Isolation of degradation mechanisms in capacitive microelectromechanical switches (RF MEMS)

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Outline

- **Introduction**
  - What are MEMS switches?
  - Reliability problems (motivation)
  - Research objective of this work
- **Results: Isolation of degradation mechanisms**
  - Accelerated stress tests, test structures, and results
- **Conclusions**

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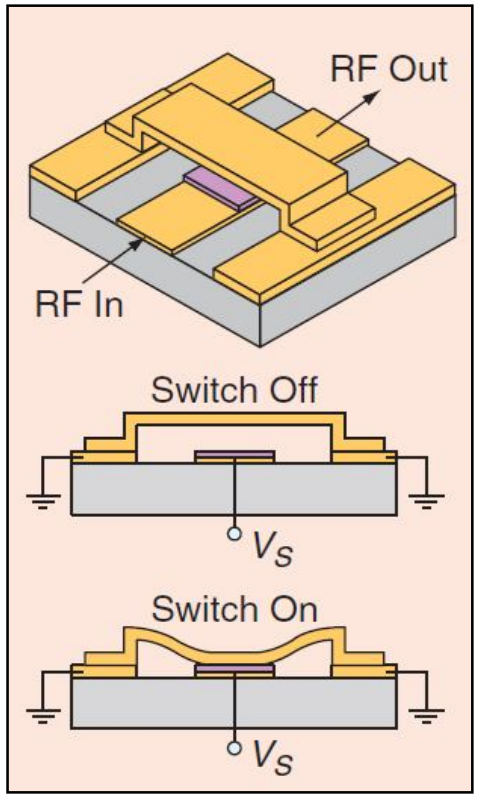
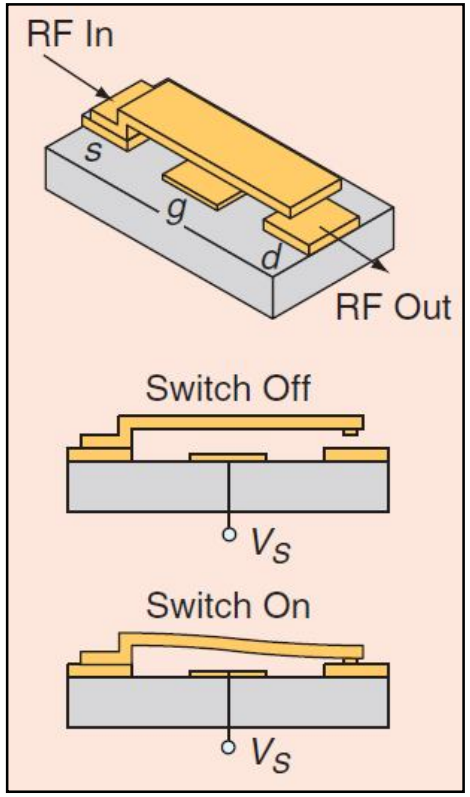
Introduction: What are MEMS switches?

❑ MEMS switches ⇒ enable reconfigurable RF systems

Capacitive switch



Ohmic switch



Images: IEEE Microwave Magazine, Koen Van Caekenberghe, January/February 2012

☺ RF MEMS switches

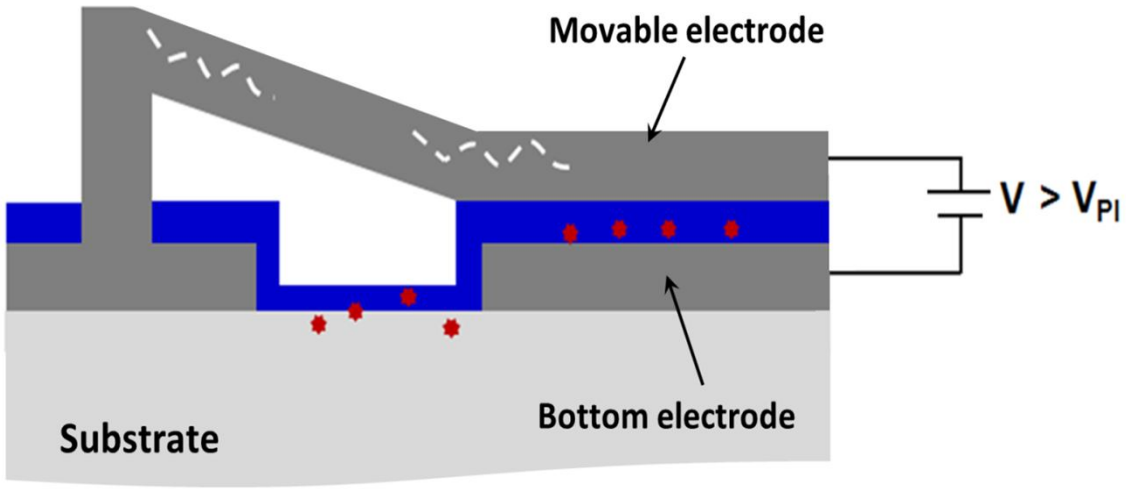
- very good RF performance
- good integration capabilities
- wide range of applications
- potentially low cost
- strong industry interest

☹ Reliability problems

- stress control during processing
- packaging/capping process
- environment (T, RH, radiation)
- dc contact degradation
- **charging effect**
- **mechanical degradation**

Introduction: Reliability problems

MEMS in the DOWN-state



Dielectric charging

- uniform / non-uniform charging
- extrinsic charge (current)
- intrinsic charge (polarization)
- air-gap breakdown
- substrate charging (?)
- charging due to radiation

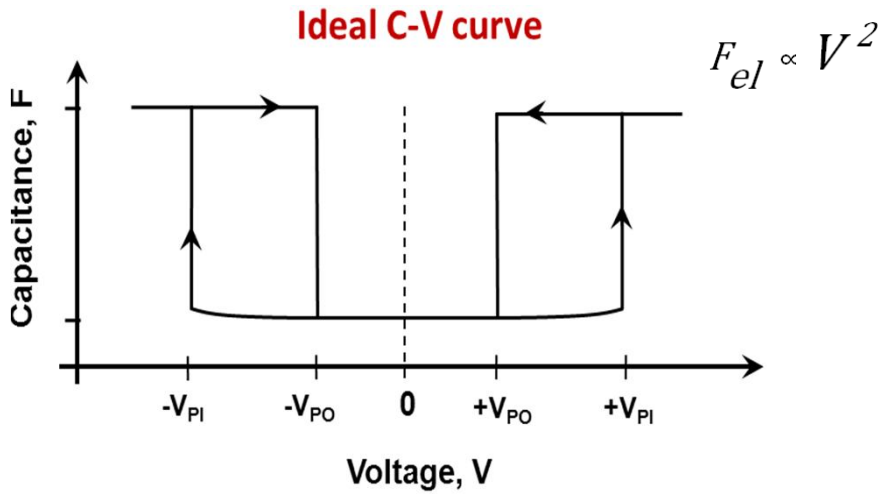
Mechanical degradation

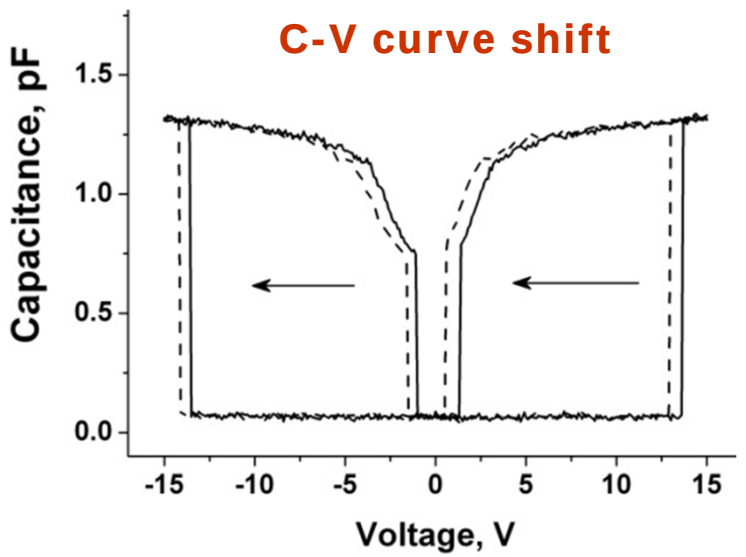
- creep
- fatigue
- viscoelastic effect

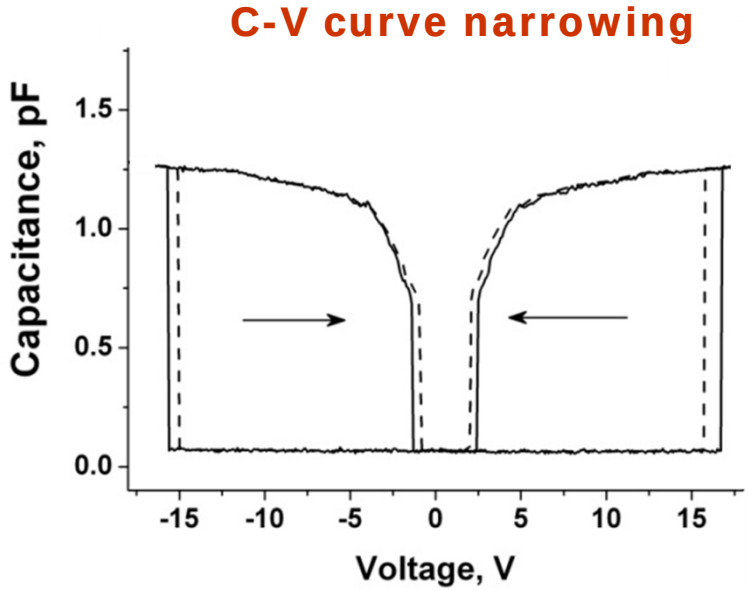
- ❑ During normal operation conditions many mechanisms can occur simultaneously.
- ❑ Device failure due to various mechanisms can be similar (difficult to isolate the real cause)
- ❑ No standard test methods and structures to isolate different mechanisms.

Motivation: Develop test methods and test structures to isolate and accelerate individual mechanisms and correlate results to real device reliability.

Introduction: Reliability problems







- charging and mechanical degradation can cause similar change in thresholds and lead to device failure

Objective of this paper:

to isolate charging effect from mechanical degradation

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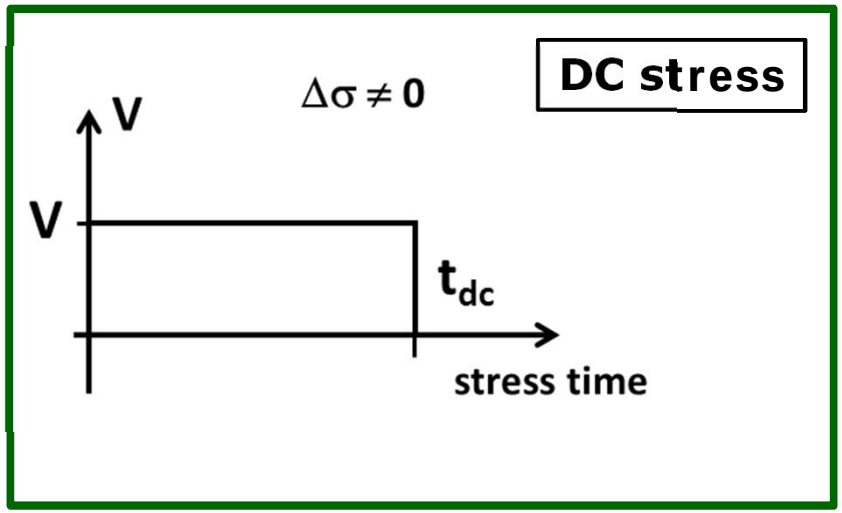
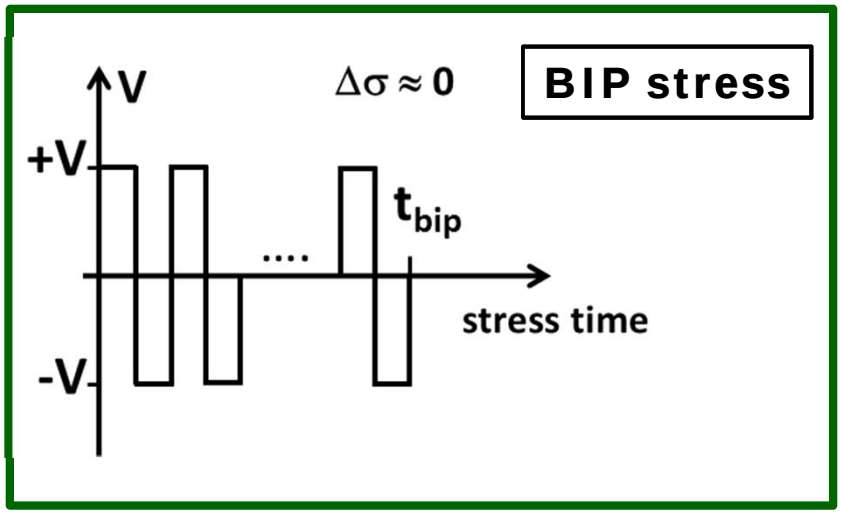
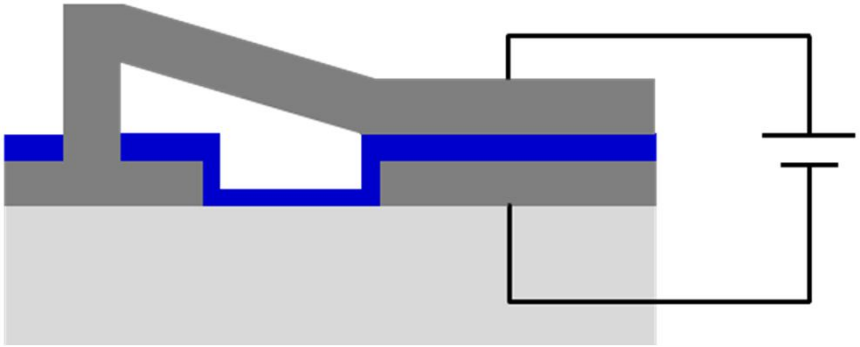
Isolation of degradation mechanisms: accelerated stress tests







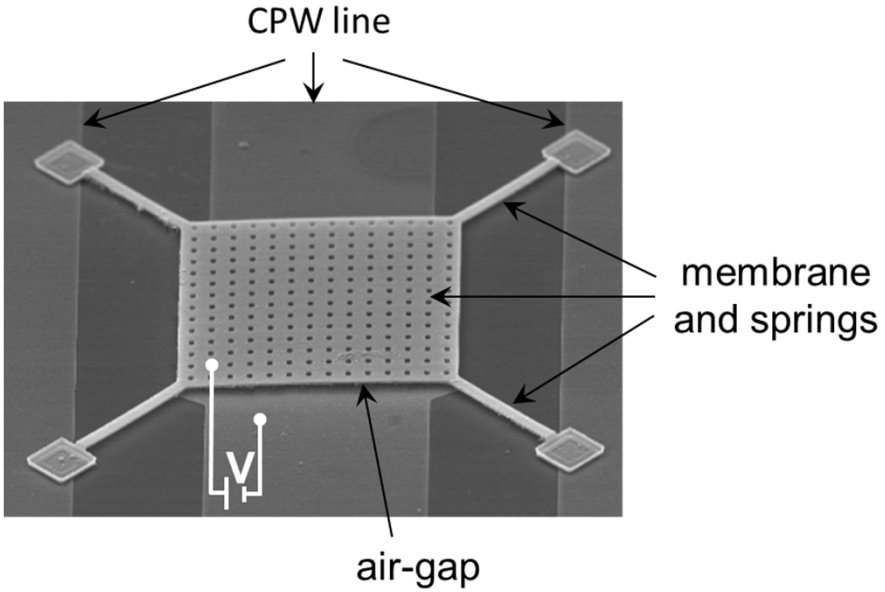
switch remains in down-state during DC and BIP stress

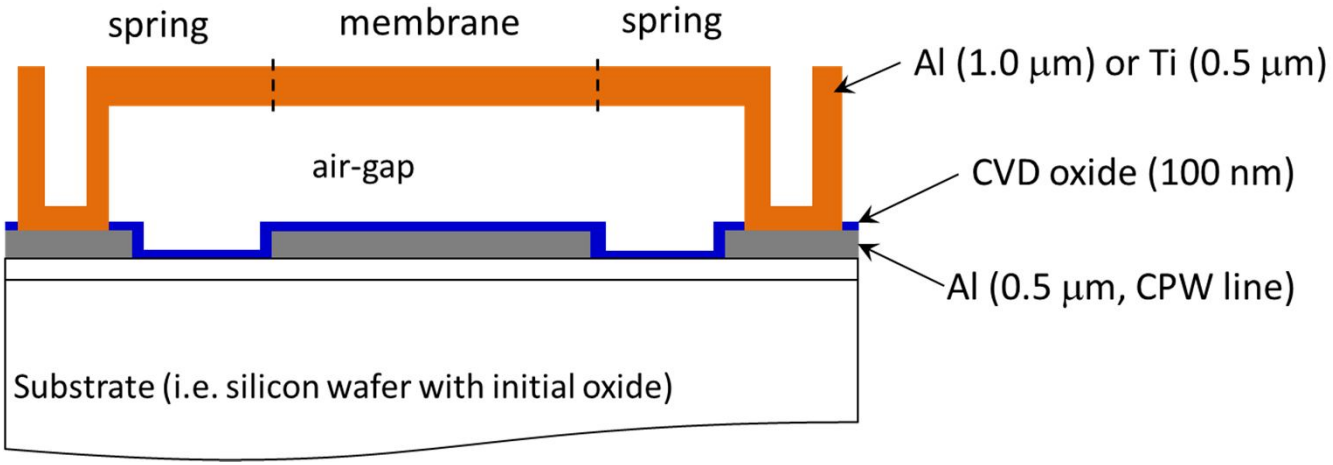
- **DC stress ⇒ charging accelerated ⇒ mech. degradation accelerated**
- **BIP stress ⇒ charging is limited ⇒ mech. degradation accelerated**

Isolation of degradation mechanisms: test structures

Test Structures:

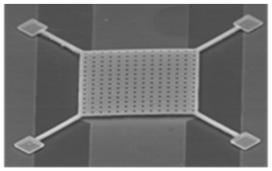
- RF MEMS capacitive switches
- Switch A: 0.5 μm thick titanium
- Switch B: 1.0 μm thick aluminium





Isolation of degradation mechanisms: measurement procedure

- dry-air environment
- room temperature



Initial pull-in tests: V^-_{PI}, V^+_{PI}

Stress Cycle 1

- DC stress: 10 min @ -25V
- Pull-in tests

--> ΔV^-_{PI}, ΔV^+_{PI}

relaxation at no bias

Stress Cycle 2

- BIP stress: 10 min @ ±25V, 50% duty cycle, 1 kHz
- Pull-in tests

--> ΔV^-_{PI}, ΔV^+_{PI}

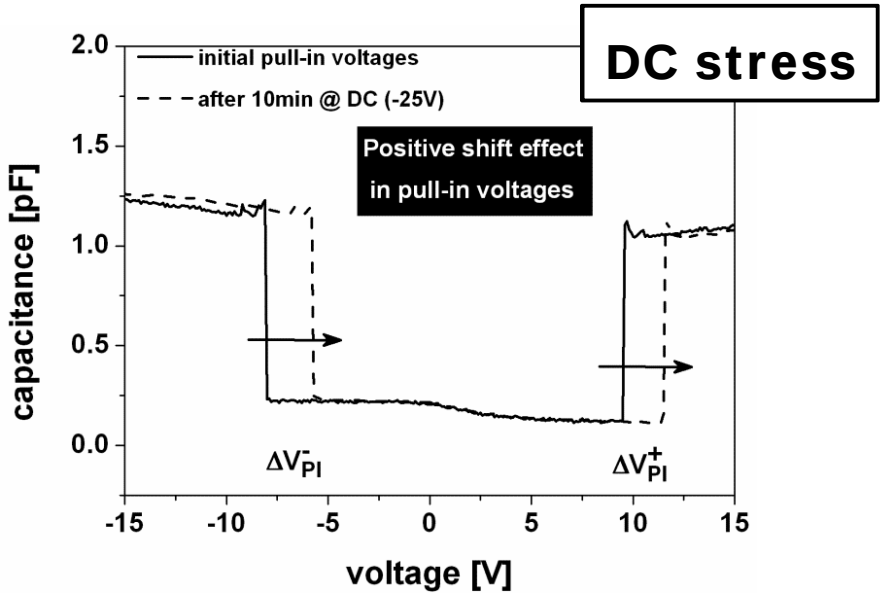
relaxation at no bias

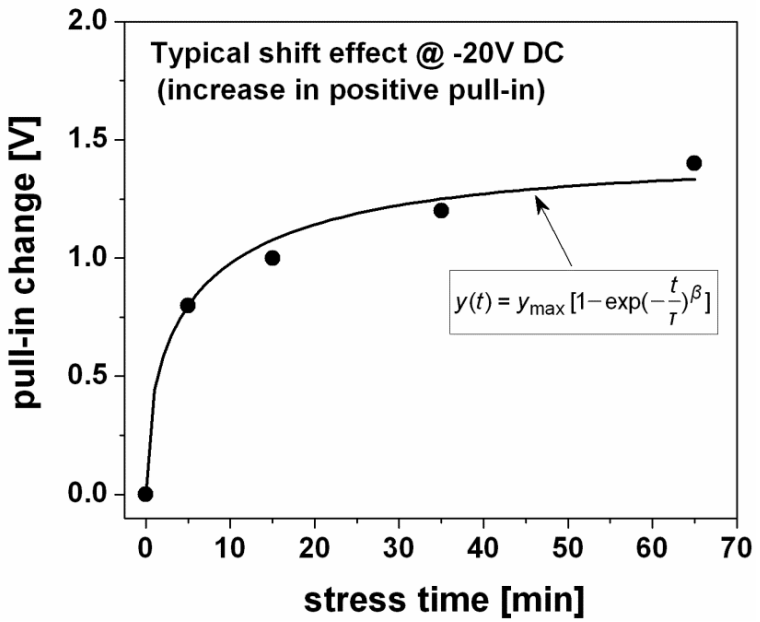
Stress Cycle 3

- BIP stress: 10 min @ ±25V, 50% duty cycle, 10 kHz
- Pull-in tests

--> ΔV^-_{PI}, ΔV^+_{PI}

Isolation of degradation mechanisms: results – titanium switches





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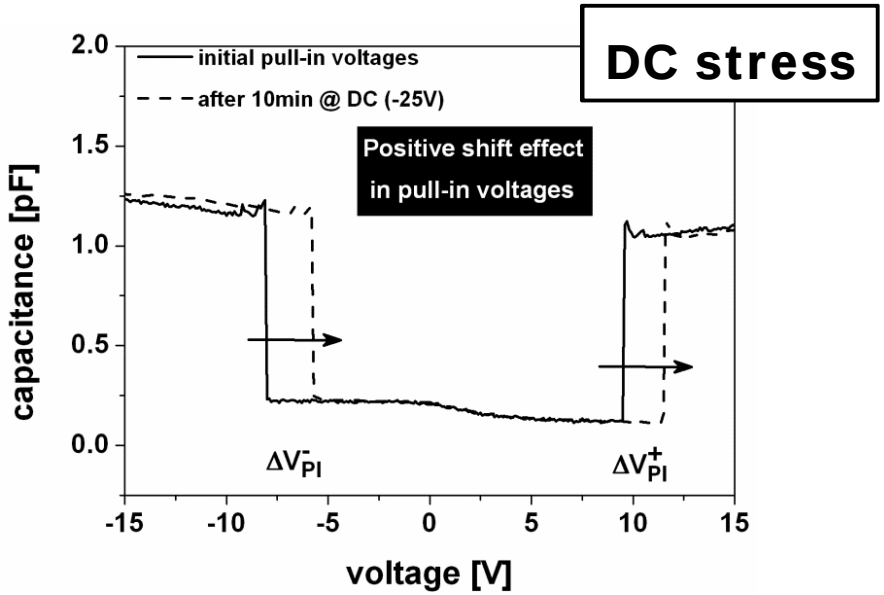

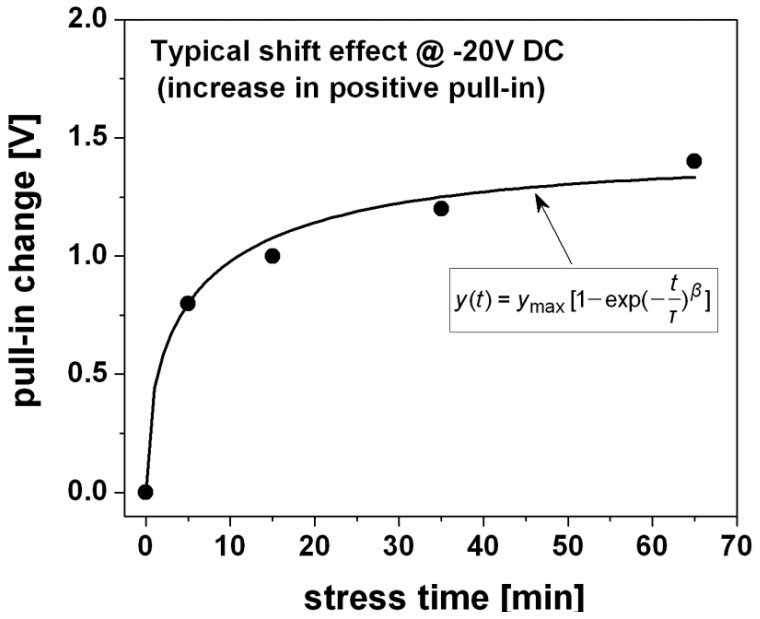

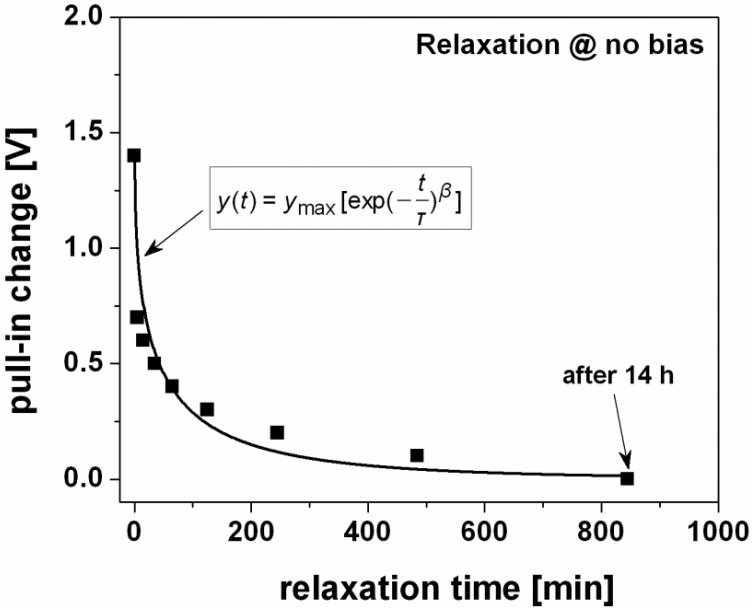

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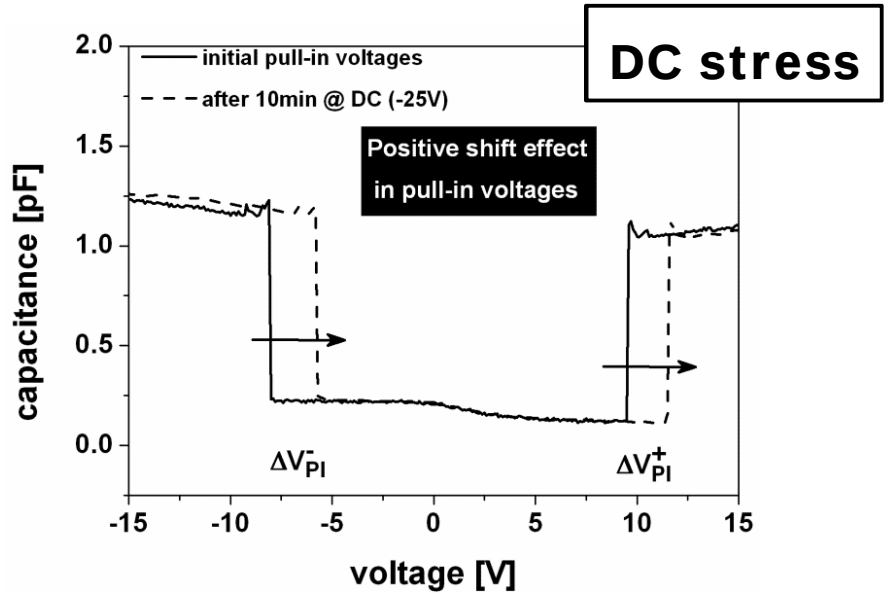

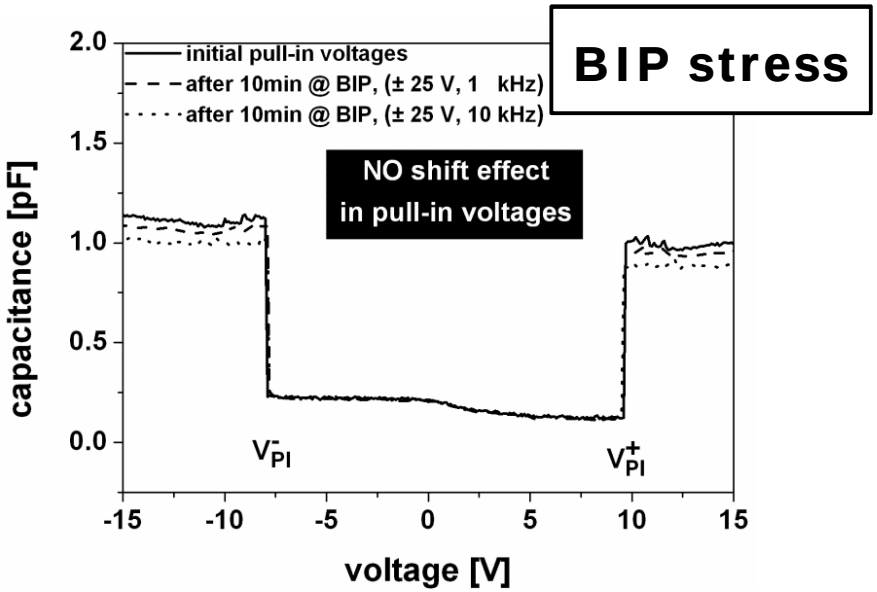

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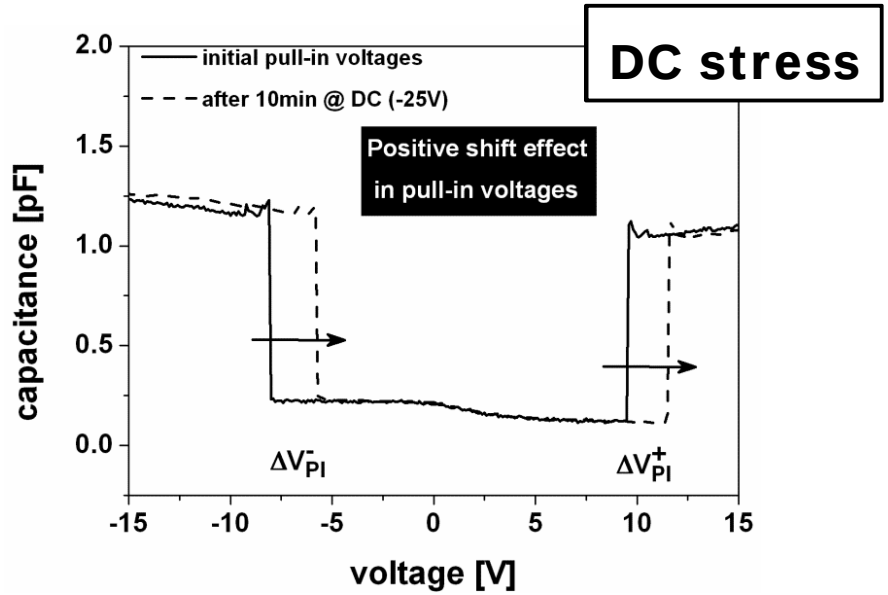
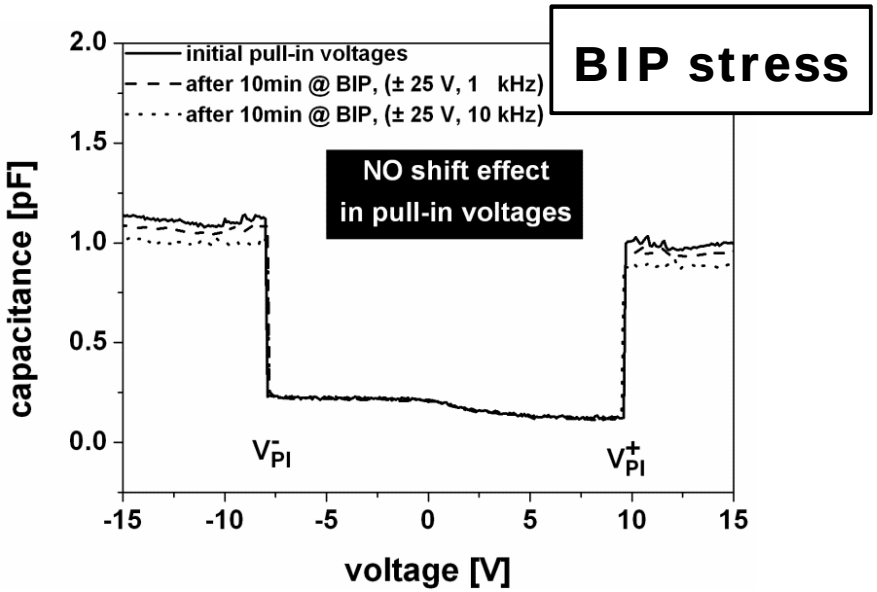
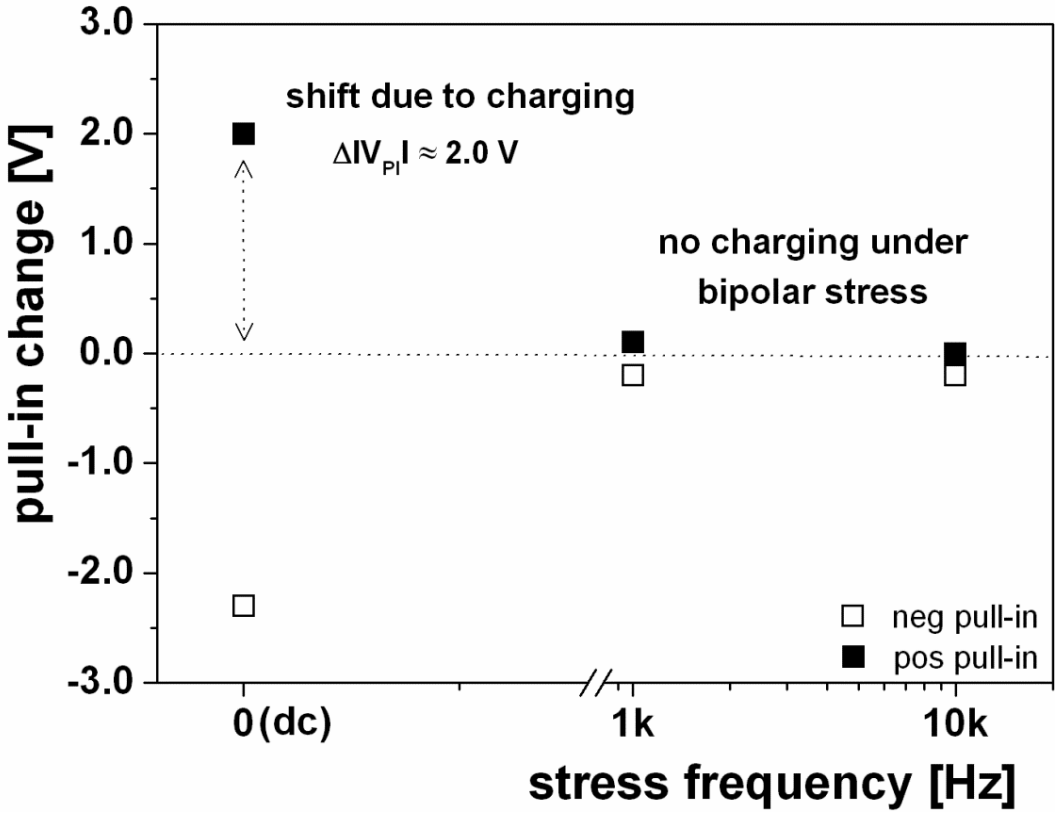
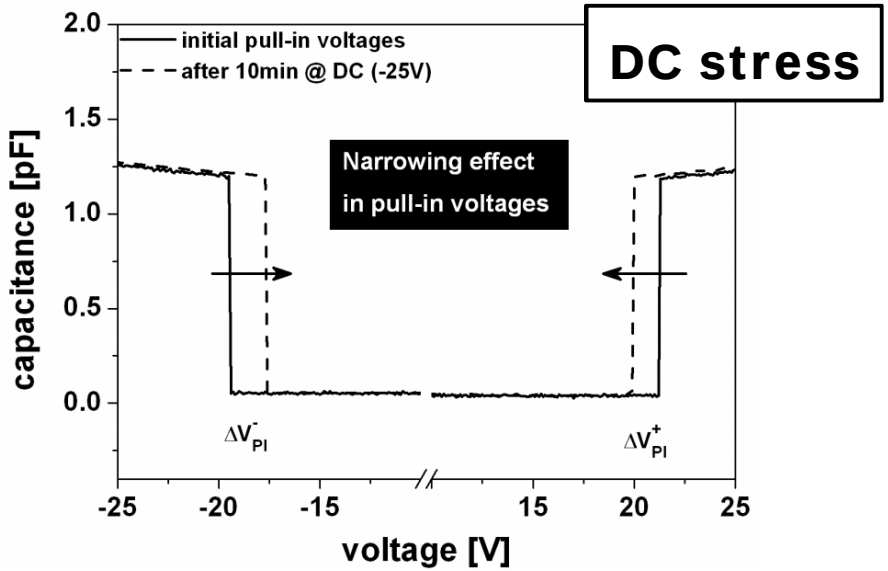
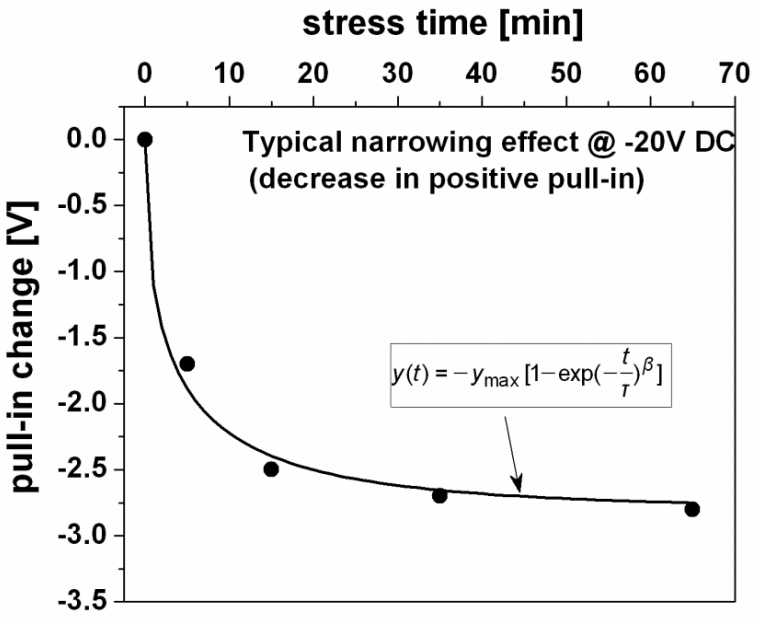






Isolation of degradation mechanisms: results – aluminium switches





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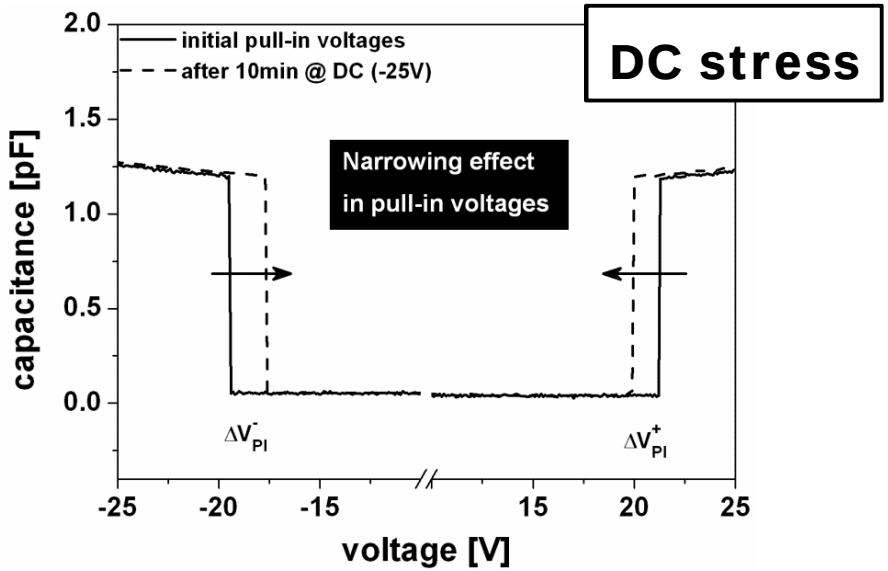

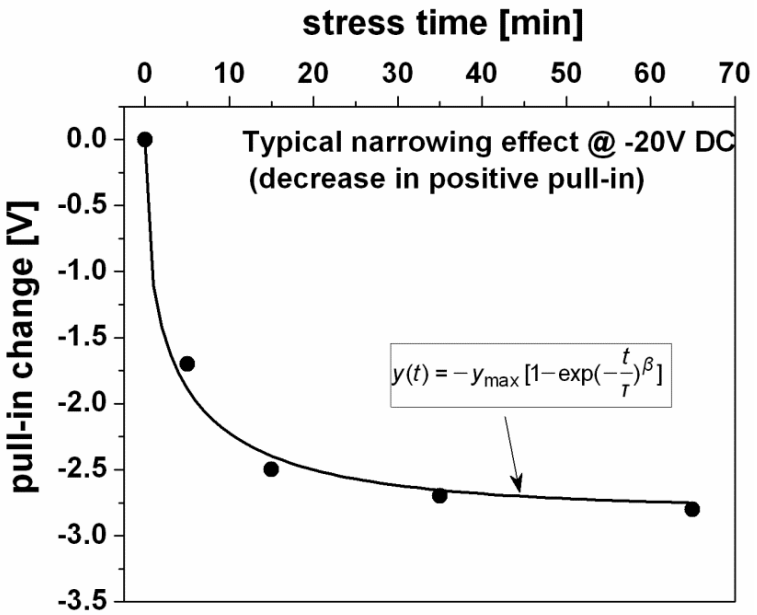

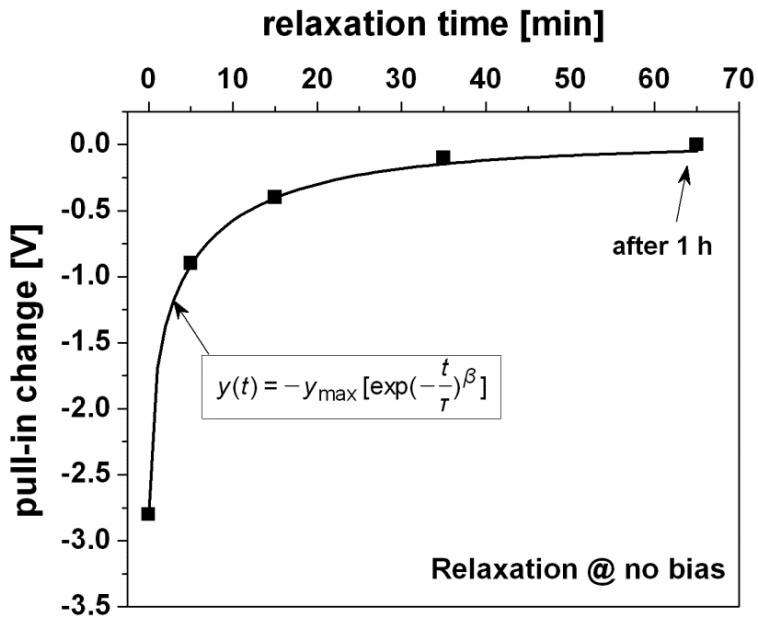

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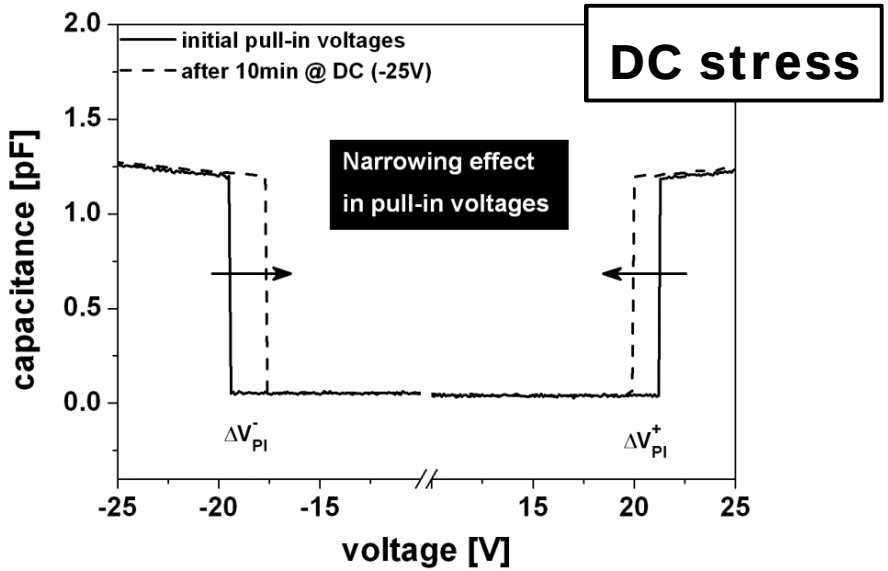

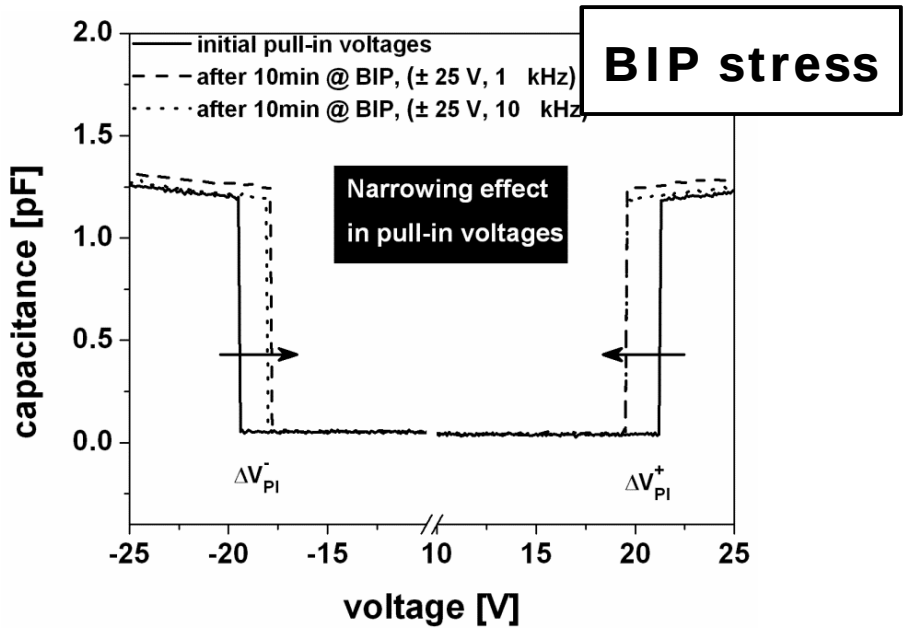

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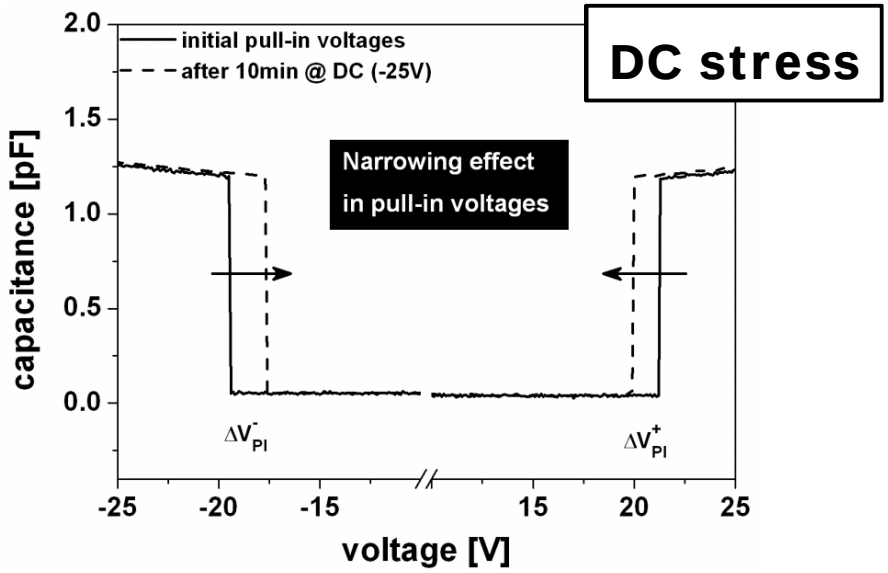
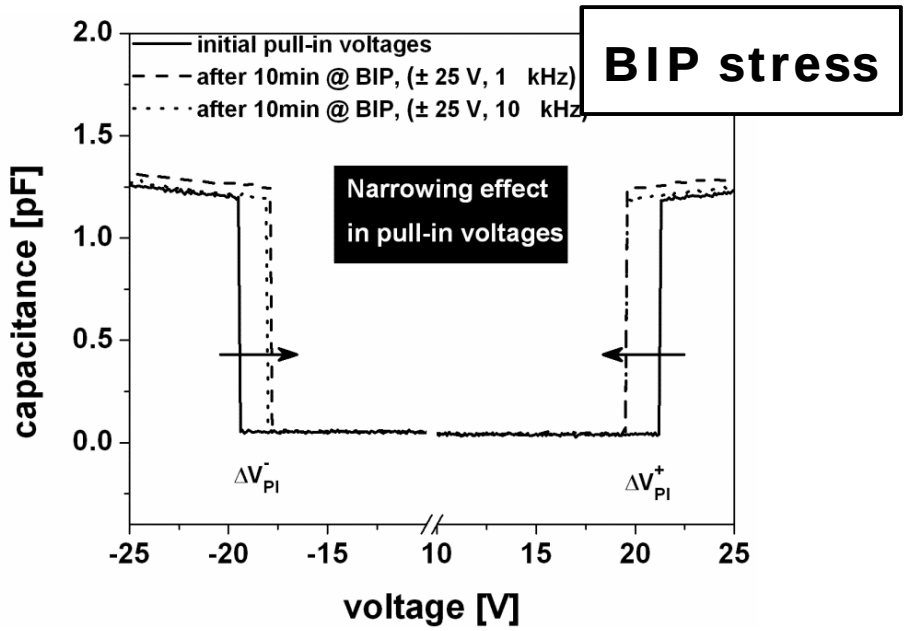
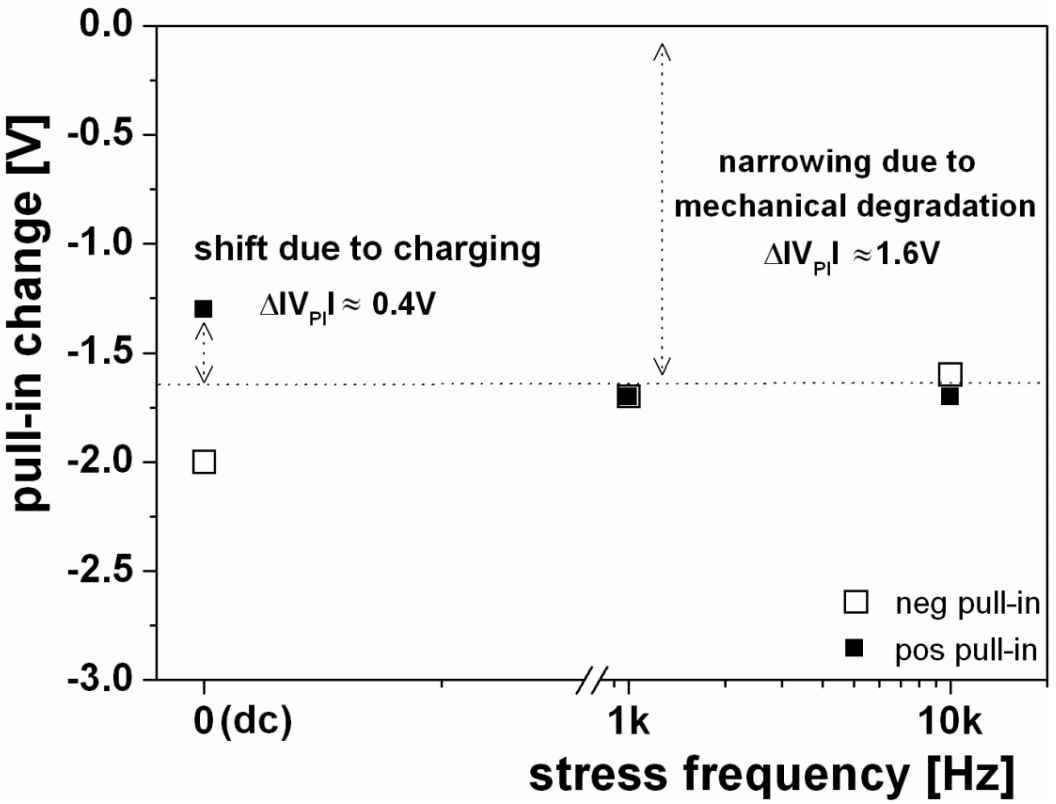
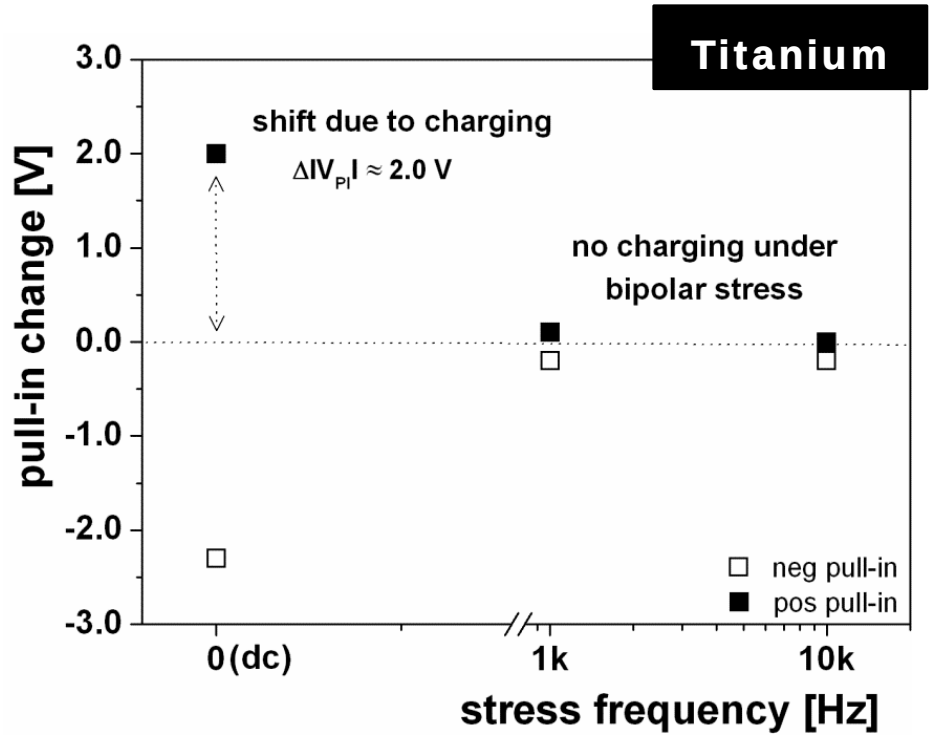
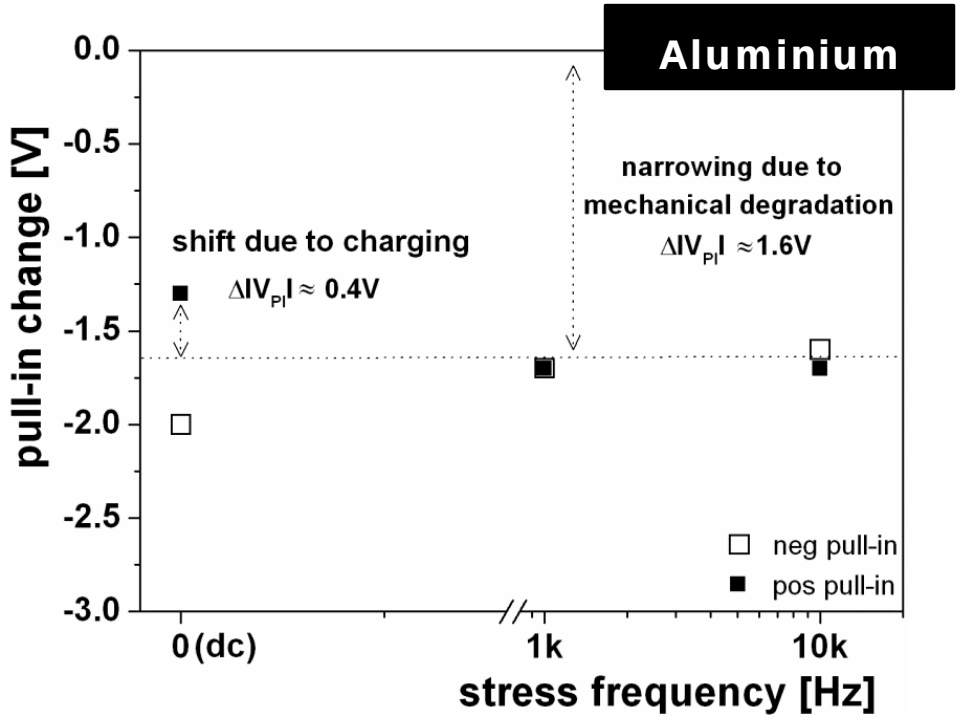






Isolation of degradation mechanisms: titanium vs. aluminium





	DC stress @ -25V	BIP stress @ ±20V, 1kHz, 10kHz	Dominating mechanism
Titanium switches	shift	no change	charging
Aluminium switches	narrowing and shift	narrowing	mechanical degradation

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Conclusions

- **Simple theory and test method for isolation of charging from mechanical degradation in capacitive switches**
- **Experiments on MEMS capacitive switches support the theory and test method**
- **Experiments show that dominant reliability issue may be technology dependent (e.g. materials, process, and device layout)**
- **This work can contribute to establish standardized reliability tests**

- **Other activities in the project:**
  - investigation of the radiation influence on MEMS switches
  - isolation of “substrate charging” effect (i.e. method, test structure)
  - understanding of physics of charging and mechanical issues

Acknowledgments

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