Reliability of MEMS/MOEMS/BioMEMS/ Lab-on-a-chip

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Introduction

- Microsystems: MEMS/MOEMS/BioMEMS/Lab-on-a-chip, etc.
- Packaging and testing of integrated circuit is well-advanced
    - Maturity of IC industry
    - Wide applications
    - Availability of infrastructure
- Packaging and testing of Microsystems is not well advanced.
- No standard microsystem device packaging is available

Fundamental differences: IC and MEMS

- Standard packaging needs to be protected from the environment.
- MEMS packaging needs to be designed to react with the environment.

MEMS, LOC for Space

- Propulsion systems
- Thermal control systems
- Power systems
- Inertial guidance systems
- Attitude control systems
- Command and control systems
- Communication and radar systems
- Space environmental sensors
- Distributed semiautonomous sensors Interconnects and packaging
- Lab-on-a-chip

Space applications

- **Science instruments**

  (Remote sensors, bolometers, thermopiles, Golay cells,), shutters, filters, micro fluidics, lab-on-a-chip, pointing and steering devices, deformable mirrors, adaptive optical elements, gratings, RF MEMS, electronic nose, etc.
- *In-situ* sensors such as penetrators and magnetometers.
- Inertial guidance, accelerometers, gyroscopes, etc.
- Propulsion, thrusters, micro valves
- State-of-the-health-monitoring, active thermal mechanical structures.
- Lab-on-a-chip

MEMS/LOC Life-cycle

- Development of MEMS/LOC development(TRL 1-2)
- Assembly/Packaging studies (TRL ~3)
- Qualification studies (TRL ~4-5)
- Integration studies (TRL >5)
- Launch (TRL >8)
- Operation (TRL >8)

Note: TRL values assigned approximately

Qualification from Mission Assurance point of view

- Identification of technology failure modes
- Certainty of non-failure modes during the life of the mission
- Define project requirements
- Assess and characterize with reference project requirements
- Extensive qualification processes (Vibration, thermal cycling tests, etc.)

Integration of MEMS, Microfludics, and Advanced Packaging

- MEMS/LOC offer significant promise for future space systems.
- They can realize functions in a fraction of size, weight, and power of macro-scale functions
- MEMS design enables significant miniaturization this will be impossible if packaging is neglected for system applications.
- Additional components for signal processing and interfacing.
- Tremendous interest in MEMS, microfludics, LOC and little research on advanced packaging. Very poor integration of these three.

MEMS on a single chip

- MEMS can be integrated with associated electronics on the same chip to produce better electrical output.
- Integration can be done in the same wafer level or through wafer bonding or utilizing multi-chip module carriers.
- Lab-on-a-chip will be of similar in nature, but you will have added extra components and other problems associated with chemical reactions.

Technology related issues

- Special application of science and engineering
- Systems engineering and its design
- Components, their design and assembly
- Thermal management
- Radiation environment
- Life cycles prediction and assessment
- Over all reliability

Infrastructure issues

- Die specific issues
- Reduction die size
- Increase in input/output count
- Qualification (Technology acceptance for NASA applications)
- Availability of standardized packaging support
- Computer aided design.

Interconnections

- Wire bonds
- Tape automated bonding
- Flip-chip
- Area array packaging
- Direct metal deposition
- Conductive adhesives
- Finer line width wire bonds, etc.

MEMS Reliability

- Reliability requirements for various MEMS will be significantly different from one application to another application when systems incorporating MEMS, LOC are unique.
- Standardized reliability testing is not possible until common set of reliability requirements are developed.

Factors influencing Package Reliability

- Residual stress
- Stress relief
- Hermeticity
- Thermal performance
- Chemical stability
- Protection during packaging
- Shock resistance
- Electrical isolation
- Cost issues

Packaging Reliability Concerns

- Typical mechanical fatigue
- Cleaning stiction
- Contamination
- Tribological behavior
- Fatigue on polysilicon
- Media compatibility
- Passivation
- Alternative chip mounting techniques

Over all Failure Mechanisms

- Uniform corrosion
- Localized corrosion
- Galvanic corrosion
- Silicon etching
- Polymers swelling
- Polymer dissolution
- Interfacial permeability
- Adhesive strength
- Fatigue crack initiation
- Fatigue crack propagation
- Environmental assisted cracking
- Creep, etc.

Microsystems Reliability and Key Failure Mechanisms

- Failure by stiction
- Environmental induced failures
- Cyclic mechanical fatigue
- Dampening effect
- Delamination
- Corrosion
- Materials incompatibility

Physics of failure methodology

- Application, environment, life time expectation, sample selection, etc.
- Testing of MEMS at varied stress levels.
- Analysis (Statistical analysis, life time distributions, physical analysis, etc.)
- Failure mode, site, and mechanism determined.
- Models established, reliability, and quality evaluation.

Space systems

- Qualification of devices for space systems
- Reliability
- Battery of test methods to establish above to validate the efficacy of MEMS
- Variety of MEMS, Micro fluidics, LOC configurations makes difficult in terms of qualification procedures.
- Building in quality of MEMS, LOC, etc.

Process development

- Development of new materials for the application
- Device and system design
- Fabrication techniques
- Packaging/assembly methods
- Test and characterization tools

Potential materials

- Single crystal silicon
- Polysilicon
- Silicon nitride
- Silicon dioxide
- Silicon carbide
- Diamond
- Shape memory alloys
- Giant magenetoresistive materials
- Etc.

Understanding material properties

- Material properties of existing MEMS materials
- Development of new materials
- Very important to know
  Modulus, residual stress, reflectivity, chemical, electrical, thermal, etc.

Future MEMS Implementations

- Miniature and reconfigurable micro-nano spacecraft.
- Merger of MEMS, LOC, Micro fluidics, and advanced packaging.

CONCLUSIONS

- Advanced packaging has been in use to miniaturize the satellite platforms. MEMS, LOC represents new frontier, especially when combined with advanced packaging and microelectronics.
- MEMS and LOC could lead to small and capable satellite systems, adequate for a variety of space mission roles provided advanced packaging issues are addressed in advance.
- Reliability and quality assured packaging, integration of MEMS, LOC could provide the infrastructure necessary to enable the construction of true micro/nanospacecraft without compromise.

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