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Test Challenges in Multi-technology Platforms within the INTEGRAMplus Service

Chris Reeves, Workshop on Reliability & DfX Engineering for SiP Technologies, Pallanza, 29th May 2008



INTEGRAMplus Contents

- Introduction to QinetiQ Microsystems
- Some Microsystems Trends
- Introduction to INTEGRAMplus
- Testing during the Fabrication of Microsystems
- Reliability issues?
- Acknowledgements

QinetiQ Proprietary

Microsystems at QinetiQ

- MEMS activities started c.1991/2
 - Identification of MEMS as emerging disruptive technology
 - Silicon technology base from IC industry
- Largest MEMS group in the UK
 - An integrated team of about 30 staff
 - Diverse range of device and system applications
 - Advanced CAD capability
 - Dedicated MEMS fabrication facility
 - ~450m² Class 100/1000 clean room
 - Stable production worthy fabrication processes
 - MEMS materials development
 - Large portfolio of MEMS based solutions



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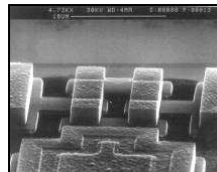
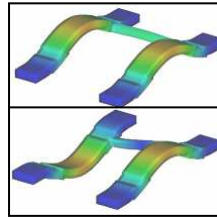
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QinetiQ Proprietary

Microsystems at QinetiQ

- One-Stop-Shop for Microsystems solutions:
 - Device Physics & Modelling
 - Microsystems design
 - Layout
 - Fabrication
 - Evaluation
 - Electronics & system design
 - Materials Characterisation



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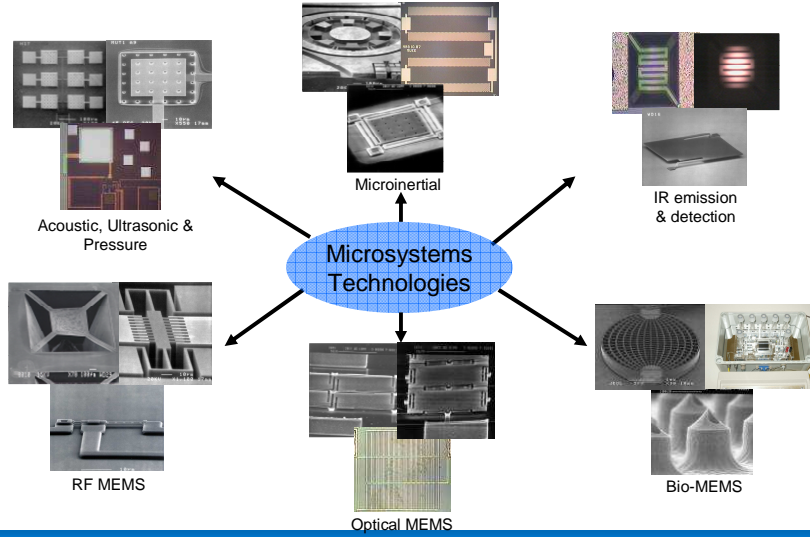
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Some Microsystems Application Areas



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Microsystems Trends: Emerging Markets

- Emerging and growing (multi-domain) markets
 - Biomedical and healthcare
 - Energy
 - Environmental
 - Aerospace
 - Security
 - Communications
- Market Predictions:
 - BioMEMS
 - est. end user sales for \$250M (2005), >\$1B by 2010 (Nexus)
 - Polymer Micro-components
 - est. €1.5B by 2007 (Yole)
 - Monolithically integrated MEMS & CMOS
 - est. \$2.1B by 2007 (Yole)

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Microsystems Trends: Smarter Products

- Increasing levels of complexity / higher levels of functionality
 - functions across multiple physical domains
 - optical
 - mechanical
 - electrical
 - fluidic
 - biological
 - physical sensors (pressure, inertial, acoustic...)
- Increased levels of integration to achieve this
 - More than just silicon technology
 - use of glass and polymer
 - Multi-technology combinations

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Microsystems Trends: Product Development Challenges

- There are significant challenges facing developers of products in these emerging markets including:
 - **multi-technology integration**
 - **multi-domain interfacing**
 - **diversity of potential solutions**
 - **lack of a virtual prototyping capability**
 - access to integrated technologies
 - cost of entry
 - time to market
 - lack of standards
 - market acceptance
 - lack of a single source across the supply chain

In-line and off-line test and measurement is critical

Reliability is essential for acceptance

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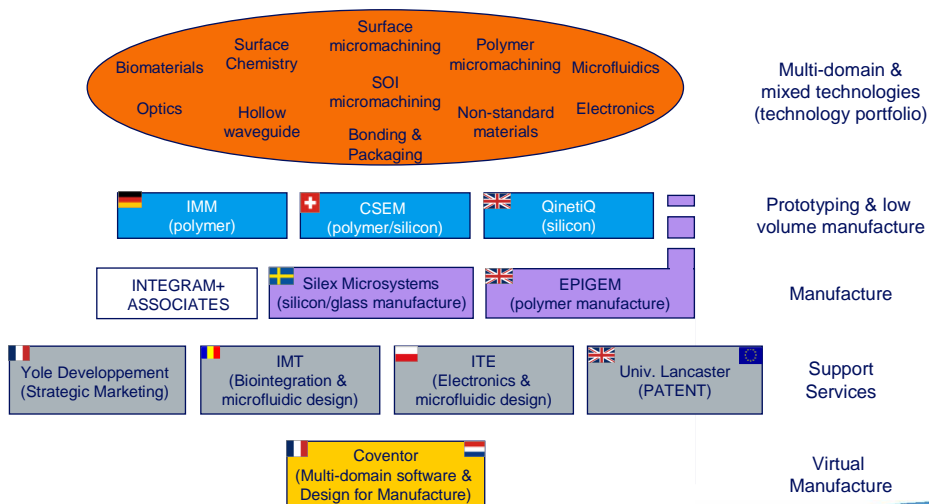
INTEGRAMplus Introduction

- European Commission Framework Six Initiative grant, lead by QinetiQ to form a pan-European interdisciplinary consortium including industry, government and academic partners.
- Consortium of complementary competences across Europe linked with a network of supply chain partners and aims to provide industry with a world-leading facility.
 - **Address and stimulate future market needs for higher levels of integration in stable, manufacturable MNT processes**
 - Multi-domain integration, mixed technologies (silicon-polymer), smart (integrated) MNT products
 - Emerging markets: biomedical & healthcare; pollution & security; et al.
 - **Provide seamless service across the MNT supply chain**
 - Concept to production
 - Bringing together complementary capabilities
 - Extended supply chain network
 - **Reduce barriers to access MNT**
 - Training and standardisation
 - Provide development platforms and standard modules
 - Reduce the cost-of-entry and promote design re-use
 - **Provide cost effective MNT prototyping services**
 - Virtual manufacturing based on Design for Manufacture principles

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Test and Measurement during the Fabrication of Multi-technology Microsystems

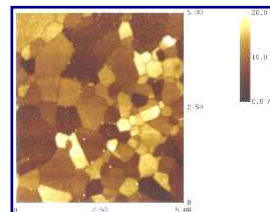
- 2 inter-related requirements (holistic approach):
 - **Process Development - Stabilisation**
 - Determine fundamental materials properties
 - Refine process flow
 - All techniques applicable
 - High proportion off-line
 - **Process Control**
 - Quality and reproducibility
 - In-line non-destructive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

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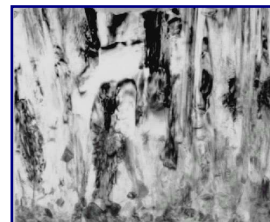
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Required Materials Metrology Data

- Composition (bulk and surface)
- Microstructure
- Mechanical
 - Strain (Stress)
 - Young's Modulus
 - Density
- Electrical
 - Resistivity & dielectric constant
- Optical
 - Reflectivity, refractive index, etc..
- Thermal
 - Thermal conductivity & heat capacity
- Etc....



AFM of metal grain structure



TEM of polysilicon

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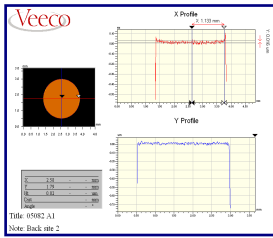
Required Dimensional Metrology Data

Parameters

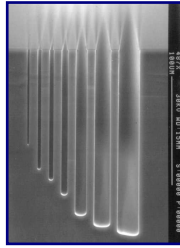
- Layer thickness
- Surface & interface roughness
- Bow of wafer & released structures
- Lateral feature sizes
- Sidewall roughness & profile

Techniques

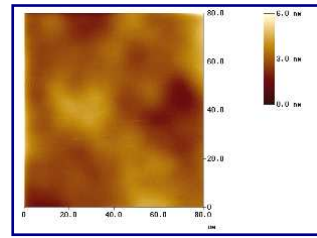
- Optical (microscopy, interferometry, SE)
- AFM, profilometry
- SEM, TEM
- Vernier alignment scales (on-chip)



3-D micro-interferogram of MEMS membrane



SEM



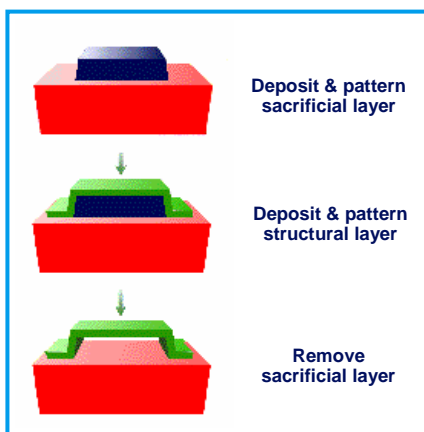
AFM – surface morphology

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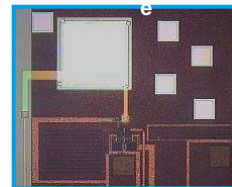
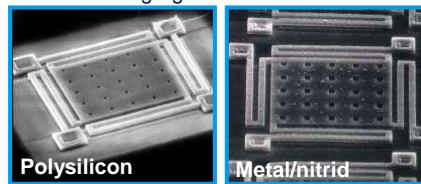
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Sacrificial Surface Micromachining

- Polysilicon
- Metal/nitride (CMOS compatible)



High-g accelerometers

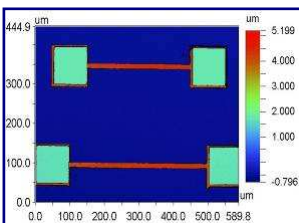
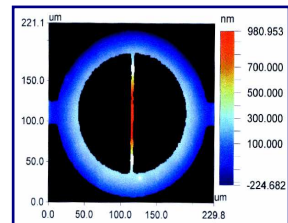
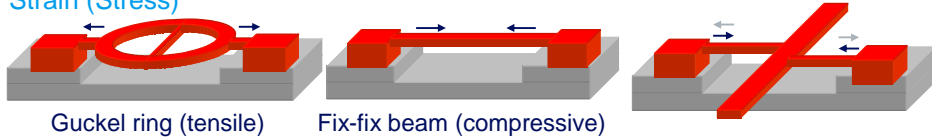


Microphone on CMOS

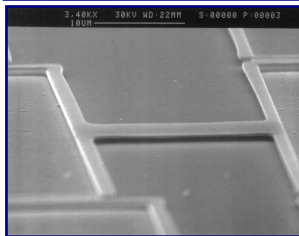
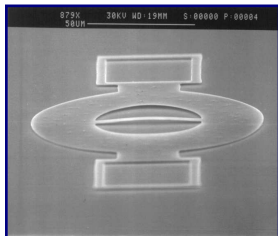
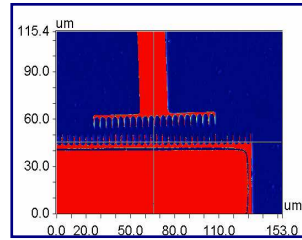
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Some Critical Aspects of Surface Micromachining: Test Structures: In-plane Strain (Stress)

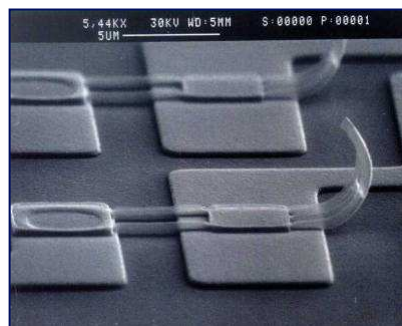
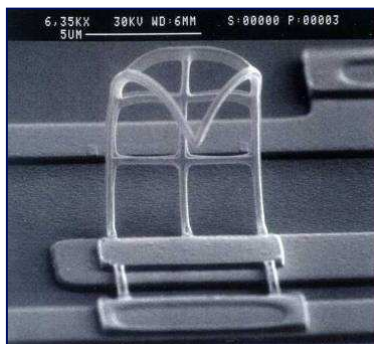


Push-pull indicator beam (tensile-compressive)



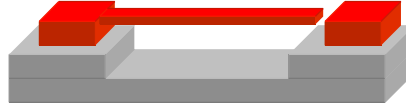
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Why in-plane strain alone is not enough...

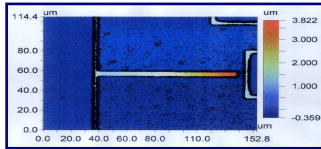


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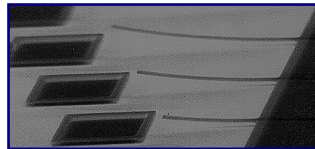
Strain (Stress) Gradient Evaluation



High stress gradient

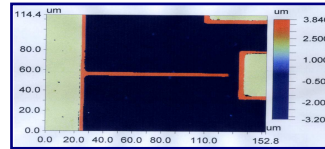


Wyko interferometric image

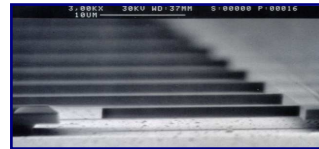


SEM image

Low stress gradient



Wyko interferometric image

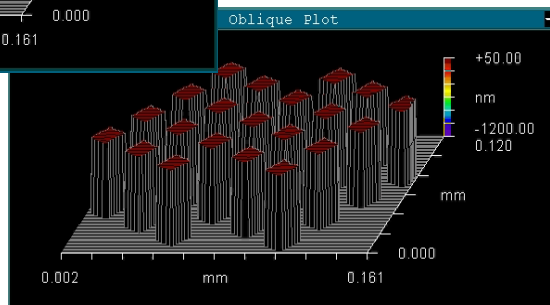
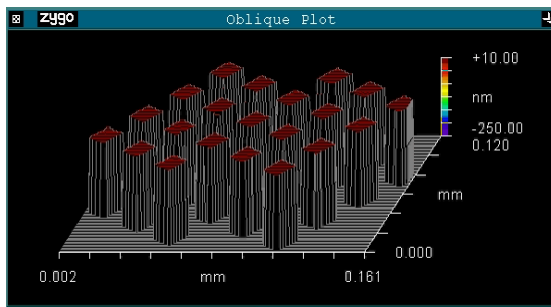


SEM image

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On-wafer dynamic functional test (19kHz)



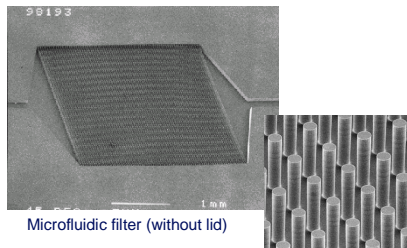
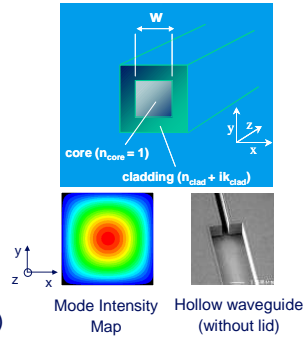
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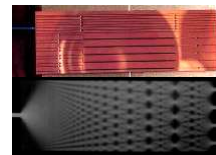
INTEGRAMplus Platforms: Multi-domain Integration

Combined microfluidic and optical platform

- Rectangular (square) cross-section light canals
 - Support single or multi-mode propagation
 - Low loss, high fidelity, broad band
 - Range of monolithic optical functions "for free"
 - Large step index confines mode to air/fluid core
 - Attenuated total internal reflection
 - Lower index wall than core (e.g. metal-coated, $n < 1$)
- Canals also act as fluidic channels
 - Dimensions suitable for microfluidics (50-125 μm)



Microfluidic filter (without lid)



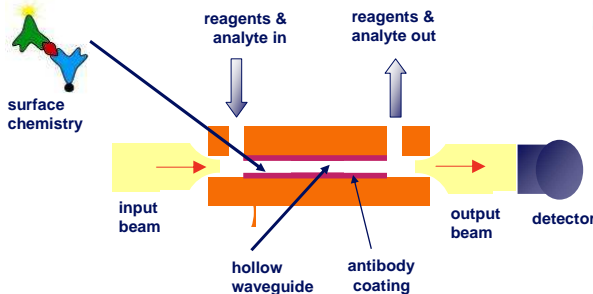
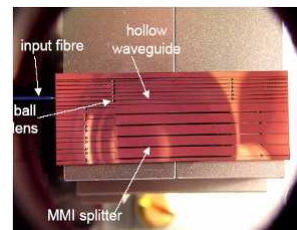
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Novel integrated microfluidic/optical bio-diagnostics detection platforms

Hollow waveguide in silicon or polymer

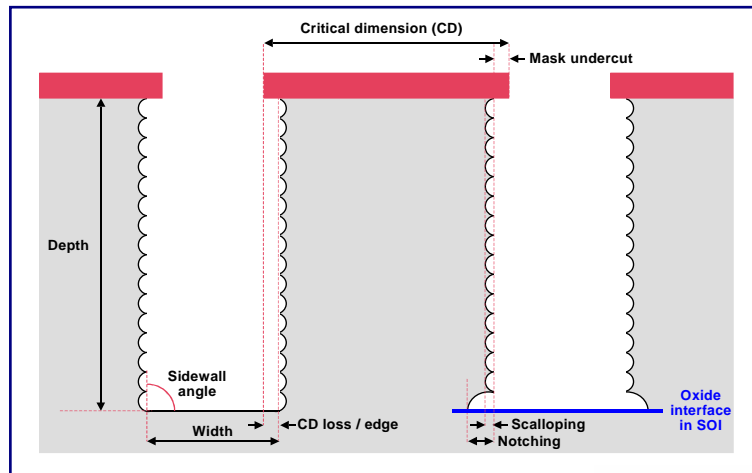
- Light and fluid guided and interact in same channel
 - Change in optical transmission or fluorescence for high sensitivity
 - Optical (cell) excitation, analysis and/or manipulation
 - Microfluidic functions easily integrated
- Ready to accept detection chemistry



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Some Critical Aspects of High Aspect Ratio Micromachining

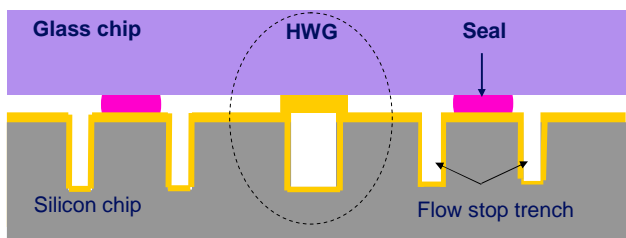
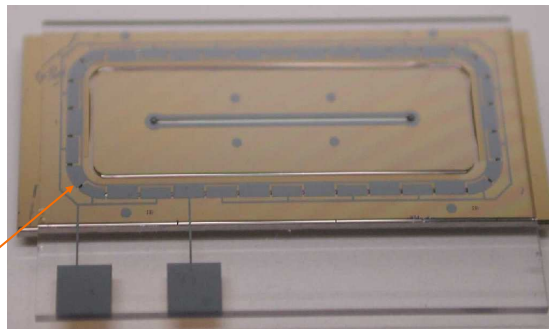


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HWG Sealing Process

- Guides defined using DRIE in silicon
 - blanket metalized
- Polymer (direct dispense) to define seal
- Glass or silicon lid
 - patterned metal
 - electrodes to detect water in seal test structures



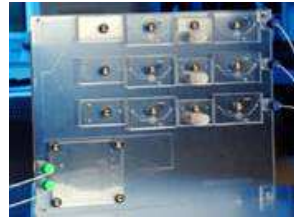
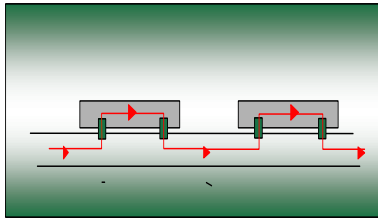
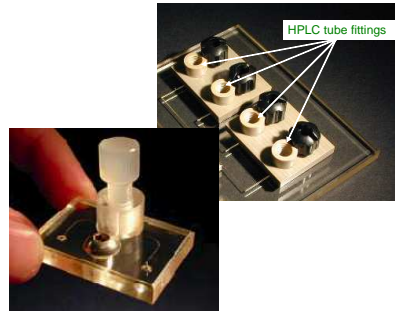
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Fluidic Interconnects

- Need to interface to macro-world
 - most standard fittings based on HPLC
 - Omnifit™, Cheminert™, Nanoport™
 - others include Microport™, Luer-Lock™, open port, capillary...
- Inter-module
 - Fluence™ System
 - based on face seal of polymer ferrule with externally applied pressure
 - rapid prototyping using standard modules on a fluidic backplane



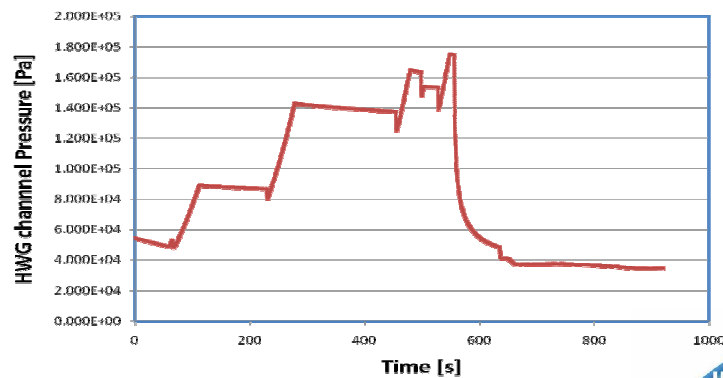
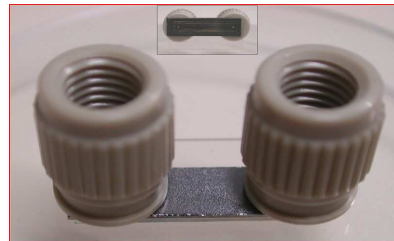
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HWG Leak Test

- Chip from previous slide with connectors fitted
 - 140kPa of maximum gauge pressure using PDMS seal



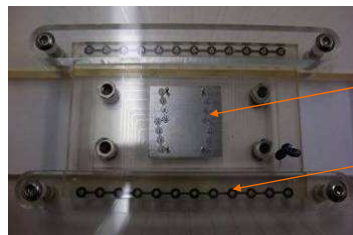
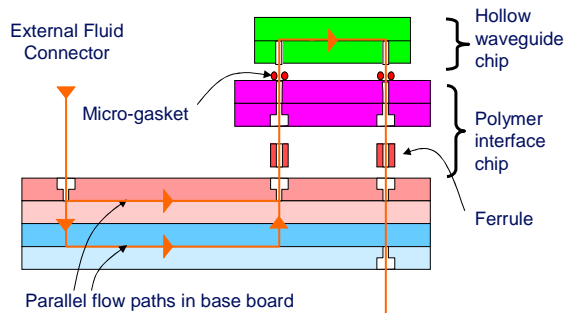
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Silicon-Polymer Microfluidic Interface Design

- Designed to fit on standard fluidic backplane
- Polymer interface plate
 - micro-gaskets to connect waveguide chip
 - external pressure gives face seal
- Intermediate layer bond of waveguide base to lid
 - low bond profile
 - low temperature
 - tolerant of non-perfect surfaces and wafer bow
- Provides flexible interconnect approach



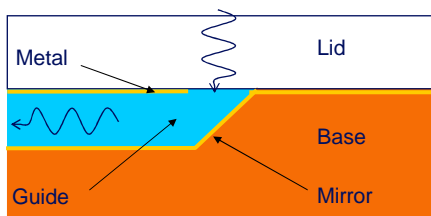
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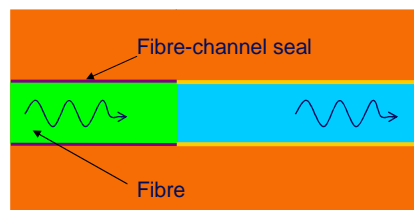
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Optical Interfacing

- 2 main routes identified:
 - free-space coupling
 - best for low-cost, disposable applications
 - couple via angled reflector through lid (wet etched)
 - fibre-coupling
 - edge coupling but simple interfacing to sources / instruments
 - requires more challenging edge seal to ensure leak tightness



Out-of-plane (cross-section)



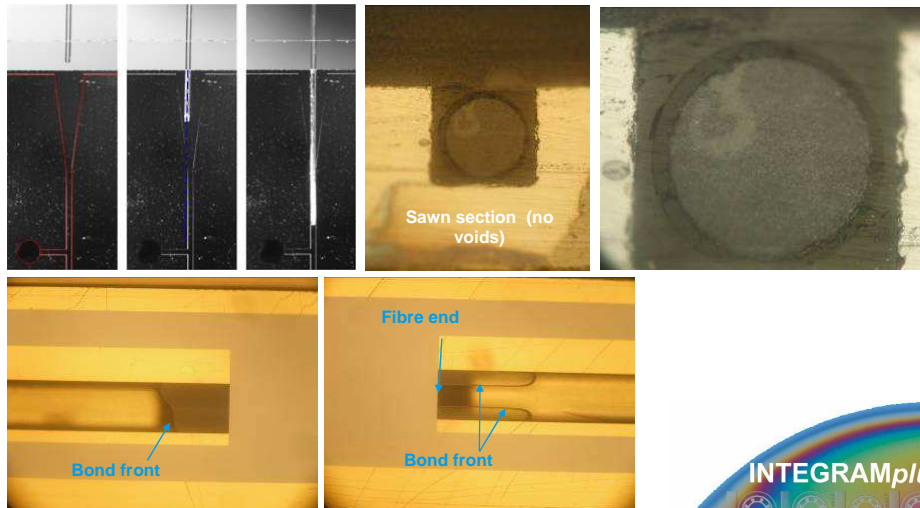
In-plane (plan view)

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Fibre Coupling to Hollow Waveguide

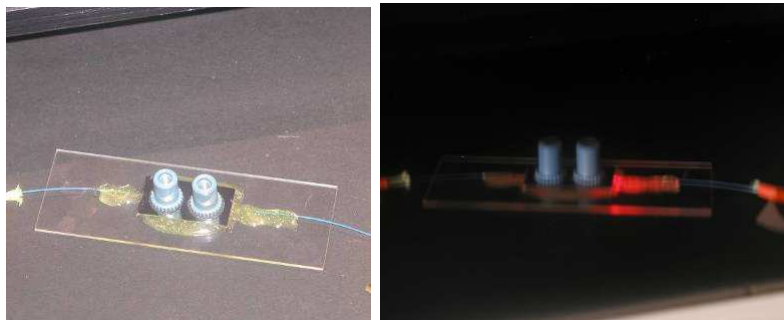
- Fibre insertion into guides
- Wicking of glue into lidded guides



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Fluid Core Hollow Waveguide Optical Tests



- Quantification of the fluorescence
 - Materials optimisation
- Coupling efficiency/loss
 - Optimise fibre : guide geometries in design
- Surface functionalisation
- Bio-diagnostic assay qualification

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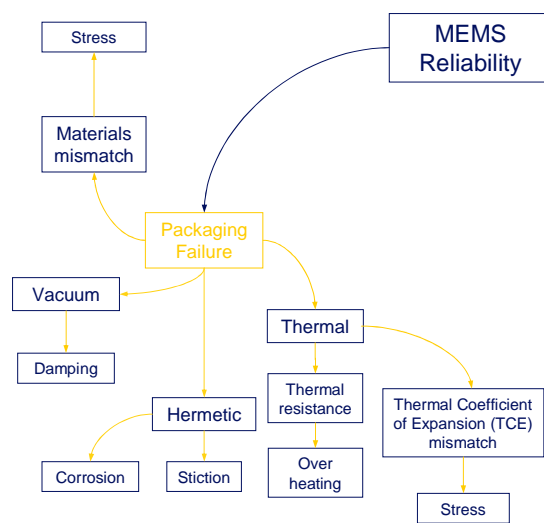
Parametric Testing

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

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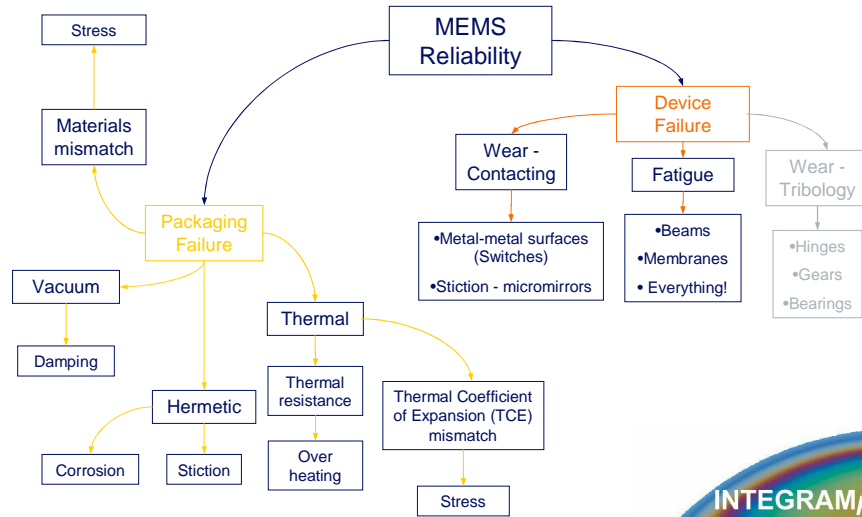
Typical Microsystems reliability issues



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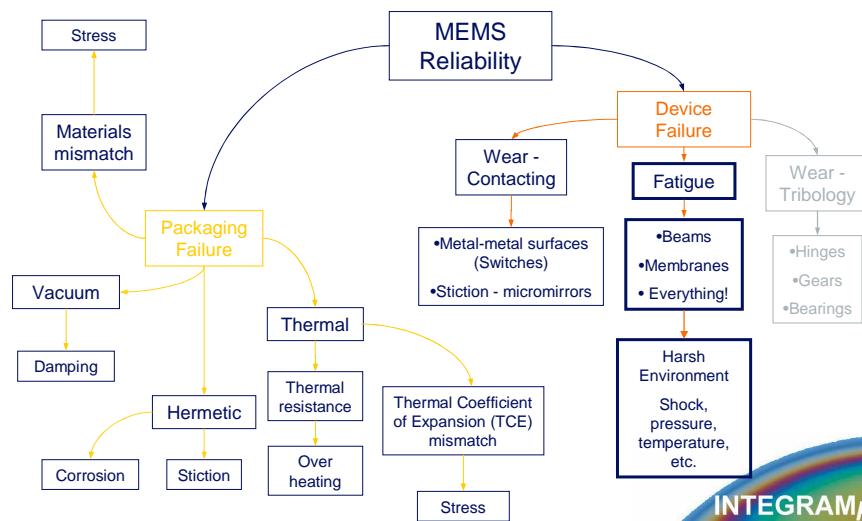
Typical Microsystems reliability issues



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Typical Microsystems reliability issues



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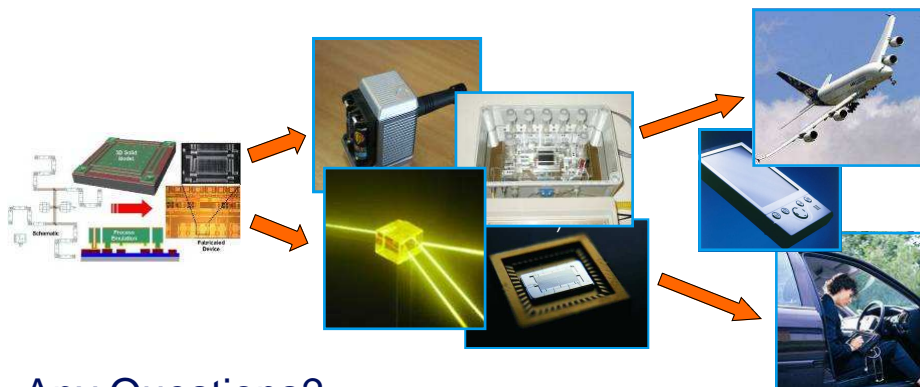
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 - Tom Harvey & Tim Ryan (Epigem)
 - Pawel Janus (ITE)
 - Gerold Schropfer (Coventor)
 - Bogdan Firtat (IMT)
 - Tomas Bauer (Silex)
 - Frithjof Von Germar (IMM)

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INTEGRAM*plus* - Big Business from Small Beginnings



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