Dielectric charging effects in RF MEMS capacitive switches

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(RF-) MEMS

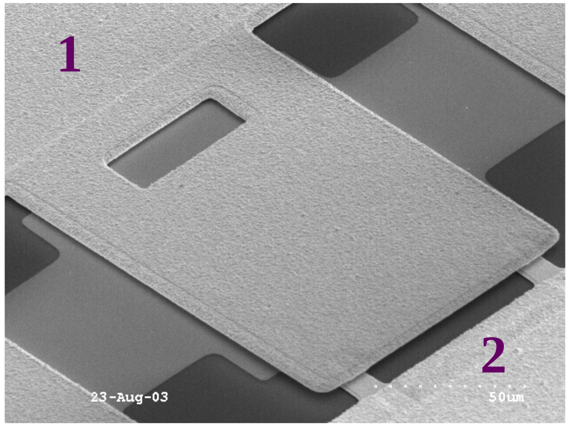
- Many types of devices and wide application areas
  - environment (sensors…)
  - biomedical devices (microfluidics, μ-TAS…)
  - imaging (displays…)
  - telecoms (high-frequencies components - RF-MEMS…)
  - astronomy and space (adaptive optics, communications…)

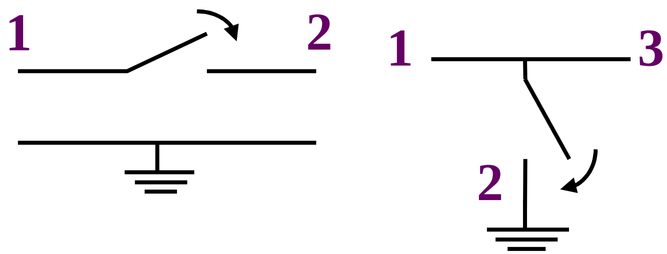
- Key role in the ongoing miniaturization of future electronic modules
  - integration, scale reduction, low-cost fabrication
  - low insertion loss, low power consumption, high isolation
  - actuation: electrostatic, magnetic, thermal…

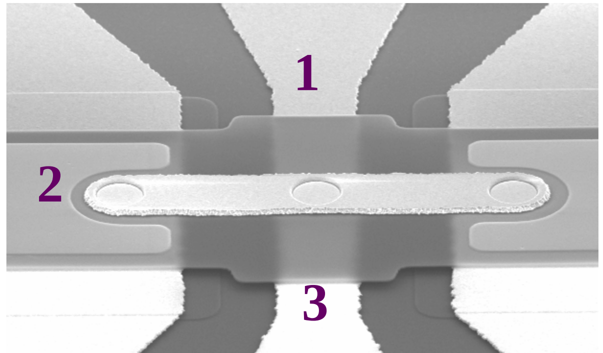
RF MEMS - still in a state of research and early development
- Packaging
- Compliance with environmental stress factors (temp, humidity, shocks/ vibrations…)
- Reliability

Contact- and dielectric-based RF-MEMS switches

- **Basic blocs components**
  - **New materials investigation**
  - **Reliability and increasing performance**
- **Complex tunable functions for RF applications using basic MEMS components: filters and meta-materials, phase shifters, MEMS-based reflect-array antennas….**







Designed at IRCOM and realised at CEA LETI

Series configuration

Shunt configuration

Contact- and dielectric-based RF-MEMS switches

- **Basic blocs components**
  - **New materials investigation**
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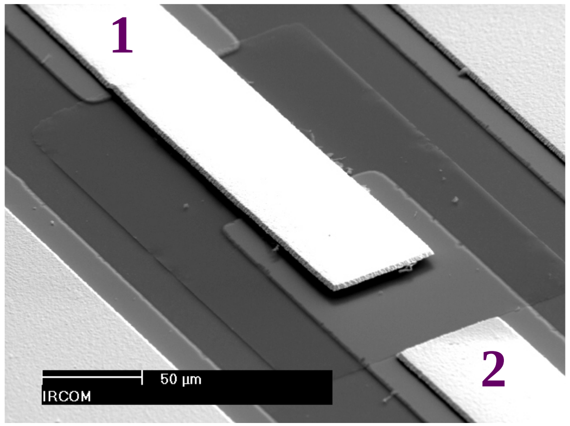
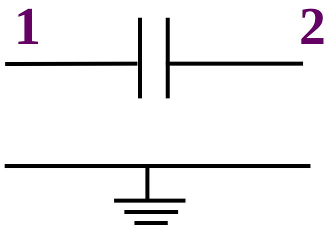
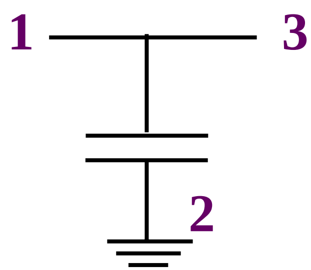
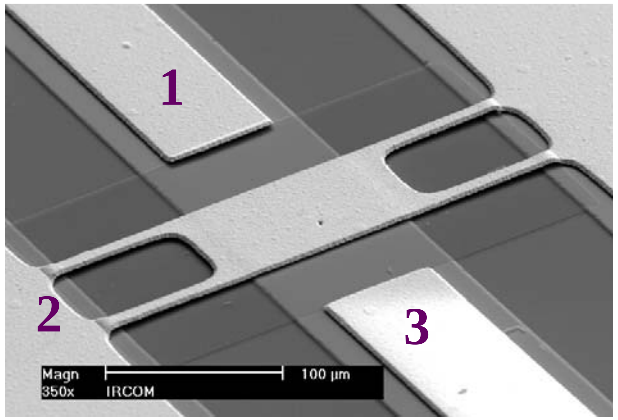




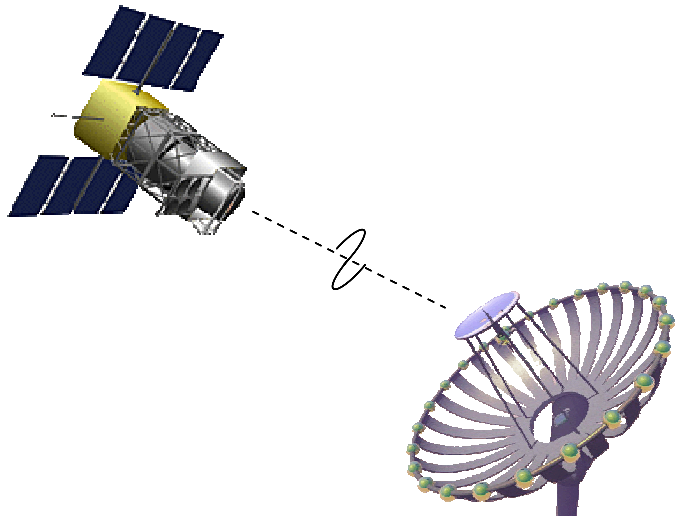


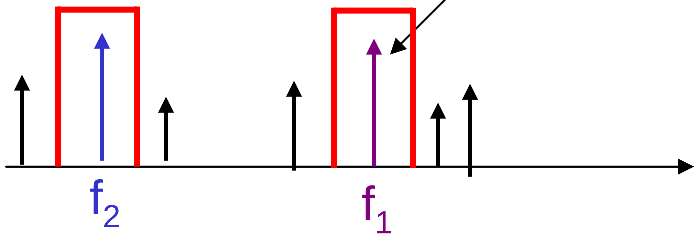


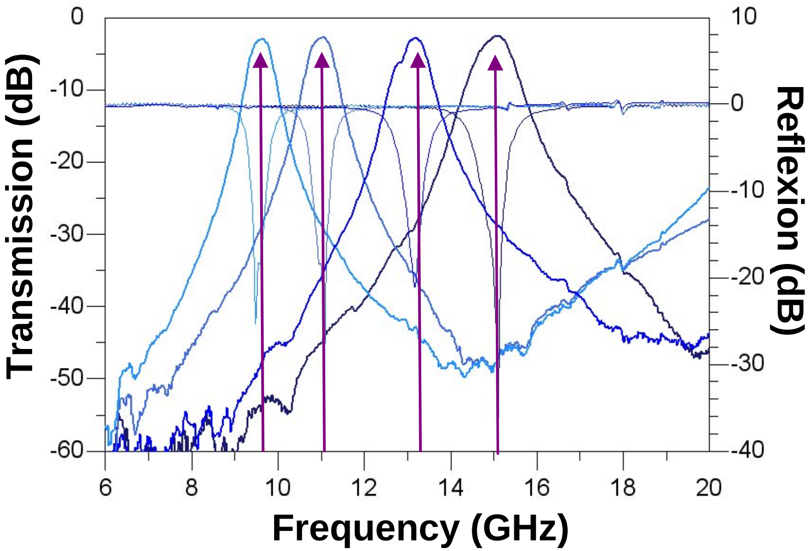
Series configuration

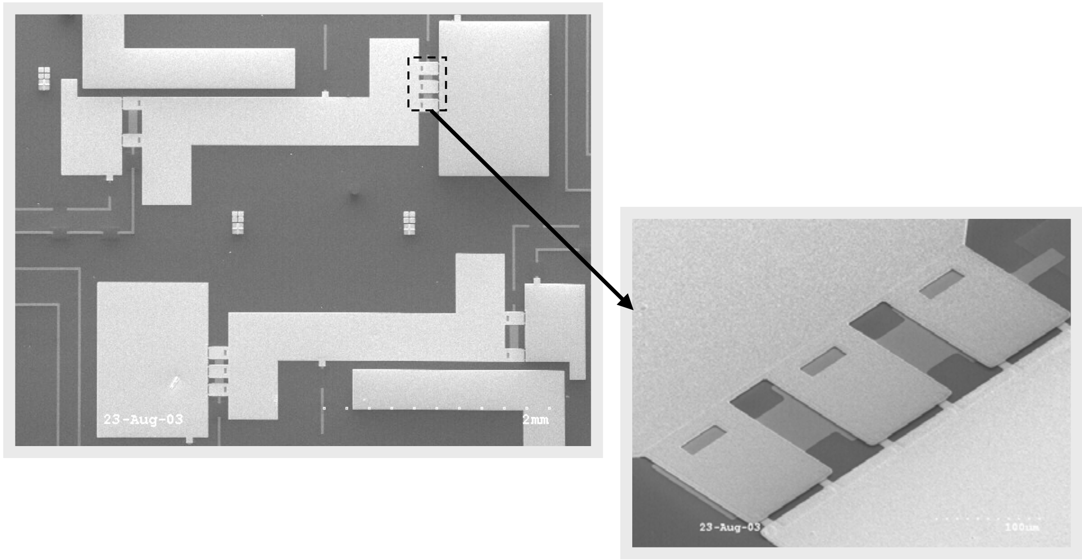
Shunt configuration

Example: reconfigurable filtering







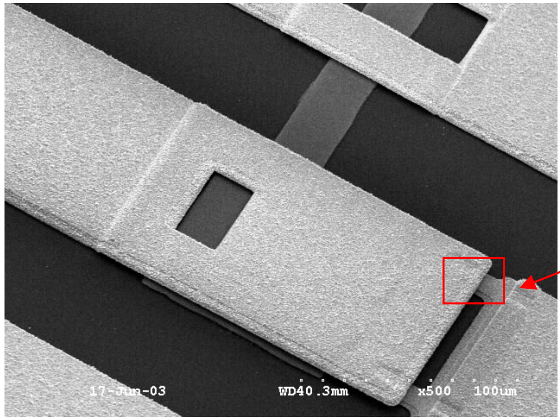


Reliability problems

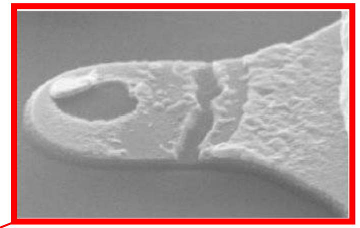
- **Device related** (intrinsic- due to the mechanical nature, design…)
- **Process related** (materials, fabrication…)

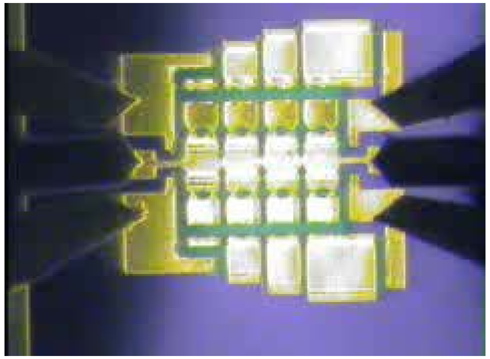
- **Stiction**
  - Metal-to-metal contact: degradation through electro-migration, contamination
  - humidity
  - dielectric charging
- **Buckling** of the beam
  - mechanical stress, temperature
- **Creep**

High power handling- contact/ ohmic switches

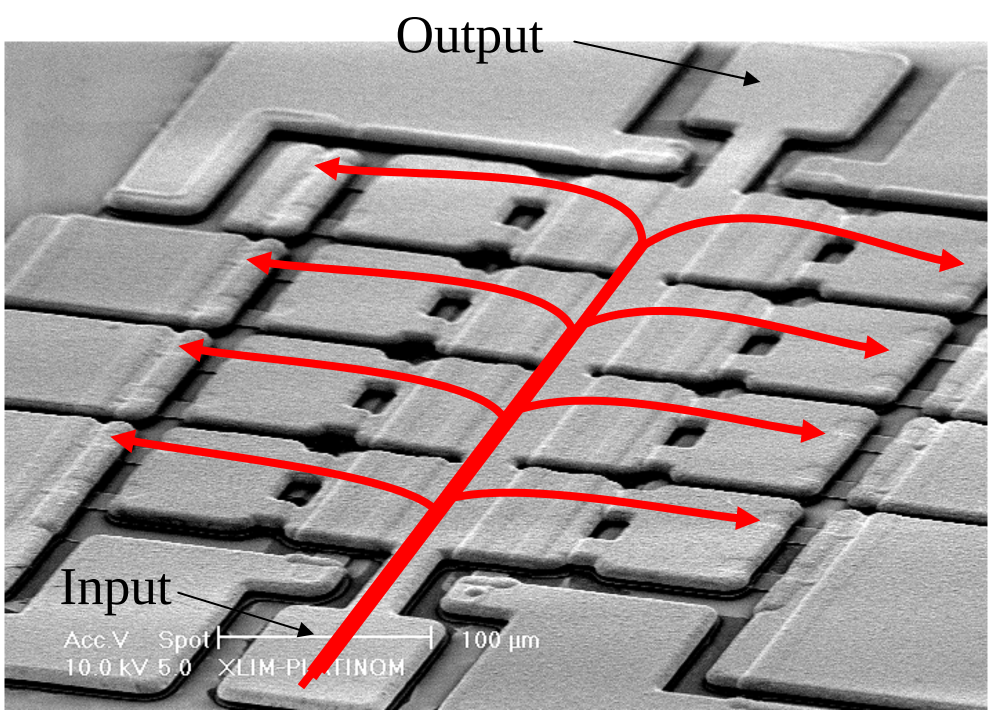


Melt contact finger



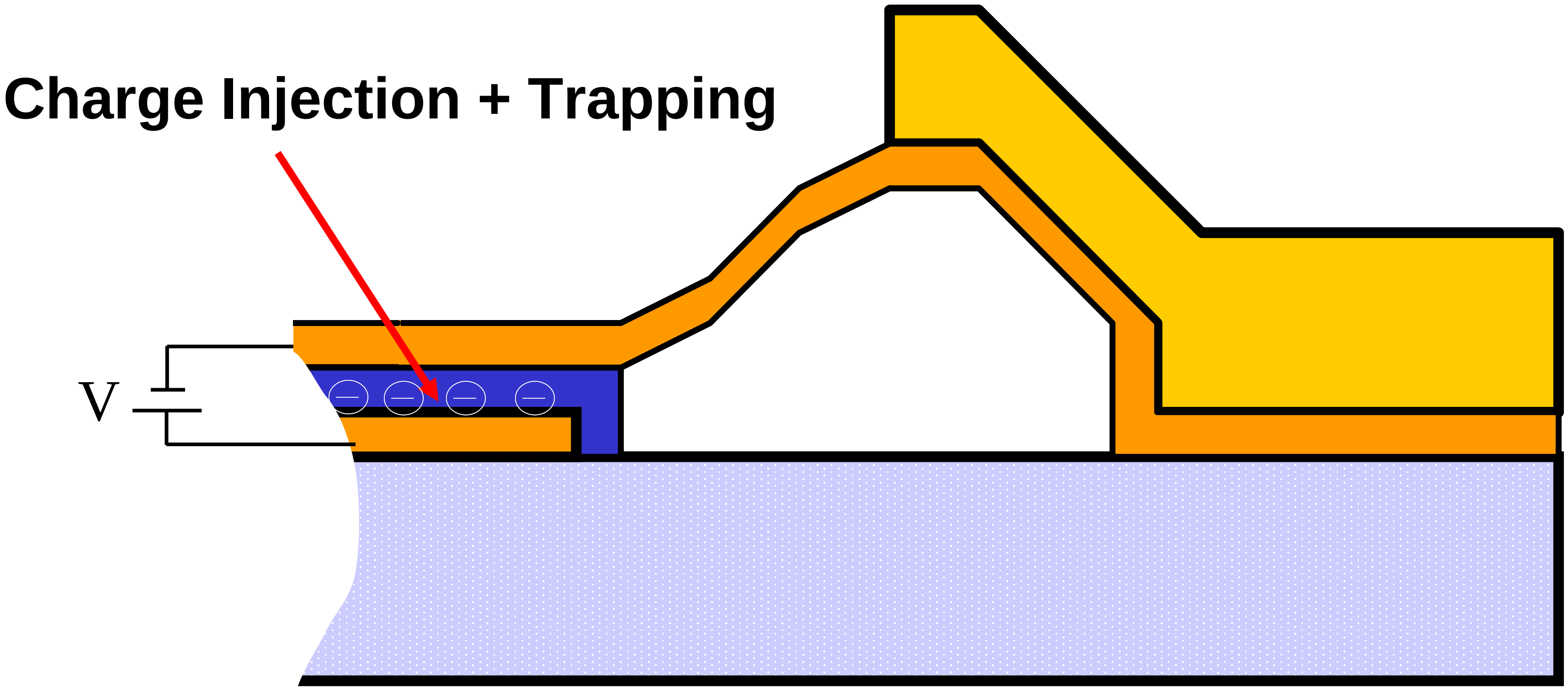


Current balance on each switch



Dielectric-based RF-MEMS

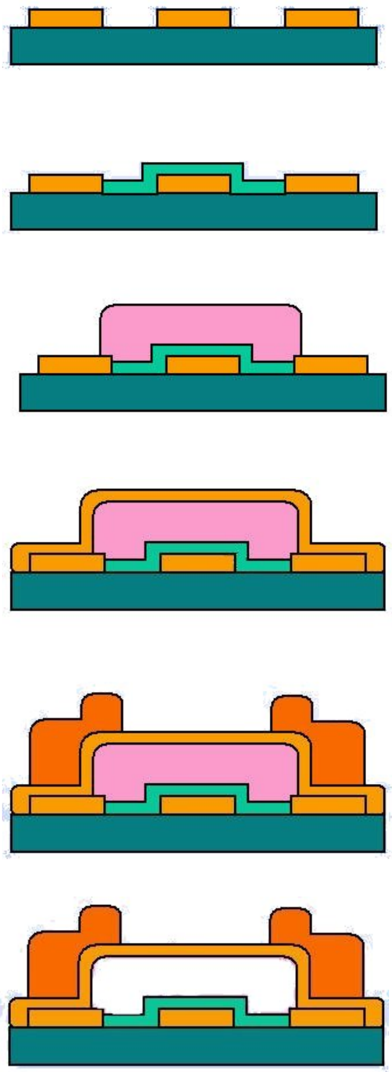
Typical applied voltage >20 Volts over 0.2 µm (~1 MV/cm)

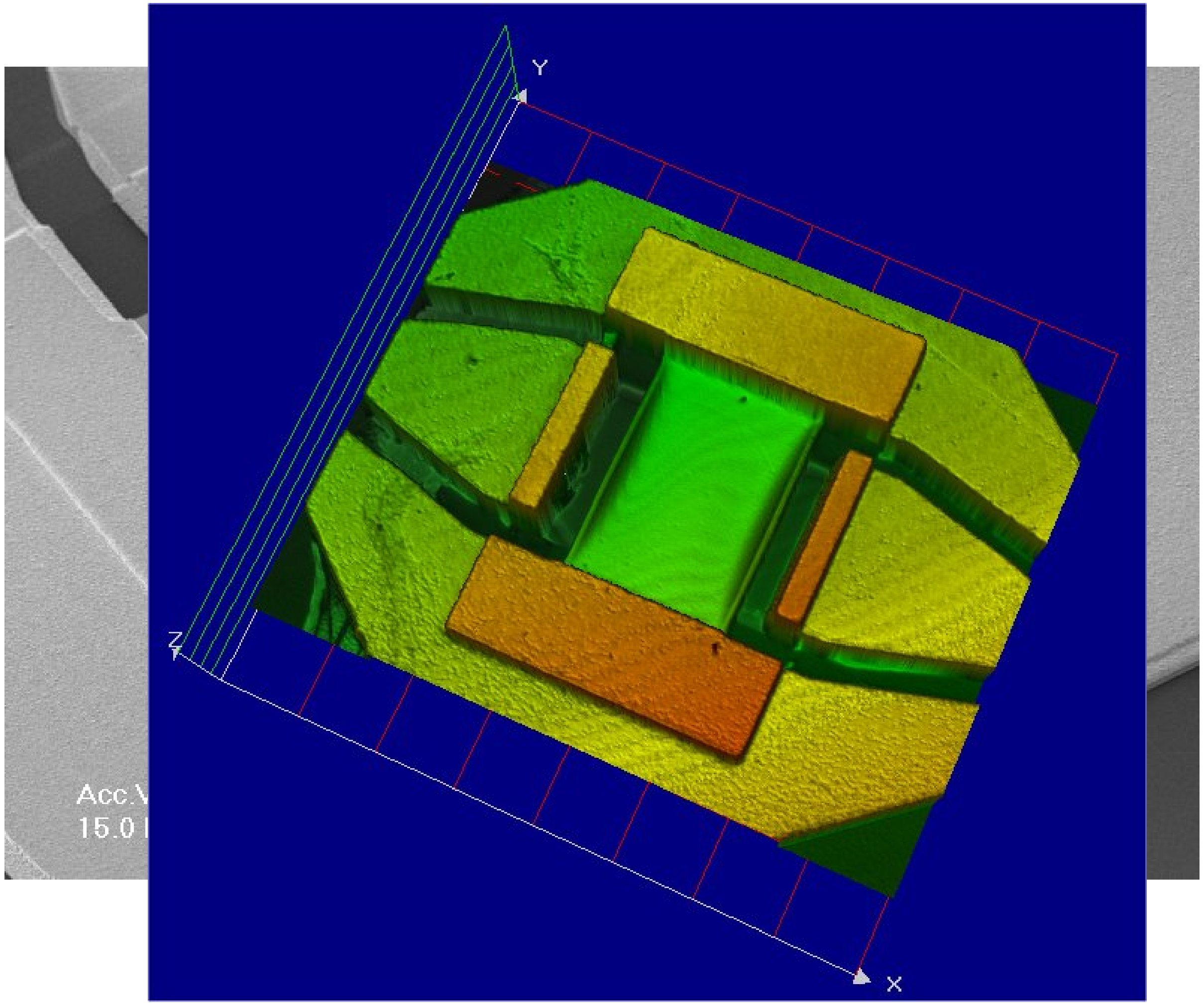


Dielectric charging is the main failure mode of capacitive MEMS switches

- electrical trap generation
- changing the values of Vpull-in and Vpull-out

Test structure - fabrication





Dielectric materials

- **BST – $Ba_xSr_{1-x}TiO_3$, x = 2/3, amorphous, ε_r = 18 – 20**
  - **low breakdown voltage $\Rightarrow$ high thickness needed**
- **Al_2O_3- alumina, amorphous, ε_r = 9- 10**
  - **high breakdown voltage for thinner layers thickness ~ 200 nm**
  - **low temperature deposition**
  - **good surface roughness**
  - **limitation of OH chemical bonds (avoid charge accumulation)**
- **Deposition methods: PLD or PECVD**

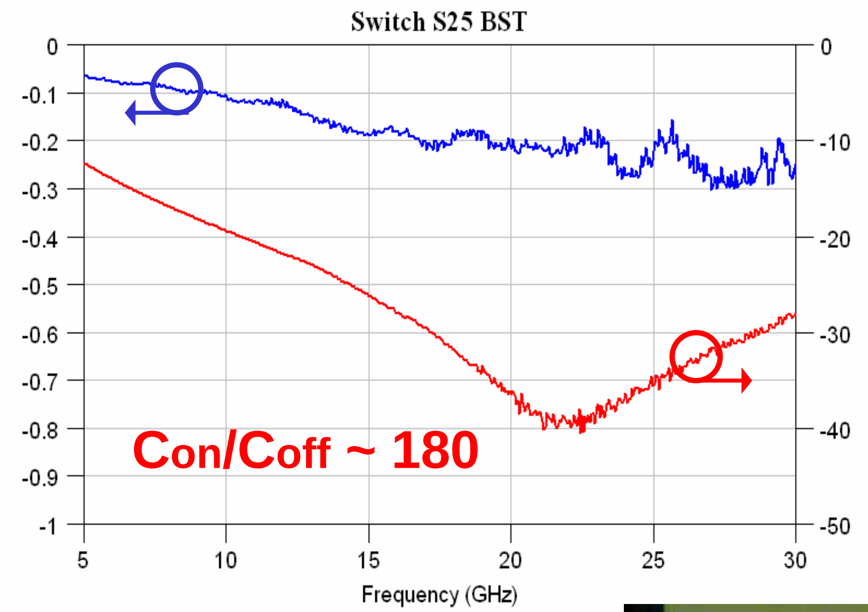
Key parameters: dielectric constant, voltage break-down for a given thickness, roughness…

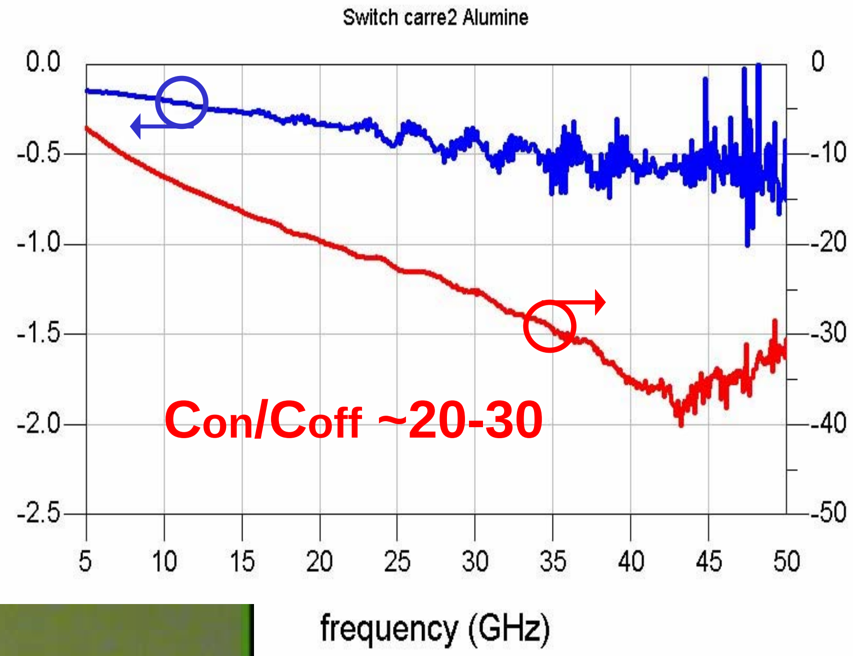
RF performances

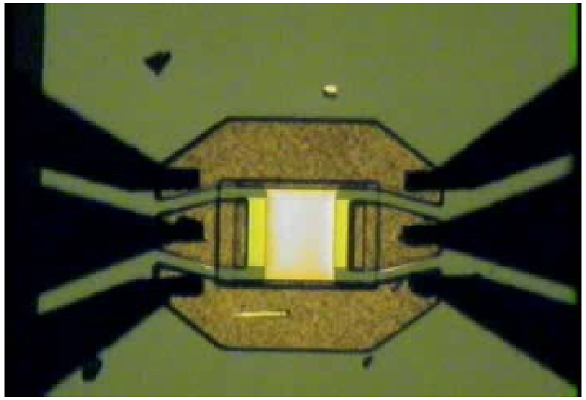
S_{21} – up-state: isolation

S_{21} – down-state: insertion losses

Comparison BST/ Alumina



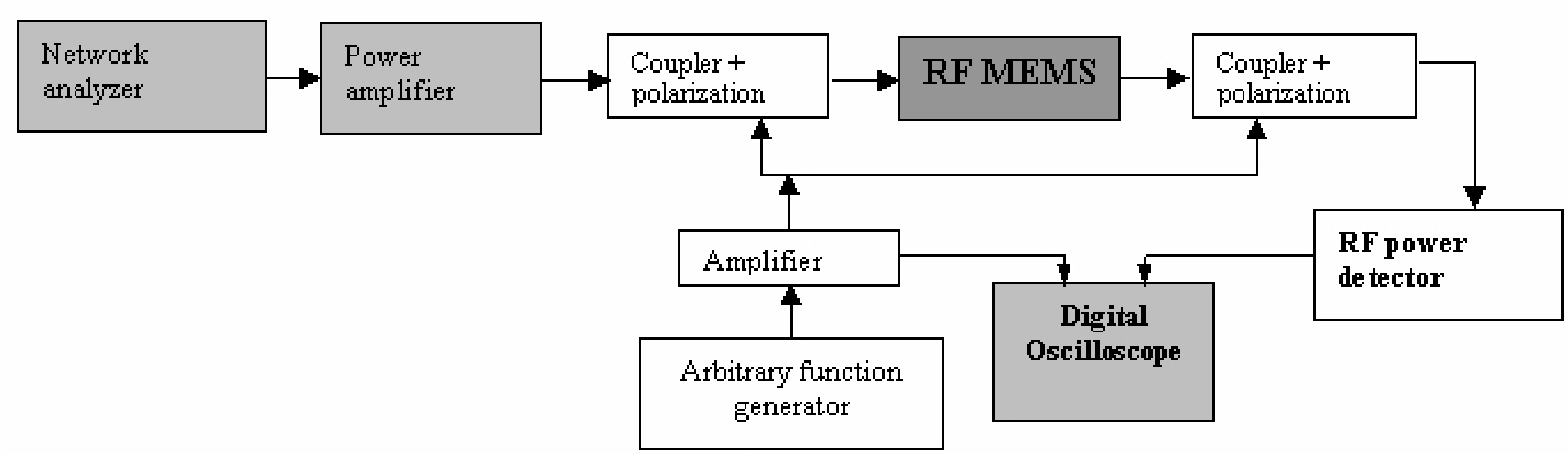




Test bench for dielectric charging

Charging mechanisms:

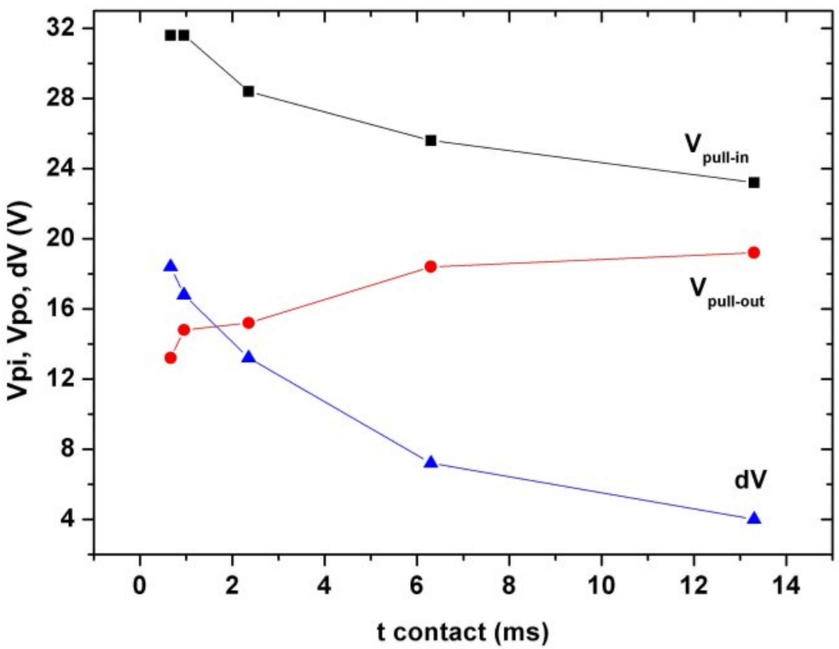
- transfer and trapping of charges
- screening of the applied electric field
- actuation electrical force modification
- capacitance modification in time

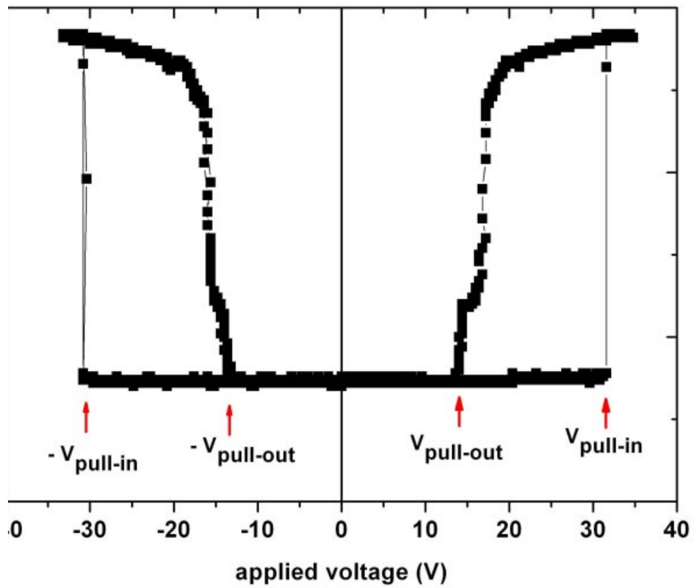


- different polarization waveforms (sin, sq, triangular, user-defined …)
- transmitted power recordings ≈ capacitance variation during actuation

Hysteresis curves

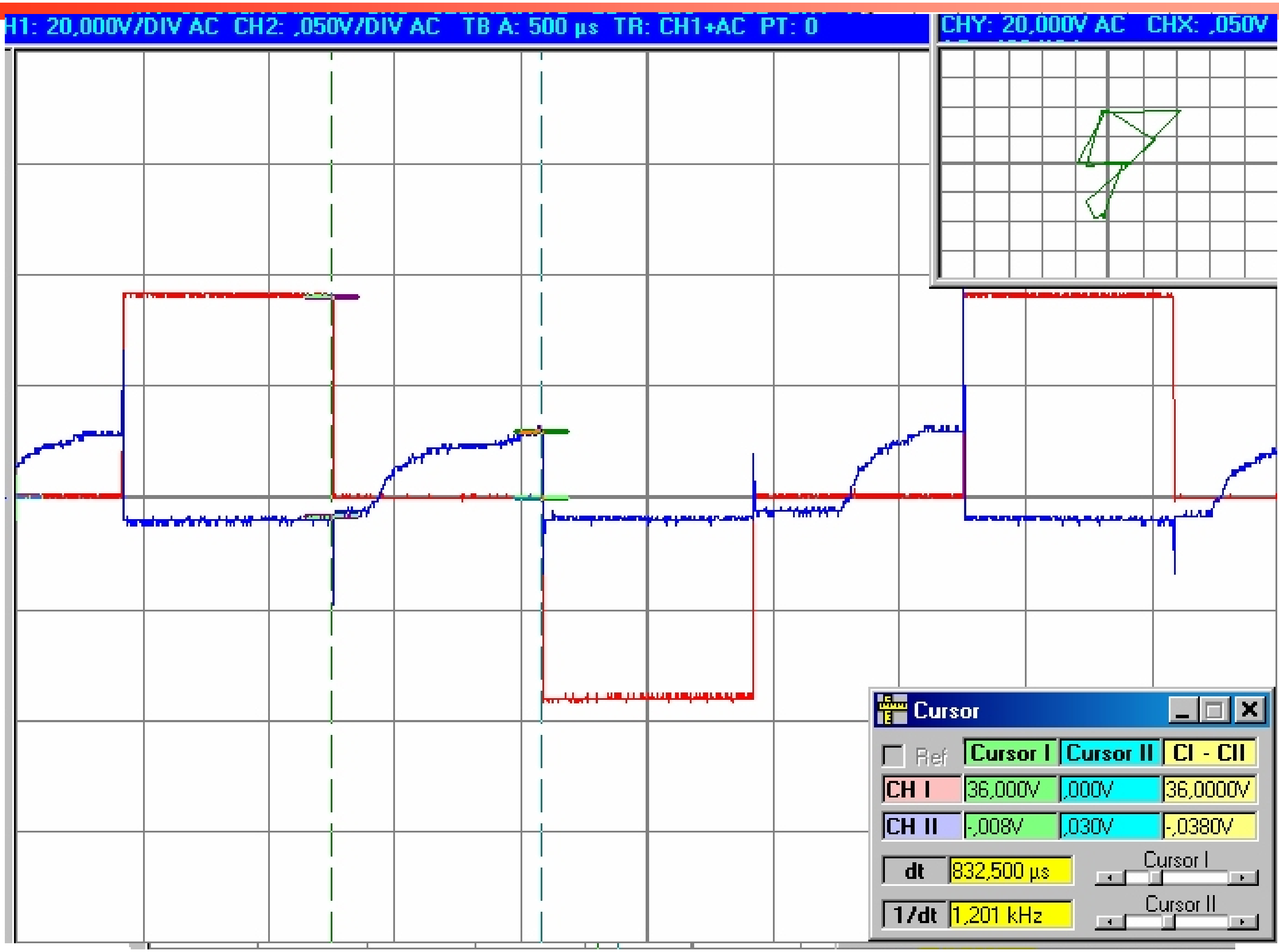
- **200 nm-thick Al2O3 (PLD)**
- **triangle waveform (35 V amplitude, 270 Hz)**





•cycling by measuring the evolution of $V_{pull-in}$, $V_{pull-out}$, $dV = V_{pull-in} - V_{pull-out}$ when applying polarization waveforms of different types, amplitudes or frequencies (= contact times)

Cycling



400 nm-thick Al2O3 (PECVD), 300 Hz, 39 V amplitude, ambient atmosphere

Summarizing…

- switch lifetime depends on:
- type of dielectric (charging/ discharging)
- breakdown voltage, thickness
- actuation voltage, frequency, waveform type, (contact time/ actuation period, total contact time)

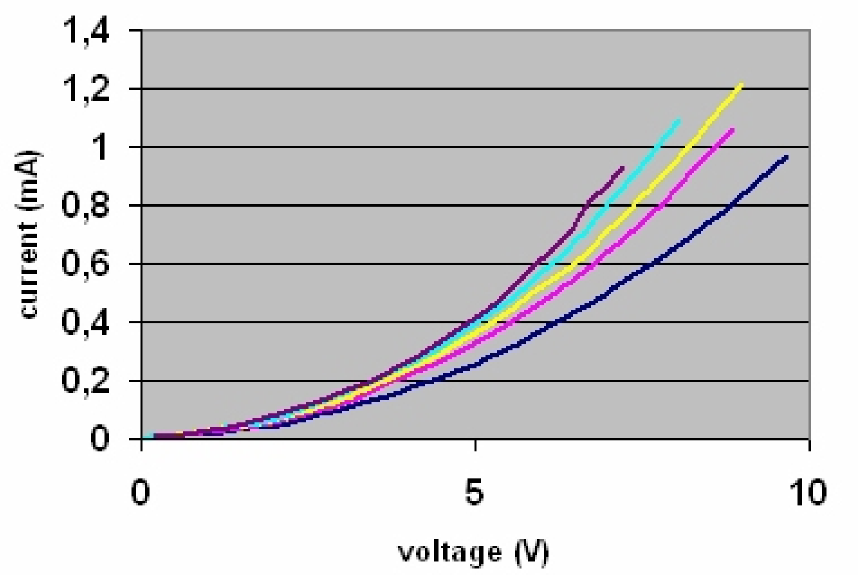
- identification of charging mechanisms – charging model?
- cycling: controlled atmosphere, stress factors (temp, humidity…)
- standard tests development for space qualification

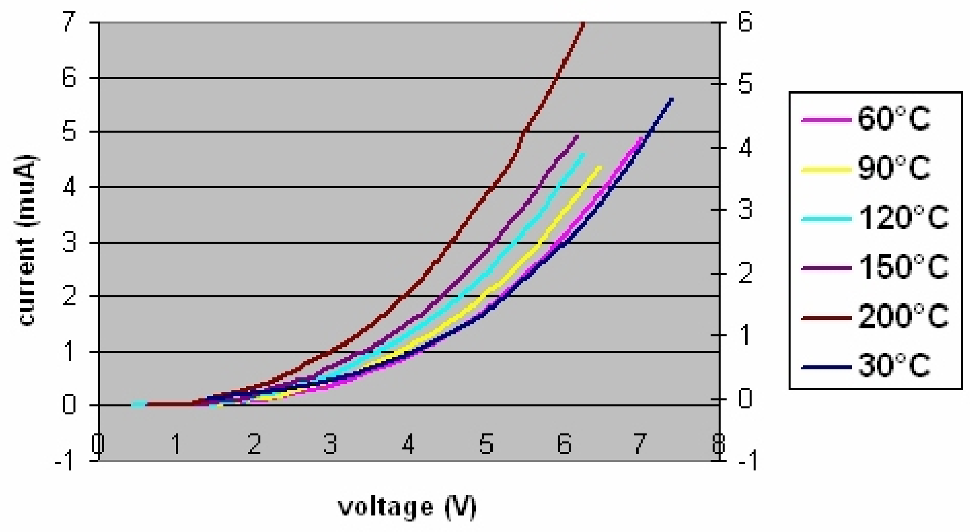
New materials vs. new designs

Aim: create conductive paths in the dielectric for faster discharging

How: doping with metals – metallic nano-clusters – LECBD technique

Materials: nc Co: Al_2O_3- 5%, 9%, 17% vol.

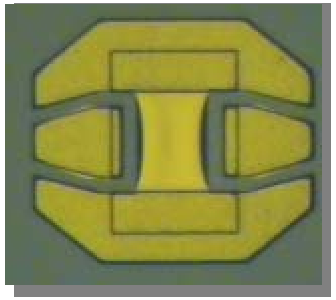


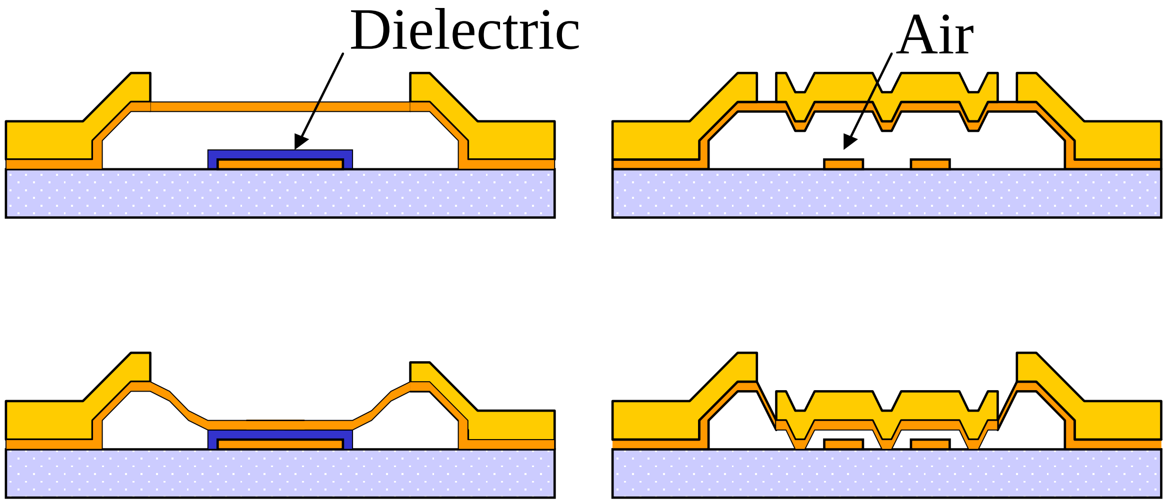


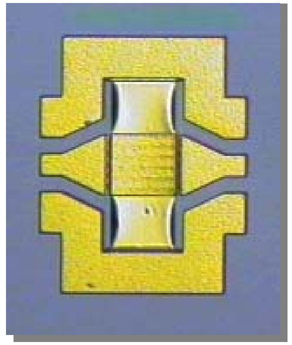
•MIM capacitances: I(V) curves for 200 nm-thick nc Co: Al_2O_3- 17% and 5% vol.

•SCLC- type conduction

New materials vs. new designs



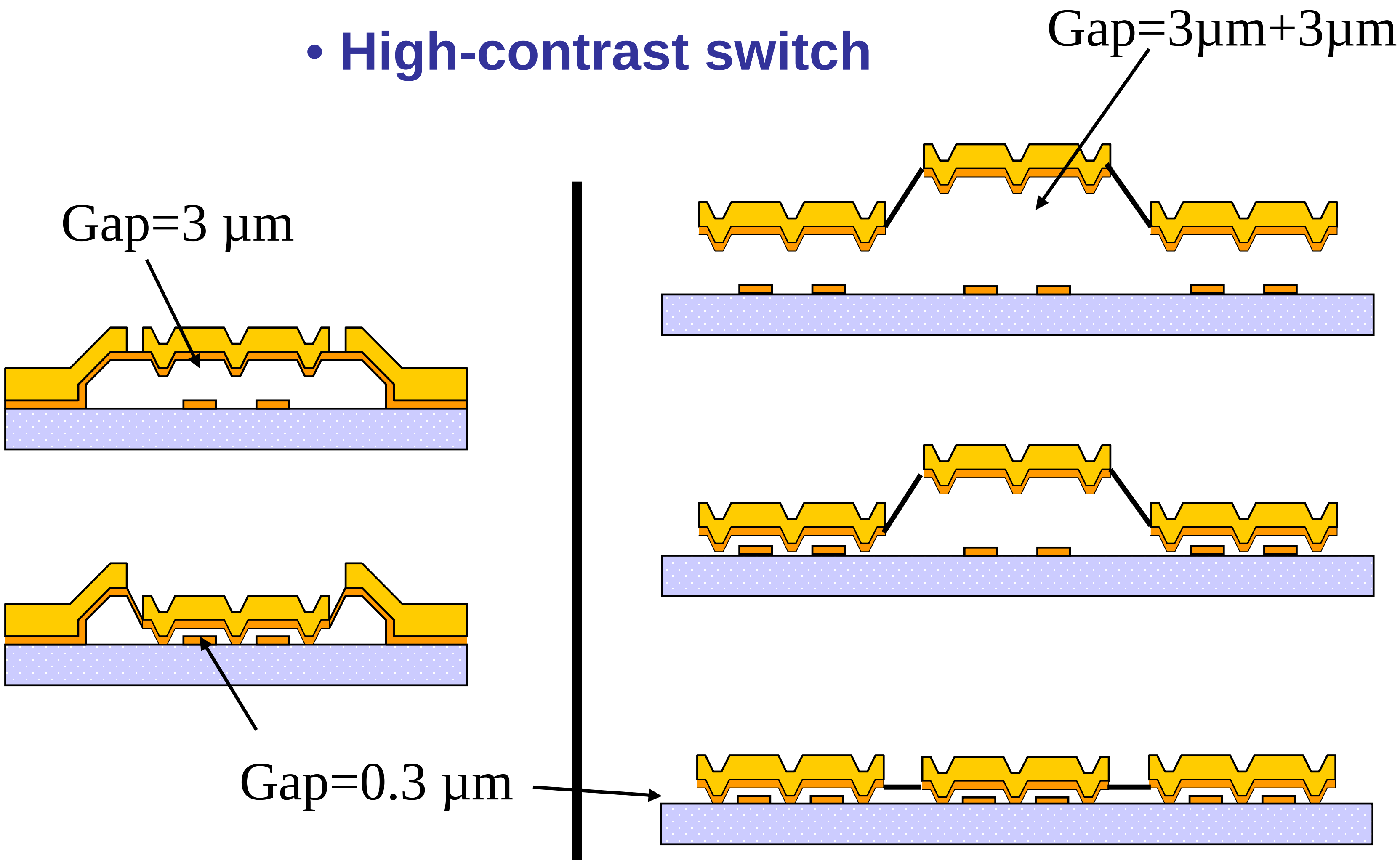




- No trapping, no complicated actuation waveform
- No drift in C(V)
- No failure using unipolar bias
- Large structure
- Low on to off ratio

Proximity mode RF-MEMS Switch

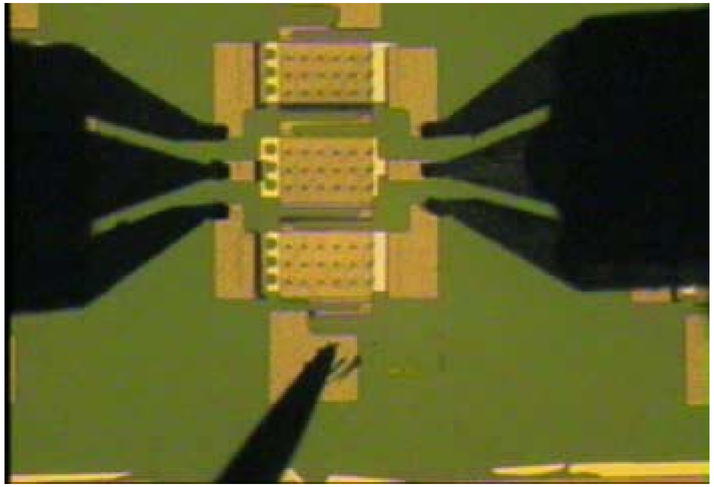
• **High-contrast switch**

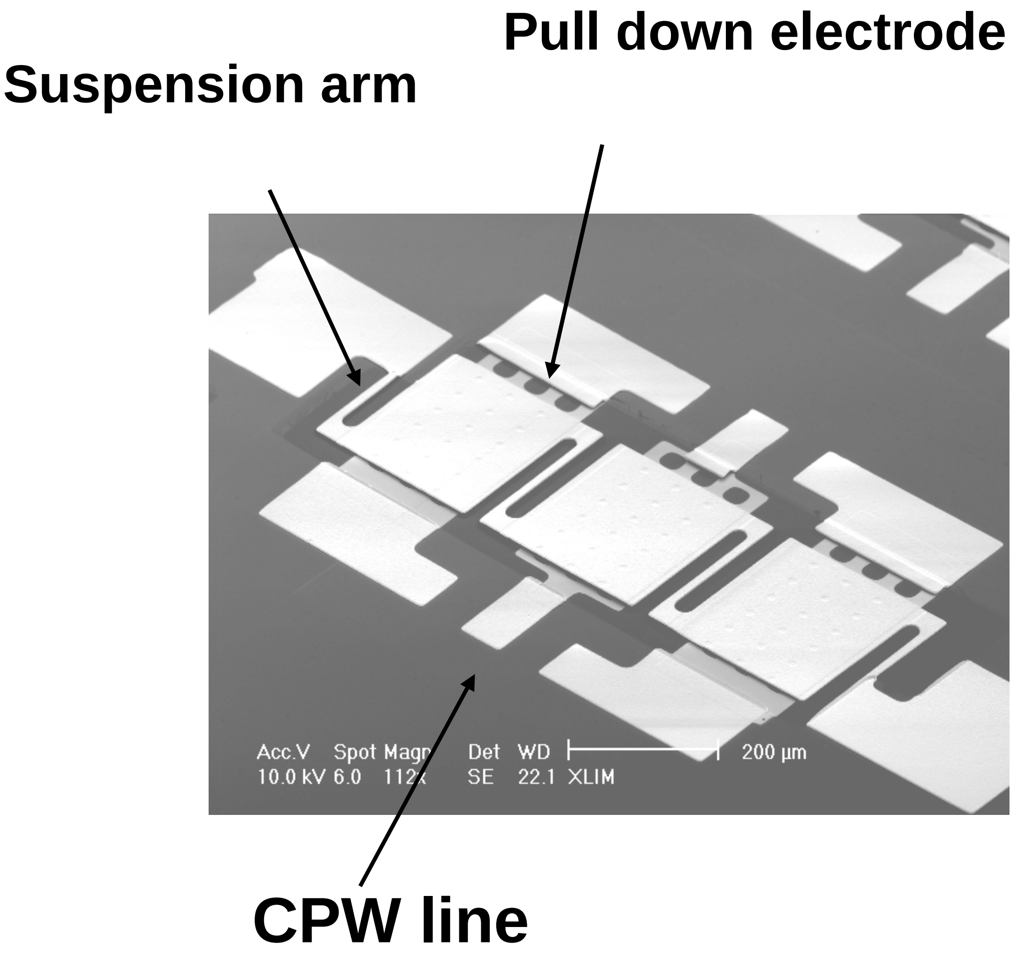


• **On/Off < 10**

• **On/Off > 10**

Proximity mode RF-MEMS Switch





Conclusions – RF MEMS switches

- Very good RF characteristics
- Proximity- contact MEMS switches can be a viable solution to the charging problems
- Still a lot of work to do:
    - Reliability
        - fabrication (design, materials, stress…)
        - characterization/ testing
    - Packaging
    - Space qualification

Collaborations

- IRCOM- & SPCTS- UMR CNRS – University of Limoges
- Alcatel Alenia Space
- ESA/ ESTEC
- DGA