MEMS RELIABILITY: FMEA

FMEA: Failure Mode Effect Analysis

is "a systematic and structured study of the potential failures that might occur in any part of the MEMS to determine the probable effect of each on all other parts of the system and on probable operational success, with the aim of improvement in the design, product and process development". **FMEA can be used to determine which failure mechanisms have to be addressed during reliability testing.**

How

List the failure mechanism (the physics behind the failure), the failure defect (what one sees), the failure mode (what one measures) and the failure cause (what causes the defect to occur) and assigns three numbers:
- Severity: Estimation of the severity of the defect by a number between 10 (very bad) and 1 (no problem).
- Occurrence: Estimation of the probability that a certain failure mechanism will occur.
- Detectability: Ranks the detectability of a certain defect during inspection (detect/screen failures in order to avoid later in-field failures).

RPN (Risk Priority Number) = severity (S) x occurrence (O) x detectability (D)

The failure mechanisms with highest RPN have to be addressed first.

Additional information that can be added for reliability test:
- Acceleration factor: how can the failure be accelerate and tested (if available).
- Where, when does this kind of failure occurs. Ex. in space; during processing, during packaging, in-use, in regions with very low temperature, only at high power conditions etc.
- Is the failure mechanisms typical for this device or more general

Capacitive RF-MEMS switch

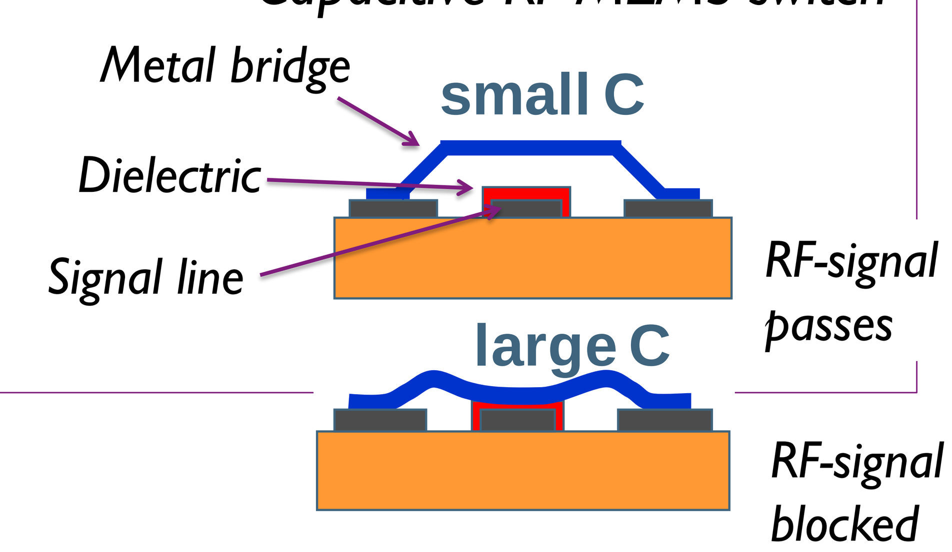
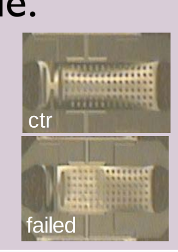
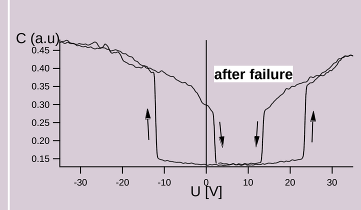
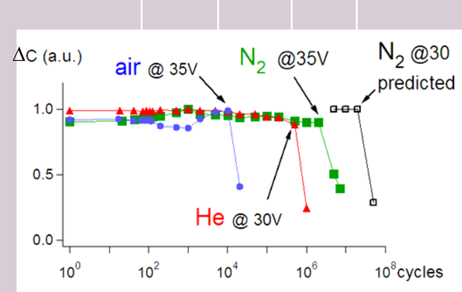
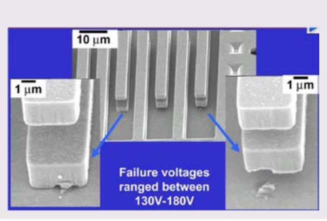
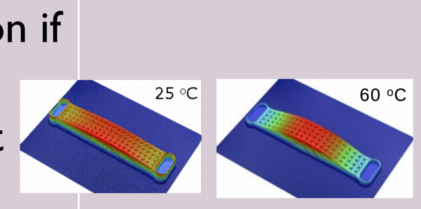
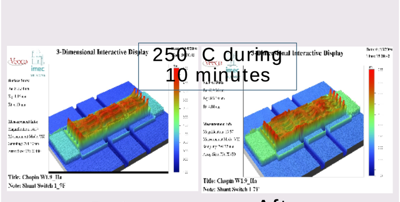
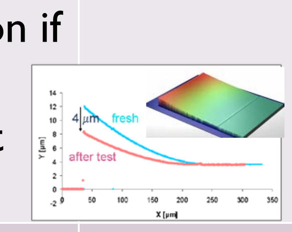
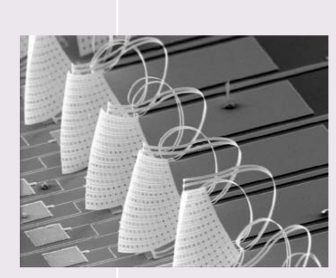
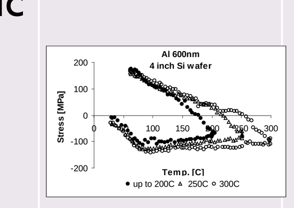
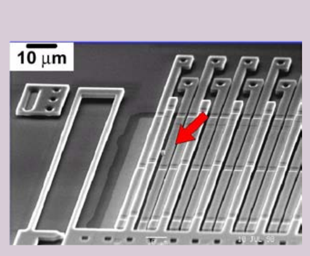
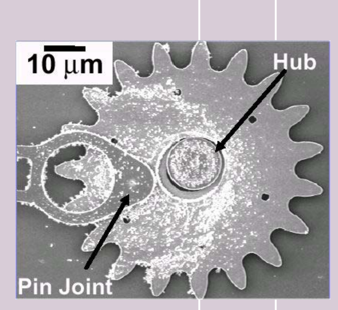
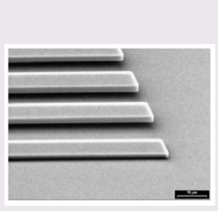
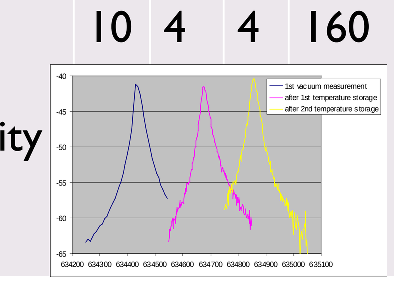


Table: First 6 of 18 failure mechanisms found for RF-MEMS switches.
Charging is the most important failure mechanism for capacitive switches, welding for ohmic switches

Failure mechanism	Failure defect	Failure mode	Failure cause	S	O	D	RPN	Acceleration factors	Where when	Test structures	Device specific or generic
Charging of the dielectric of capacitive switches	Non-permanent stiction to bottom electrode. 	Drift in pull-in and pull-out voltage and up-capacitance, dead device 	1. Electric field induced charge injection 2. Air gap breakdown 3. Electron emission 4. Radiation 	8	10	2	160	- Electric field - Time in downstate - Voltage - Small gap	1. In down state of switch. Enhanced at high humidity. Substrate dependent. 2,3: Gap and gas dependent and gas 4. Radiation only in space.	Yes MIM or simple bridges on dielectric	All electrically actuated MEMS with dielectrica have this problem.
Micro welding of ohmic switches (metal-metal)	Stiction 	Drift in contact resistance, dead device (short)	1. Soft metals coming into contact (cold welding) 2. High current through metal contact (hot switching) 3. ESD	9	7	4	252	Current Temperature	Soft materials coming in contact. Mostly during hot switching.	Yes Bridges on metal	All metal-metal contact devices with current flowing through contacts
Temperature induced elastic deformation of the bridge	Non-permanent deformation of the bridge, possibly stiction if deformation causes contact 	Drift in pull-in and pull-out voltage, dead device	Temperature 1. Different thermal expansion coefficients 2. Environmental temperature 3. Power RF induced temperature	7	7	5	245	Temperature	Bad design. Devices with materials with different CTE.	Yes Bridges	All devices with materials with different CTE
Plastic deformation of the bridge 	Permanent deformation of the bridge, possibly stiction if deformation causes contact 	Drift in pull-in and pull-out voltage, dead device	1. Creep 2. Temperature higher than elastic region 3. Stress larger than elastic region	7	7	3	147	Temperature Stress 	When temperature or stress, during processing or use, exceeds the elastic region of the MEMS. Design dependent	Yes: films 	All devices with movable part
Structural stuck device	Particles, shorts between metals, contamination, stiction 	Drastic change in pull-in and pull-out voltage, dead device, short	1. Contamination, particles, remaining sacrificial layer 2. Wear: particles 3. Fracture 4. Lorentz forces 5. shock 	9	5	4	144	Shock Cycling (wear) High current (4)	Dirty environment (particles) Environment with large vibrations, shock	Best tested on real MEMS. Design dependent	All devices with movable part
Capillary forces	Stiction 	Dead device or delay in time	1. External humidity (leaky package) 2. Processing related humidity 3. Outgassing 	10	4	4	160	Humidity	Environment with high humidity. Incomplete outgassing before packaging.	Yes Any MEMS	Any MEMS that come into contact

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