Successive Conduction Modes in Si_3N_4 Capacitive RF-MEMS Switches

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Agenda

- RF MEMS reliability basics
- Techniques for charge trapping reduction
- Testing and conduction mode identification in capacitive MEMS switches
- Conclusions

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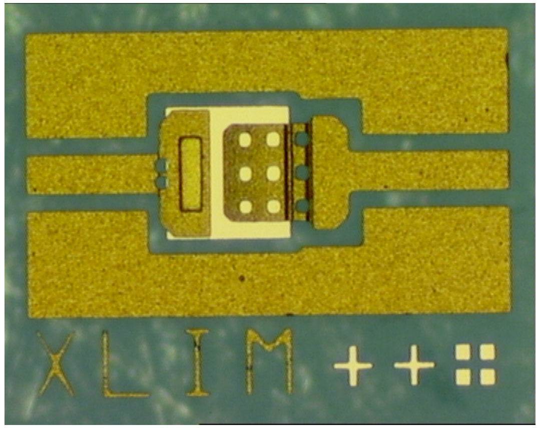
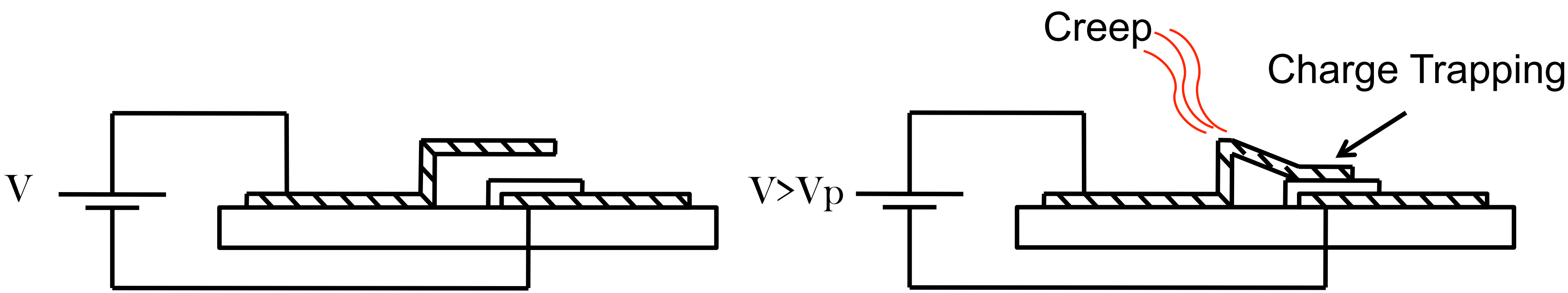
RF-MEMS Reliability Basics (1)

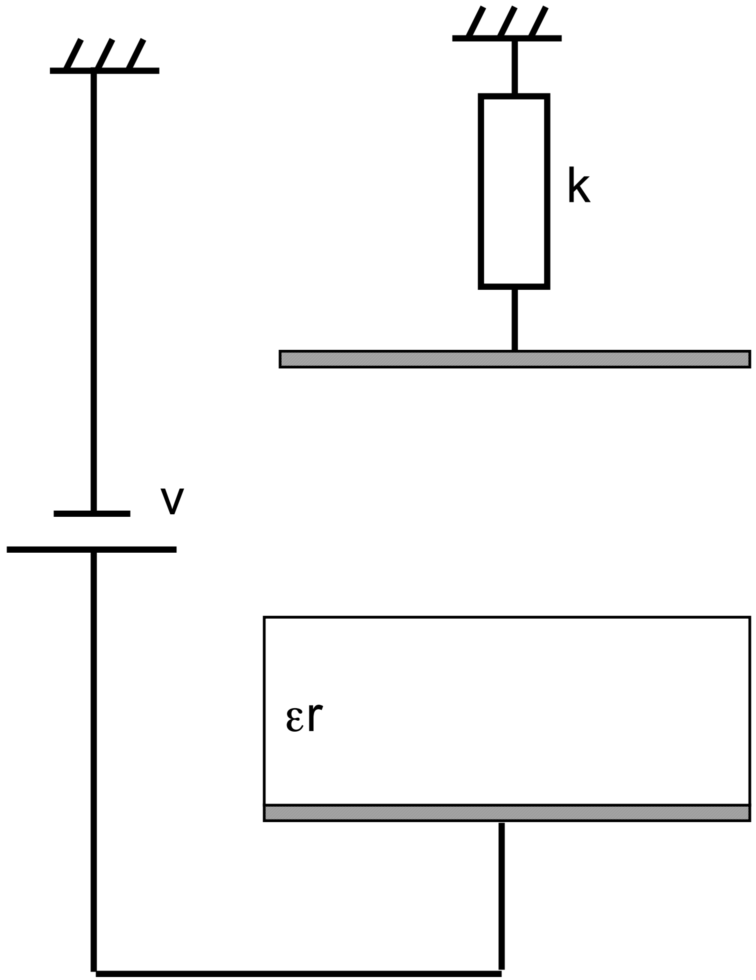


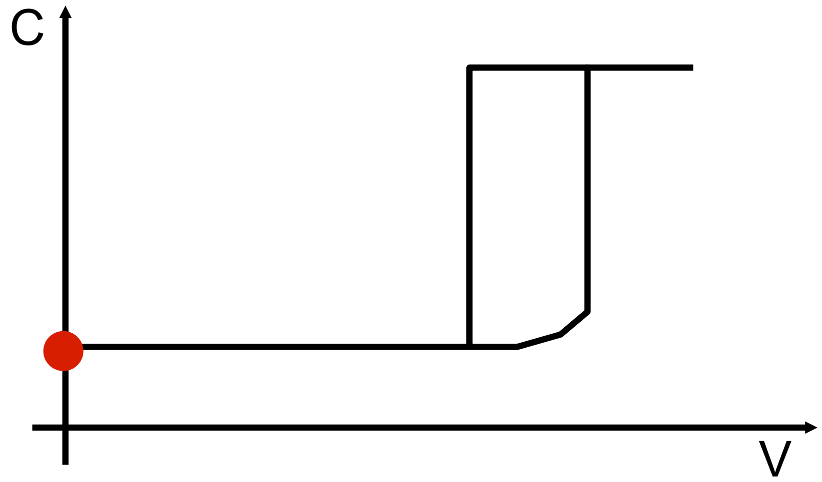
- Two main mechanims are at play:
  - Mechanical creep
  - Charge trapping



Charge injection and trapping

- Injection inside the dielectric layer





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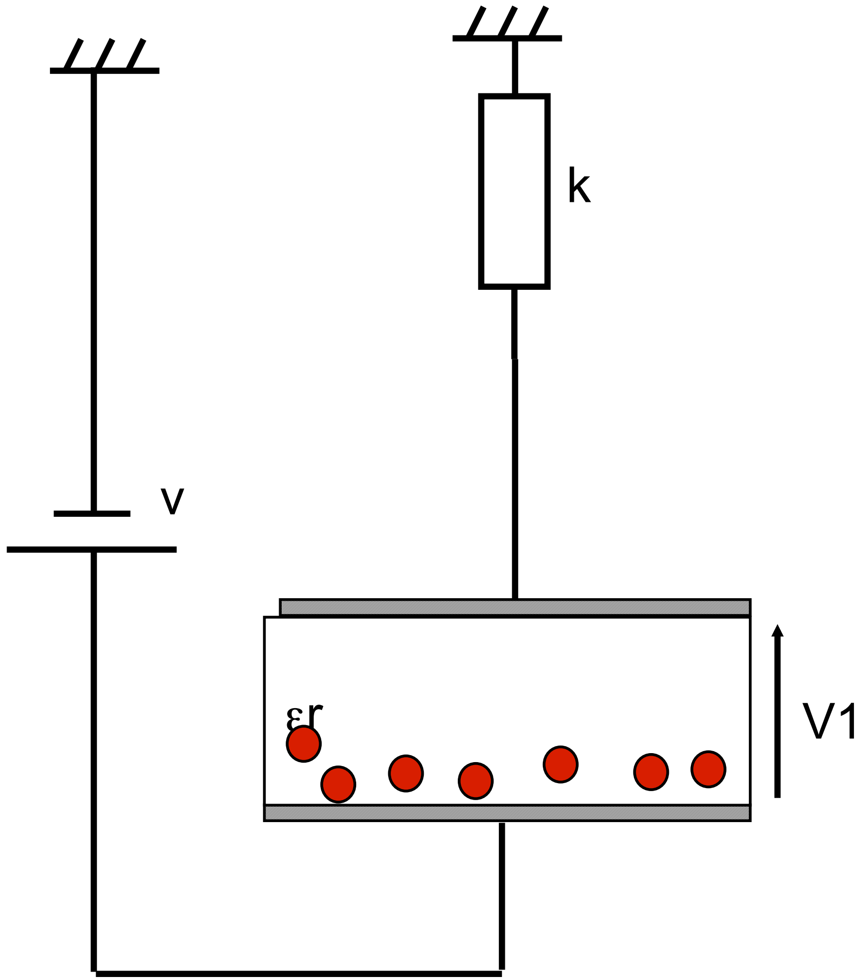

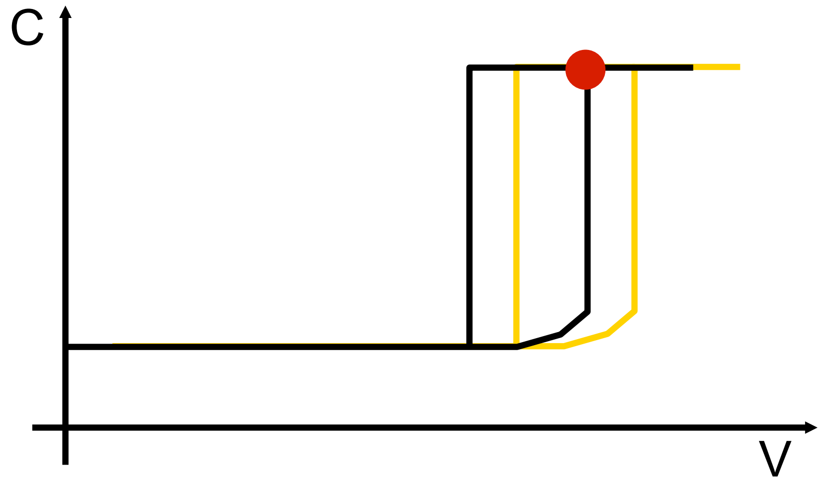

Charge injection and trapping

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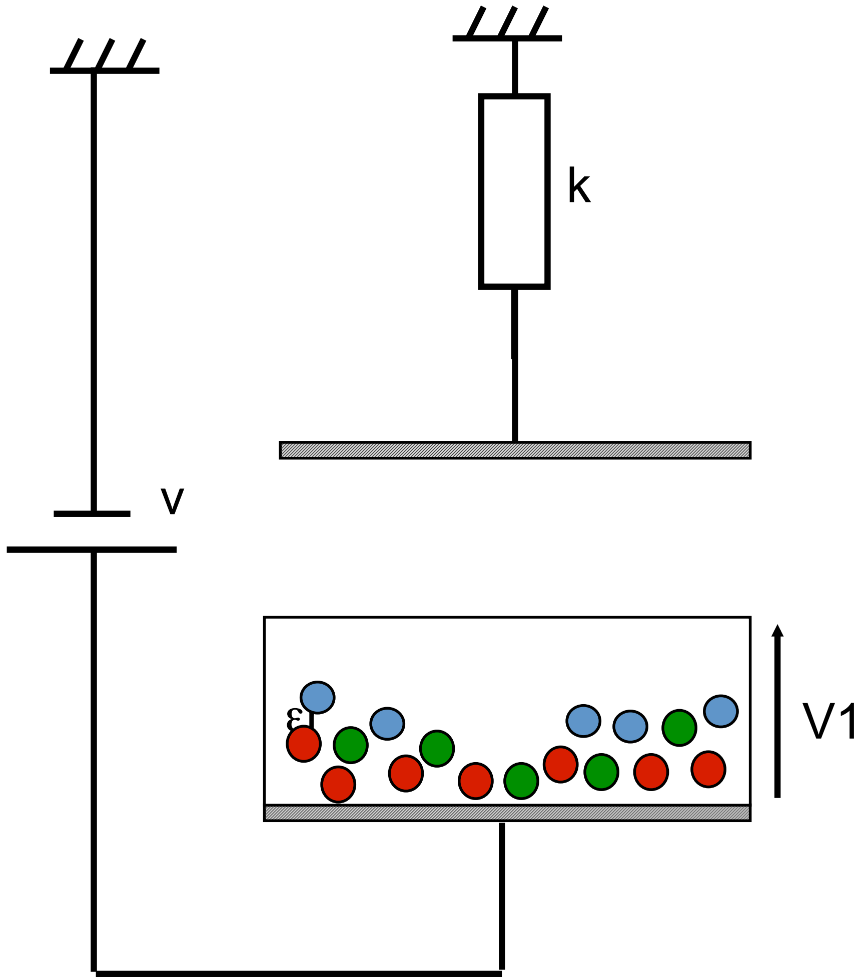

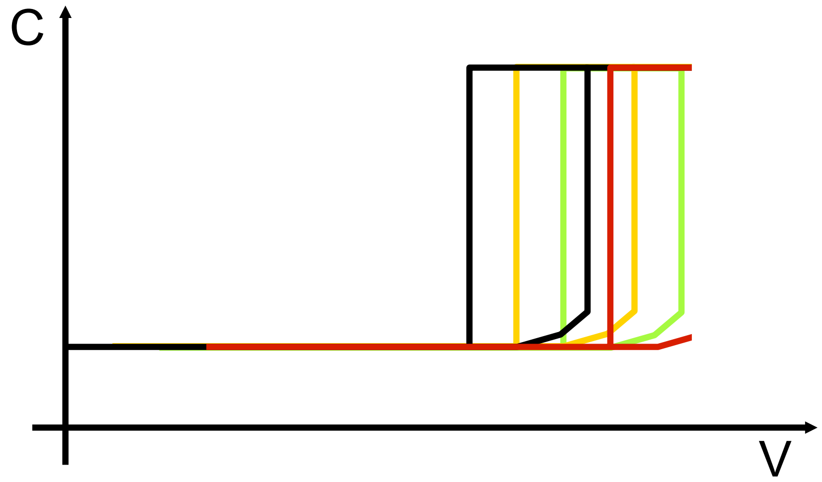

Charge injection and trapping

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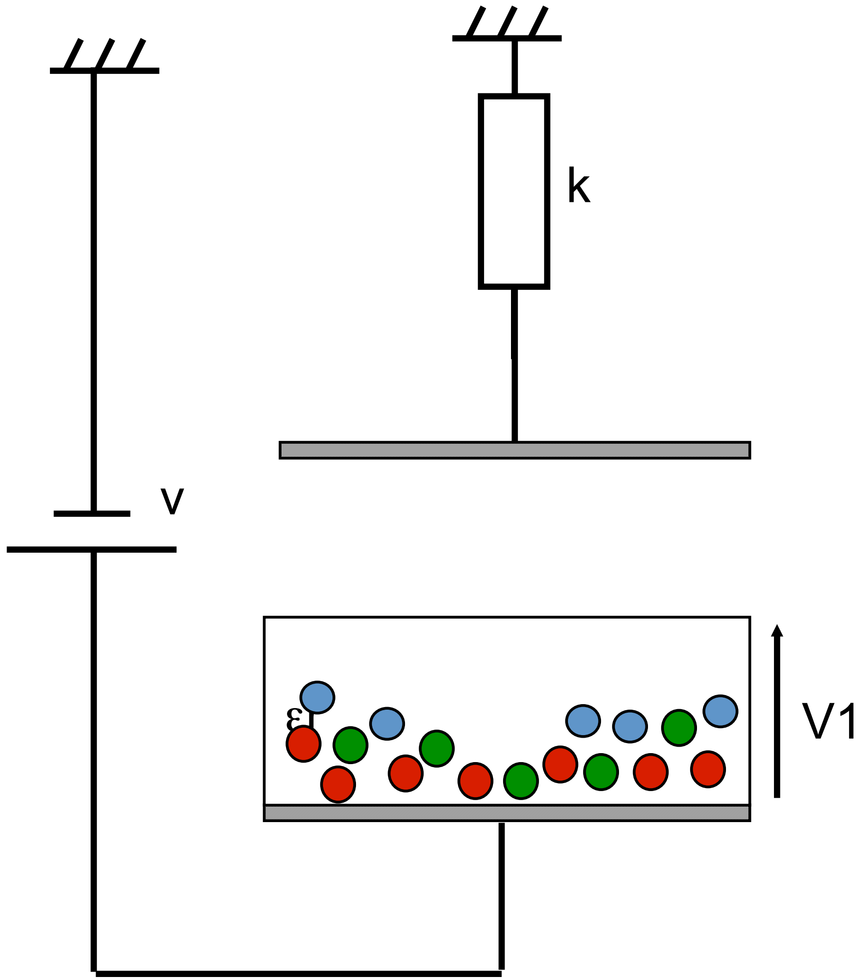
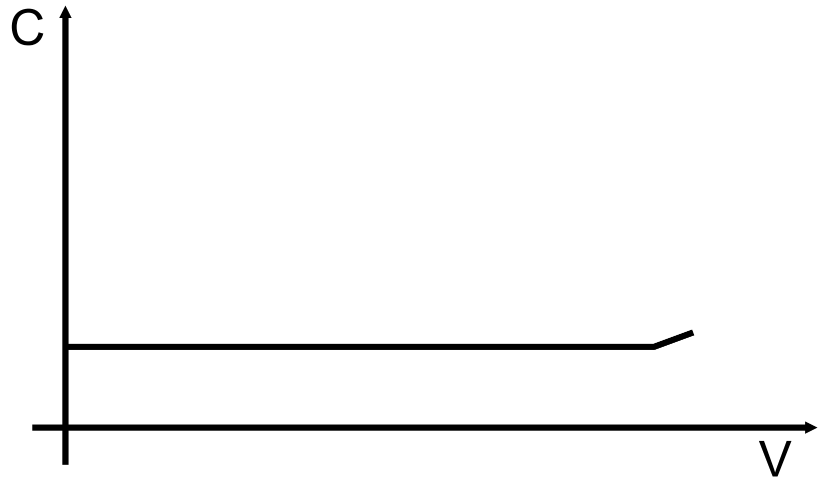
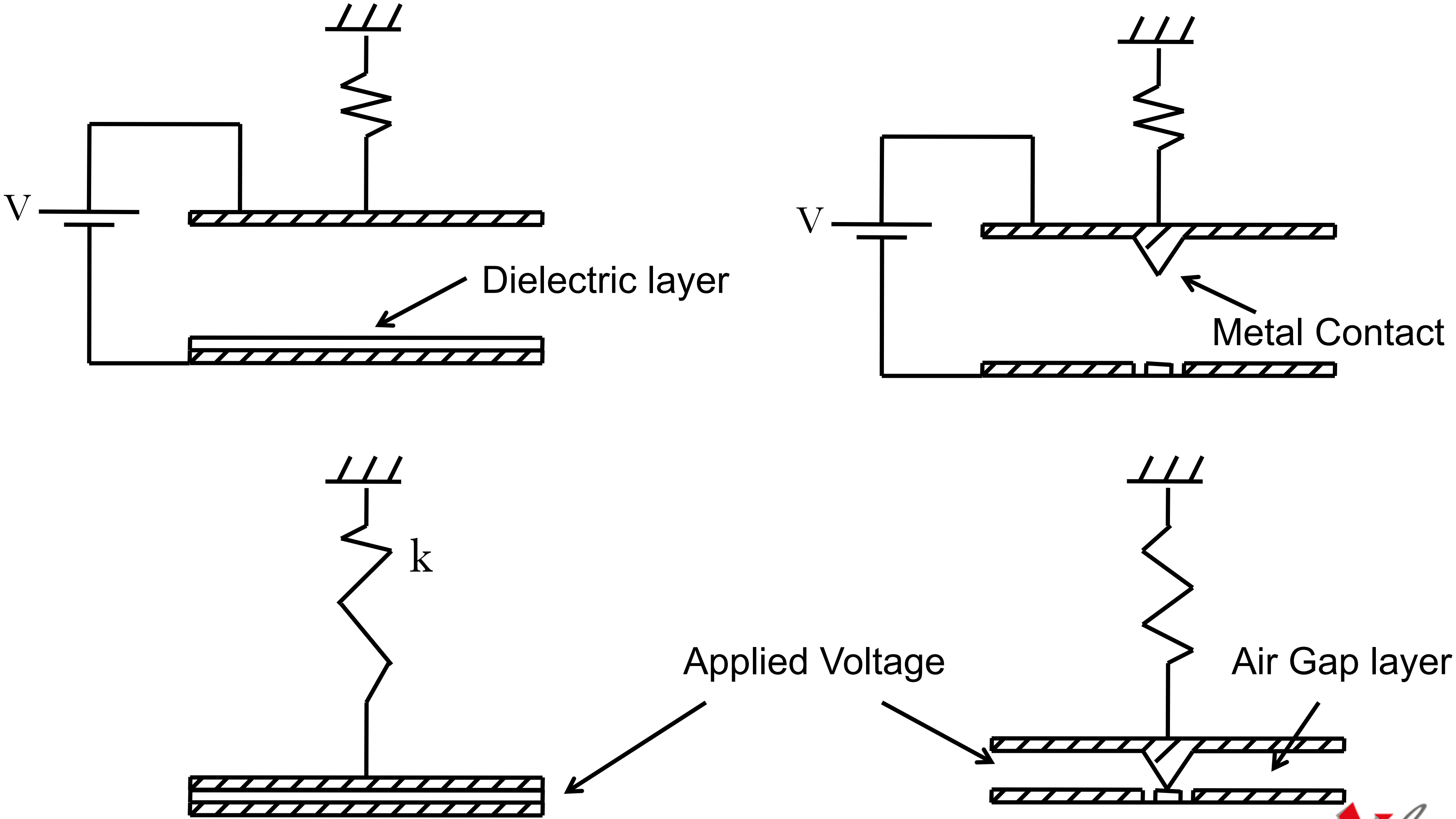


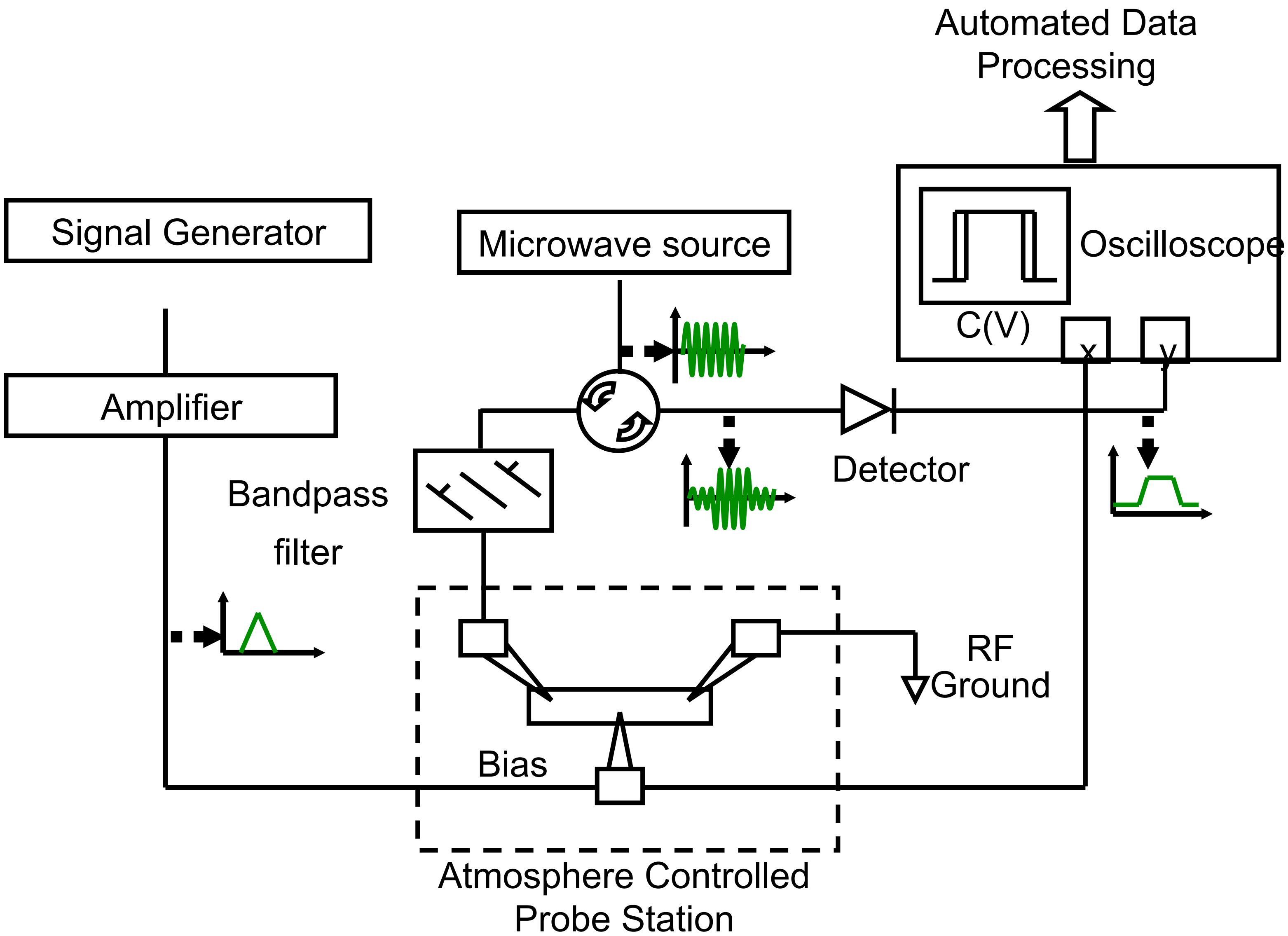


Switch failure!

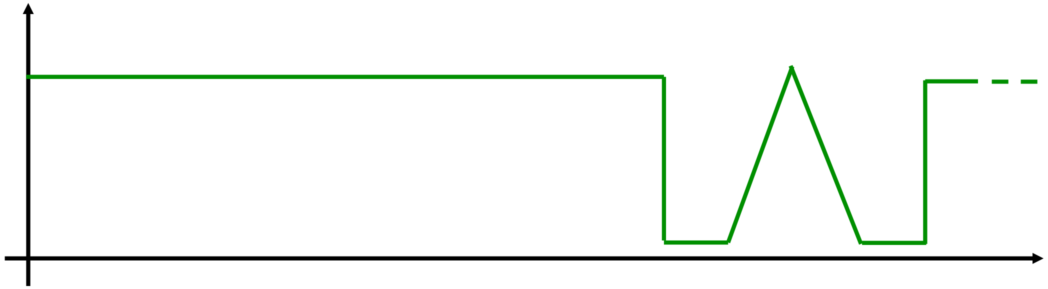
Capacitive Switches vs Ohmic



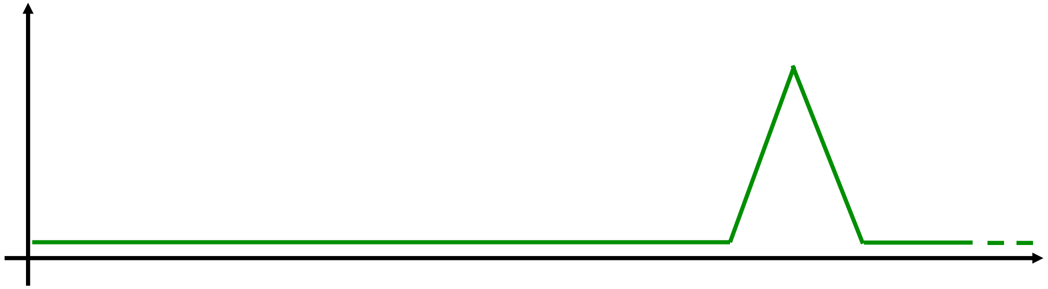
Testing sensitivity to charging



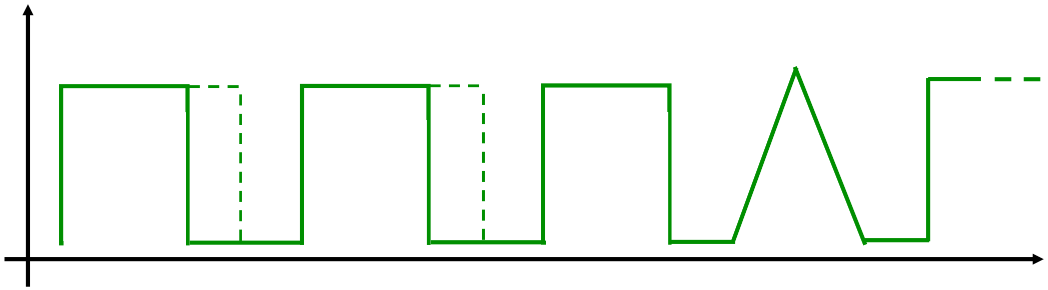
Waveforms for RF-MEMS reliability assessment



90% down state
-> quick charging



<10% down state
-> discharging



Cycling & variable suty cycle
-> Variable stress

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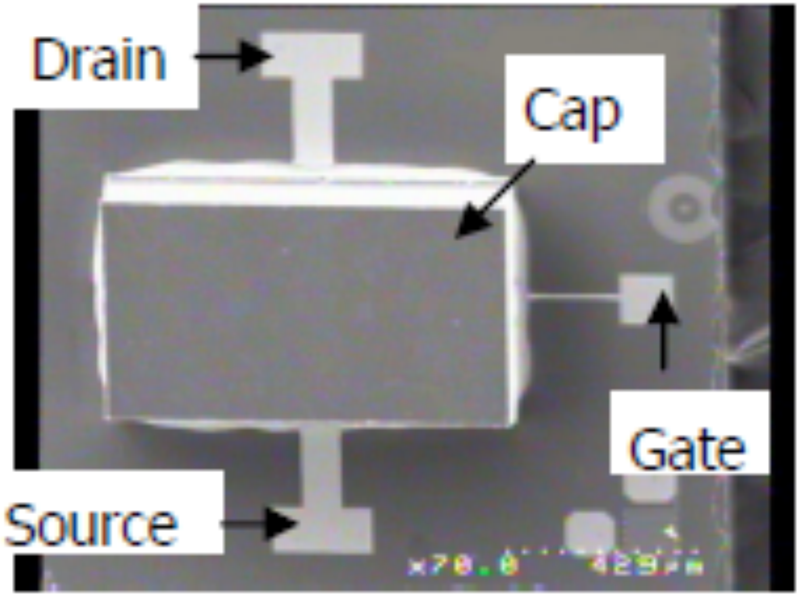
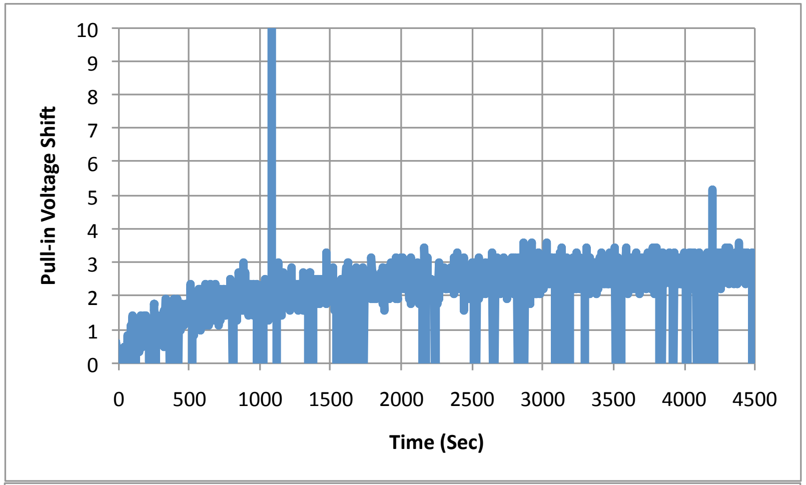
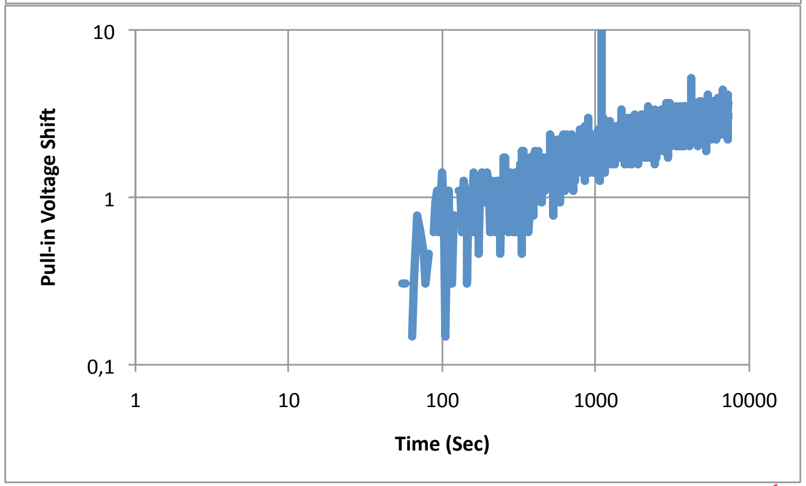
Example 1:
Radant (Ohmic) MEMS Switch
@ 70°C - 99% in the down state

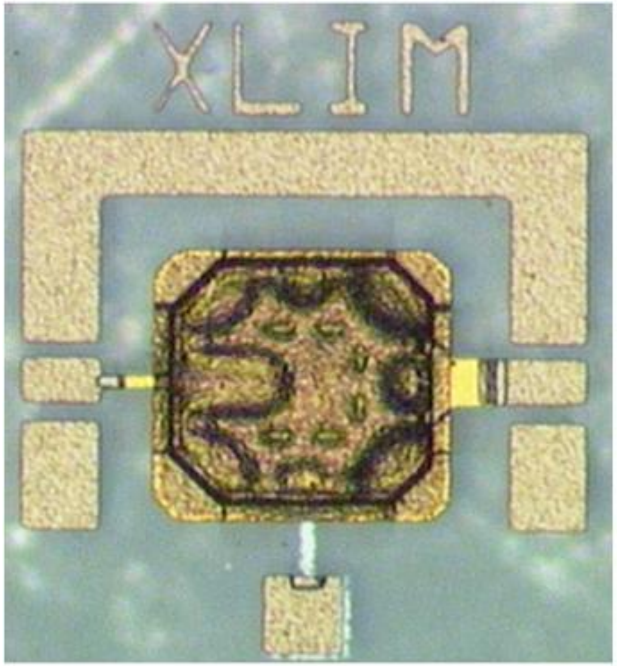


90 Volts applied. Vp is 81 Volts.

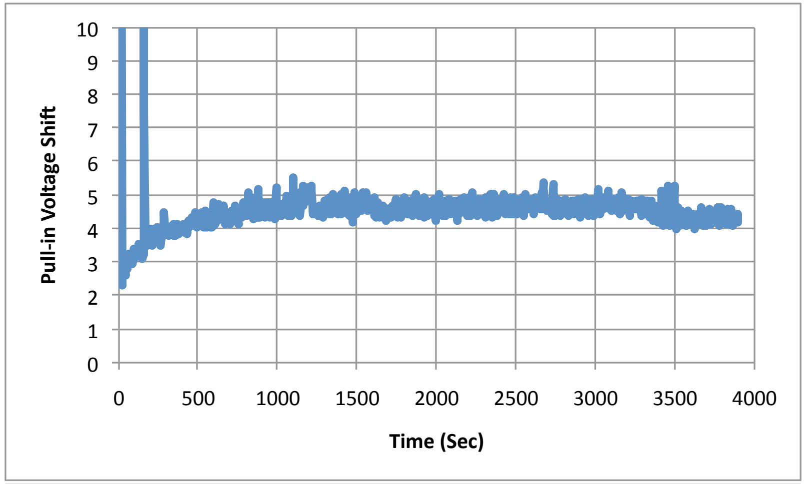


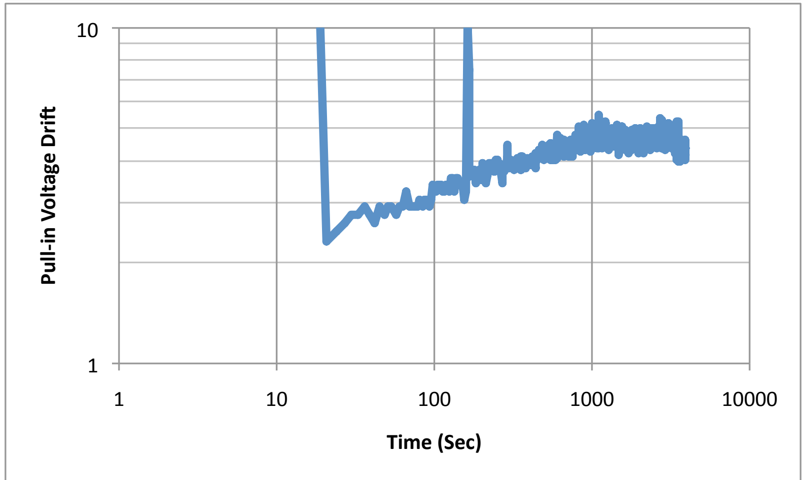


Example 2
XLIM (Ohmic), MEMS switch
@ 70°C - 99% in the down state



30 Volts applied. Vp is 24 Volts.





Charging in RF MEMS
Current Status

- Ohmic switches have very little sensitivity to charging
  - Testings on commercially available / optimized switches show little or no drift.
- Large contrast capacitive switches suffer from quick and large drifts because of charge trapping

For Capacitive Switches…

- Measured drifts on large contrast capacitive switches are on the order of Volts/minutes
- This is accelerated with temperature, and applied voltage
- In other words:
  - large contrast, RF-MEMS, *capacitive* switches do not work at present, while *ohmic contact* switches, are on their way to the market

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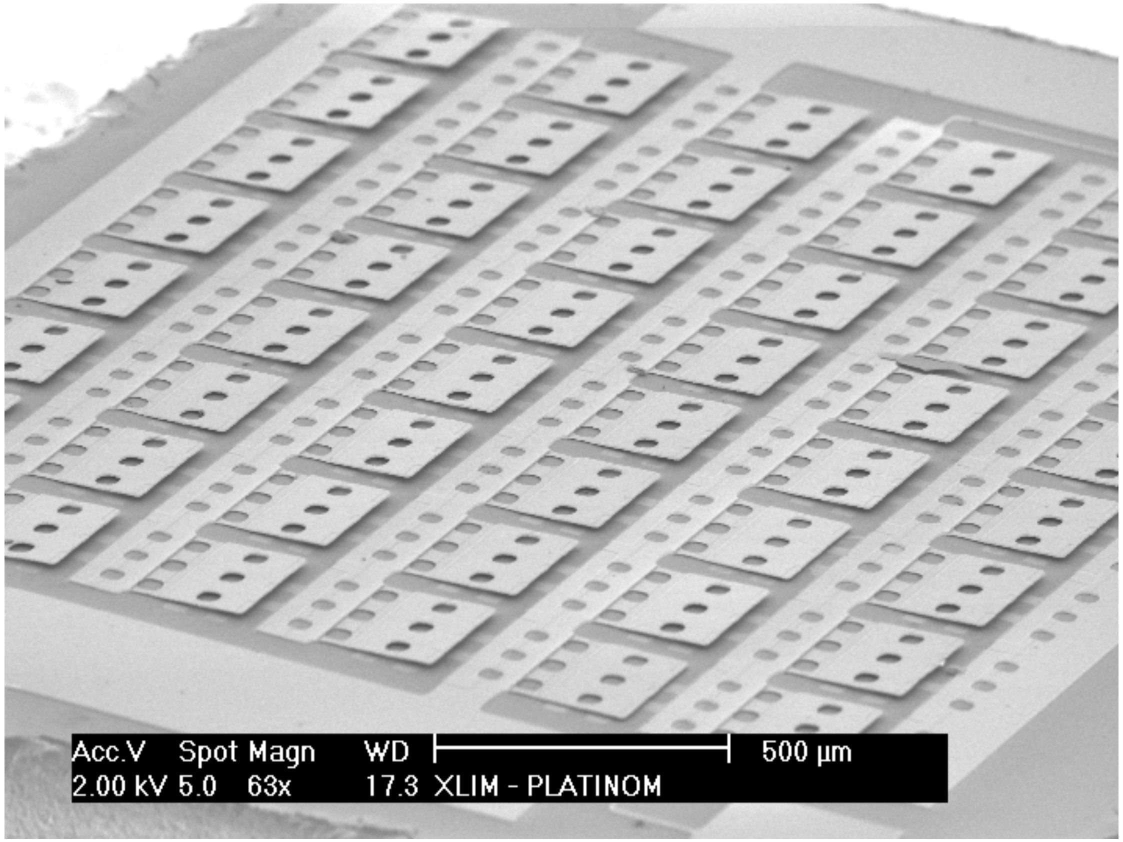
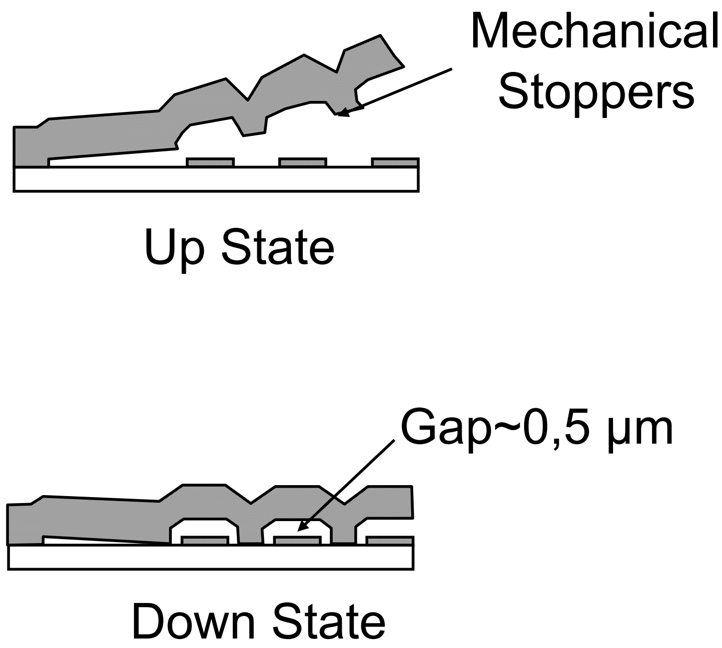
Strategies to reduce the influence of charging

- Remove the dielectric layer





Completely (XLIM)

Strategies to reduce the influence of charging

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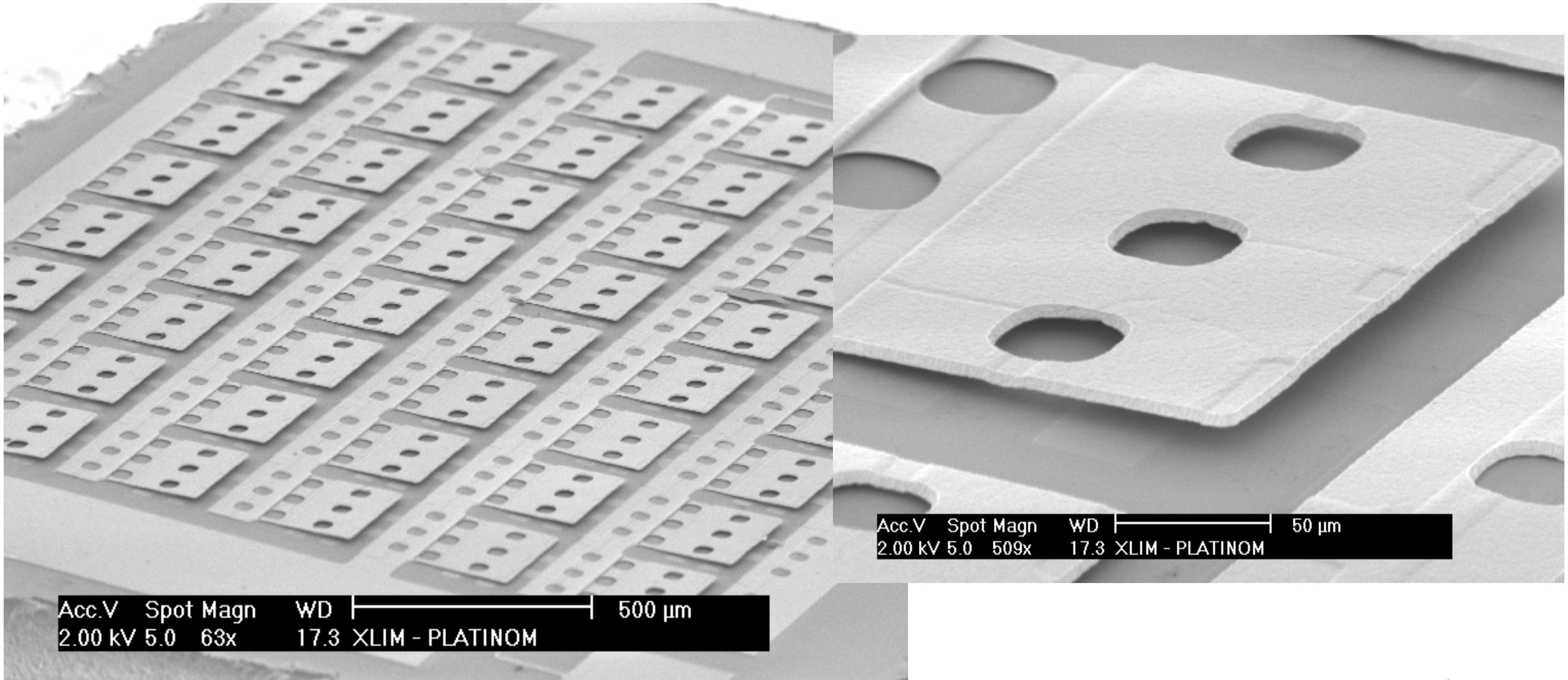

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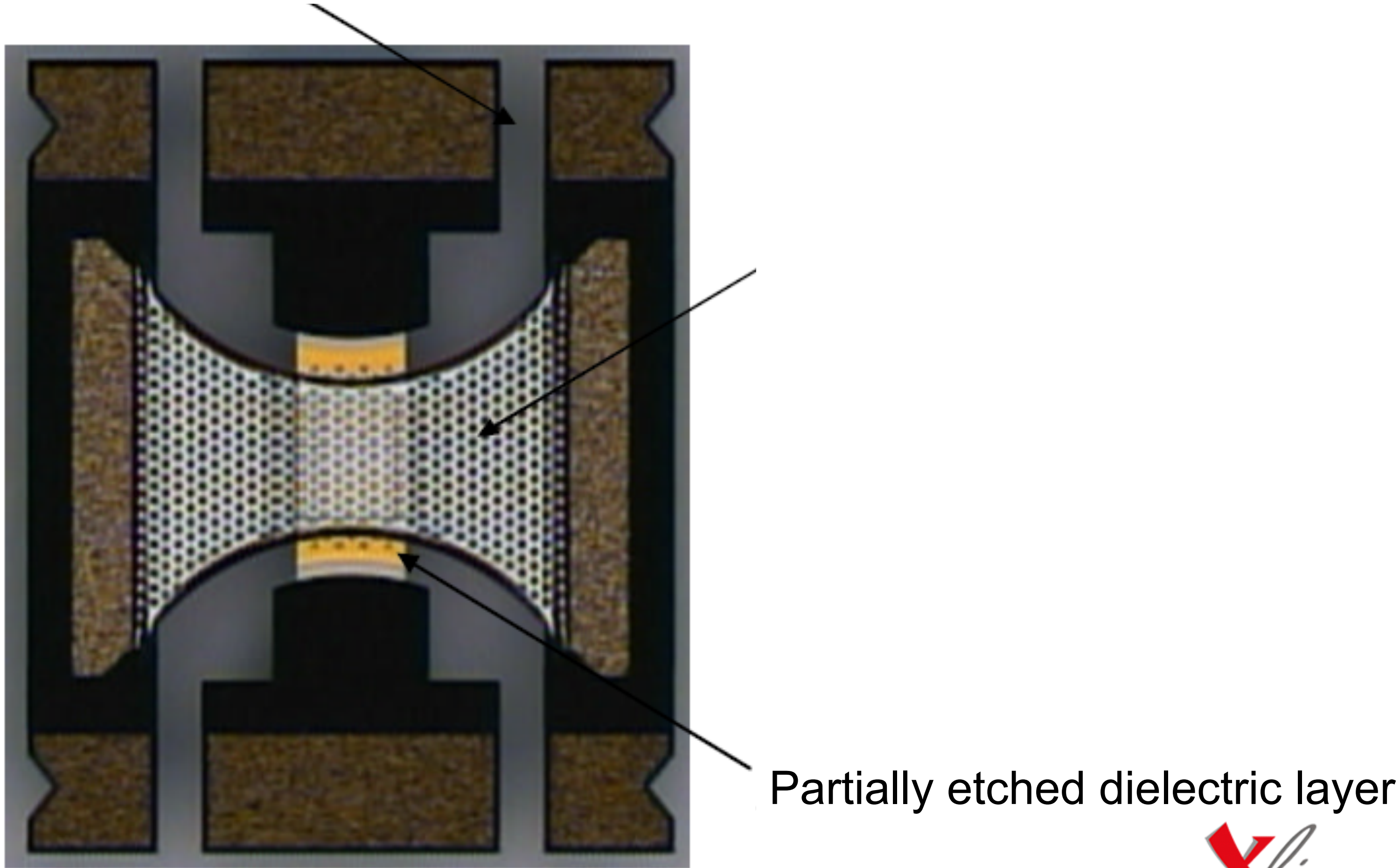
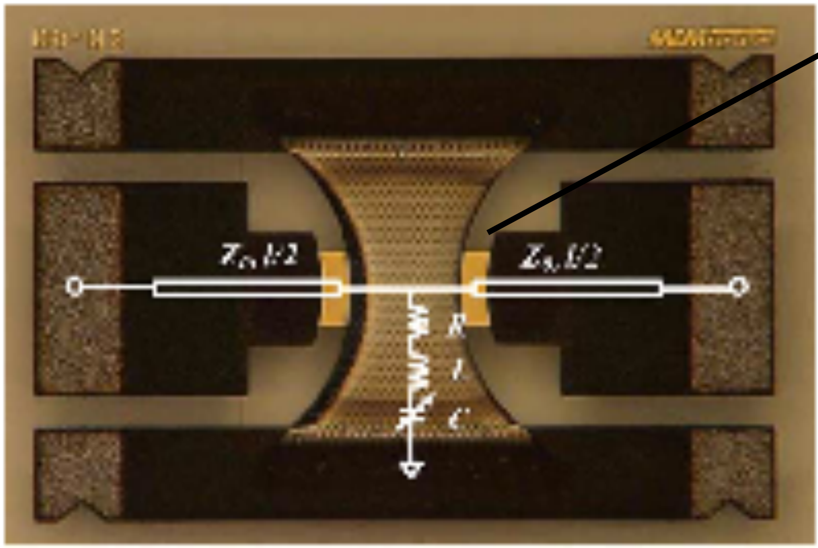
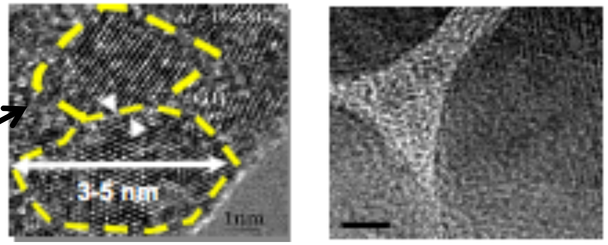


Strategies to reduce the influence of charging

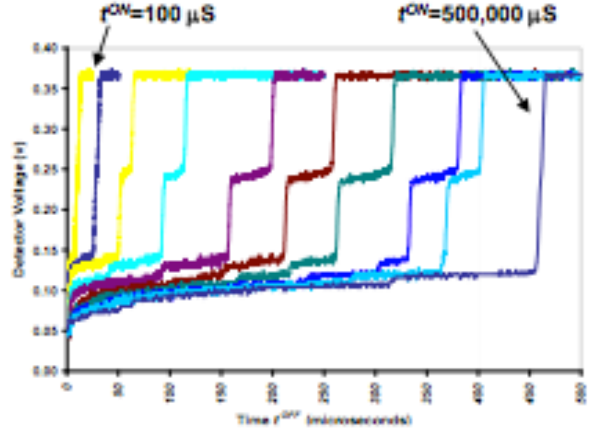
- Make the dielectric layer (a bit) conductive



(MEMTRONICS)



UNCD Dielectric



Charge “evacuation” depends on the time
In the down state. The switch has to be released
Every 100 sec, roughly, 0.0005% of the time

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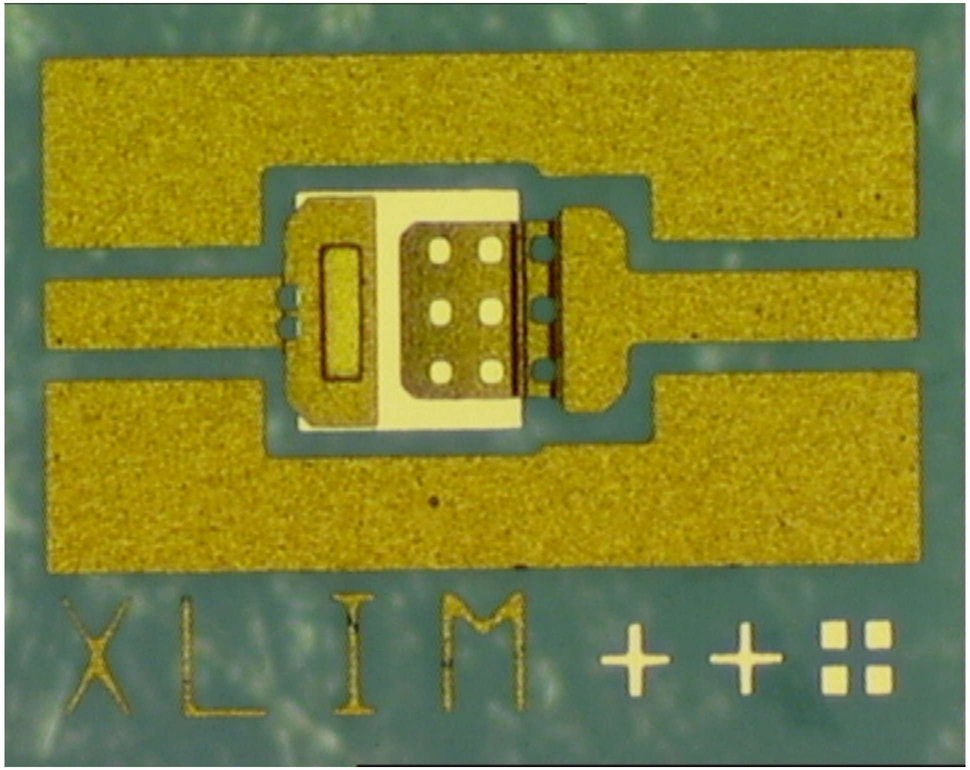
Strategies to reduce the influence of charging

- Current strategies to reduce charge trapping in dielectric layers lead to compromises:
  - Reduced Contrast, dielectric less (Viable)
  - Current consumption (Complicated)
  - Reduced contrast and current consumption

Objectives

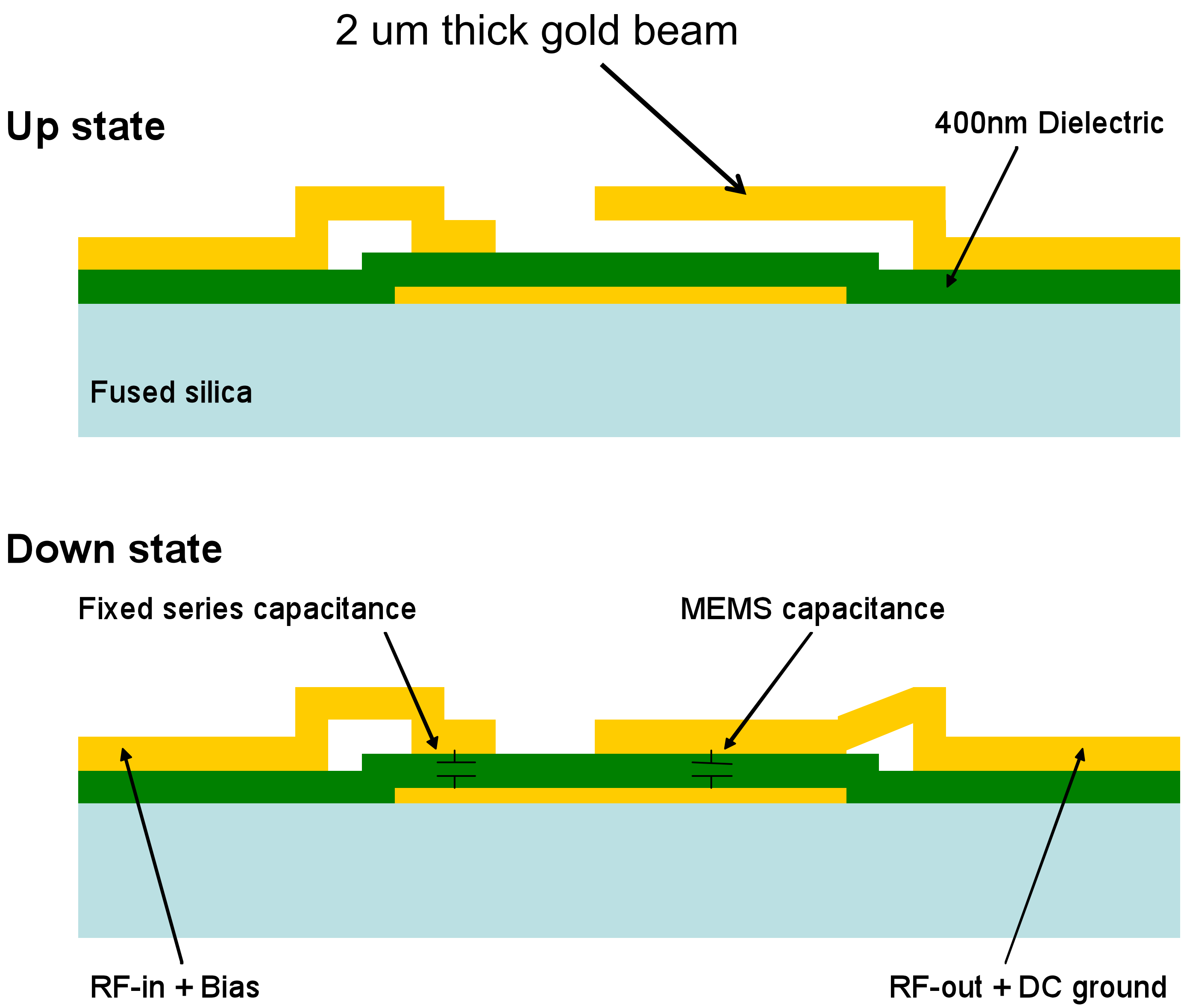
- Fabricate “basic” MEMS capacitive switches
- Measure the control voltage drifts, under various temperatures
- Identify charge injection mechanisms
- Then, try enhanced structures that will reduce charging

Generic Capacitive Switch



Cantilever beam, insensitive to temperature up to 80°C

Generic Capacitive Switch



Reliability Testing Procedure

- Test Sequence

Scattering parameter measurements

Con / Coff Ratio has to be similar
For all dielectrics

↓

Waveform electric stress description

Standard stress

↓

Conduction mode identification

Temperature variation
290->355K

↓

Charging measurement vs time

10 min stress at 25% Duty cycle Unipolar stress
(good survavibility of the switches)

↓

Model fitting (2 traps or others)

Simple, well known approach

↓

Activation energy extraction

Gives a first insight into behavior

Xlim
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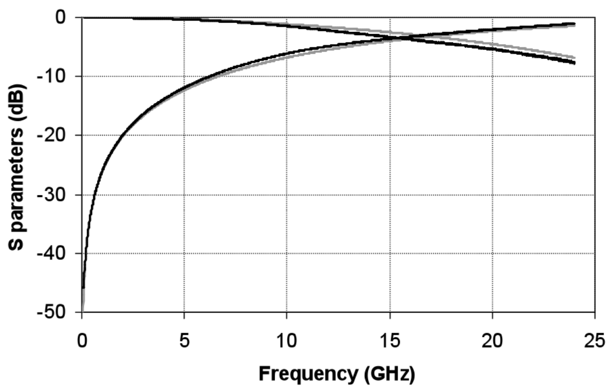
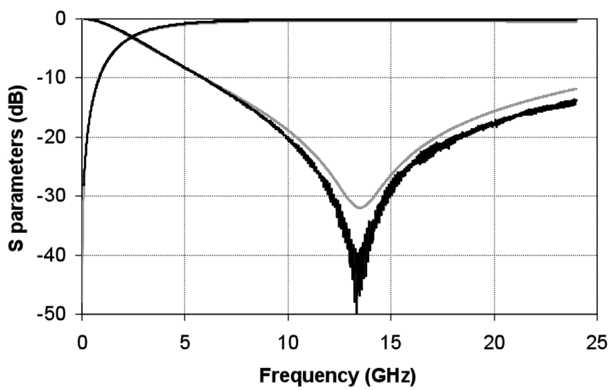
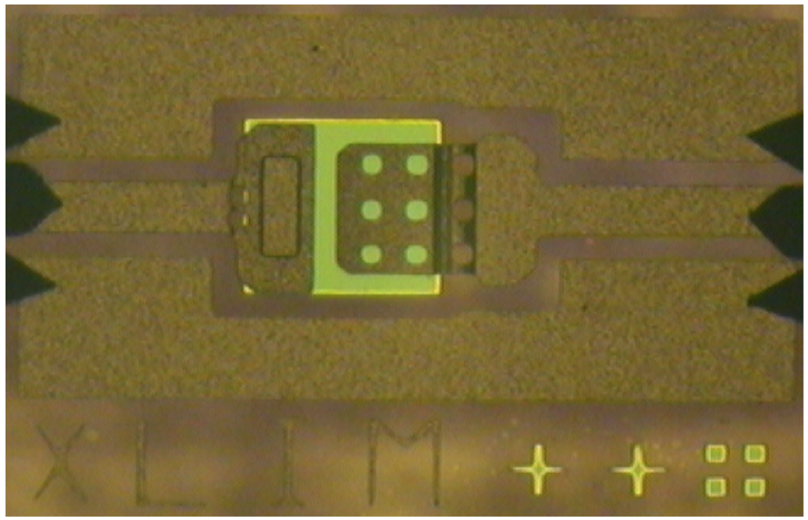
Microwave Performances

- SiN switches – S parameters



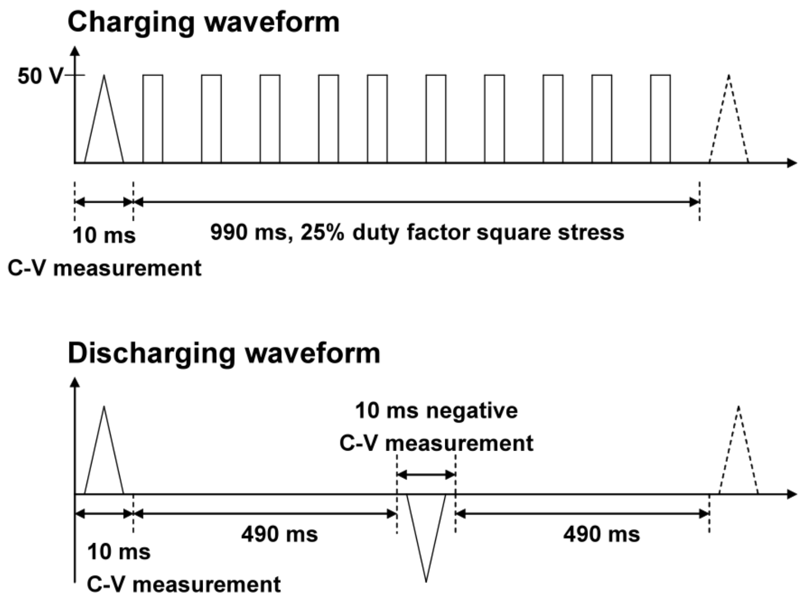


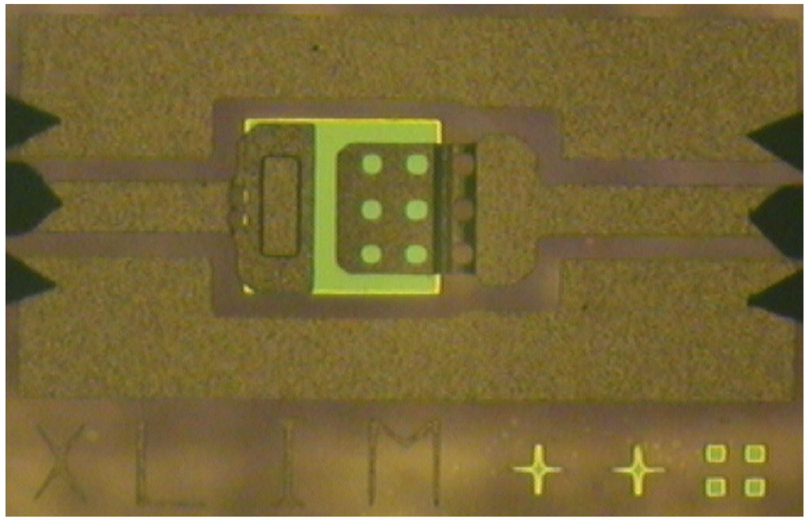


Con =650 fF
Coff = 80 fF

Testing Procedure

- SiN Switches – C(V) extraction





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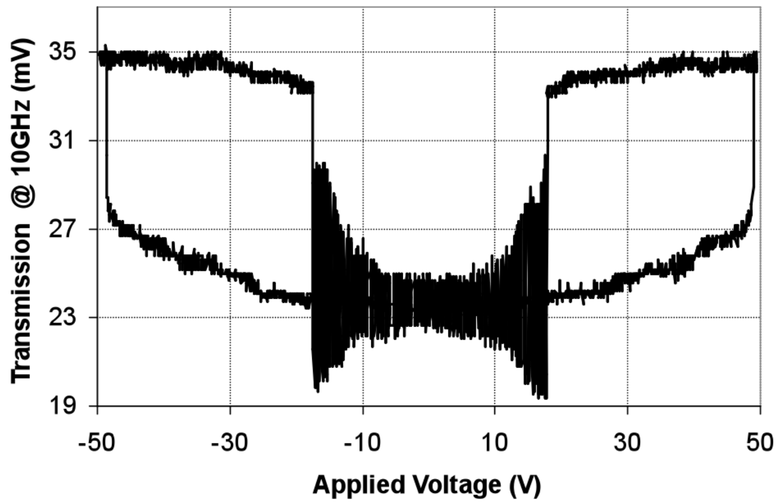
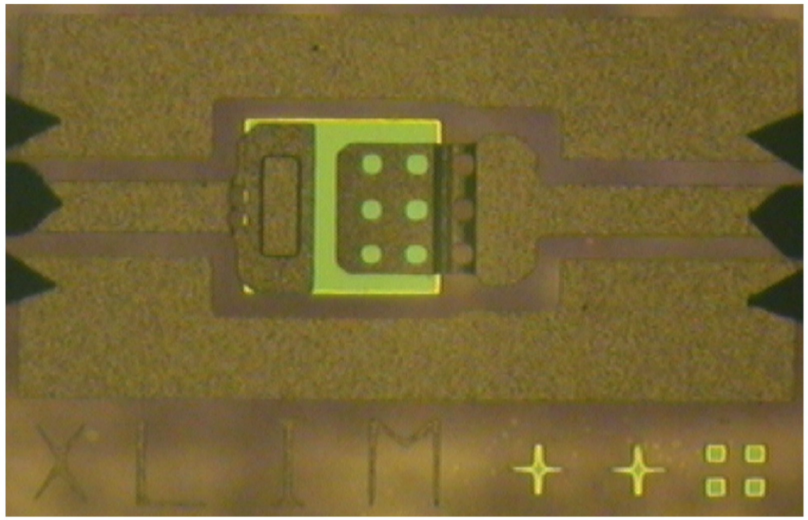
Static Characteristics

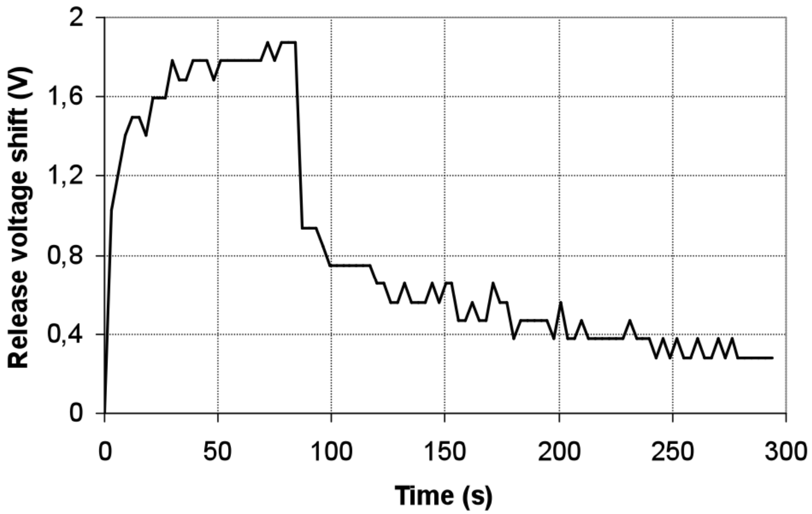
- SiN Switches – C(V) curve

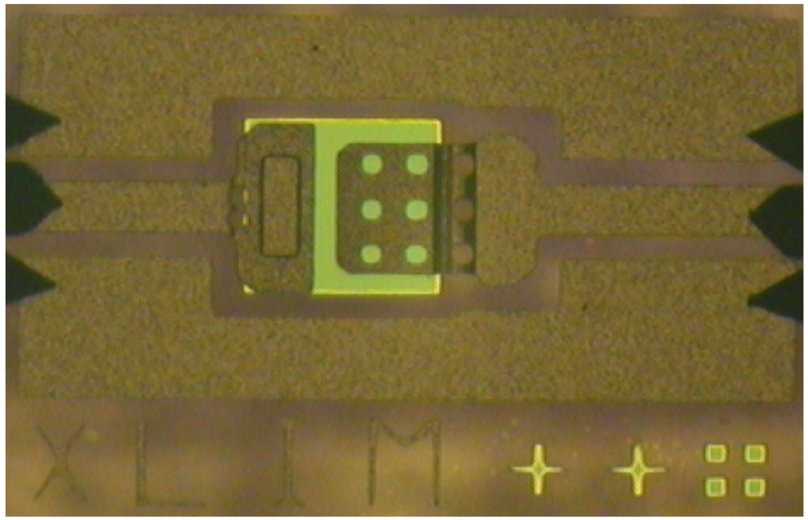




Charging/Discharging Sequence

- SiN Switches – Typical Charging Discharging sequence

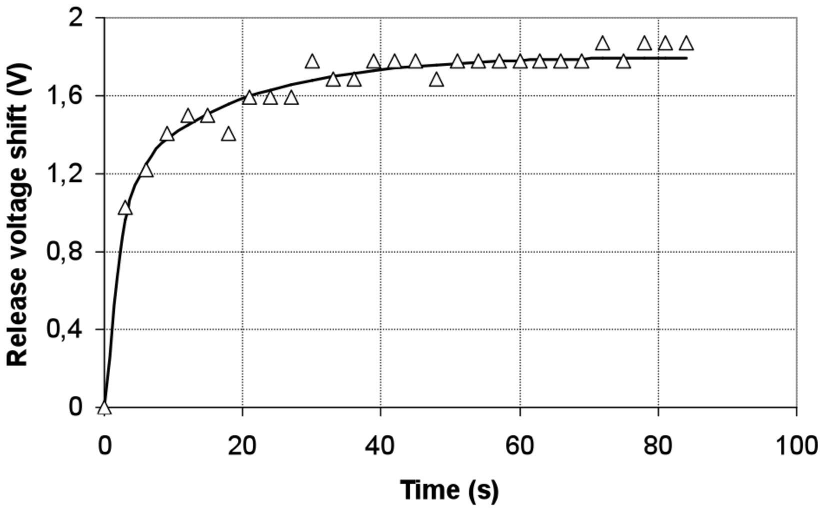


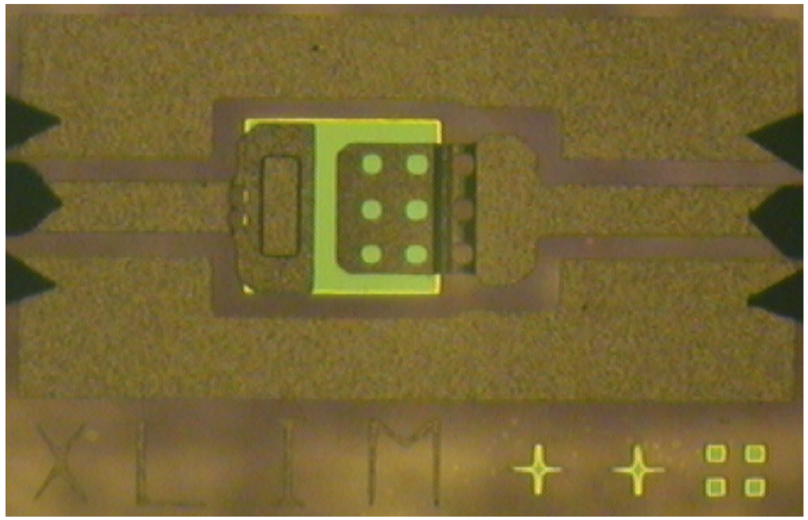


No "Cumulated time in the down state" FoM

Cantilever Switch Description

- SiN Switches – Modelling

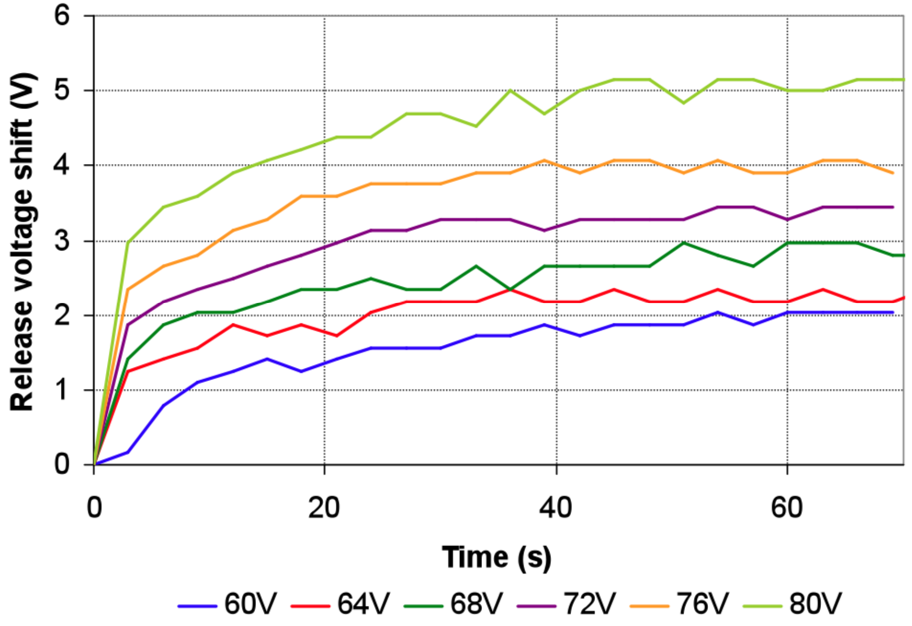


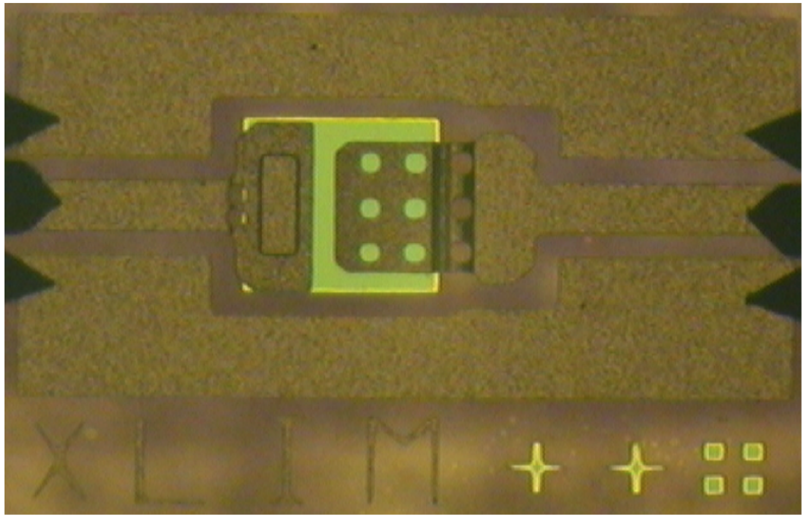


$$V_{shift} = V_a.\exp(-t/t_a) + V_b.\exp(-t/t_b)$$

Effects of Voltage

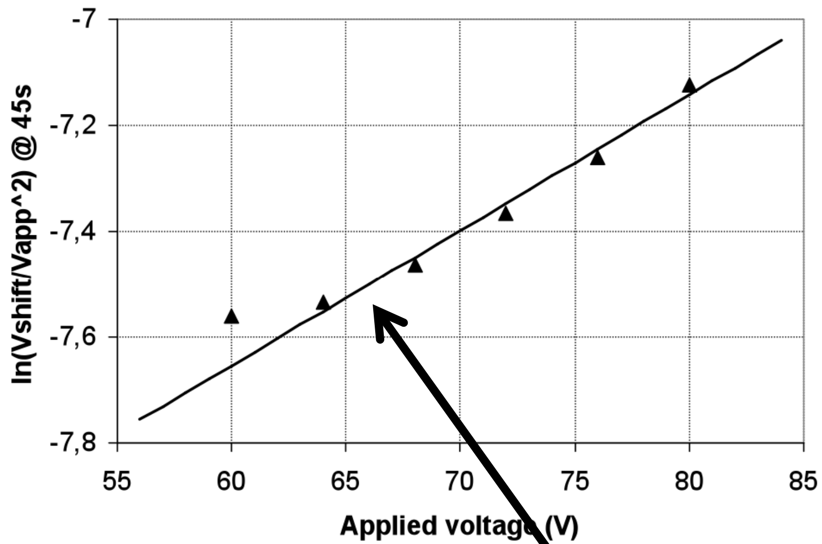
- SiN Switches – Modelling

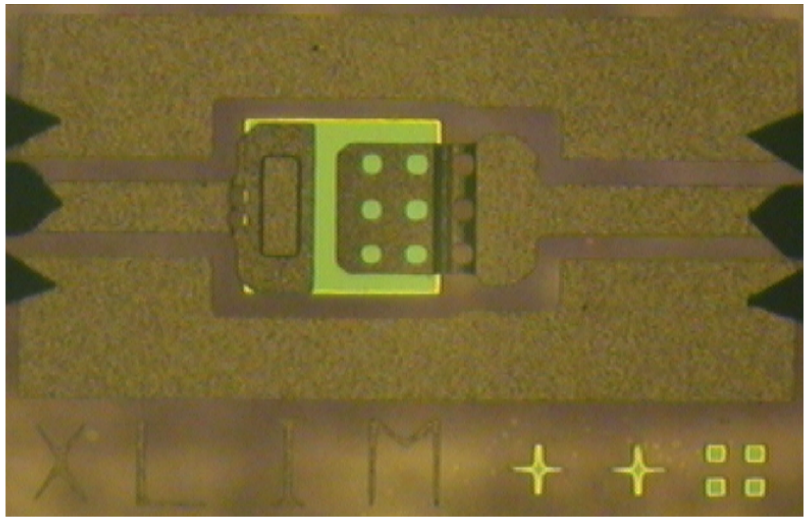




Conduction Characteristics

- SiN Switches – Modelling





This characteristic can be either
Fowler Nordheim or Frenkel Poole but Fowler Nordheim is temperature insensitive

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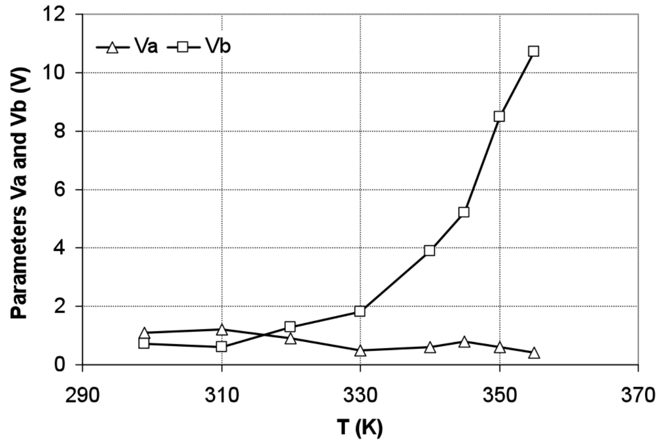
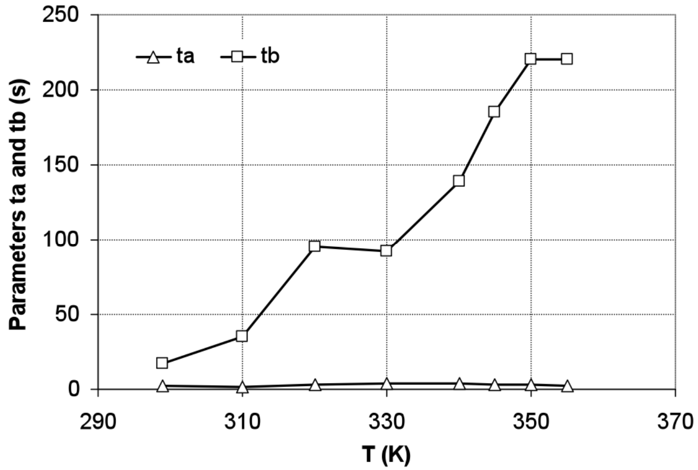
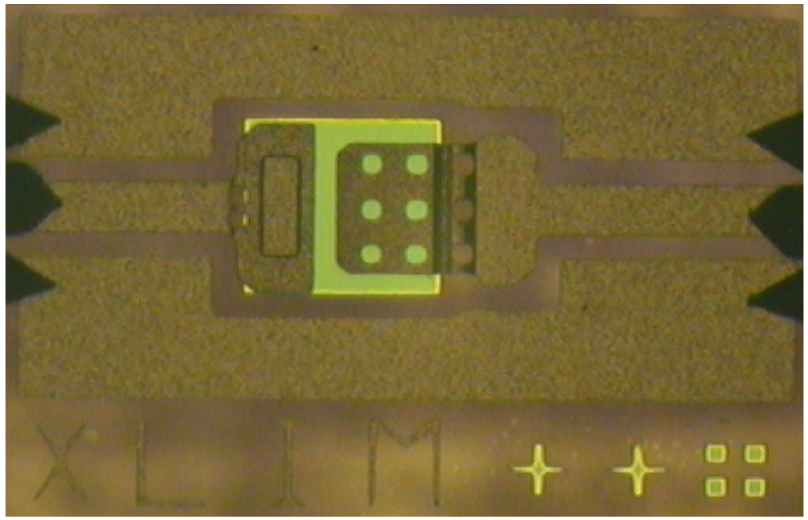
Model Fitting w Temperature

- SiN Switches – Modelling



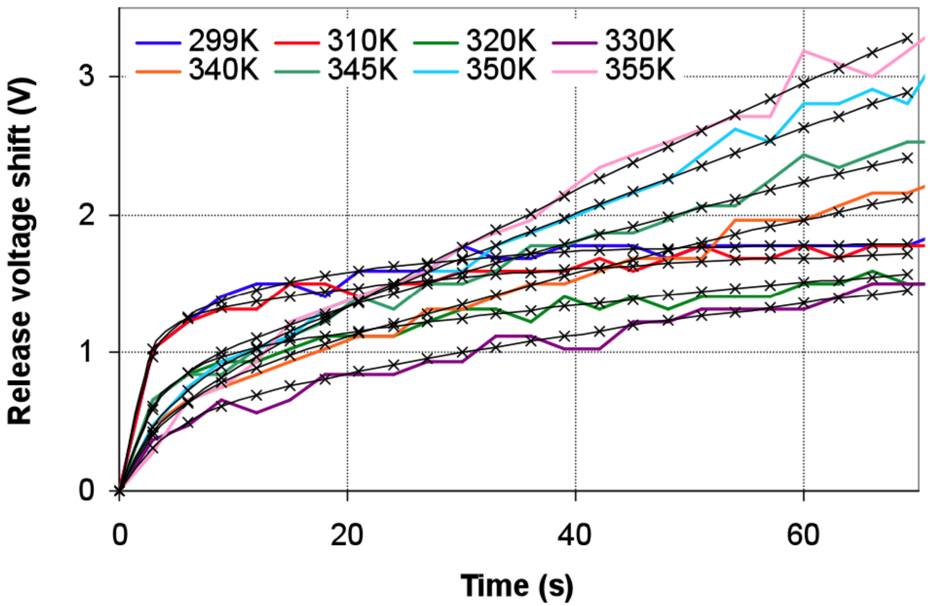


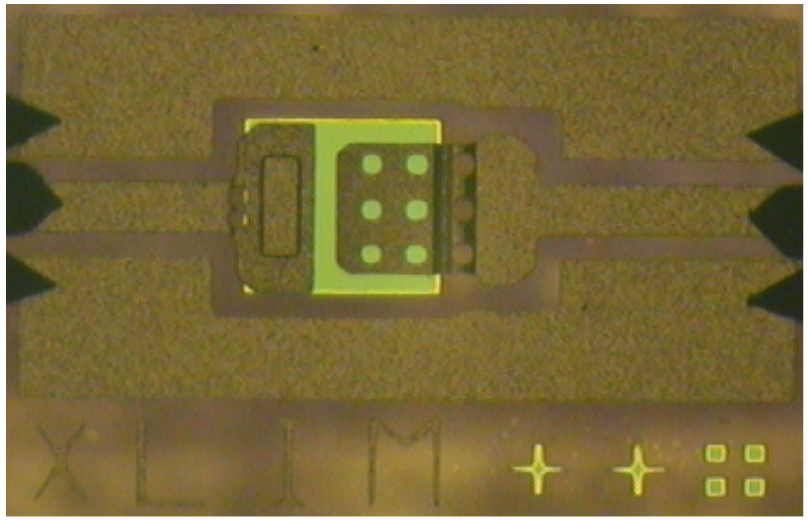


Trap 'a' is insensitive to temperature :
Fowler Nordheim and next Frenkel Poole

Model Fitting w Temperature

- SiN Switches – Modelling w T°





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Conclusions

- Sucessive conduction mechanisms could be observed in RF-MEMS structures
  - The first phenomenon is independent of temperature
  - Then, temperature plays a significant role
- This was found also on Al_2O_3 dielectric based switches
- Acknowledgments:
  - This work has been supported by ESA

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Acknowledgements

- Thales Alenia Space Toulouse