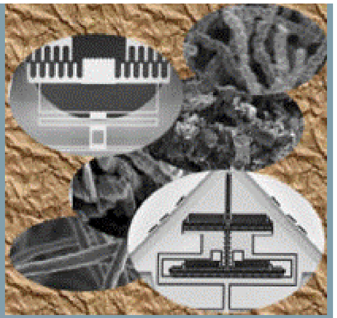

ENDORFINS:
ENabling **D**eployment **O**f **RF** MEMS technology **IN S**pace telecommunication.

P. Czarnecki[1,2], P. Soussan[1], X. Rottenberg[1,2], P. Muller[1], P. Nolmans[1], P. Ekkels[1,2],W. De Raedt[1], H.A.C. Tilmans[1], R. Puers[2],O. Vendier[3], L. Marchand[4] and I. De Wolf[1,5]

[1]IMEC, Leuven, Belgium

[2]E.E. Dept. of KULeuven, Leuven, Belgium

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[4]ESA/ESTEC, Noordwijk, The Netherlands

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6th ESA Round Table on Micro&Nano Technologies for Space Applications

8-12 October 2007, ESA/ESTEC Noordwijk, The Netherlands

Outline

- ENDORFINS
- Capacitive RF MEMS switch
- Failure modes
- Materials
- Design
- Processing
- Results
- Conclusions

ENDORFINS (1)

Title:

- **EN**abling **D**eployment **O**f **RF** MEMS technology **IN S**pace telecommunication.

Objective:

- Perform an in-depth assessment of the reliability and related failure modes of RF-MEMS, in view of their deployment in space and improve this reliability (for switches) through processing optimization.

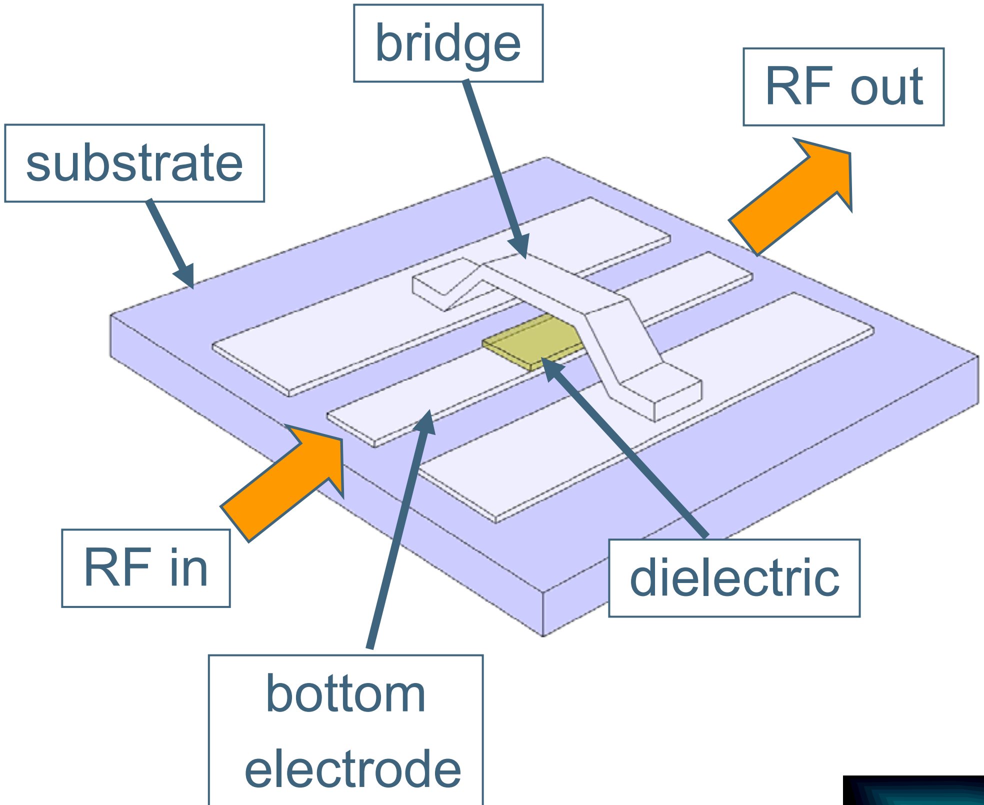
- 2 years project, started in August 2005.

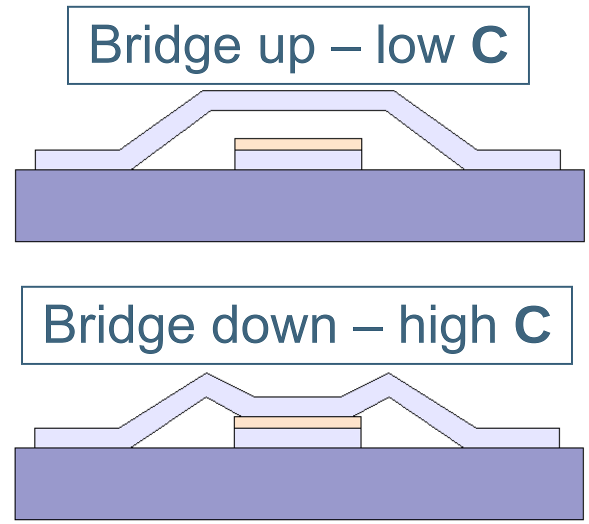
ENDORFINS (2)

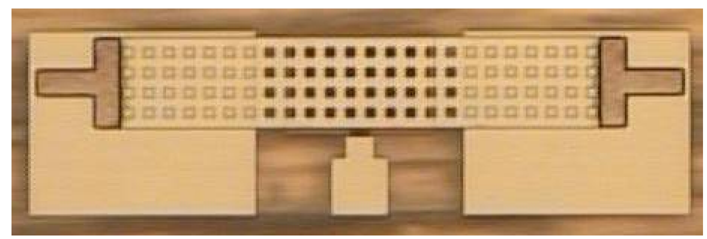
Purpose:

- study the possible applications in space
- study the reliability issues and failure modes that prevent the deployment of RF-MEMS in space
- define corrective actions to improve the reliability with focus on processing steps and materials used (focus on RF-MEMS capacitive switches), taking into account packaging.
- apply these corrective actions (where possible) to the processing and investigate their effect on the reliability.

Capacitive RF MEMS switch

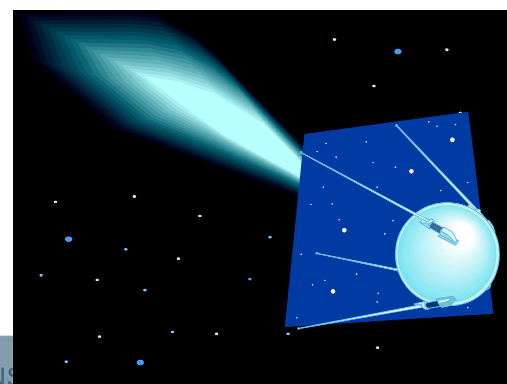






Aim:

- high **lifetime**
- high **C_{down}**



FMEA: ENDORFINS approach

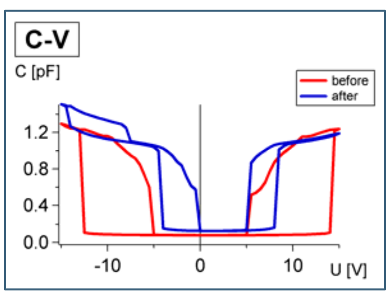
FMEA: Failure Mode & Effect Analysis

- List all (theoretically expected) failure mechanisms
- Assigned severity (S) and occurrence (O)

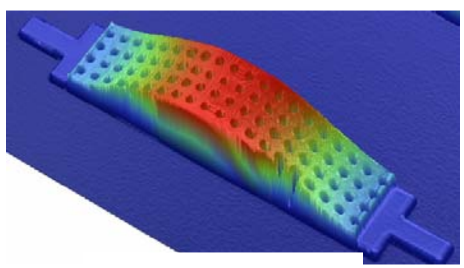
number (1-10) and calculate Priority Number: **PN=S*N**

- Select failure mechanisms with highest **PN** to study
- Identify processing steps and test structures (design)

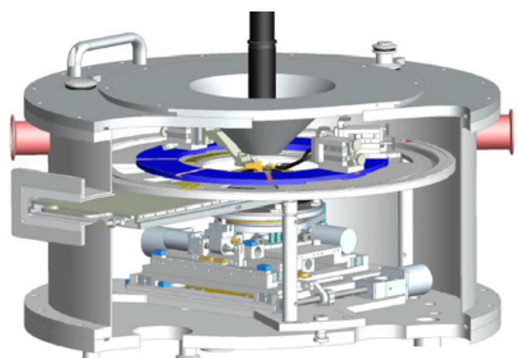
to optimize reliability and prevent failures



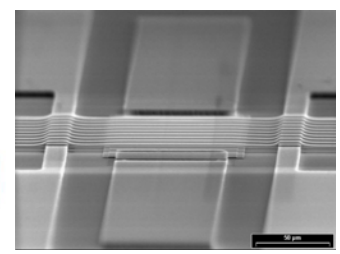
charging



T-stability



tests



MEMS Switch

Failure modes: FMEA

	Potential Failure Mechanism	Sev	Failure Defect	Failure Mode	Occ	R N	Possible
1	Dielectric charging of the insulator of capacitive switches	8	Stiction to bottom electrode. Not-permanent (charges flow away when charging cause is taken away).	Drift in CV curves, drift in Pull-in and Pull-out voltages, Dead device	10	80	1. Electric Field Ch 2. Air-gap Breakdo 3. Electron emissio 4. Radiation
2	Micro welding (ohmic switches and capacitive switches with contact metal on dielectric)	9	Stiction	Dead Devices, drift in contact resistance, anomaouls switching behaviour (temporary stiction).	7	63	1. soft metals com welding) 2. high current thro contacts (often at welding) 3. ESD
3	T-induced elastic deformation of the bridge (ohmic and capacitive switches)	7	Non-permanent) deformation of the bridge (is restored when T-source is removed);, possibly stiction if large deformation (to bottom electrode or top of cavity if packaged).	Shift of electrical parameters (pull-in/pull-out V, capacitance, contact R...); change of mechanical properties	7	49	1. Different Therm Coefficients (CTE) 2. Environment Te 3. Power RF Signa Temperature 4. Non uniform ten
4	Plastic deformation of the bridge (ohmic and capacitive switches)	7	Permanent deformation of the bridge, possibly stiction if large deformation (to bottom electrode or top of cavity if packaged).	Shift of electrical parameters (pull-in/pull-out V, capacitance, contact R,...); change of mechanical properties	7	49	1. Creep 2. Thermal induce properties (for T>T
5	Structural Short (electrical and non-electrical connections) (ohmic and capacitive switches)	9	Particles, shorted metals, contamination, remains of sacrificial layer, stuck bridge	Changes in electrical parameters, dead devices	5	45	1. Contamination; sacrificial layer ma 2. Wear Particles 3. Fracture 4. Lorenz Forces 5. Shocks
6	Capillary Forces (ohmic and capacitive switches)	10	Stiction	Dead device	4	40	Presence of humic incorrect release st
7	Fusing (ohmic and capacitive switches)	10	Opens, roughness increase	Dead Device	4	40	High RF power pul
8	Fracture (ohmic and capacitive switches)	10	Broken bridges and hinges	Dead device	4	40	1. Fatigue 2. Brittle materials 3. High local stress
9	Dielectric breakdown of the insulator. capacitive switches)	9	Dead device, possibly stiction	Short between bridge and actuation electrode	4	36	1. ESD 2. Excessive charg
10	Corrosion (ohmic and capacitive switches)	7	Dendrites formation, oxidization, changes in color	Degradation of electrical and mechanical properties, shorts	5	35	1. Presence of wat (chemical reaction 2. Corrosive gases reaction (ex. Oxida
11	Wear Friction Fretting corrosion (ohmic and capacitive switches)	8	Surface modifications, Particles (Debris), Stiction	Shorts, opens, shift of electrical parameters, contact resistance shifts	4	32	1. Sliding Rough S
12	Creep (ohmic and capacitive switches)	6	Deformation of the bridge in time	Electrical and mechanical parameters shifts	5	30	High metal stress a temperatures, cree
13	Equivalent DC Voltage (ohmic and capacitive switches)	7	Self biasing Stiction	Anomalous switching behaviour, changes in electrical parameters	4	28	High RF power in collapsing or stiction of mobile part
14	Lorenz Forces (ohmic and capacitive switches)	7	Self Biasing Stiction	Anomalous switching behaviour, changes in electrical parameters	4	28	1. High RF power in two adjacent lines 2. External Magnetic Field
15	Whisker formation (ohmic and capacitive switches)	7	Bumps in metal, holes in insulator on top of metal layers, ...	Anomalous down capacitance or contact resistance, possible increase of charging sensitivity	4	28	High compressive stress in metal resulting in grains extrusions; might be enhanced by T-steps
16	Fatigue (ohmic and capacitive switches)	8	Broken bridges and hinges, cracks, microcracks, deformation of the bridge	Electrical and mechanical properties shifts, dead devices	3	24	Large local stress variations due to motion of parts (intended or due to vibrations or thermal cycles). Enhanced probability if cracks are present or surfaces are rough
17	Electromigration (ohmic and capacitive switches)	8	cracks, opens, thickness changes (mass transport) in metal lines	Increase of resistance, opens, shorts	2	16	1. High current density in metal lines enhanced by too thin and/or narrow, and steps.
18	Van der Waals Forces (ohmic and capacitive switches)	10	Stiction	Dead device	1	10	Large very smooth and flat surfaces in close contact

Dielectric charging

(capacitive switches)

Micro welding

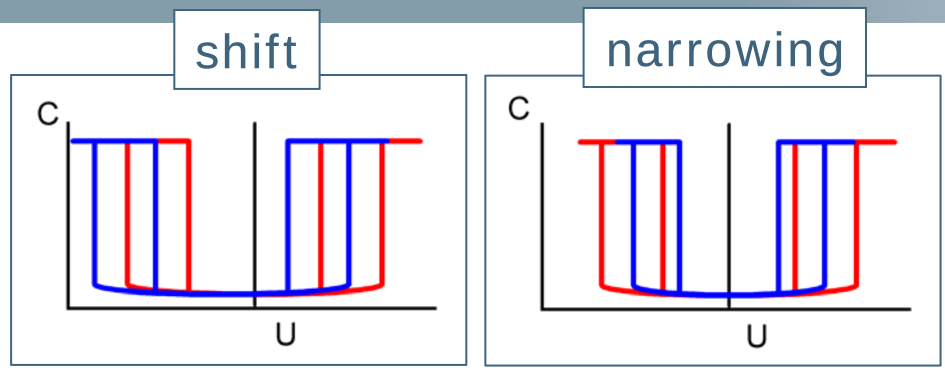
(ohmic switches and capacitive switches with contact metal on dielectric)

T-induced elastic deformation of the bridge

(ohmic and capacitive switches)

Failure modes: descriptions

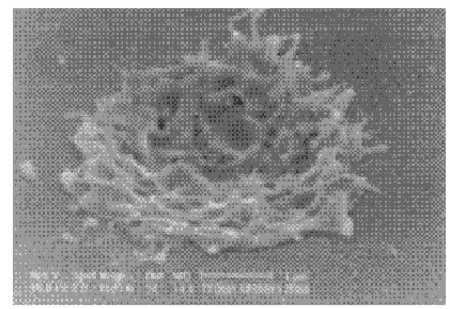
- Charging:



→ stiction

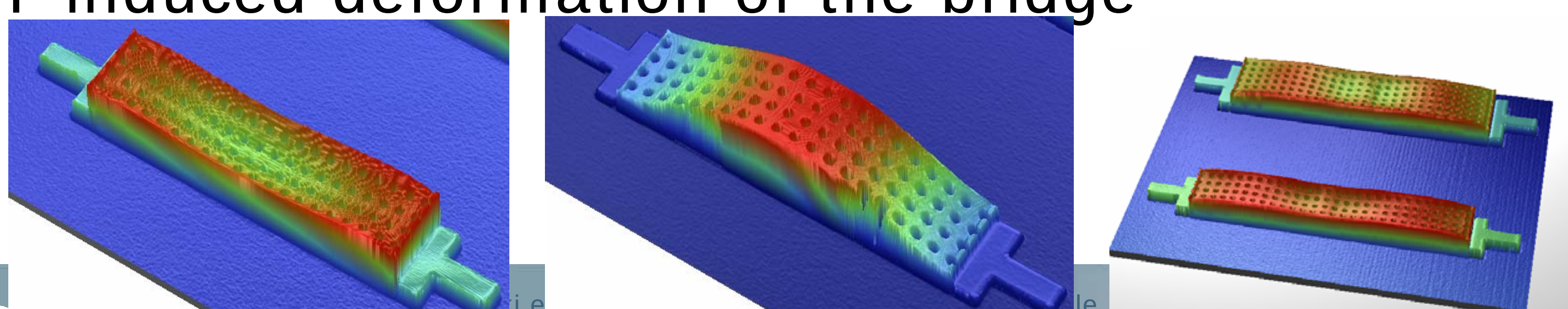
- Micro welding:
  – surface roughness increase

  after metal-metal contact



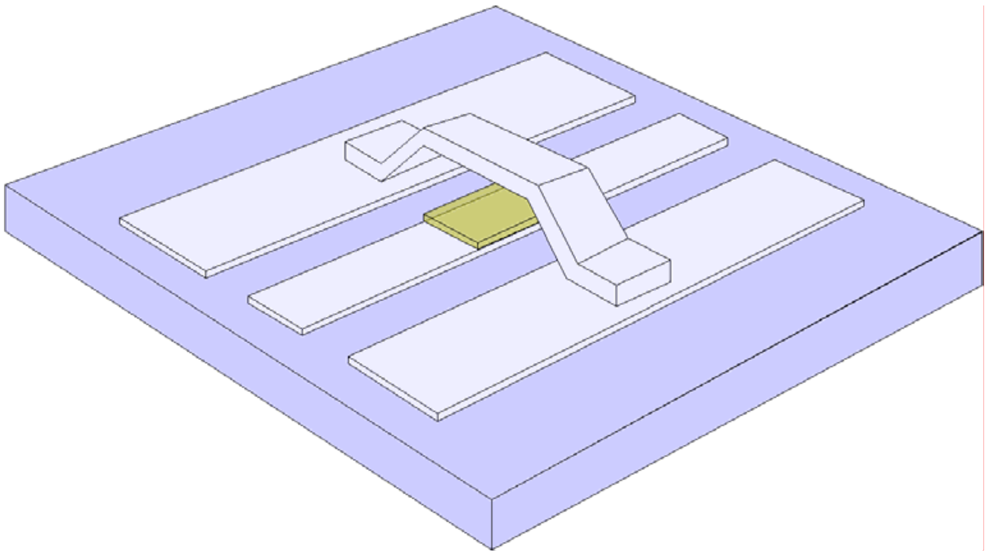
J. DeNatale, Transducers '03, Boston, June 2003

- T-induced deformation of the bridge

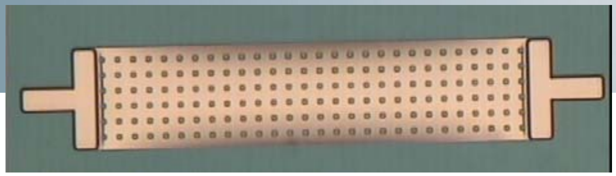


Materials

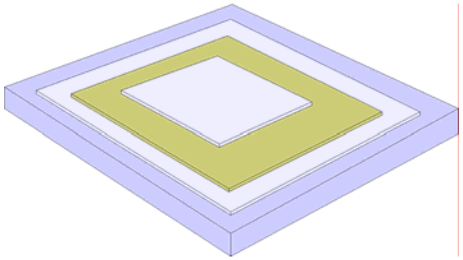
- Substrate
  - glass (AF45)
  - high resistivity Si
- Bottom metal
  - optimized for low roughness
  - no whisker formation
- Dielectric
  - TaO (two recipes)
  - AlO (native)
  - AlN (two recipes)
- Bridge
  - AlCu, different thickness

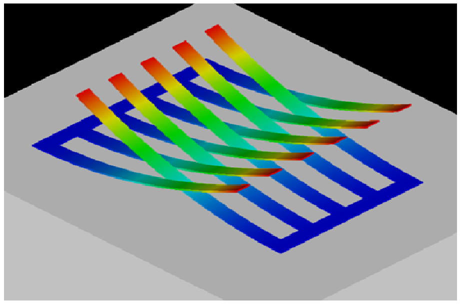


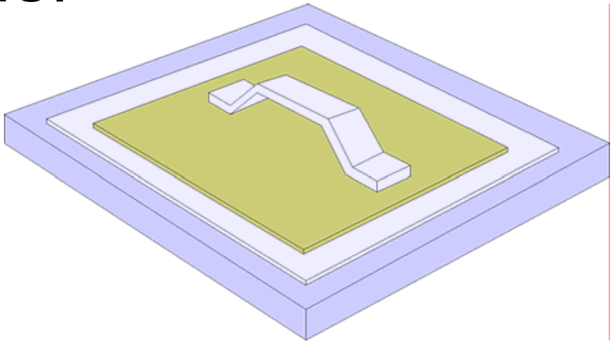
Design



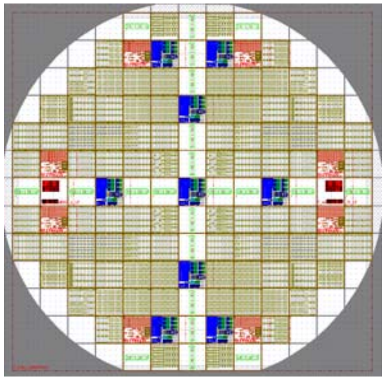
- RF performance neglected.
- MIM capacitors and simple beams.

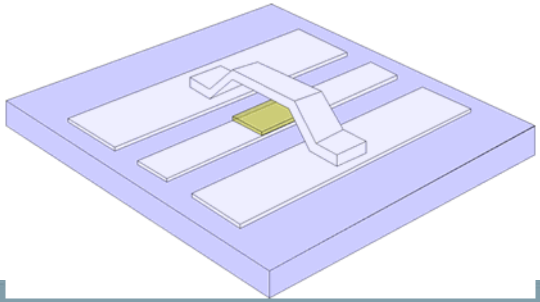


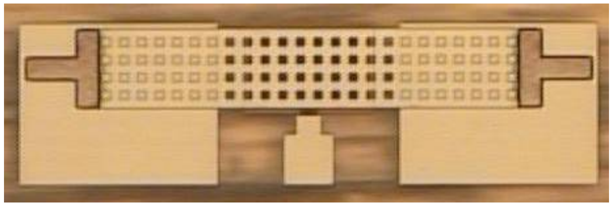




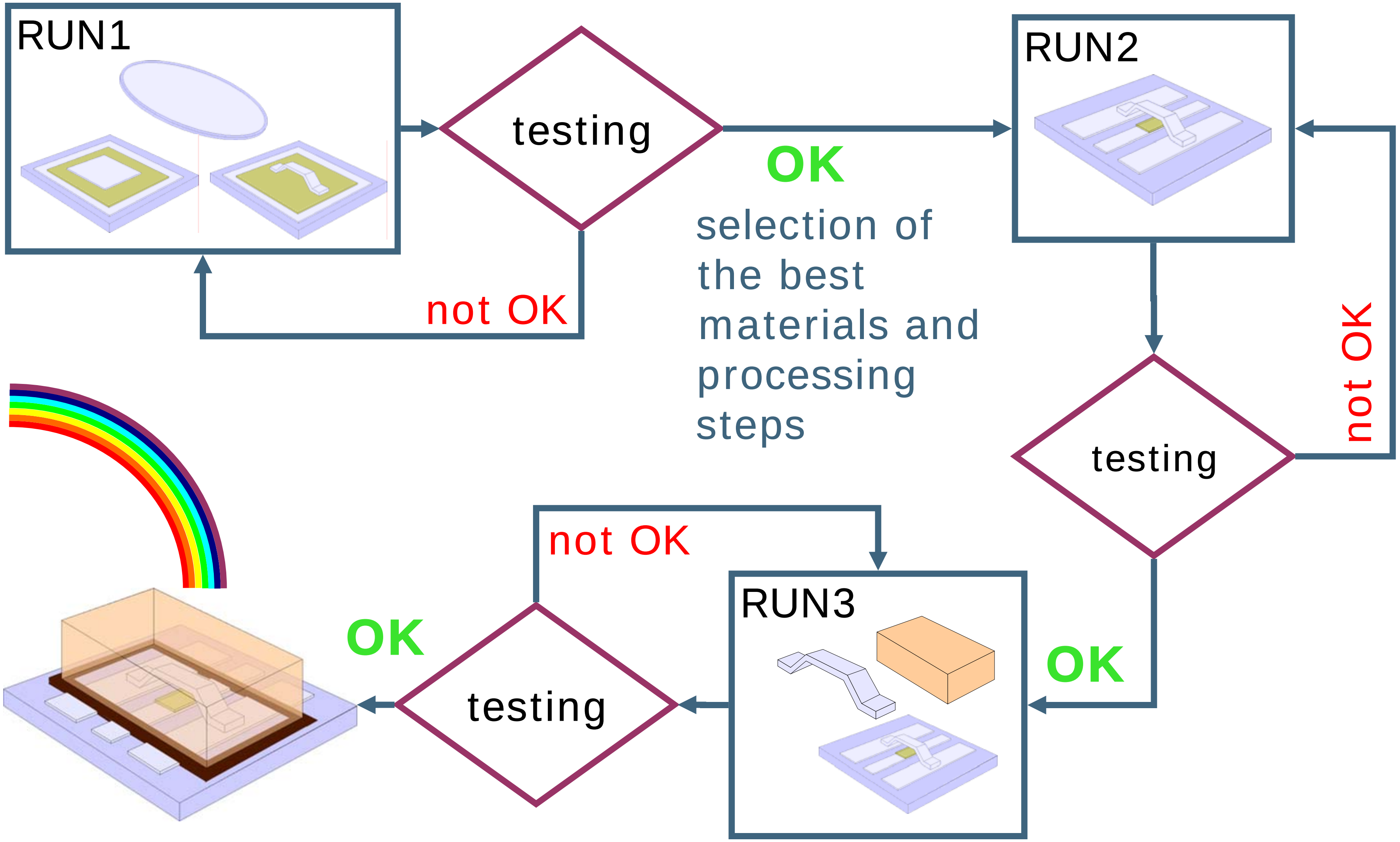
- Fully processed structures.
- Dedicated test structures.
- Many equal devices for reliability study.







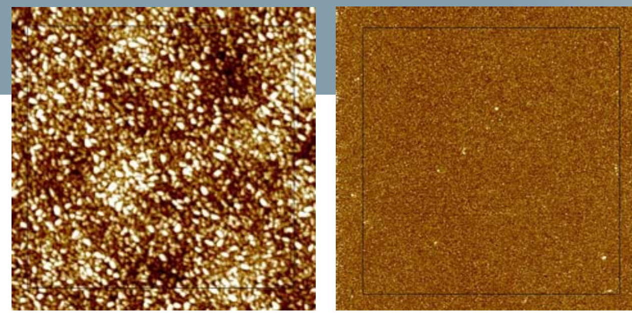
Processing

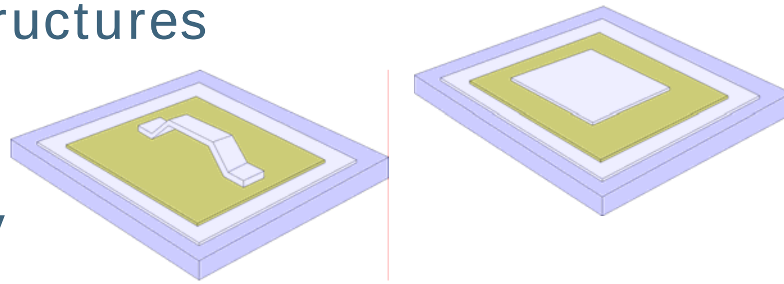


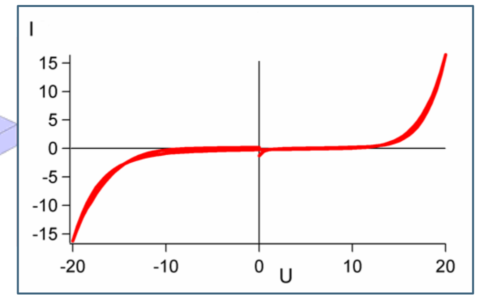
RUN1
testing
OK
selection of the best materials and processing steps
not OK
RUN2
testing
not OK
RUN3
OK
not OK
testing
OK

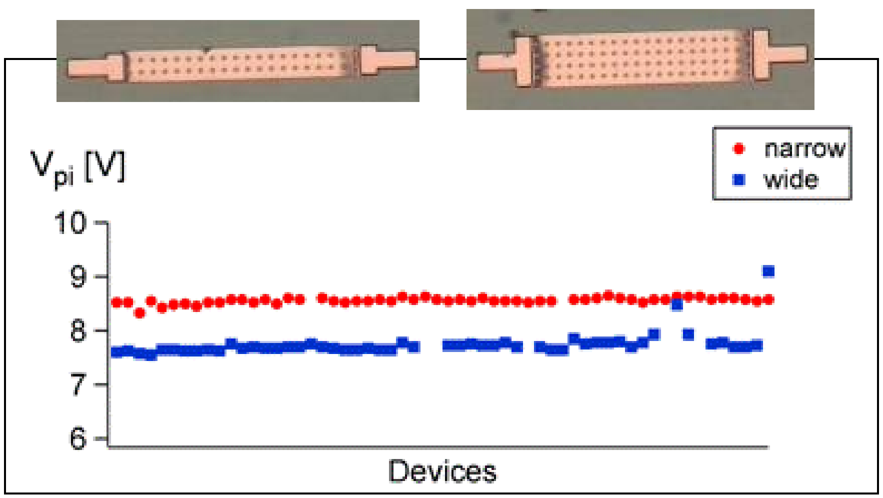
Results (1)

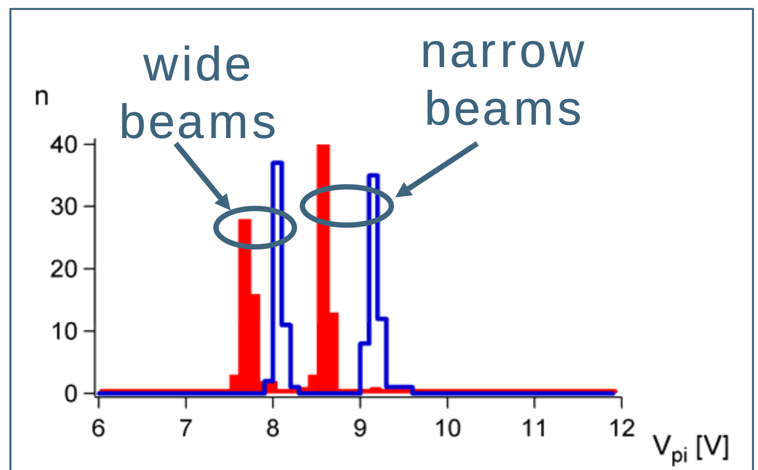
- RUN1:
  - bottom metal
  - dielectric
  - simple test structures
  - uniformity
  - reproducibility





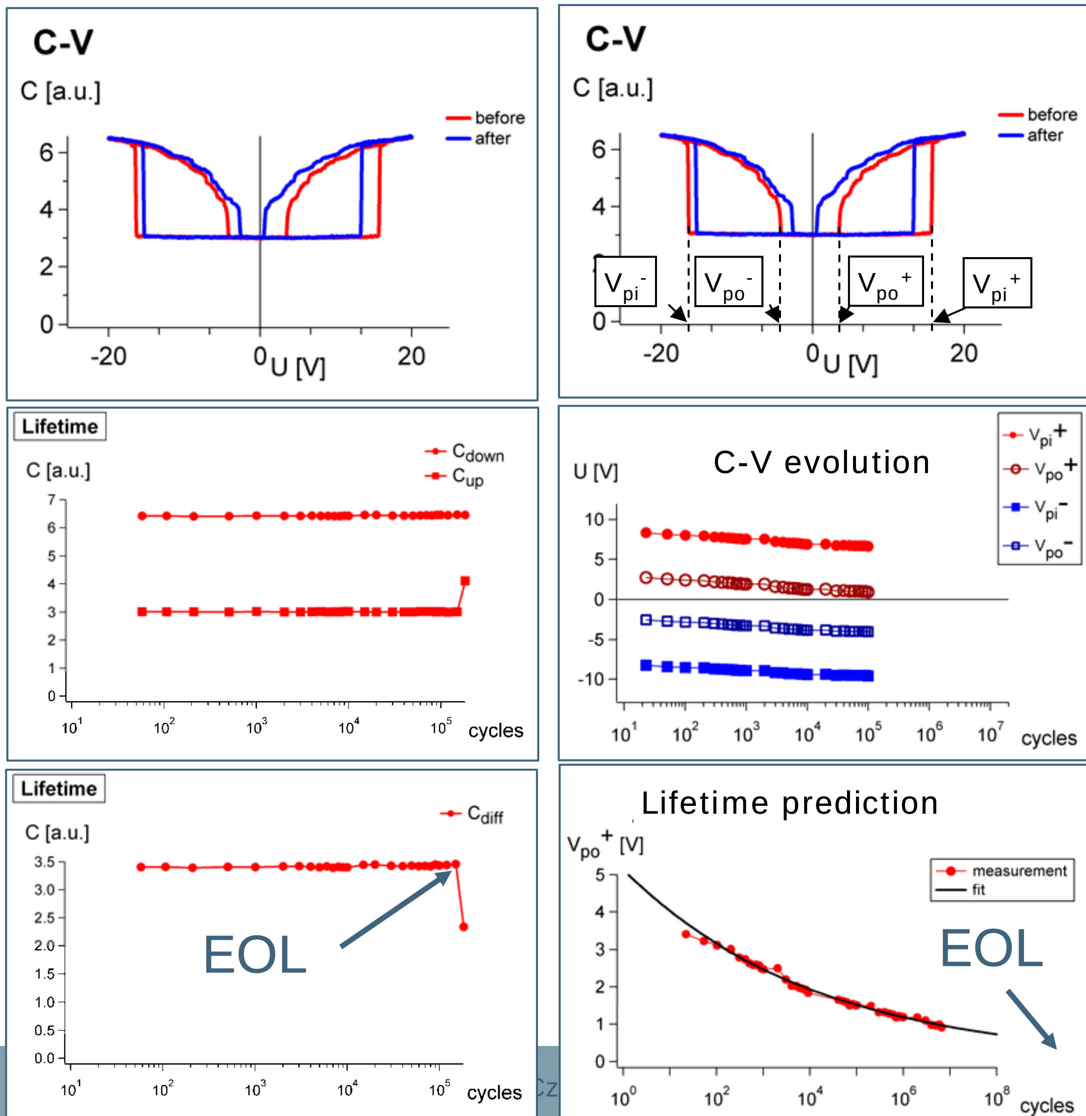


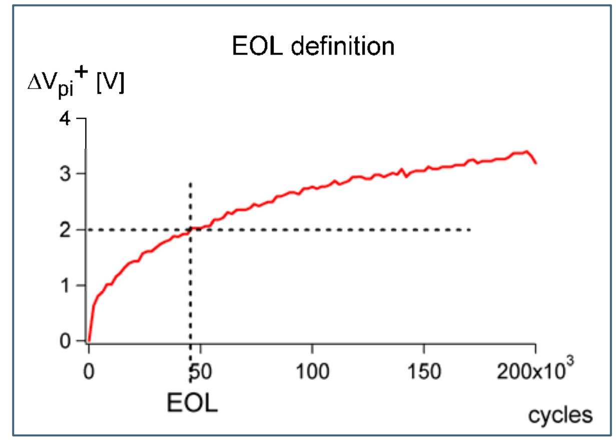


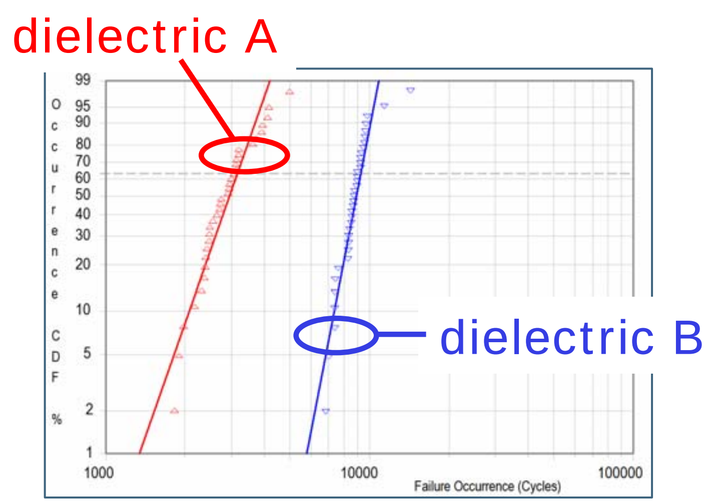


Results (2)

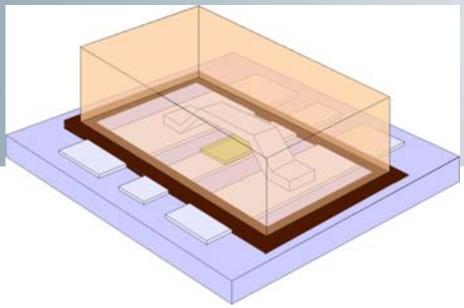
- RUN2







Results (3)



- RUN3
  - First packaging tests: no beam changes.
  - Further lifetime tests of packaged switches.

Conclusions

- Taking the reliability into account from the beginning:
  - decreases number of possible mistakes
  - saves time
  - provides better understanding of the physics behind failures
- Promising results.

- Thank you.