MOEMS technologies : highlights and trends

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MOEMS technologies : highlights and trends

This activity is performed under ESA ESTEC contract.

“Micro-Optical Electromechanical Systems

Delta Space Qualification Methodology”

Team Partners involved in this study :

- **Alcatel Alenia Space**
- **MEMSCAP**
- **SERCALO Microtechnology Ltd**
- **IMEC vzw**
- **Laboratoire d’Astrophysique de Marseille – CNRS (LAM)**
- **TECNOLOGICA**

MOEMS technologies : highlights and trends

ESA has been agreed to provide the Near Infra Red (1-5 µm) multi-object dispersive Spectrograph (NIRSpec.) for the James Webb Space Telescope (JWST) the successor of the Hubble Space Telescope (HST). The use of MOEMS technology for this spectrograph and GSFC µ-shutters were then identified as a suitable concept.

Future Telecom Payloads will require optical MEMS Switching of the RF signals in order to increase the bandwidth of these systems and therefore their data handling capabilities. Micromirrors are also proposed as a technology supporting intra/inter satellites communication in future satellite constellations as well as wavefront correction in large aperture optical systems.

The area of Micro-Opto-Electro-Mechanical Systems (MOEMS) is rapidly coming to space applications and requires dedicated support taking into account that issues on Space Qualification of such micro-systems may quickly arise and must be addressed.

MOEMS technologies : highlights and trends

The goal of this work is to address the Micro-Optical-Electromechanical Systems technologies and related applications and to identify mature processes able to be used for space application in the first phase. Then, the study will define and propose a Space Qualification procedure and methodology for the MOEMS.

This study is only a preparatory exercise and will not lead to the formal Space Qualification of the MOEMS addressed in Phase 2.

The second phase of this project is to conduct a set of delta qualification tests on actual existing standard product and to refine the qualification methodology concept to be implemented in the future for Space equipment.

The paper presented here will identify some routes to achieve this goal in order to built a set of qualification and characterization tests improving those proposed in actual existing standards as TELCORDIA, MIL-STD or Space Standards.

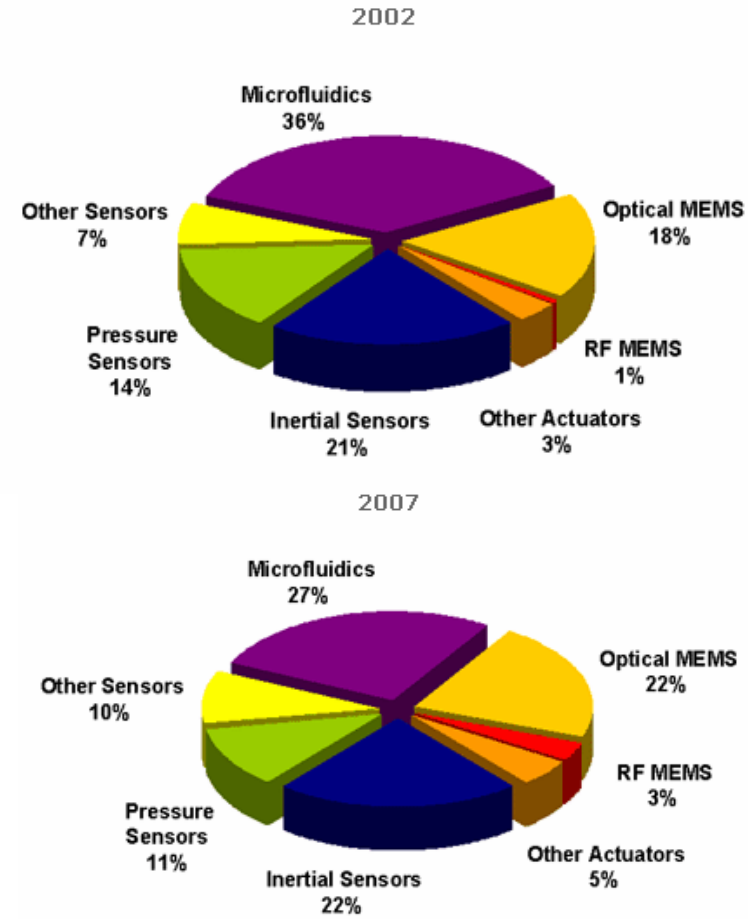
Content

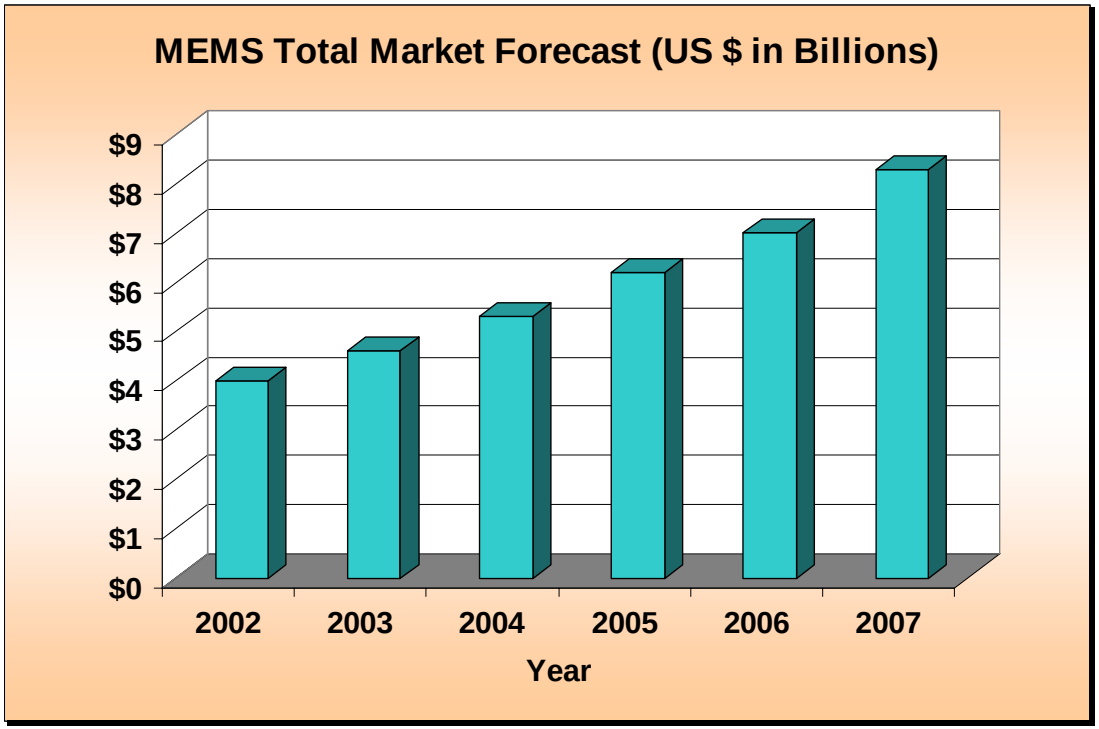
- MOEMS State of the Art
  - MOEMS market overview
  - MOEMS technologies in Space application: maturity and future prospects
- Quality and Reliability figures
  - Space environment and constraints
  - Failure mechanisms foreseen for Space application
  - Reliability issues and common failure modes
- Delta Space qualification methodology early beginnings
- Conclusion

MOEMS market trends

Share of MEMS Revenues by Device, 2002 vs. 2007

Source: In-Stat/MDR, 7/03





The foundry business in particular is growing at more than 30 percent per year.

MOEMS market overview (1)

A market survey has been conducted and help to built an internal MOEMS data base to classify the products in term of process, application, maturity, availability:

- ✓95 companies which could be market players have been identified;
- ✓Out of these, 19 companies are market players and have their own MOEMS products.

MOEMS market trends

IDENTIFICATION				PACKAGING	
MANUFACTURER	COUNTRY	PRODUCT TYPES (product manufacturer reference)	TECHNOLOGY (process name or type of technology)	REFERENCE (yes, no, if yes, package reference)	DIMENSIONS LxlxH (package reference)
Active				no	5,4 dia - 16,6 L

MARKETING				
APPLICATION (telecom, space&defense,	FAMILY (sensors, attenuator, cross connects, data transmitters, optical	MARKET SURVEY (R&D,	MATURITY (use	AVAILABILITY (specific product Not Available (NA), standard Off the

MAIN PERFORMANCES							
INSERTION LOS	ISOLATION	RESPONSE SPEED	CONSUMPTION (total	POWER SUPPLY (V	TEMPERATURE RANGE (max and min	WAVELENGTH	OTHER
< 0,7							

QUALITY		OTHER	
QUALIFICATION STATUS (Telcordia, other)	QUALITY LEVEL (commercial, military, ground, space, other)	WEB SITE	DOCUMENT REFERENCE AND BIBLIOGRAPHY

back next

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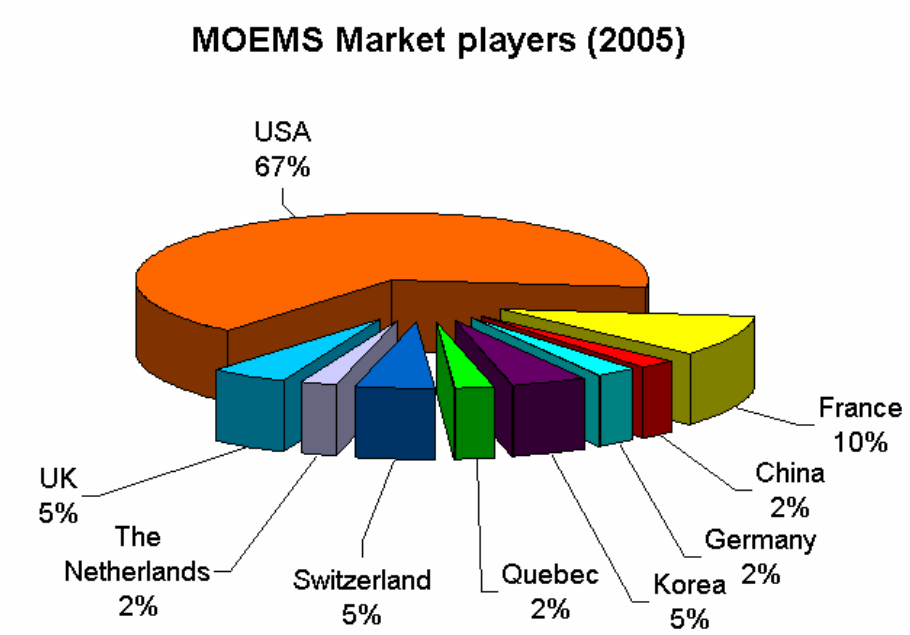
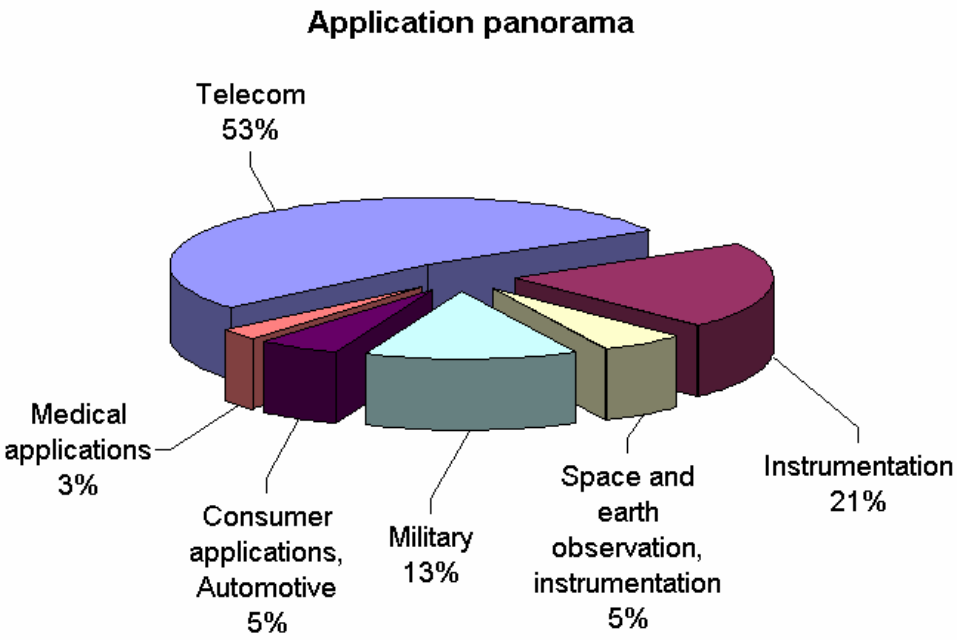
MOEMS market trends





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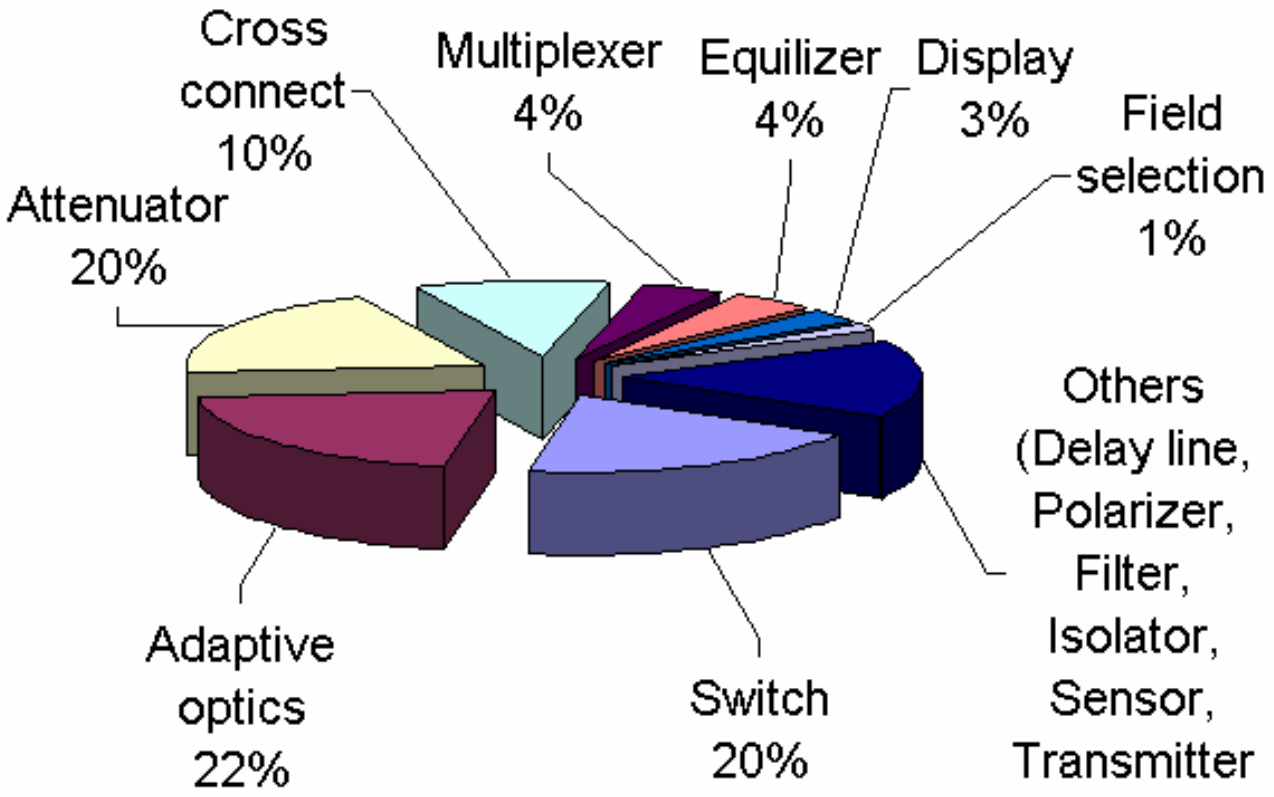
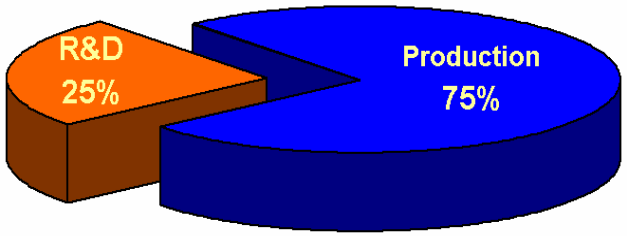
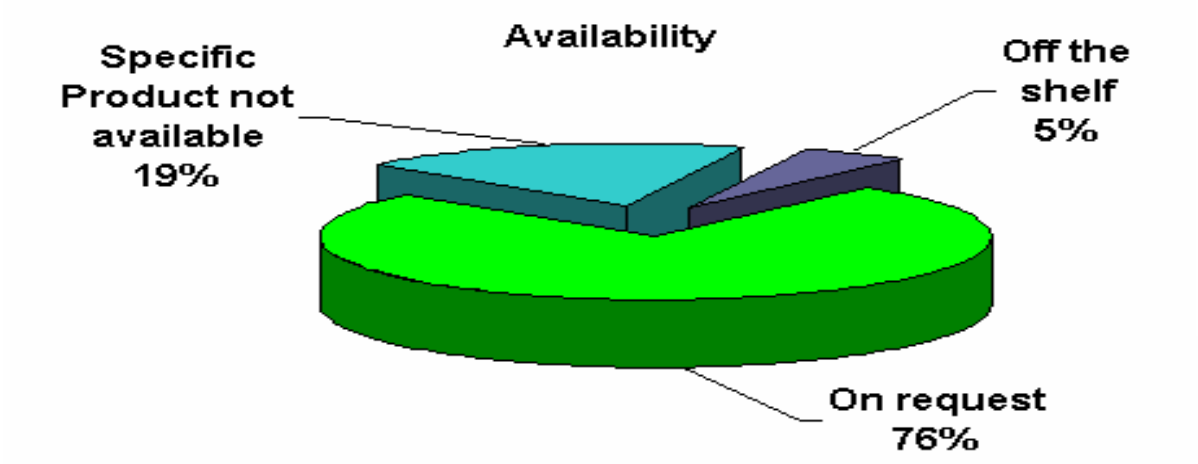
MOEMS market trends

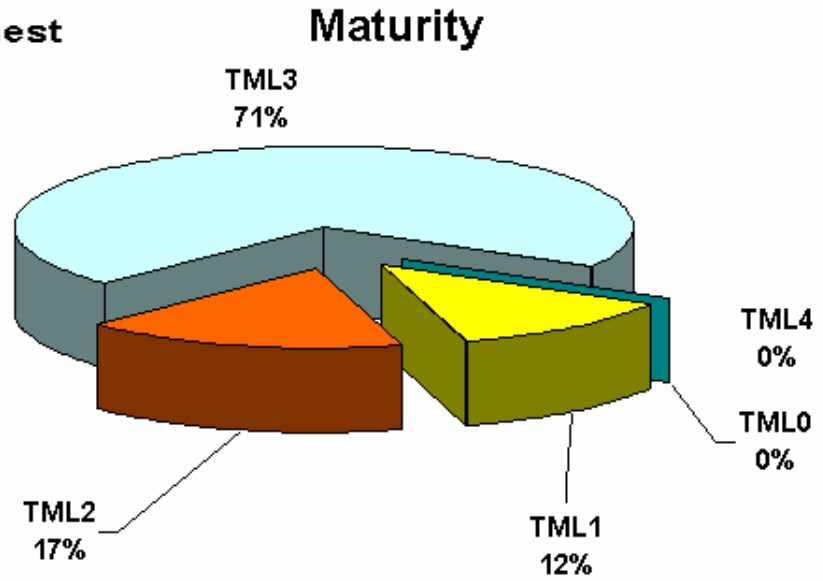
Family panorama





MOEMS market trends





Technology Maturity Level (TML) definition

	PRODUCT AVAILABLE	PROCESS REPRODUCIBLE	PRODUCT EVALUATED	PRODUCT QUALIFIED
TML0	Y	N	N	N
TML1	N	Y	N	N
TML2	Y	Y	N	N
TML3	Y	Y	Y	N
TML4	Y	Y	Y	Y

Quality and Reliability figures

- Space environment and constraints
- Existing failure mechanisms
- Failure mechanisms foreseen for Space application

Quality and Reliability figures

Space environment and constraints

- Humidity and salt atmosphere before launch
- Vibration and shocks during launch
- From room temperature to –120°C in 3’ during launch (freezing, outgassing, …)
- in flight constraints
  - ✓ Microgravity
  - ✓ Vacuum
  - ✓ Radiation
  - ✓ Extreme Temperatures

Existing failure mechanisms

To increase the performance and reliability of the system under design, MIL-HDBK-1547 defines rules to use Electrical, Electronic, Electromagnetic, Optical and Mechanical parts. Such products are considered aging sensitive, when they are subject to gradual shortening over their useful life. Aging mechanisms include the following:

- Loss of hermeticity,
- Stress relaxation,
- Oxidation and Corrosion,
- Outgassing,
- Cold flow and Creep,
- Loss of adhesion,
- Embrittlement (including thermal) and Hardening,
- Loss of Torque,
- Loss of Spring Tension,
- Electromigration,
- Parameters drifts
  - Current Leakage,
  - Breakdown Voltage,
  - Forward degradation,
- Molecular cross-linking
- Annealing
- Moisture absorption
- Radiation effects
- Through put
- Actuation speed

Existing failure mechanisms

Foreseen failure mechanisms for MOEMS are those existing for terrestrial application including Mechanical, Electrical and Optical.

➔ Mechanical

- Contact: Friction, Wear, Stiction
- Flexing: Fatigue, Work Hardening, Fracture
- Thermal Coefficient Mismatch
- Delamination, Residual Stress Compensation
- Creep, Plastic Flow
- Shock and vibration resistance
- Hermeticity

Failure mechanisms for MOEMS for terrestrial application:

➔ Electrical

- Corrosion, Oxidation
- Galvanic corrosion
- Shorts, Opens across dielectrics
- Charging effects in dielectrics
- Arcing
- ESD

➔ Optical

- Corrosion, Oxidation of reflector
- Grain Growth, Islanding
- Optical surface quality (shape, roughness)
- Mirror location precision

Foreseen failure mechanisms due to Space environment

➔ Vacuum and microgravity

- Hermeticity is not perfect (air or fluid leak), this might induce collateral effects on other equipments and components as :
  - ✓ Mechanical damp down loosing (air or fluid cushion); as a consequence, satellite micro-vibration may induce parasitic effects due to the combination of cumulated environment conditions (vacuum and temperature);
  - ✓ Contaminant Atmosphere may be modified around the satellite (used materials need to be in accordance with Authorized Material List and rules for flight hardware; see MIL-HDBK-1547C now AEROSPACE REPORT NO. TOR-2004(3909)-3316 March 23rd, 2004 section 2000 Material requirements);

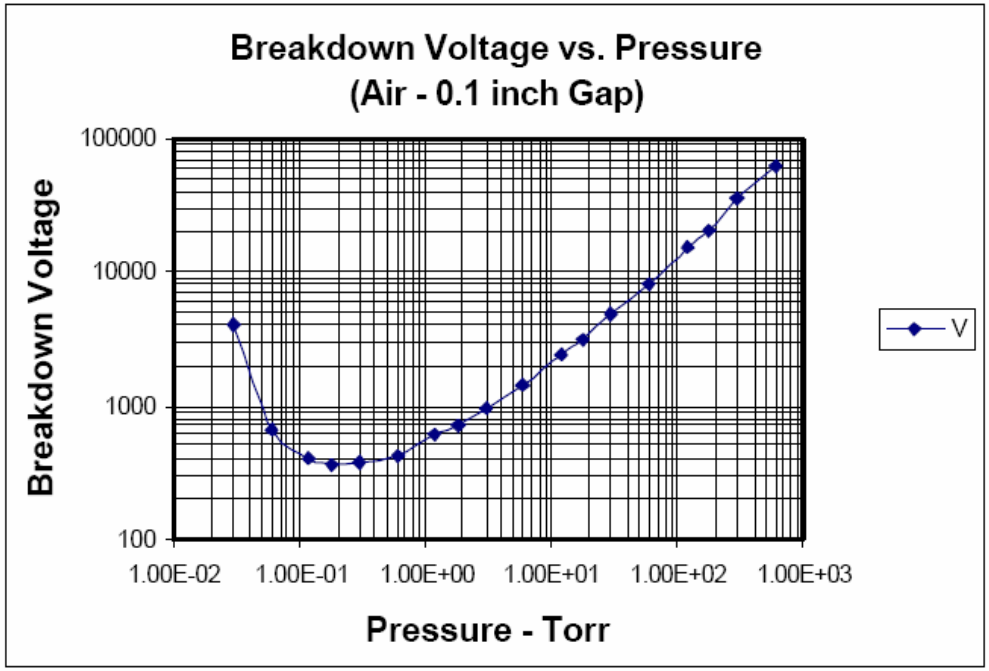
➔ Vacuum and microgravity (contn'd)

- Dust contamination inside package (due to wear and corrosion) may flown under micro-gravity and induce possible mechanical locking of actuators (unless Van der Waals force might capture them);
- Desorption mechanisms, outgasing, material vaporisation may be activated under ultra vacuum, radiation and thermal constraints.

➔ Vacuum and microgravity (contn'd)

- Electrical discharge (flashing) due to Paschen or even Corrona effect when the critical pressure is reached.

"Paschen Curve" for air, two flat parallel copper electrodes for pressures between 3x10-2 torr and 760 torr



➔ Radiation

- When using passivation or glassivation layers, radiation level may induce charge trapping and parasitic drift biasing on the actuators ;
- Heavy ion bombardment may induce atom displacements and crystal defects ;
- Total Ionising Dose may induce charging effect as observed on teflon and cables under high level ; question is open for other macromolecular materials when used (fluids or other);
- Radiation may change mechanical behaviour (tribology) and physical properties (change in transparency for example) of macro-molecular materials if any ;

➔ Radiation on optical elements (contn'd)

- Only Space Qualified fibers are allowed (if not, properties are sensitive to radiation)
- Mirrors may be contaminated by residual atmosphere around the satellite and be activated by radiation flux (also related to material or protection used)

Quality and Reliability figures

Reliability issues and failure modes

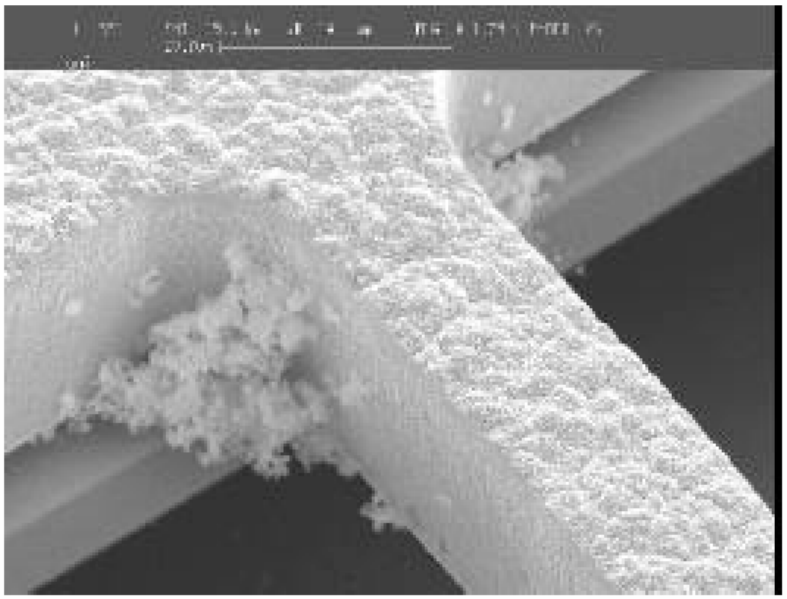


Figure 7. SEM picture of metal dust (chaff) generated due to heater touching the actuator observed after ~ 1E8 cold switching cycles.

A. Teverovsky and A. Sharma from NASA. ''Analysis of failure modes and mechanisms in thermally actuated micromachined relays for harsh environments space applications''

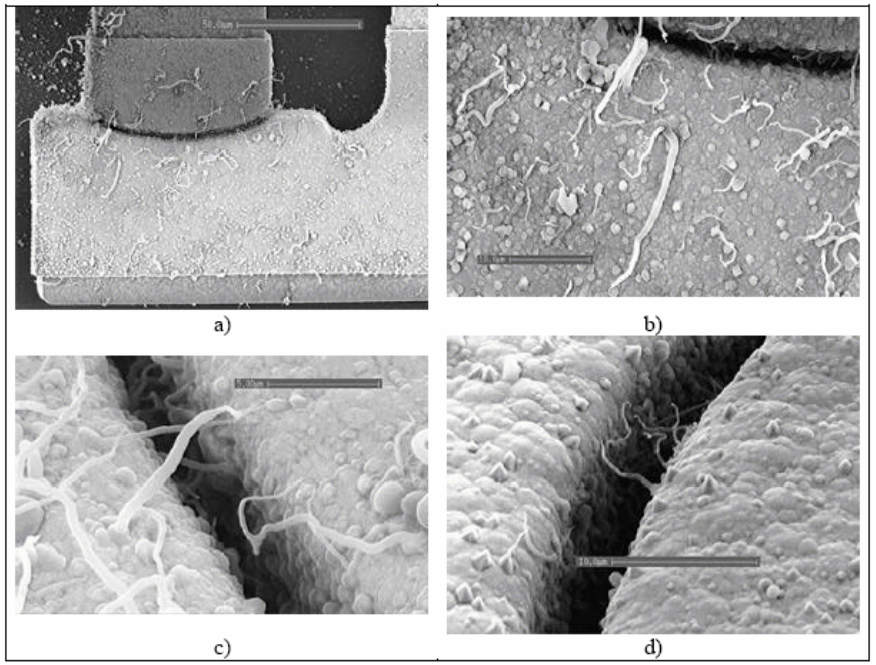


Figure 4. Grass-root-like whiskers had lengths of 10 μm to 20 μm and diameters of approximately 1 μm.

A. Teverovsky ITC 2003''Introducing a new number to the family: Gold whiskers"

Delta Space qualification methodology

Delta Space qualification methodology early beginnings

Qualification methodology Goals :

- To identify existing reliability test methods relevant for Space environment stress: assessment and risk mitigation,
- Balance each test method with respect to advantage and drawback, effectiveness, implementation,
- For two existing commercial MOEMS, to define a delta qualification programme based on existing TELCORDIA standards and propose specific tests for a full space qualification programme,
- To define associated tests condition and stress level,
- To perform a double qualification test programme exercise.

Test program assessment

MIL-STD-883 are the basic tests methods used for high-rel qualification and screening of EEE parts.

These tests methods are already part of various generic specifications including :

ECSS-Q-60-05 for Hybrid microcircuits

ESA-SCC 9010 for Integrated microcircuits

ESA-SCC 3702 for Switches

ESA-SCC 3602 for Relays, Electromagnetics

TELCORDIA GR-1209 for passive optical components

TELCORDIA GR-1221 for Reliability Assurance for passive optical components

TELCORDIA GR1073 for single mode fiber optic switches

Test program assessment

Most relevant MIL-STD-883 tests method for mechanical tests are:

Moisture resistance (m1004.7): Fast, parts to corrosion sensitivity,

Temperature cycling (m1010.8): reveals CTE mismatch, wear,creep failure,

Thermal shock (m1011.9): reveals CTE mismatch, fast, many samples for statistics,

Internal Water Vapor content (m1018.4): RGA may be necessary for other element contents,

Seal test (m1014.11): may be inefficient when using fiber connectorization

Radiation tests for fiber, mirrors, actuators element characterization.

Test program assessment

Most relevant MIL-STD-883 tests method for life tests are:

Endurance test (m1033): for operation on-off cycling, not good for stiction, depending on actuation principle. To be adapted.

Burn-in test (m1015.9), Life/reliability test (m1016.1), Steady State Lifetest (m1005.8), Agree Life (m1007), intermittent life (1006): not good for stiction, Arrhenius law characterization, applicable for infant mortality or known failure mechanism, requires DOE. To be adapted.

Test program assessment

Most relevant MIL-STD-883 tests method for Environmental tests are:

Mechanical shocks (m2002.4): including under dynamic driving conditions. As per TELCORDIA is 500 G, 1 ms compared to Space Standards is 1500G, 0,5ms.

Vibration Fatigue (m2005.2): representative of actual environment (acoustic noise during launch) ; test to be assessed according to resonance frequencies of mechanical elements.

Radiation tests: to be assessed and implemented.

Conclusion

Optical MEMS trend market has been presented and maturity was assessed for a delta Space qualification methodology.

Existing failure mechanisms on MOEMS have been balanced in term of Space constraints in order to establish a qualification test program methodology.

The second phase of this project will be conducted on two commercial products in order to validate this methodology.