Performances and Reliability of Dielectric Less Capacitive MEMS Switches

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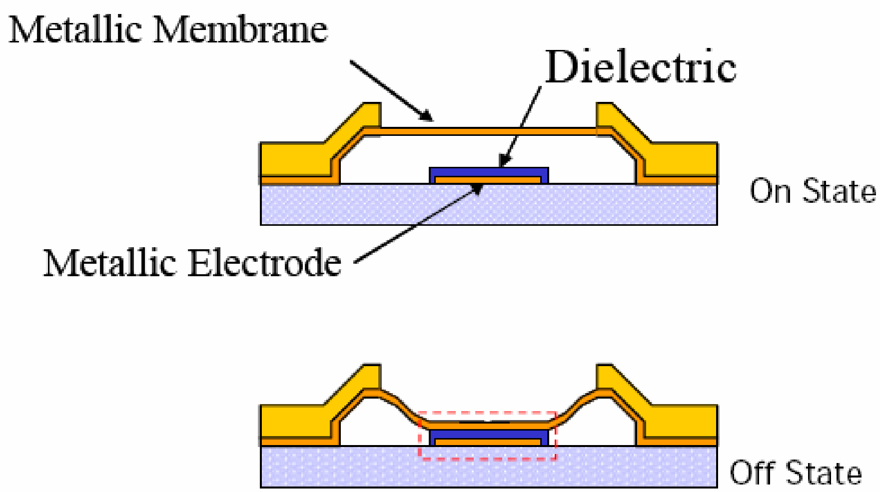
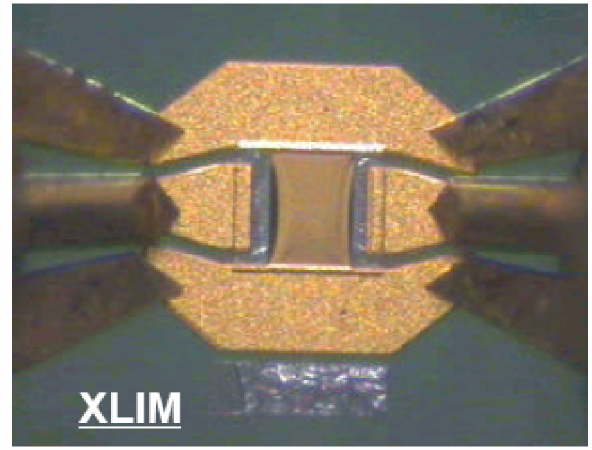
www.xlim.fr (all french website…)

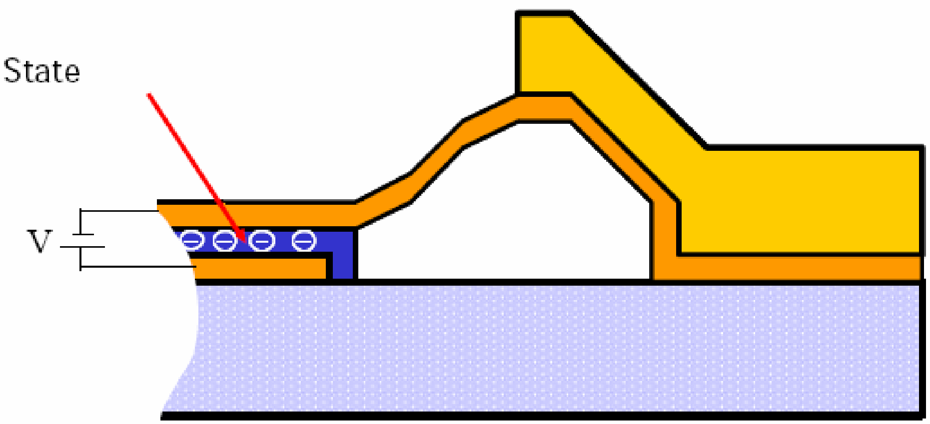
Reliability of capacitive MEMS Switches

Conventional MEMS switch





Charge Injection + Trapping

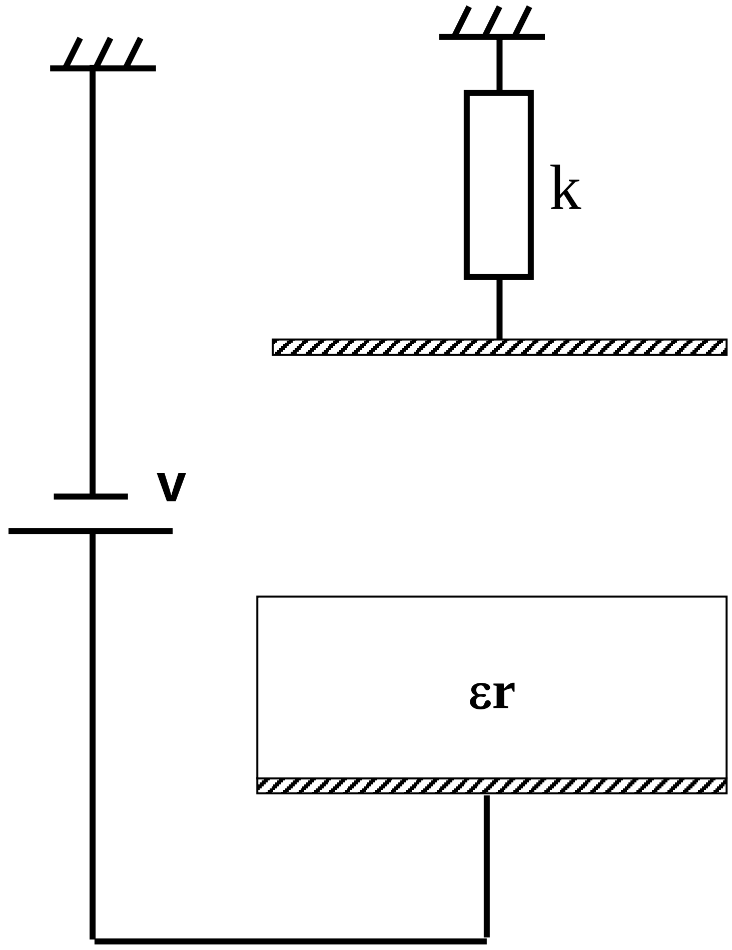


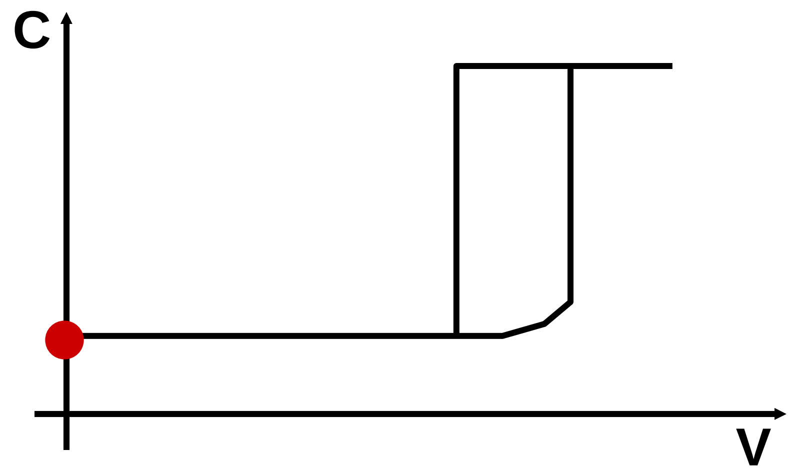
Typical applied Voltage >20 Volts over 0.2 µm

Charging is the main failure mode of capacitive MEMS switches

Charge injection and trapping

- Injection inside the dielectric layer





Charge injection and trapping

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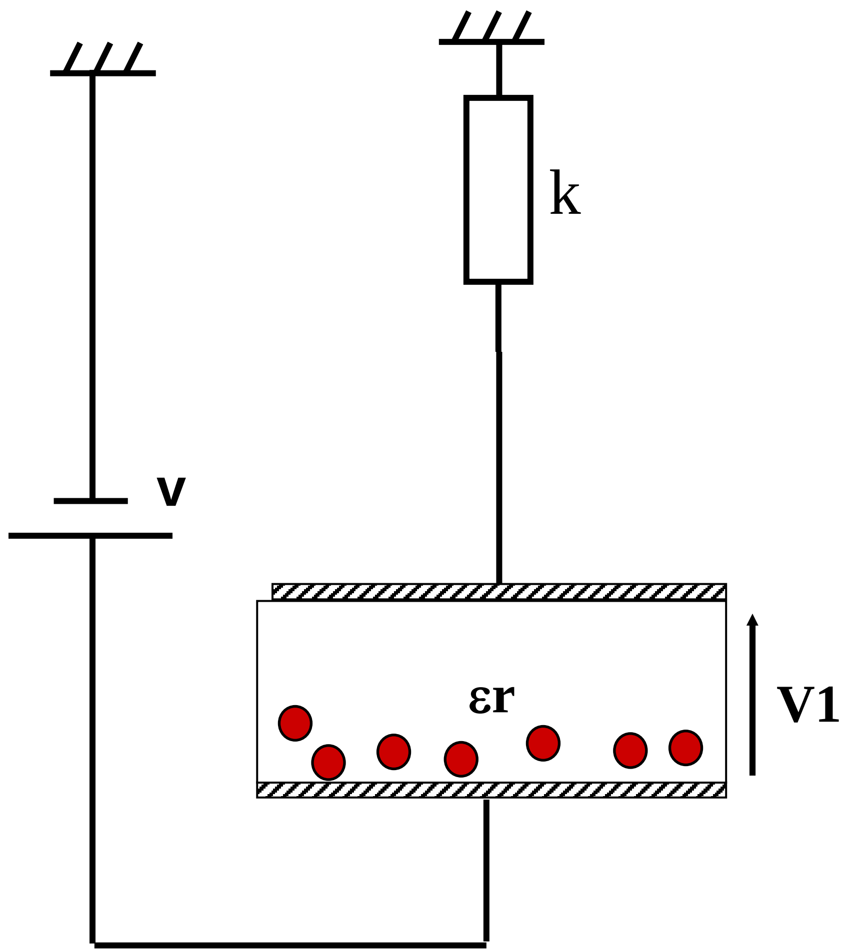

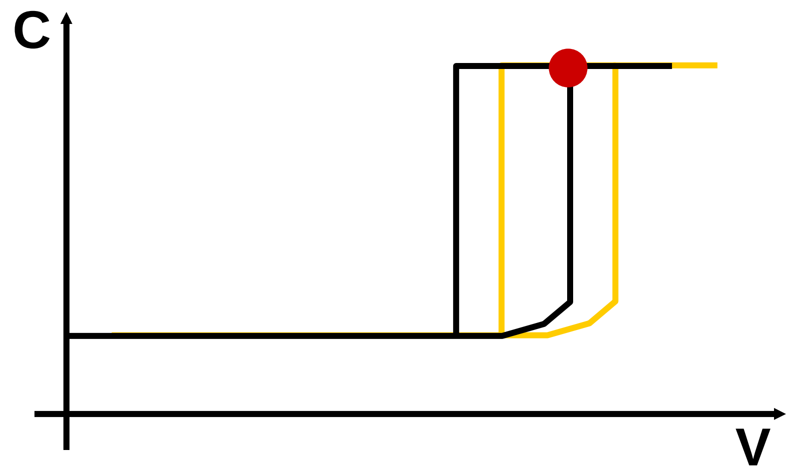

Charge injection and trapping

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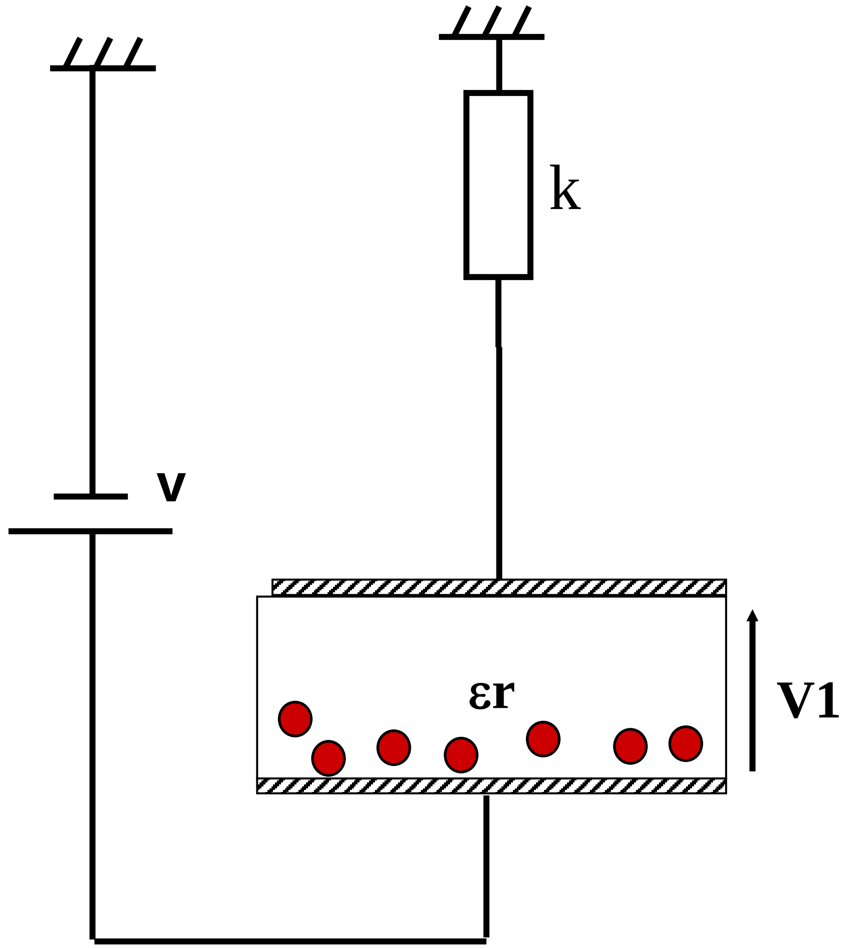

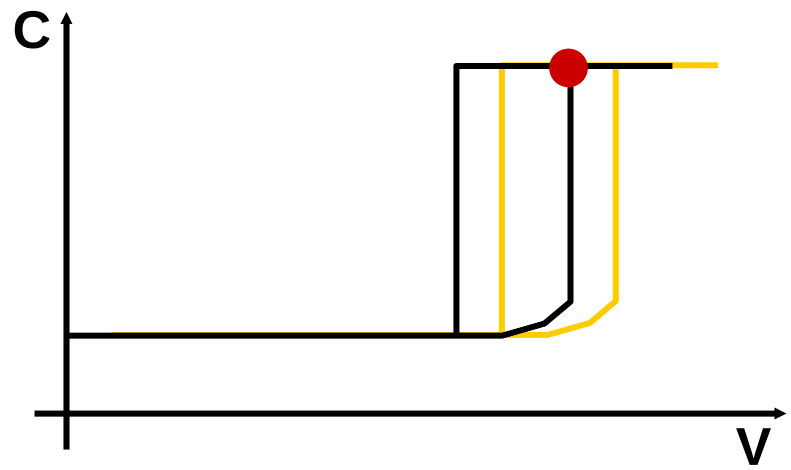

Charge injection and trapping

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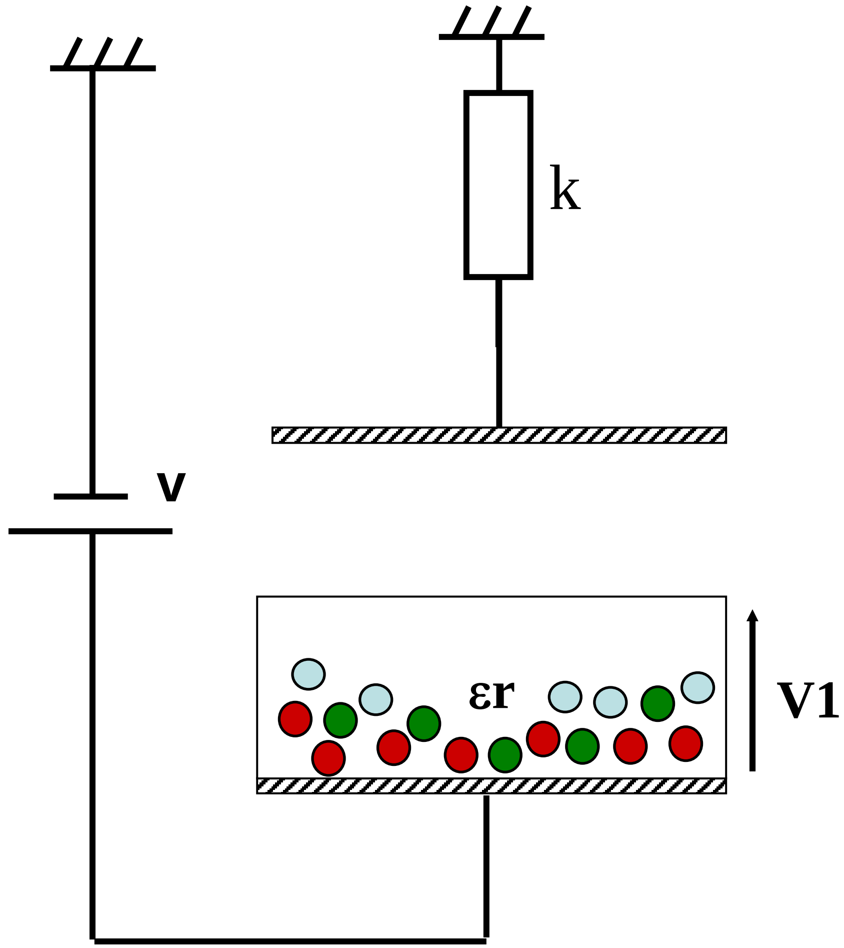

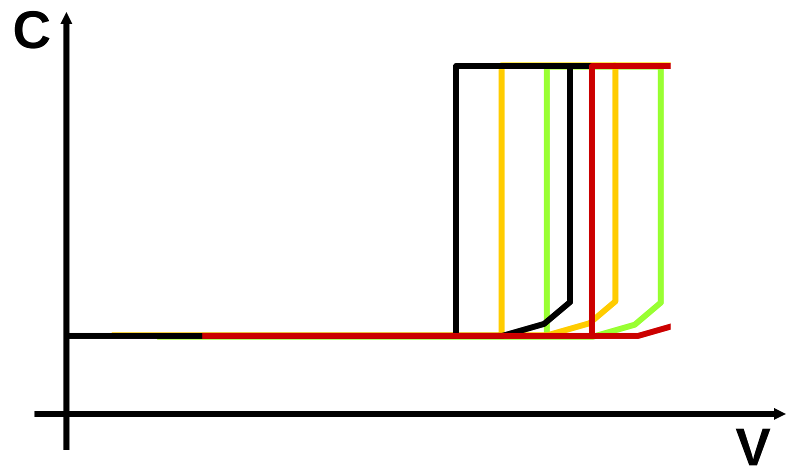

Charge injection and trapping

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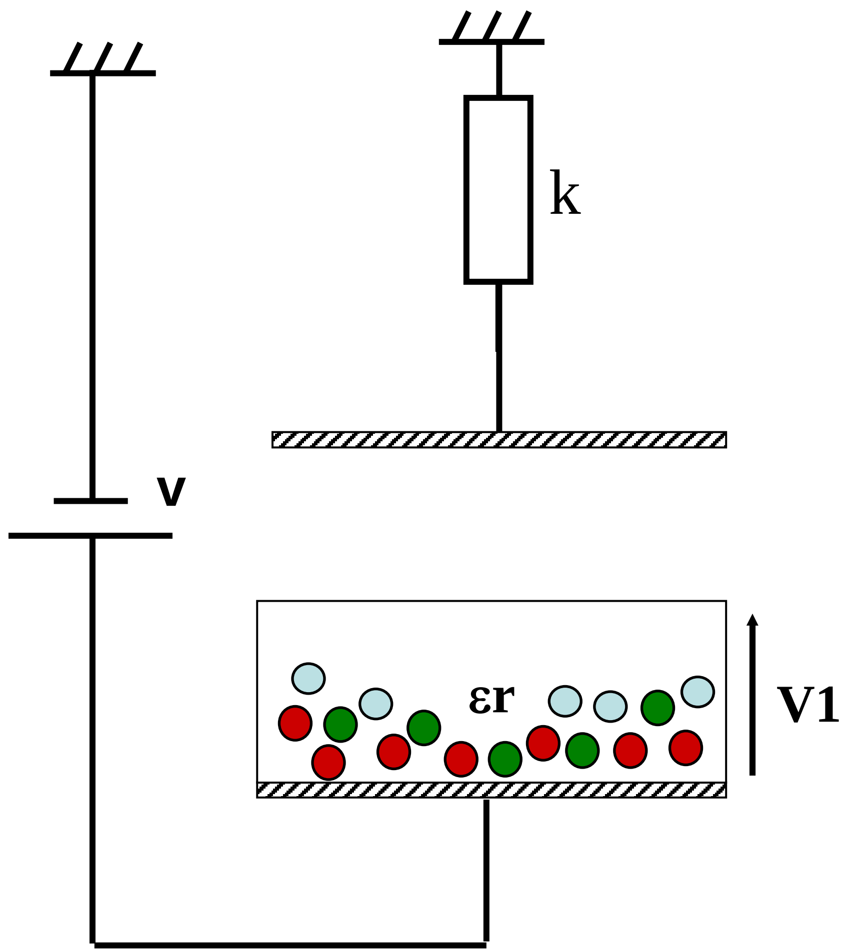
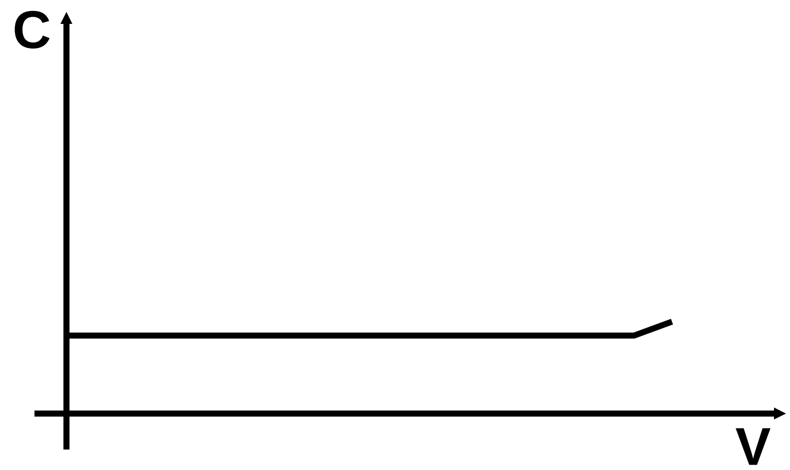
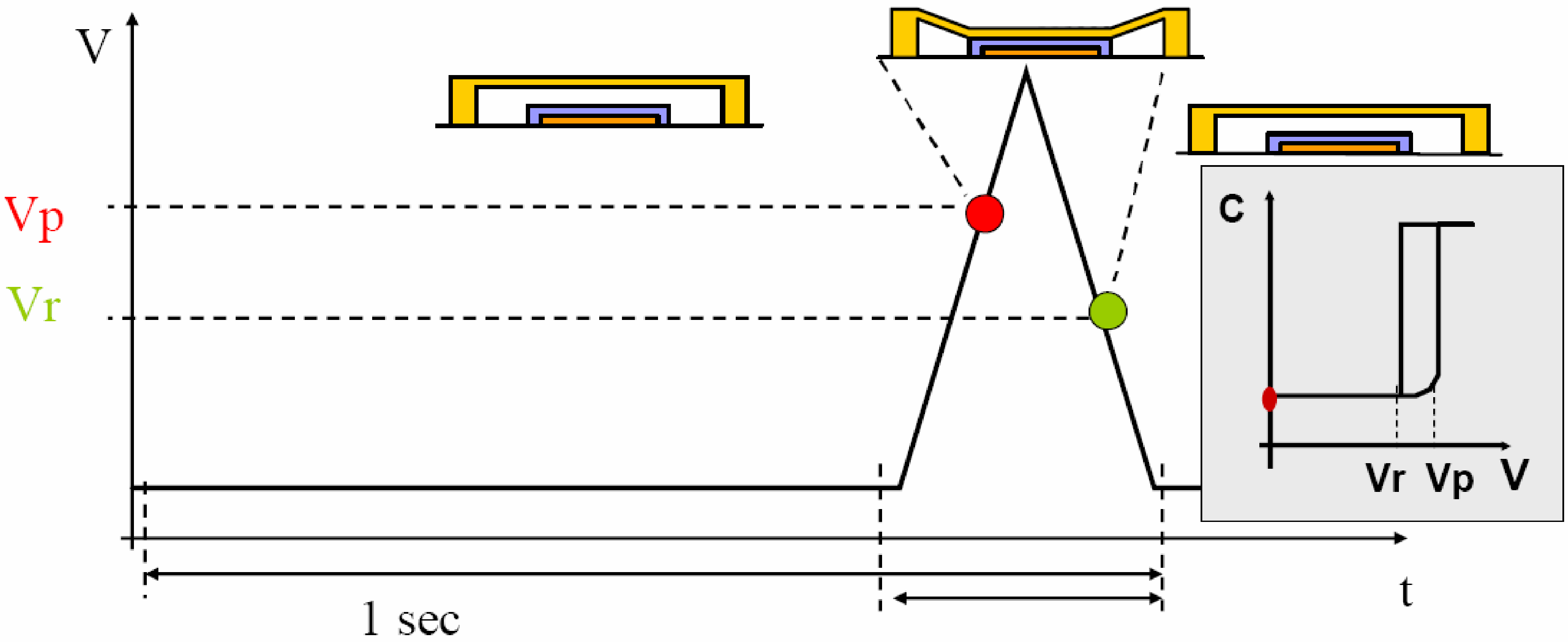




Switch failure!

How to monitor the switch charge trapping?

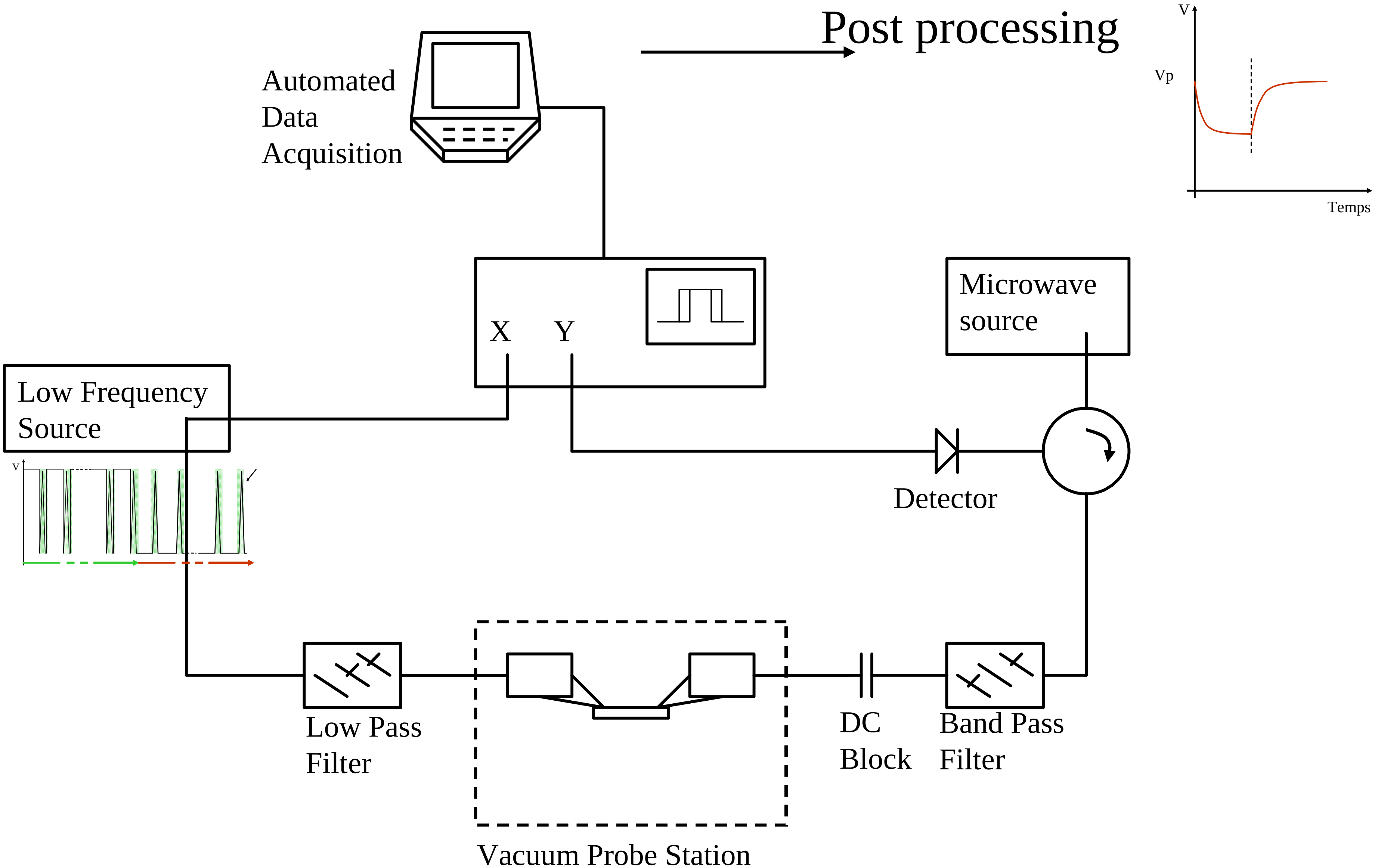
- Switch C(V) characteristic relies on the actuation mechanism



Applied actuation voltage

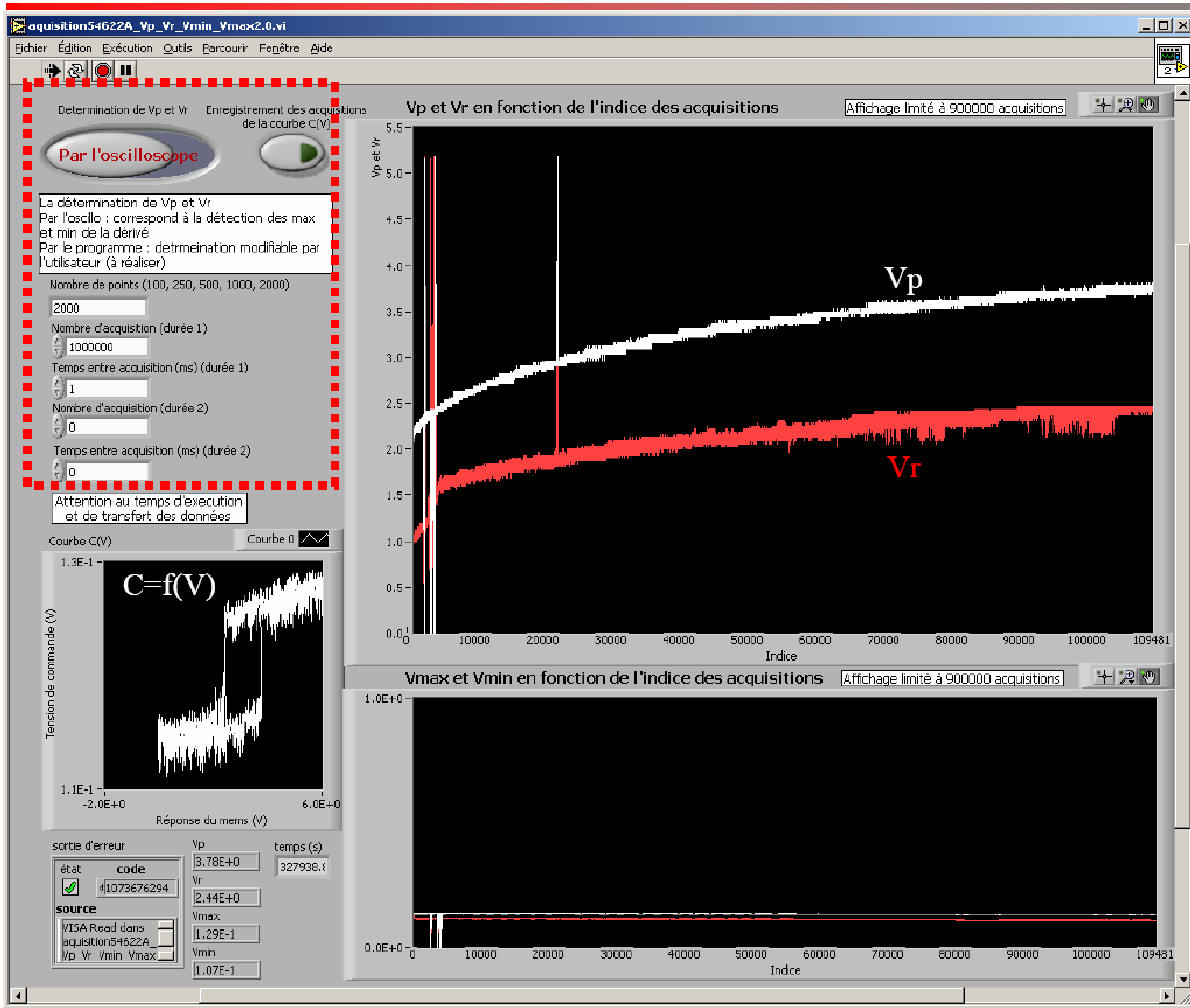
XLIM RF-MEMS reliability test bench

- Automated test bench

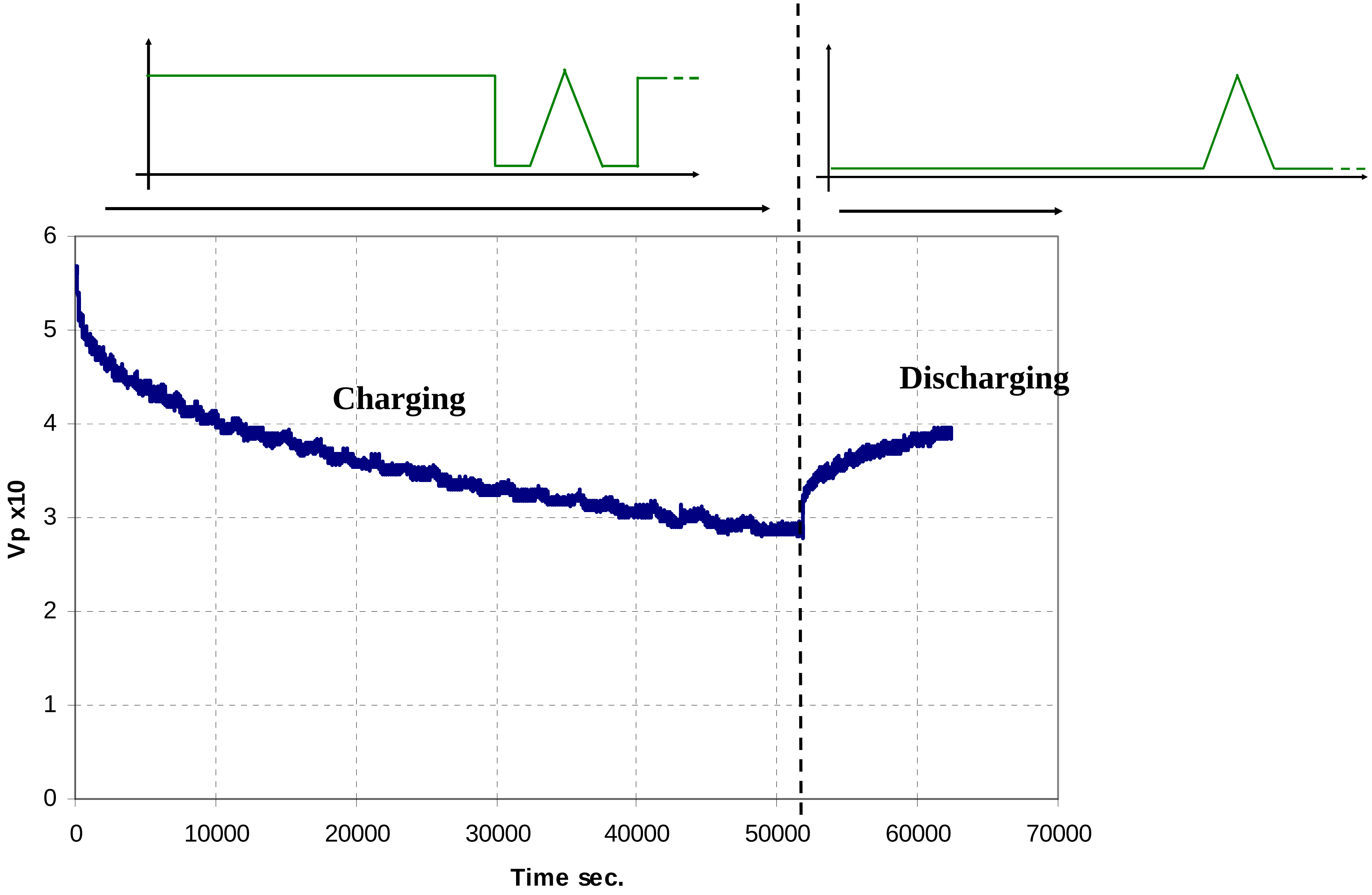


Interface

Réglage du pilotage de l'oscilloscope



Typical test sequence



RF-MEMS capacitive switches

- Charge trapping effects:
  - Pull-in voltage drift
  - Failure:
    - stiction
    - Failure to actuate

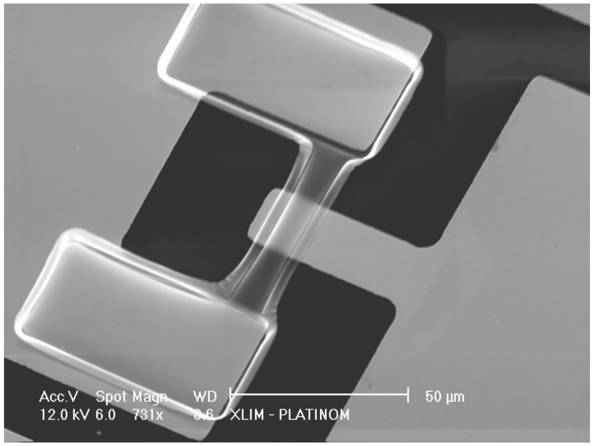
- Solutions:
  - Bipolar control voltage -> stiction anyway
  - Dielectric layers improvements

- Charge trapping is a fundamental problem for RF-MEMS:
  - Low capacitance / area -> V=Q/C -> **a small amount of Q = a lot of V**

So What?

Reduce sensitivity to Q

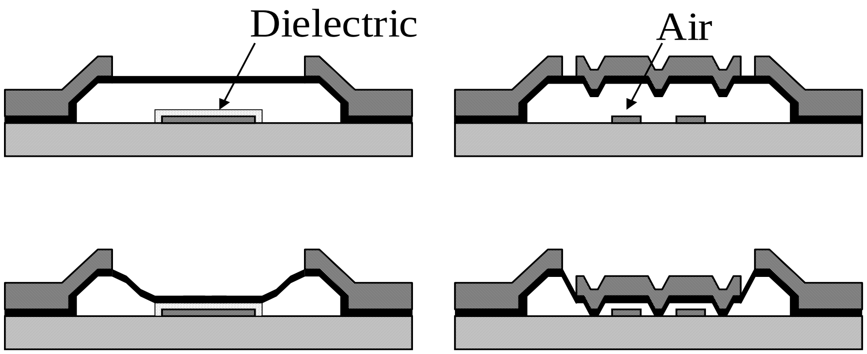
↘ **more C / surface area**



Advantages:
-much less sensitive to charges
-faster
-integrated

drawbacks:
- Lower contrast

Reduce Q



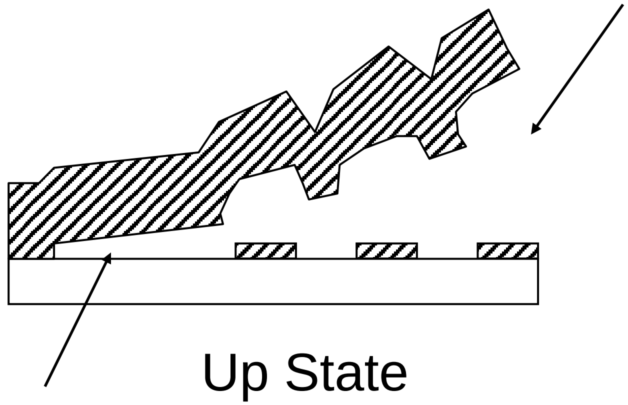
Advantages:
- Much less sensitive to charges
-Simple

drawbacks:
- Less contrast

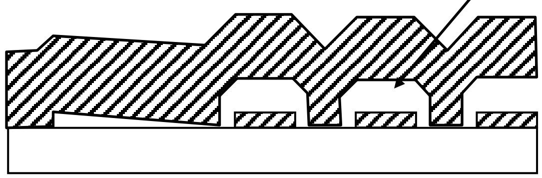
Proposed structure

- How to improve contrast??

Higher tip = low up state capacitance



Up State



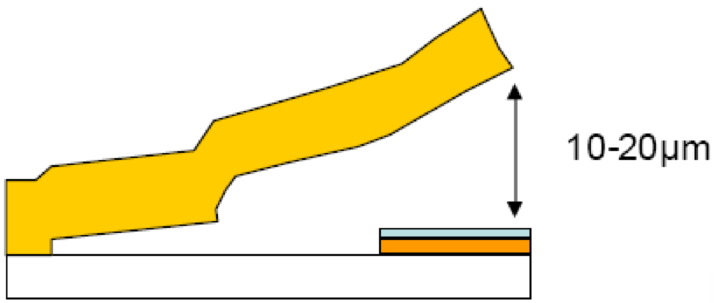
Down state

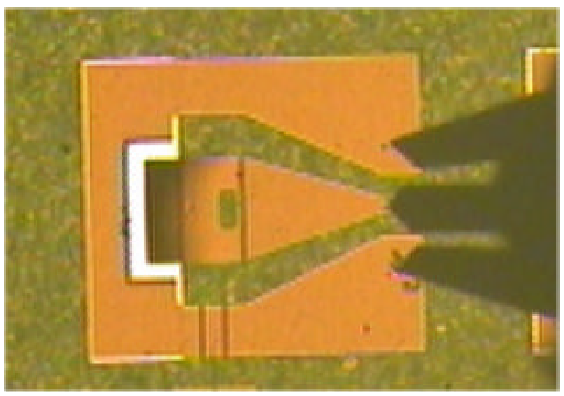
Moderate height = moderate pull in voltage

Overall, the contrast is higher than for conventional structures, and voltages remain the same

Design

Used mechanical structure

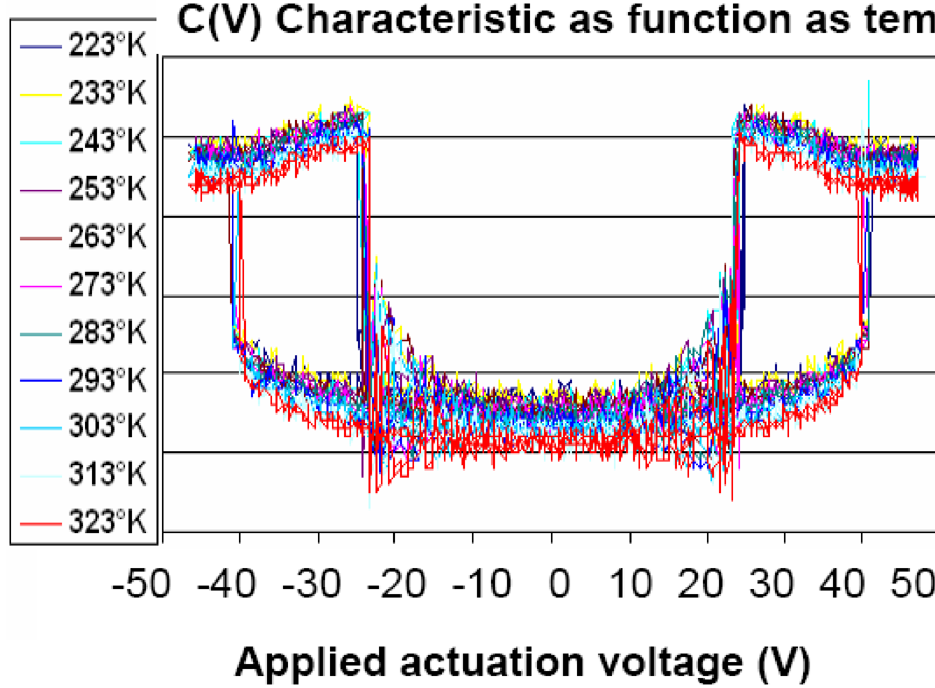




Main advantages:

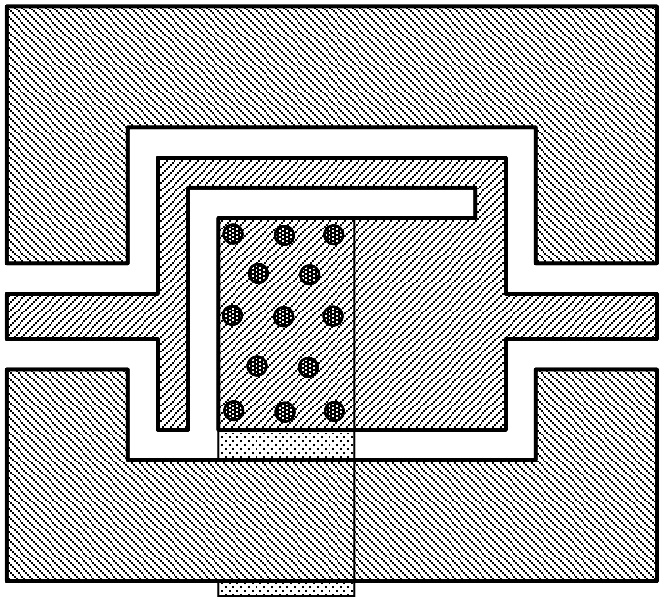
- High initial gap (controlled with internal stress)
- Strong restoring force
- Moderate actuation voltage (50-60V)
- Temperature stable

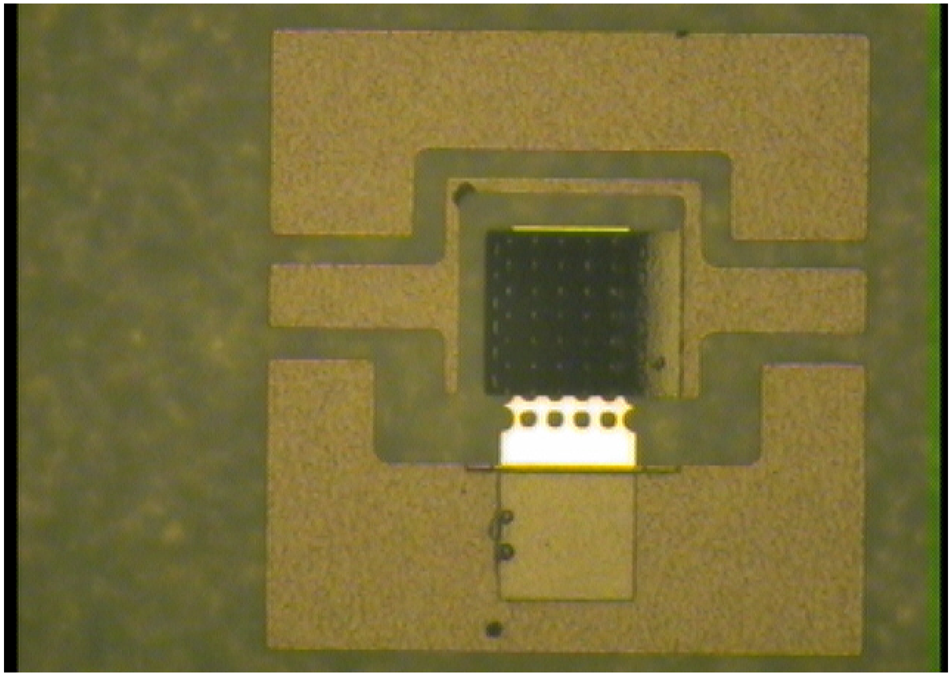
C(V) Characteristic as function as temperature

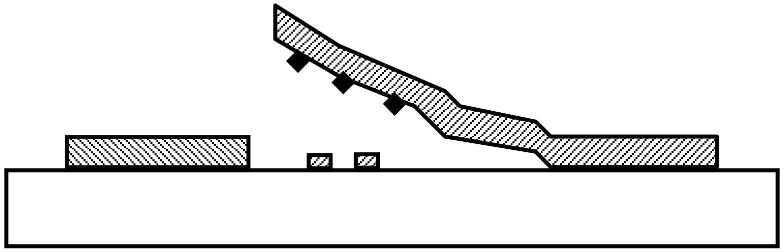


Proposed structure

- Cantilever







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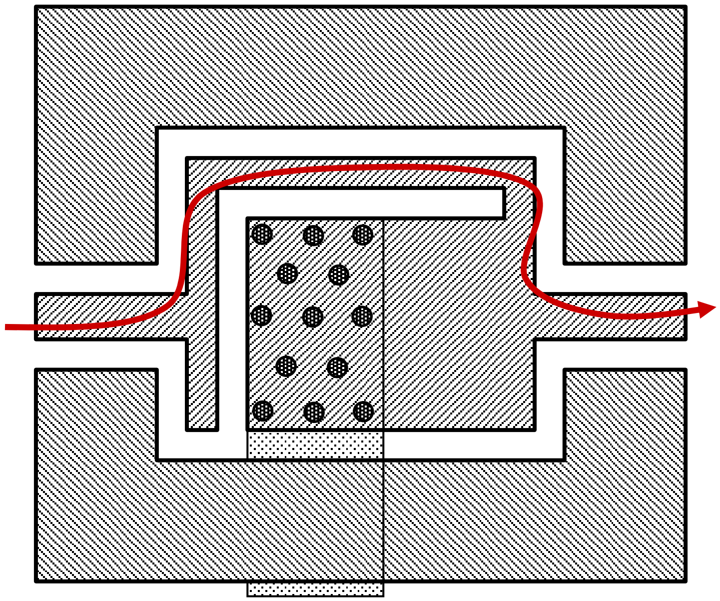

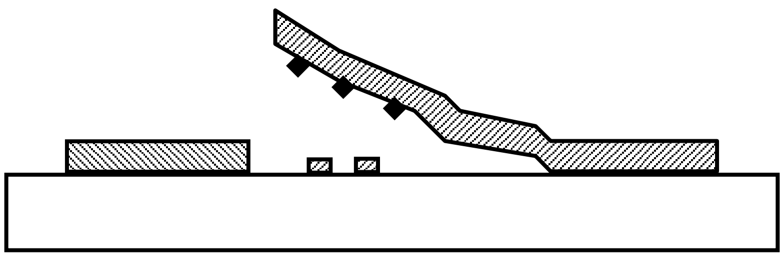

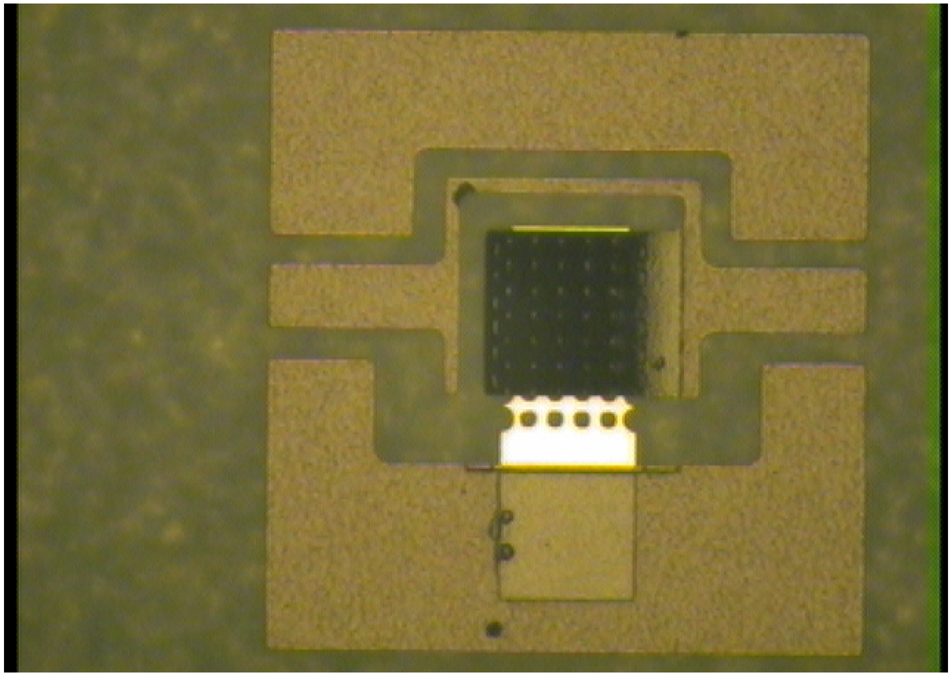

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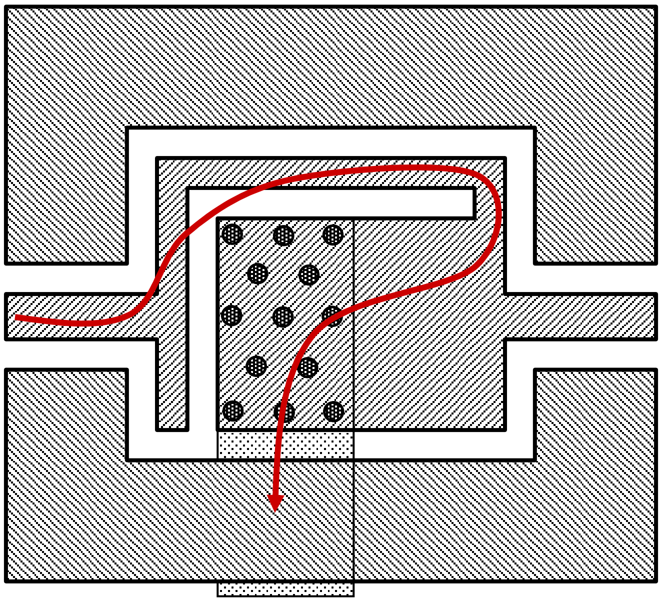
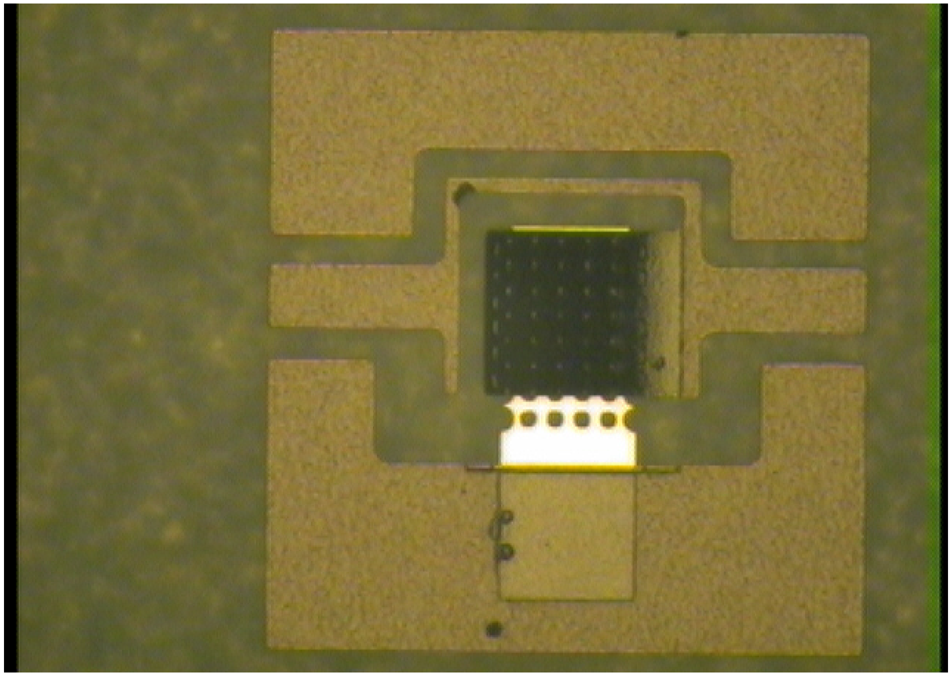
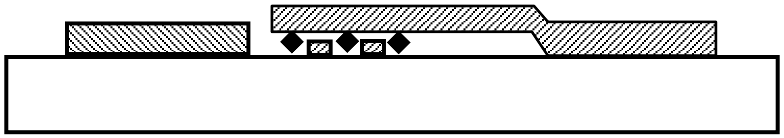
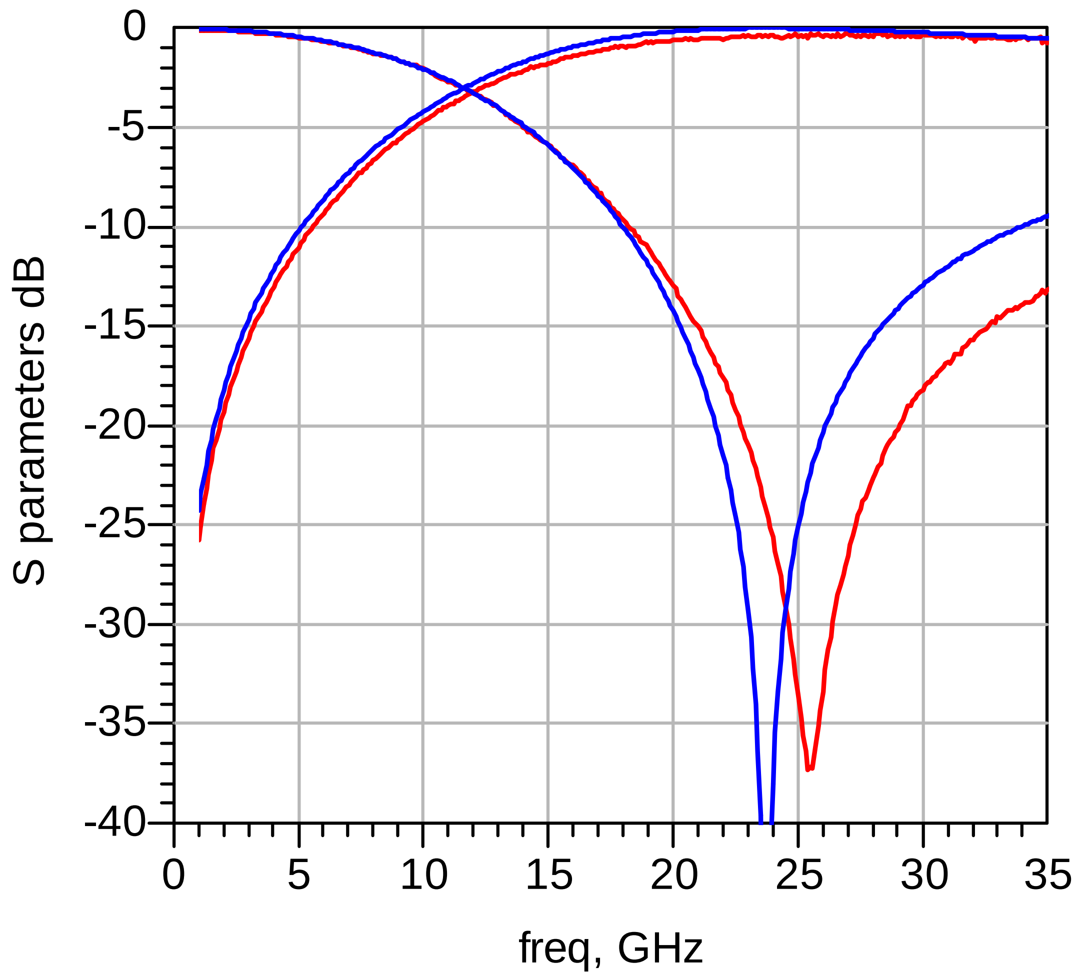




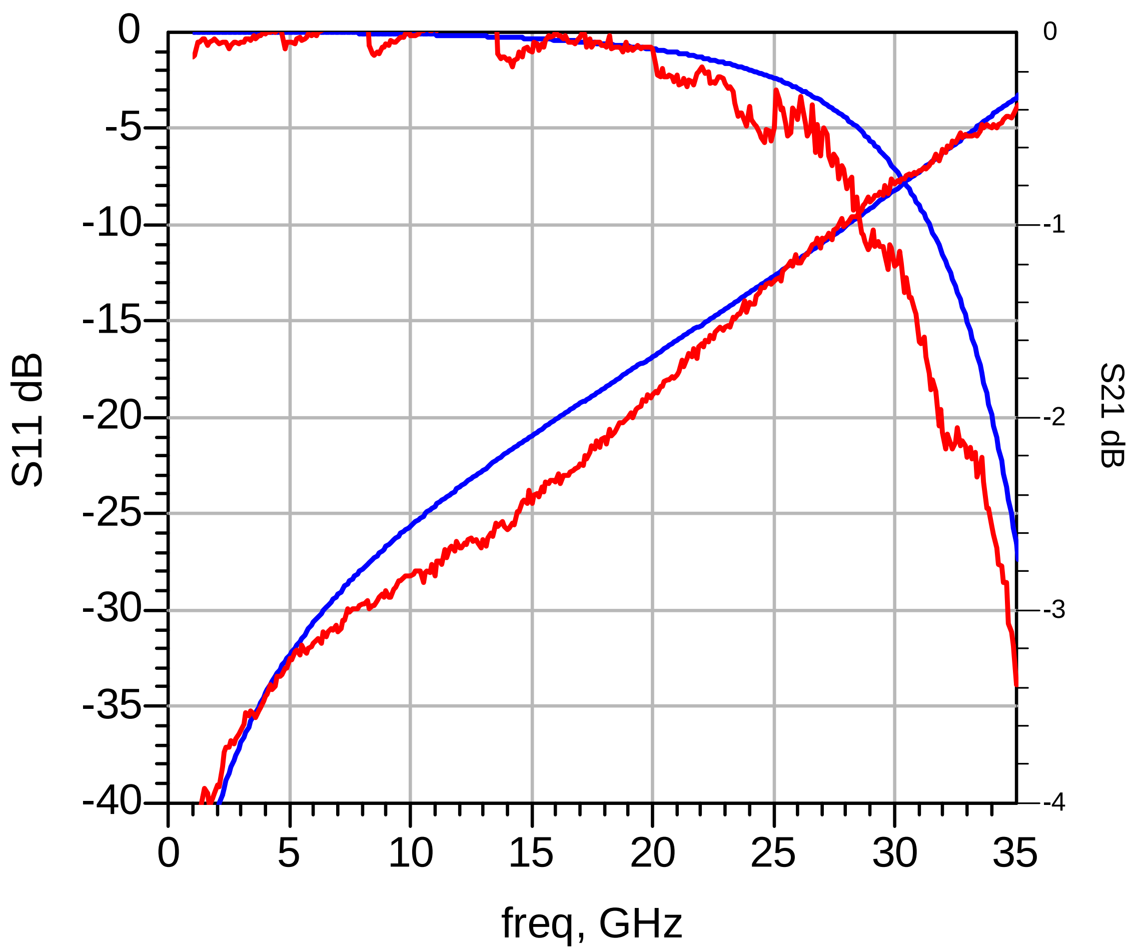


Down state



0
-5
-10
-15
-20
-25
-30
-35
-40
S parameters dB
0
5
10
15
20
25
30
35
freq, GHz

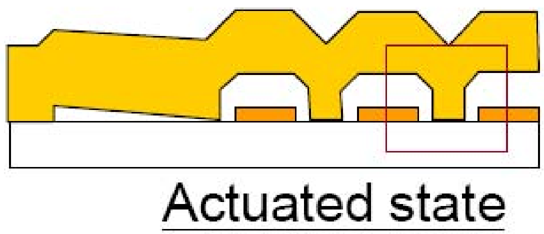
Up state

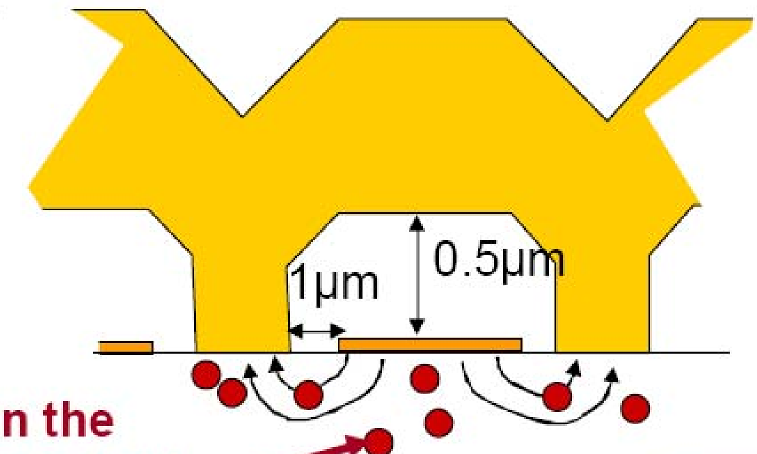


S11 dB
S21 dB
freq, GHz
0
-5
-10
-15
-20
-25
-30
-35
-40
-1
-2
-3
-4
5
10
15
20
25
30
35

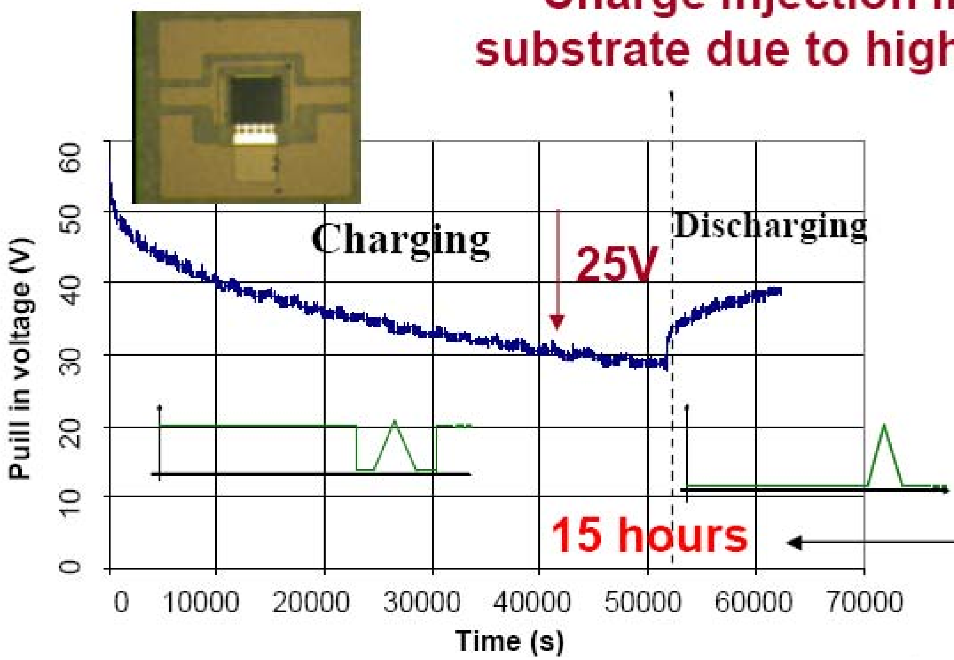
Is charging suppressed?

NO but is highly reduced…

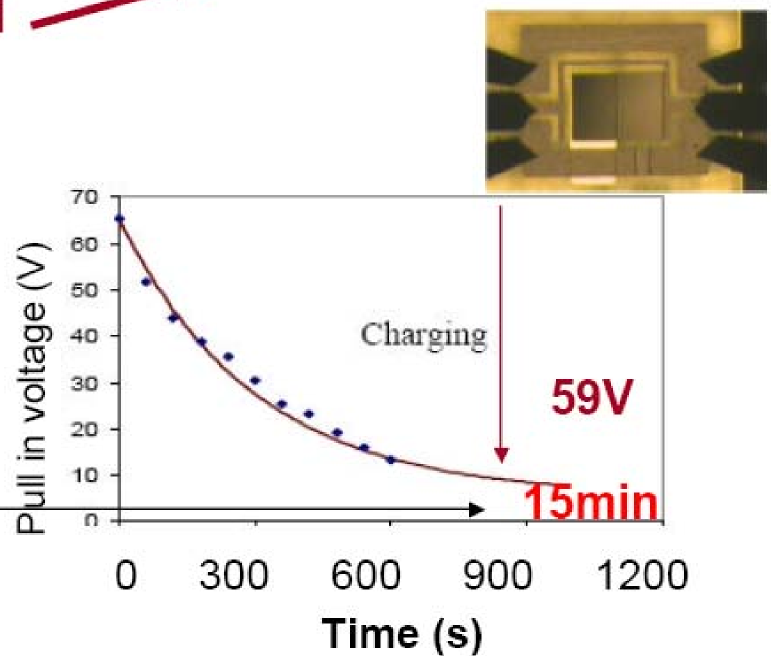




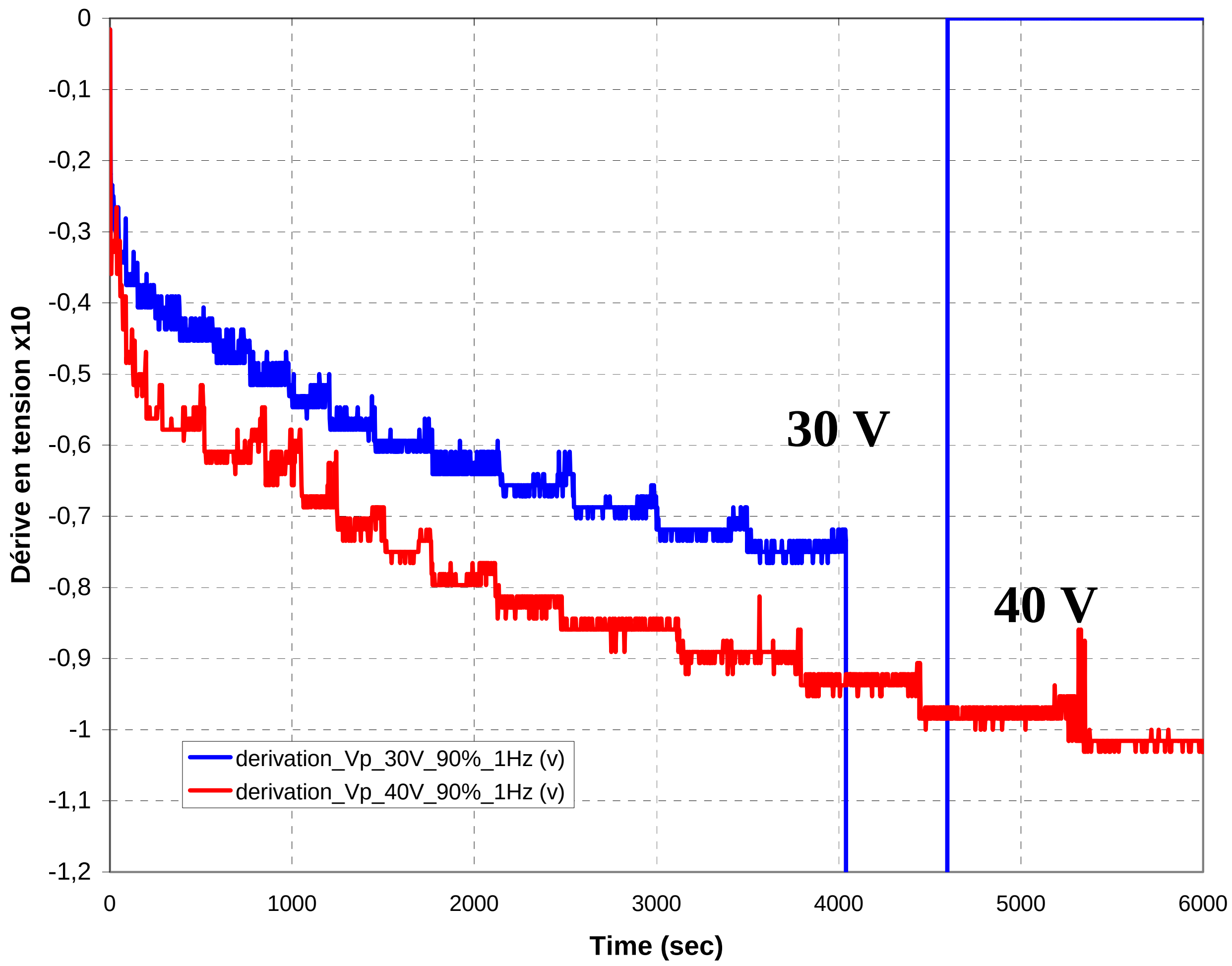
Charge injection in the substrate due to high E field



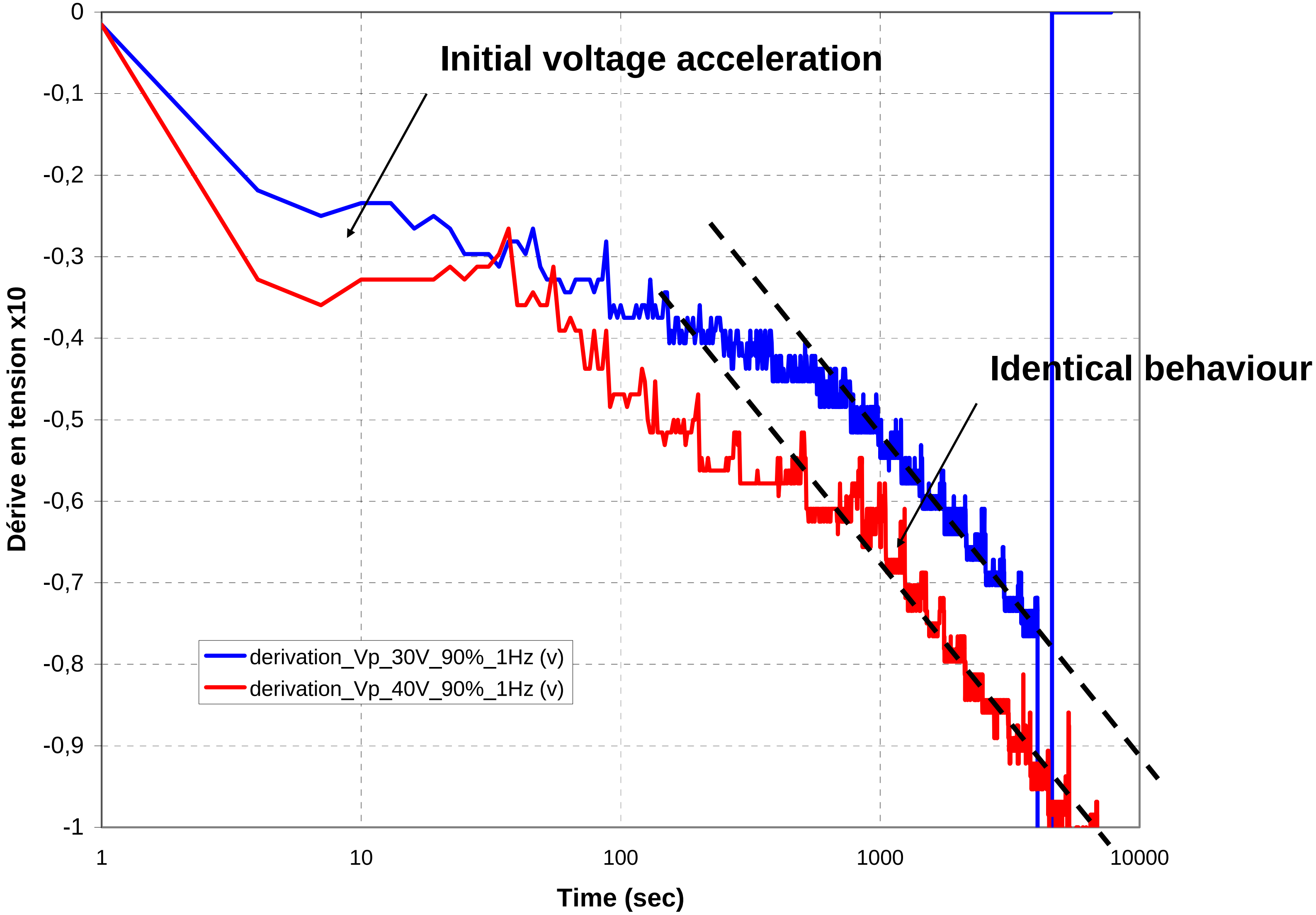
Improvement with a factor 200



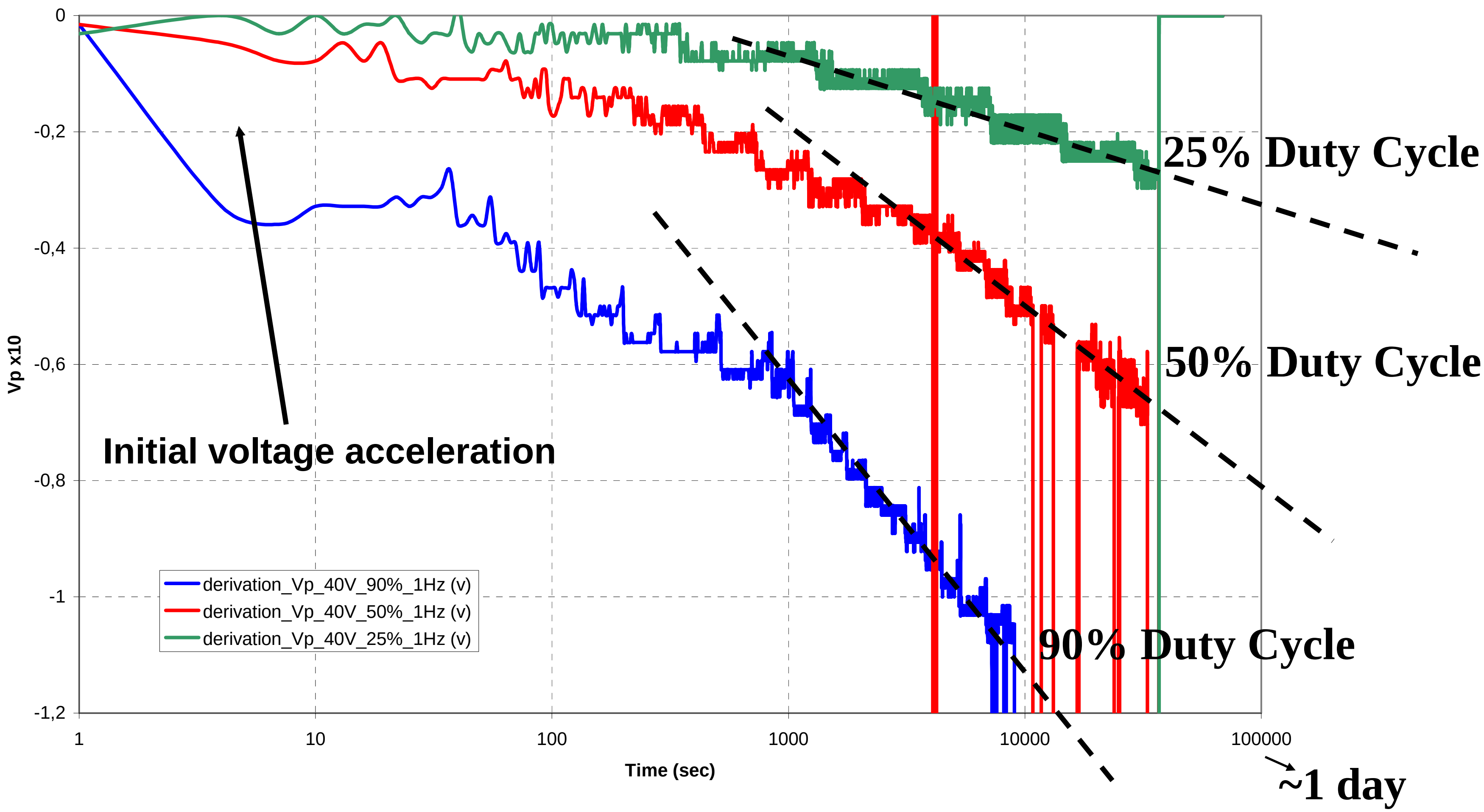
Voltage acceleration



‘Long term’ behaviour

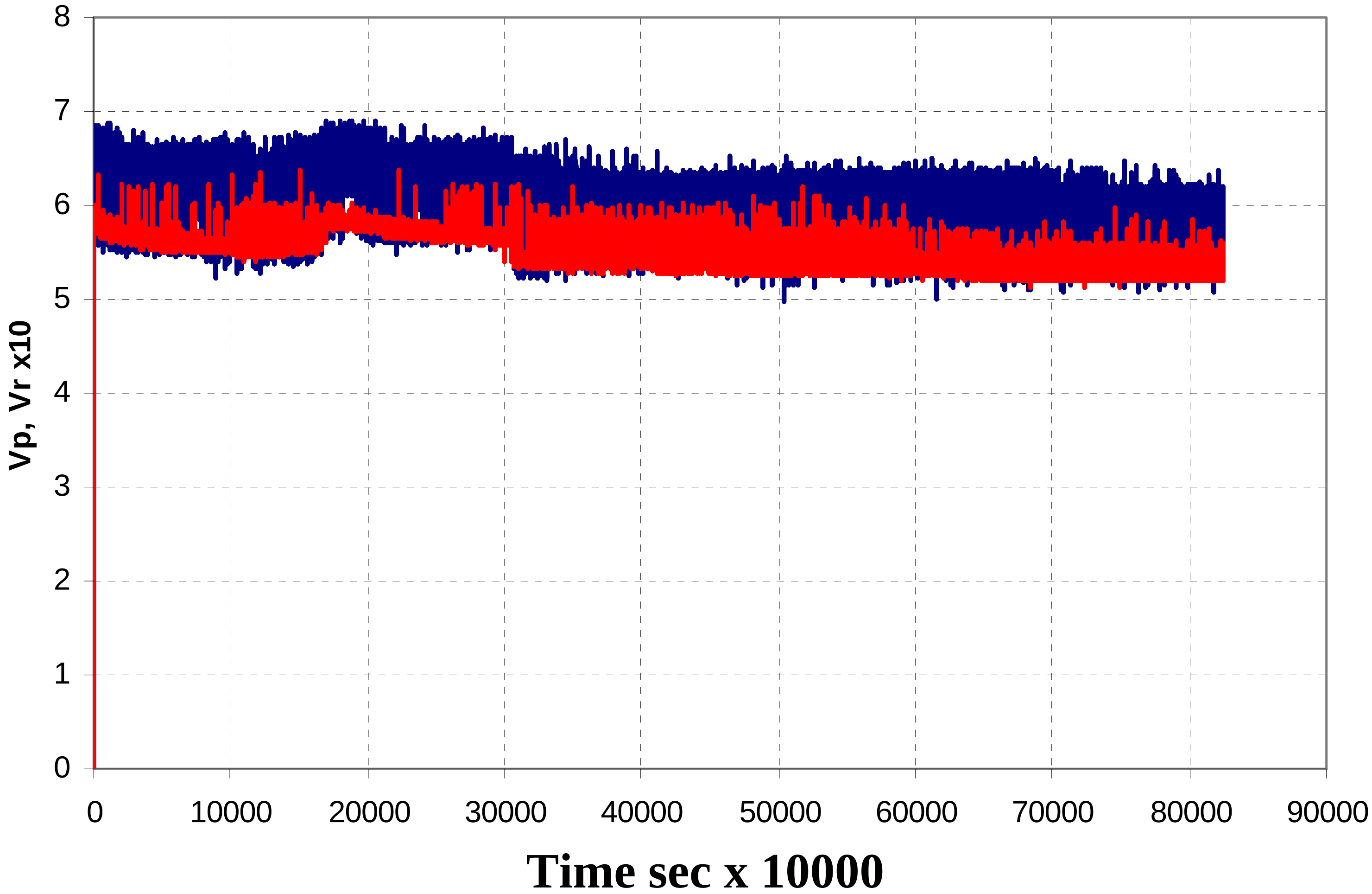


Duty Cycle Variations



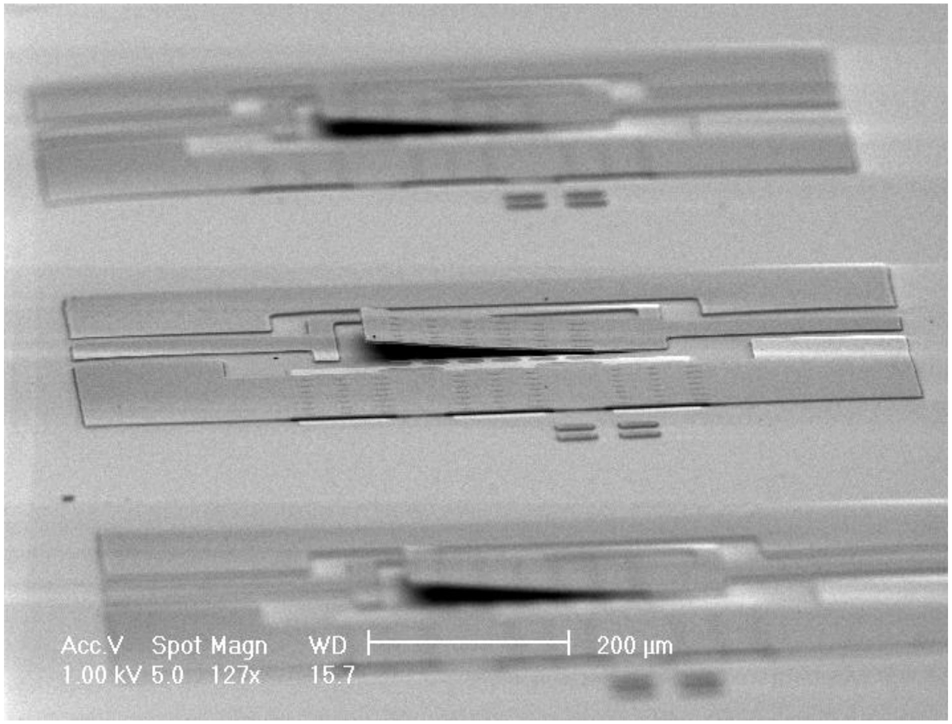
Cycling example

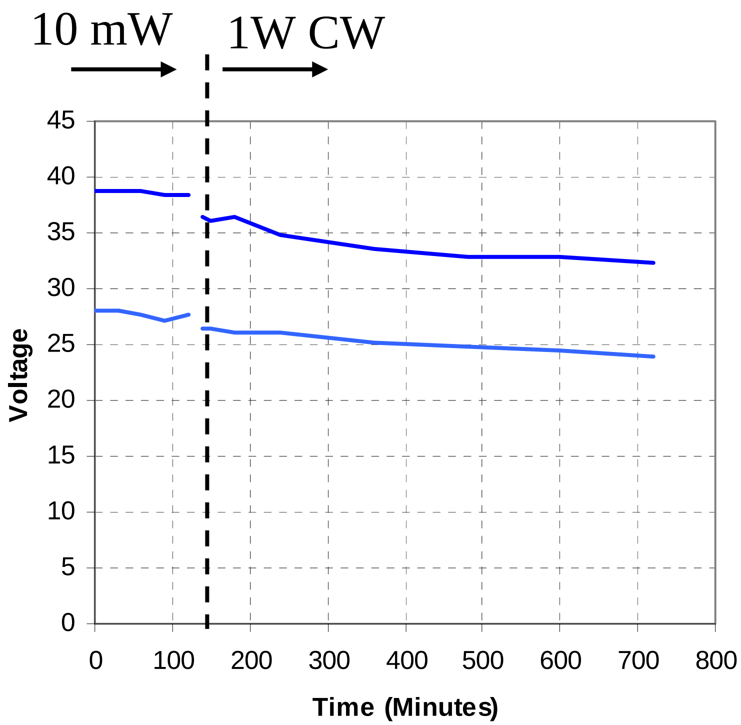
- Cycling 8.10^8 cycles – square 10 KHz 70 Volts 30% duty cycle



Effects of microwave power

- Cycling using a triangular waveform (10KHz cycling – duty factor less than 20%) ~up to 1 Billion cycles

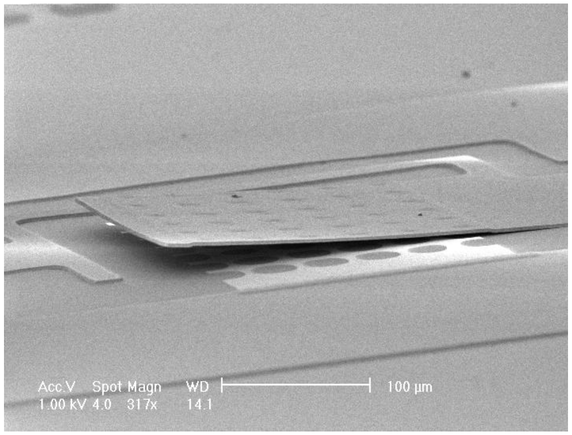


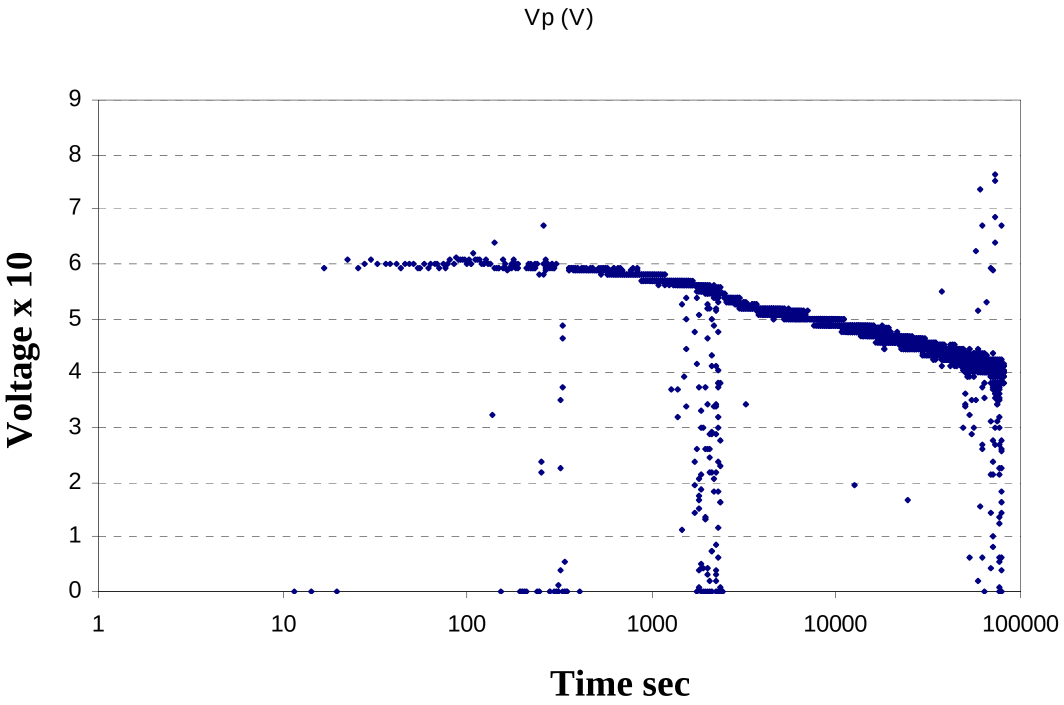


Initial influence of power on charge trapping

Cycling example

- Microwave power acceleration 1W CW (1KHz cycling – 50% duty cycle)

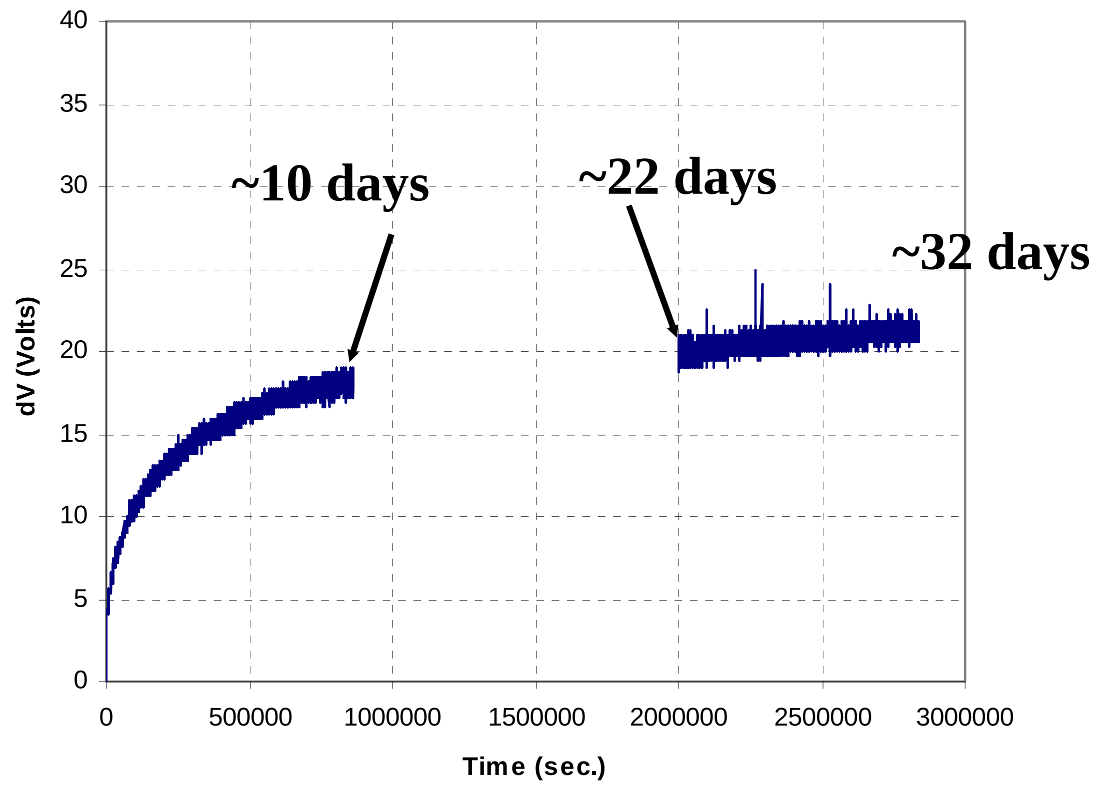




- 2 Watts 2 Billion cycles have been achieved on the same type of switch

Long term drift

- Measured voltage Drift. 60 Volts applied DC



- Switch is functionnal, and the drift is less than 1 Volt/day
- The voltage drifts more in the first day than the next 30 days
- The voltage drift is <u>more in the first minute than in the last 10 days</u>

Discussion

- Duty cycle is one of the key acceleration factors for these switches i.e. going from 50% to 90% duty cycle will result in 2 orders of magnitude of lifetime improvement.
- RF-MEMS reliability is strongly depending on the application
- More acceleration factors needed -> PoF work needed
- Switches were sent to another C(V) test bench. No voltage drift was observed.
- It is urgent to specify very detailed procedures for these measurements and ‘calibrate’ reliability test benches

Conclusions

- Dielectric less switches are very promising for RF-MEMS applications
- Reliability:
  - Accelerating factors have been identified:
    - Duty factor
    - Applied voltage
    - Temperature
  - ~1 Billion cycles 30% duty factor – 70 V square positive signal – less than 5 Volts drift in Vp
  - 1 Watt 1 Billion cycles -> acceleration factor observed
  - 1 month in the down state achieved
- Voltage drift effects… Much less than conventionnal devices

Acknowledgements / Mercis

- TAS
- Support of the french MoD
- ESA