it is necessary to produce expensive test structures and use ‘destructive’ metrology techniques.
- For SPC test structures are often too late and too expensive.
- Development of multi domain metrology is required for on wafer testing
  - Up to 70% of the fabrication cost for a Microsystem can be packaging.
- Reliability - statistical nature of the problem
  - Weibull analysis
  - Significant variation in data
    - “no two groups make the same polysilicon or metal nitride”

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