A Novel Charging Concept in Capacitive RF MEMS Switches

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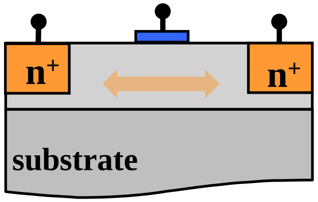
Outline

- Radio-Frequency (RF) switches and capacitive RF MEMS
- Reliability problem – “dielectric charging”
- Physical model of the switch and novel charging concept
- Experimental isolation of charging mechanisms
- Conclusions

Radio-Frequency (RF) switch

Solid-state RF Switches

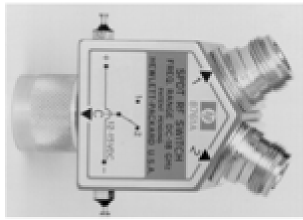


area ≈ mm^2

Consumer electronics

- **low cost**
- **high volume applications**
- **demand for better RF performance**

Mechanical RF Switches

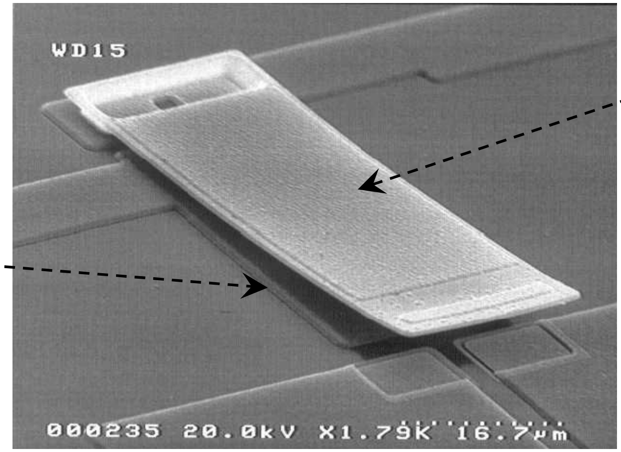


area ≈ cm^2

Test equipment, Military, Space

- **very good RF performance**
- **expensive, bulky, heavy**
- **low volume applications**

Miniaturized Mechanical switches – RF MEMS



Moving electrode

(20 µm x 100 µm)

Bottom electrode

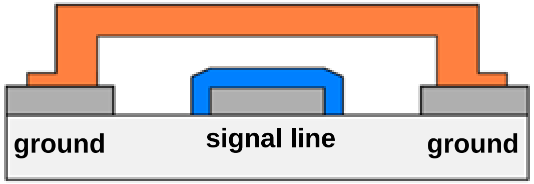
- ❑ **Ohmic contact switch**
- ❑ **Capacitive contact switch**

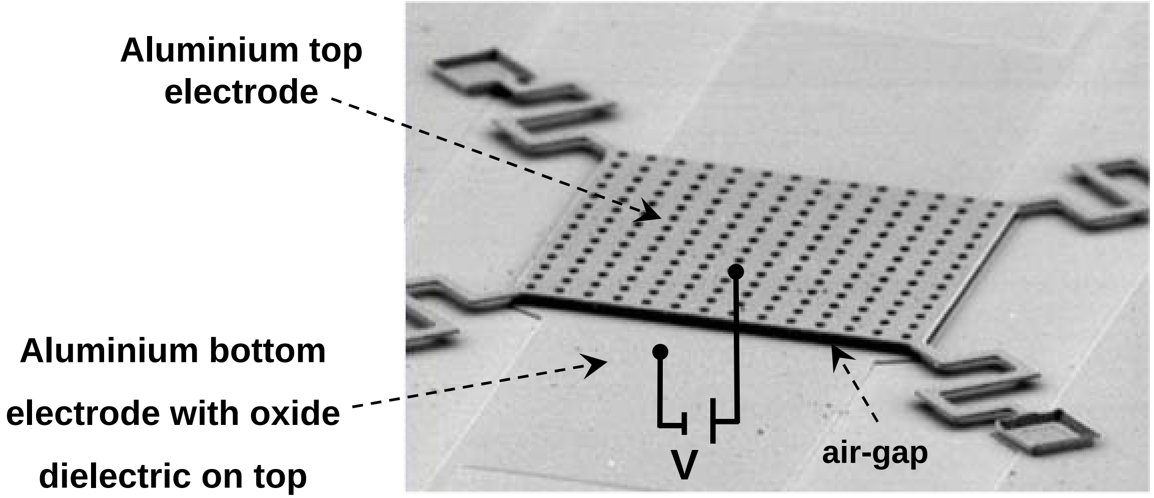
Reliability problems

- **very good RF performance (mechanical)**
- **good integration capability (solid-state)**
- **low cost (CMOS based fabrication)**
- high and low volume applications

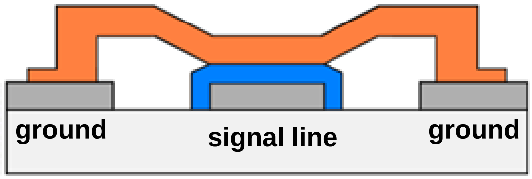
Capacitive RF MEMS switch

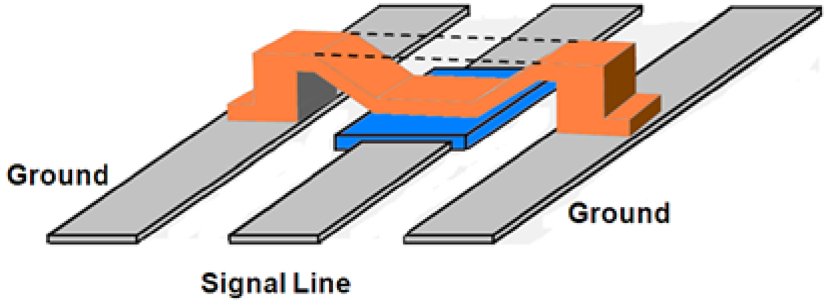
<u>UP state – low C to ground</u>



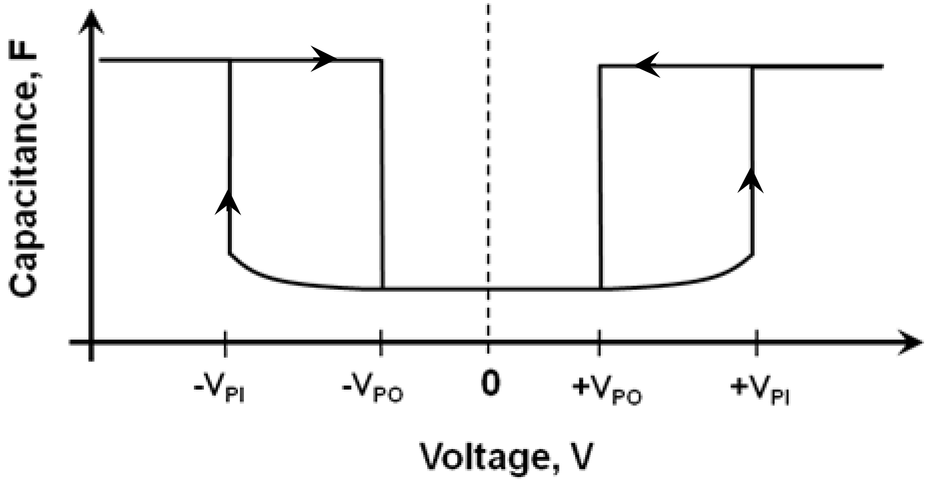


<u>DOWN state – high C to ground</u>





Reliability problem – “dielectric charging”

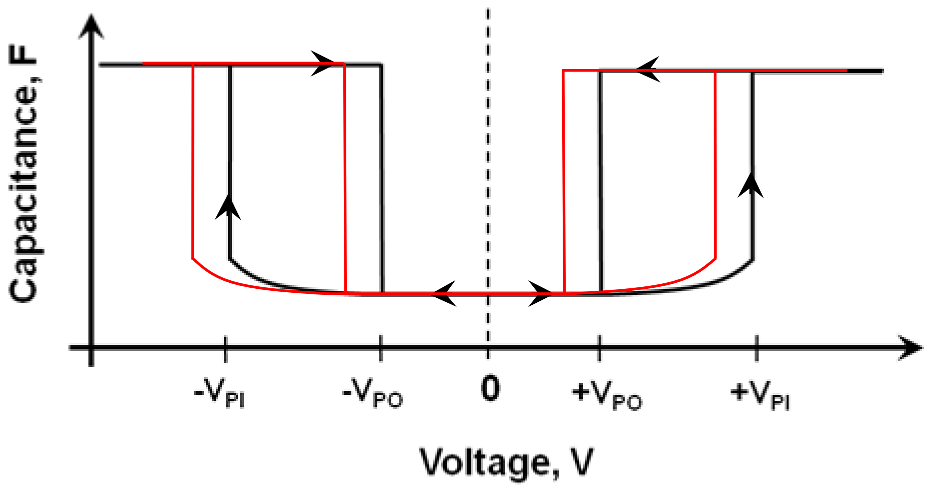


C-V curve changes over the device lifetime

- C-V cure shift effect
- C-V curve narrowing effect

Reliability problem – “dielectric charging”

Shift effect

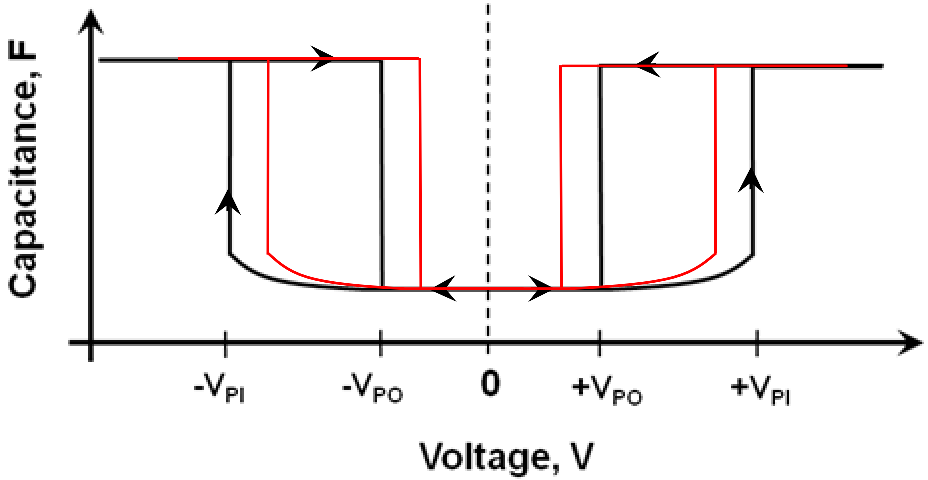


C-V curve changes over the device lifetime

- C-V cure shift effect
- C-V curve narrowing effect

Reliability problem – "dielectric charging"

Narrowing effect



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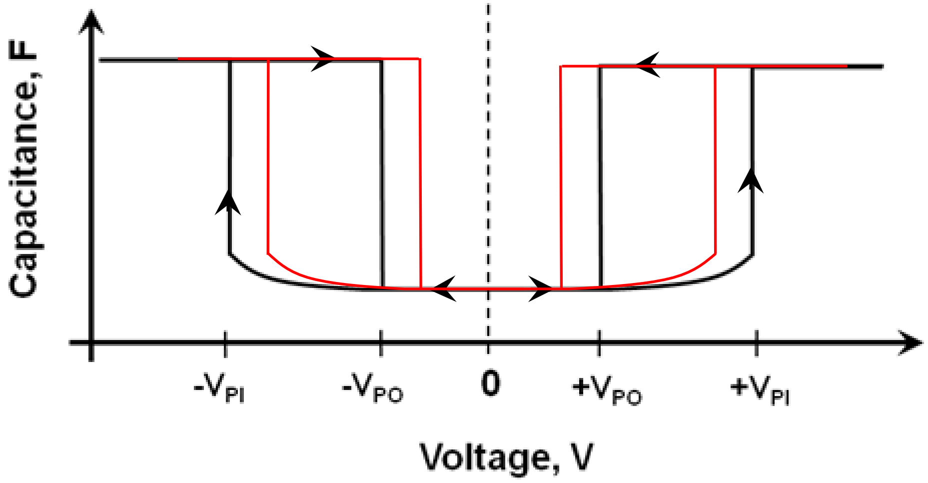
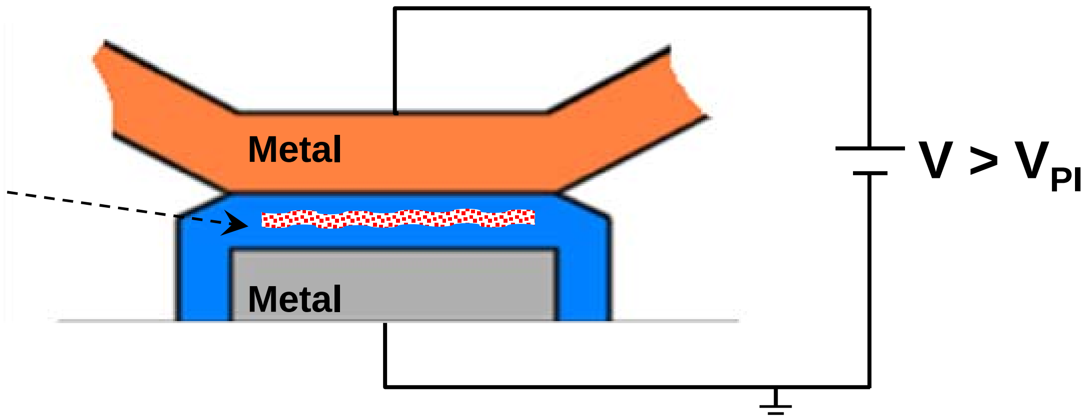
Narrowing effect



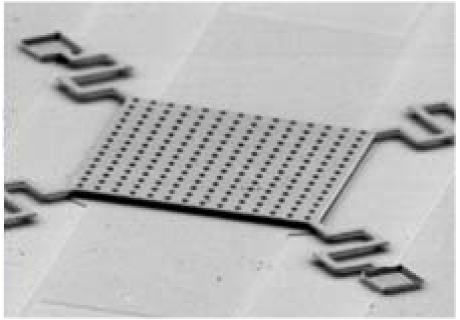
C-V curve changes over the device lifetime

- C-V cure shift effect
- C-V curve narrowing effect

Charge is induced in the dielectric during bias

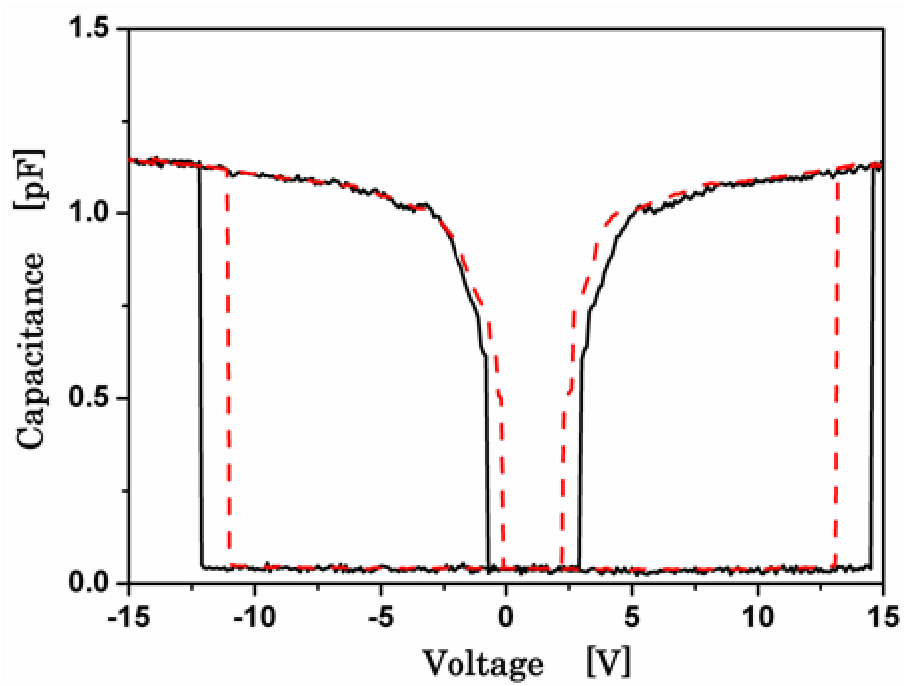


Physics of charging is not understood



Measured C-V instability in our switches

(narrowing effect)



—— before voltage stress

- - - - after voltage stress (20V)

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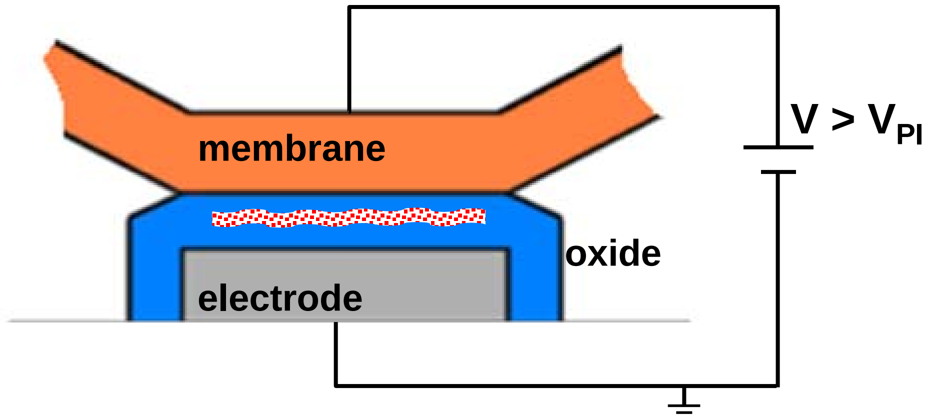
- ❑ **Physical model of the switch and novel charging concept**
- ❑ Experimental isolation of charging mechanisms
- ❑ Conclusions

Physical models:

- assume a single (dominant) charging mechanism
- do not account for the contact non-uniformities



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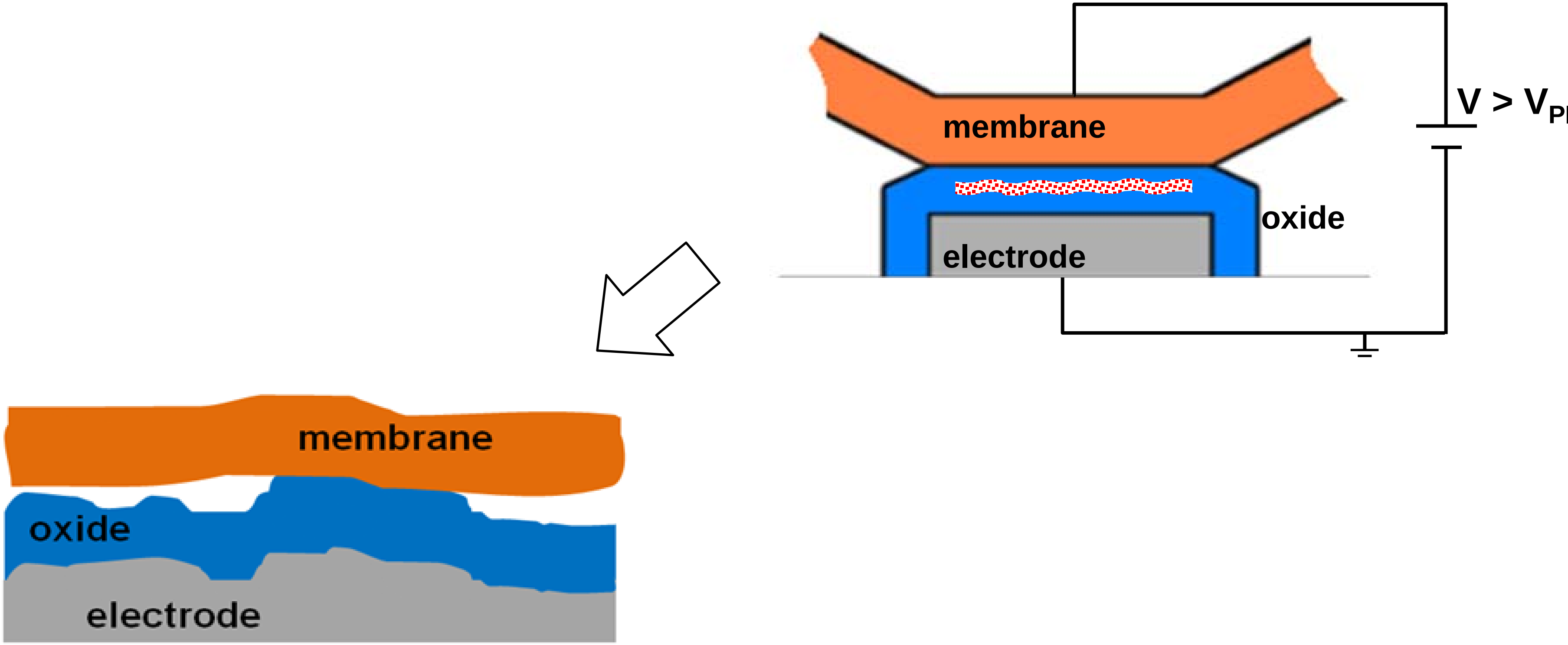
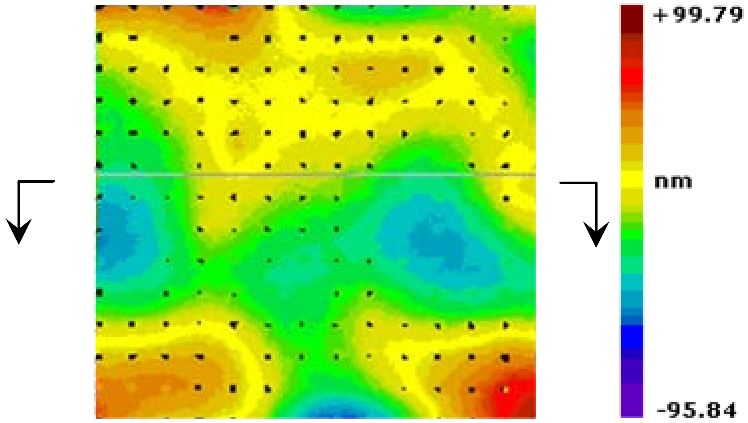
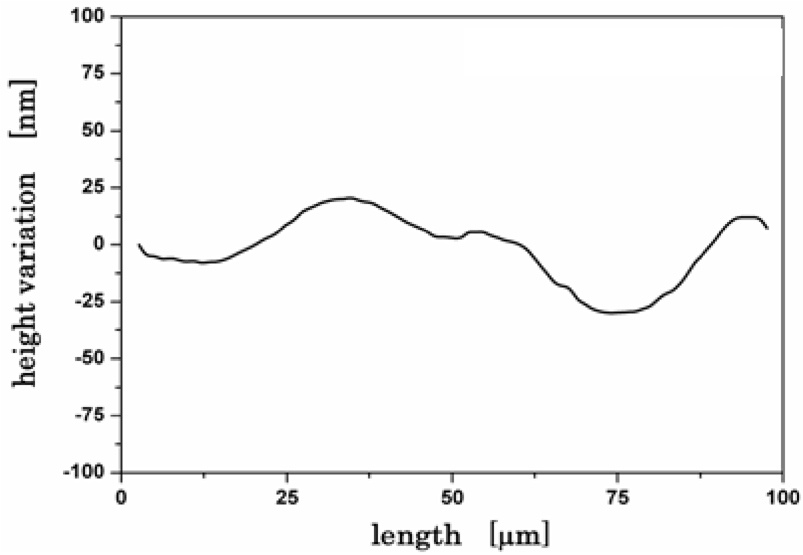


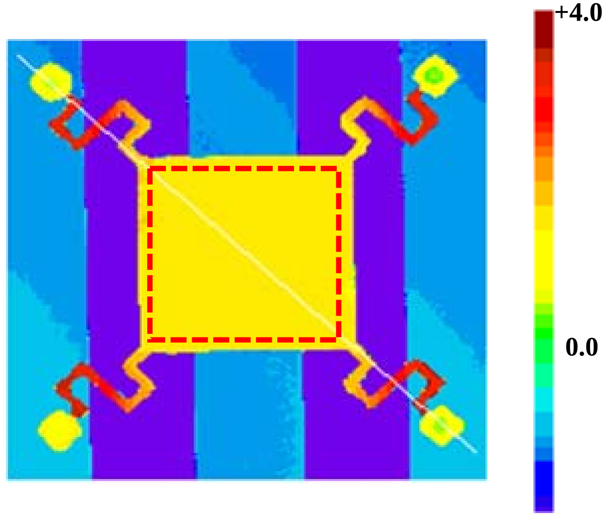
Close-Up View



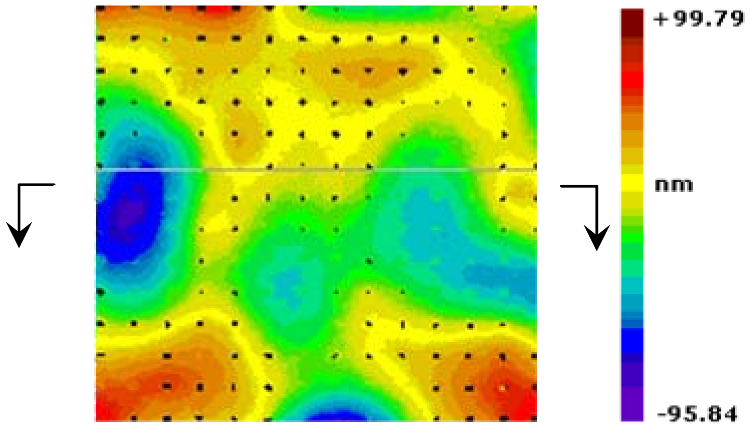


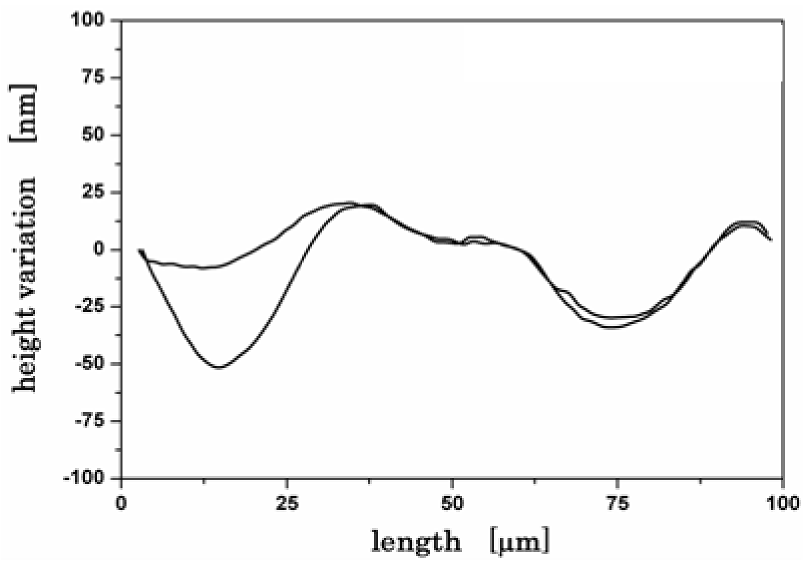
V = 20 V

DOWN-state



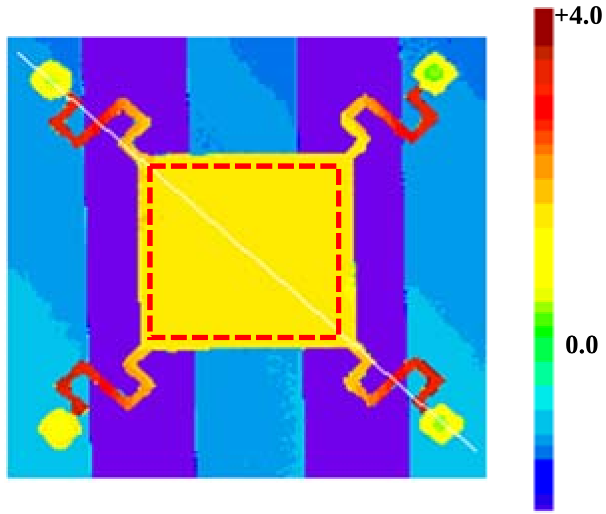
Close-Up View



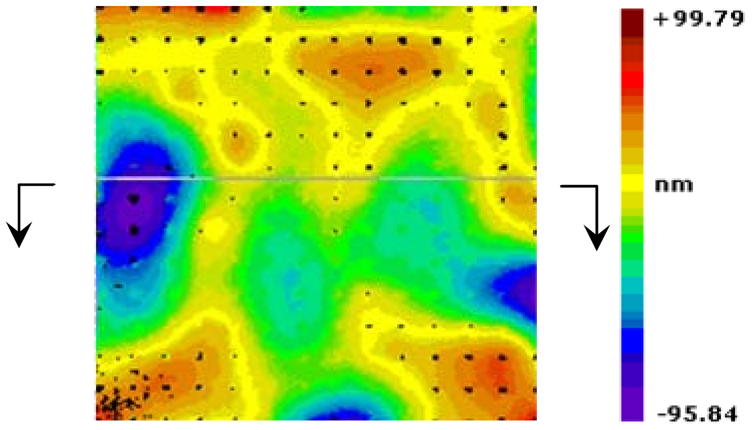


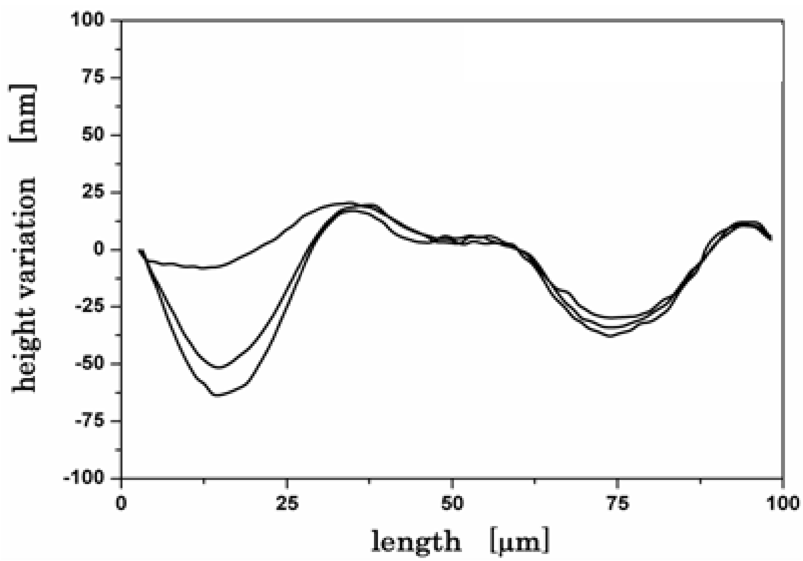
V = 30 V

DOWN-state



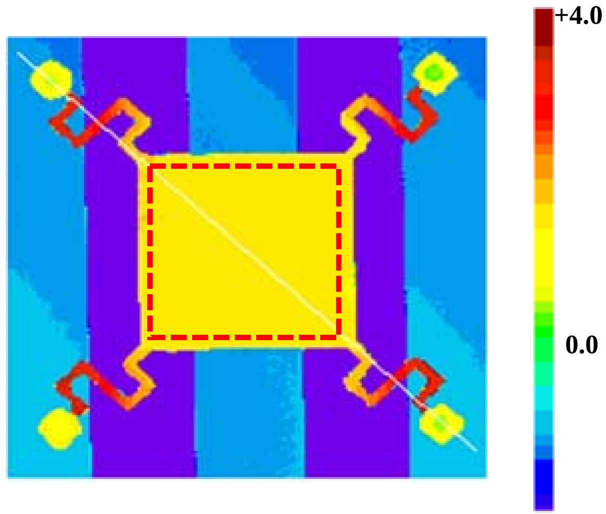
Close-Up View



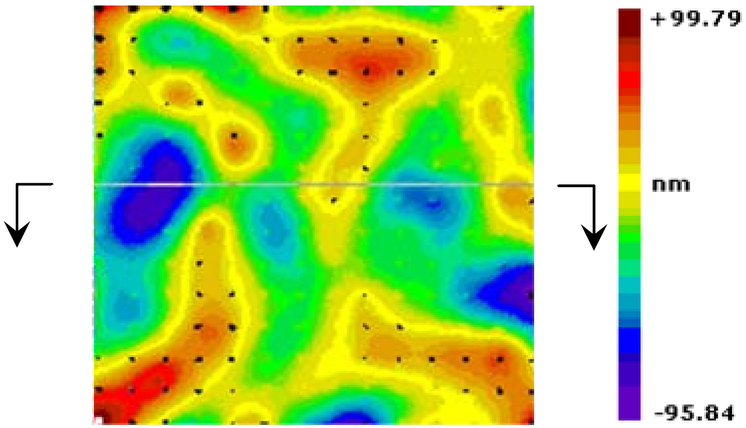


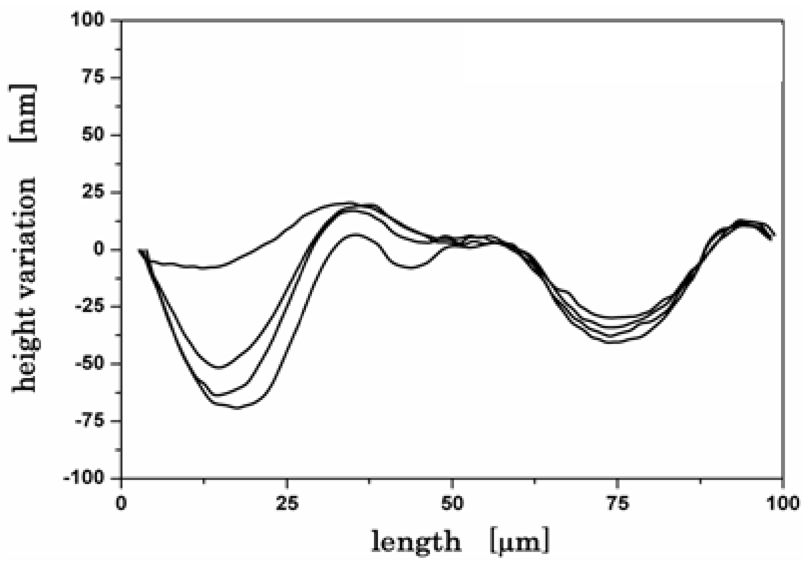
V = 40 V

DOWN-state



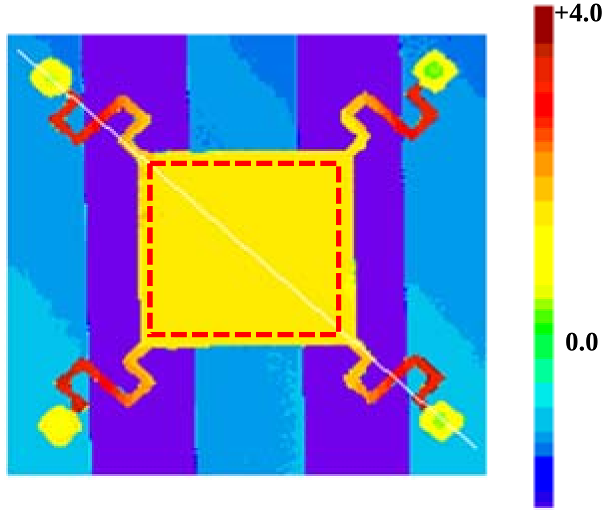
Close-Up View



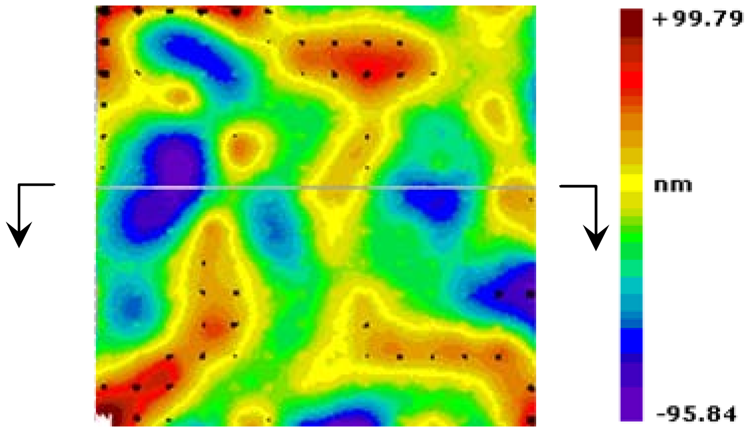


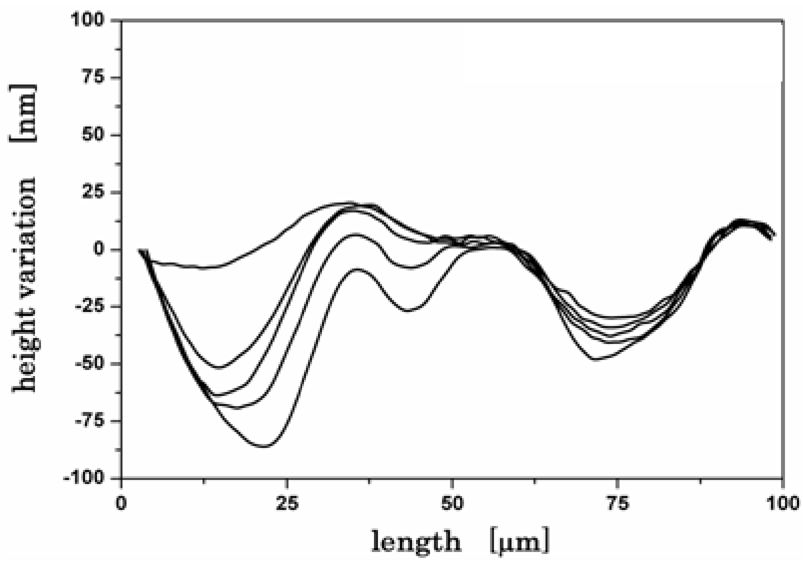
V = 50 V

DOWN-state



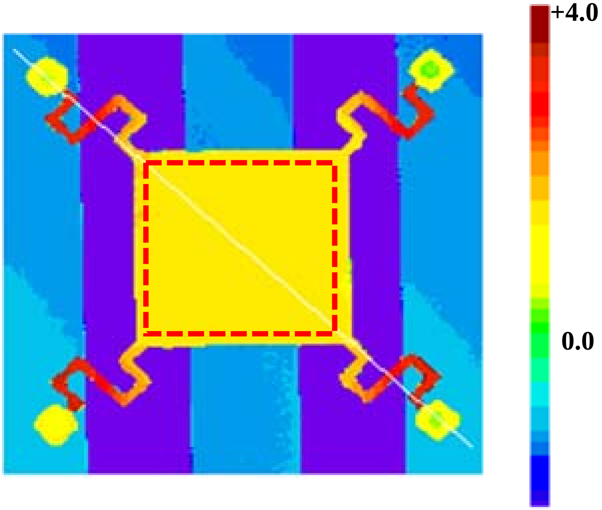
Close-Up View





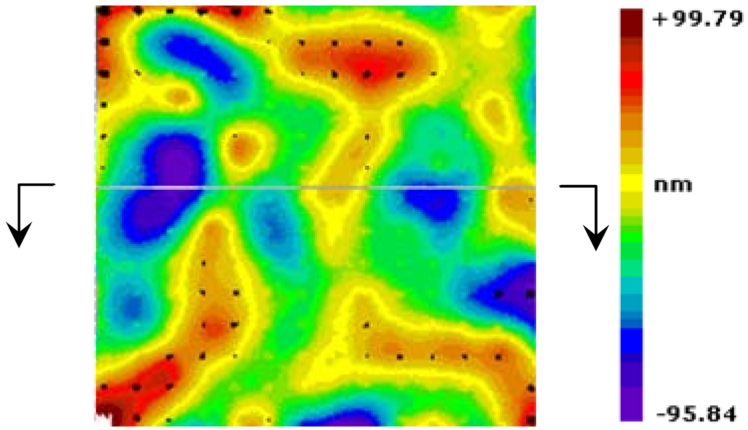
V = 60 V

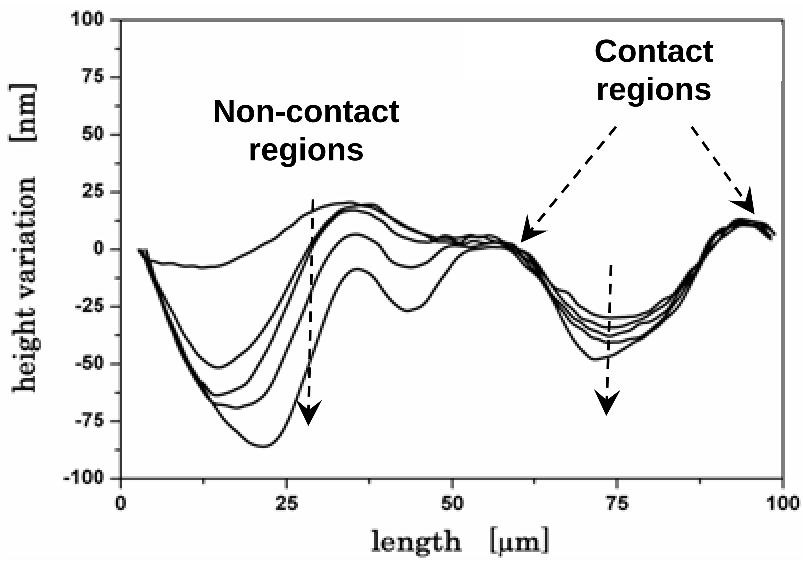
DOWN-state



Physical model of the switch and novel charging concept

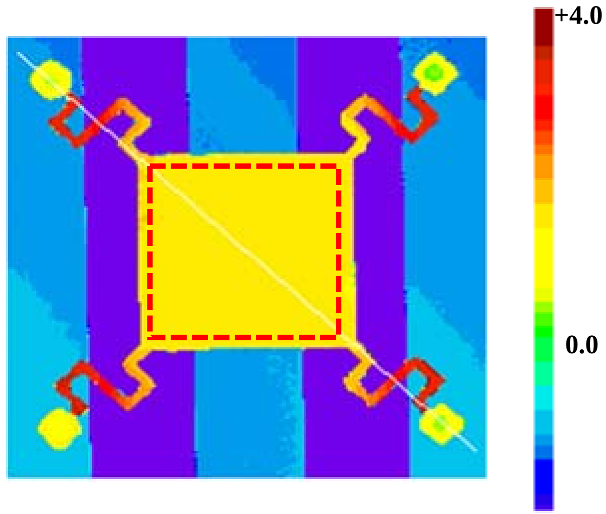
Close-Up View





V = 60 V

DOWN-state



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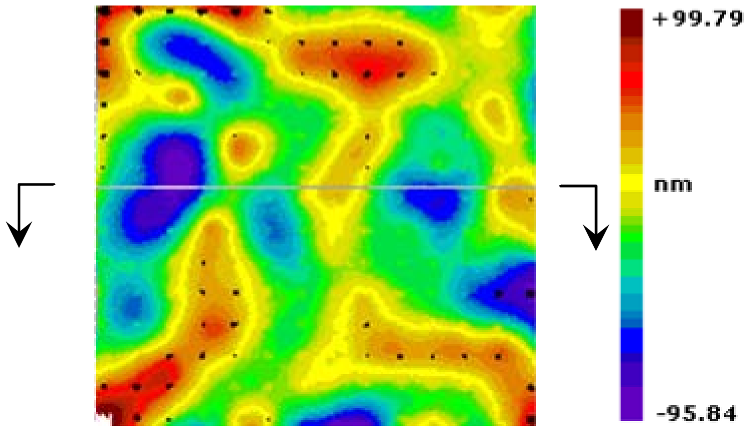
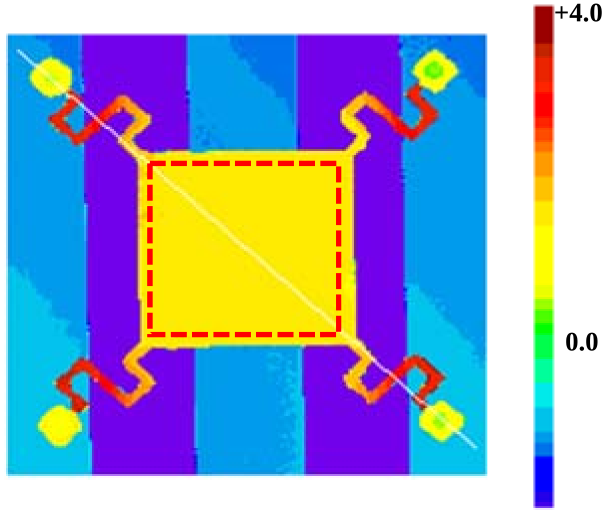
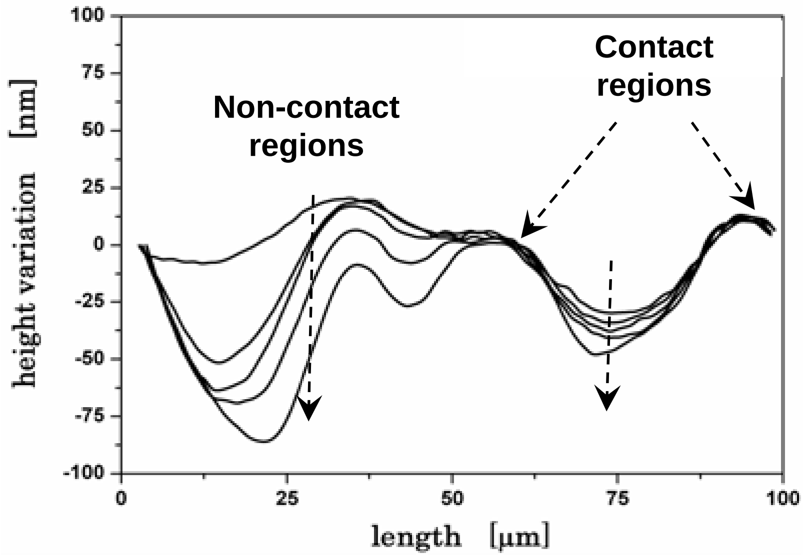
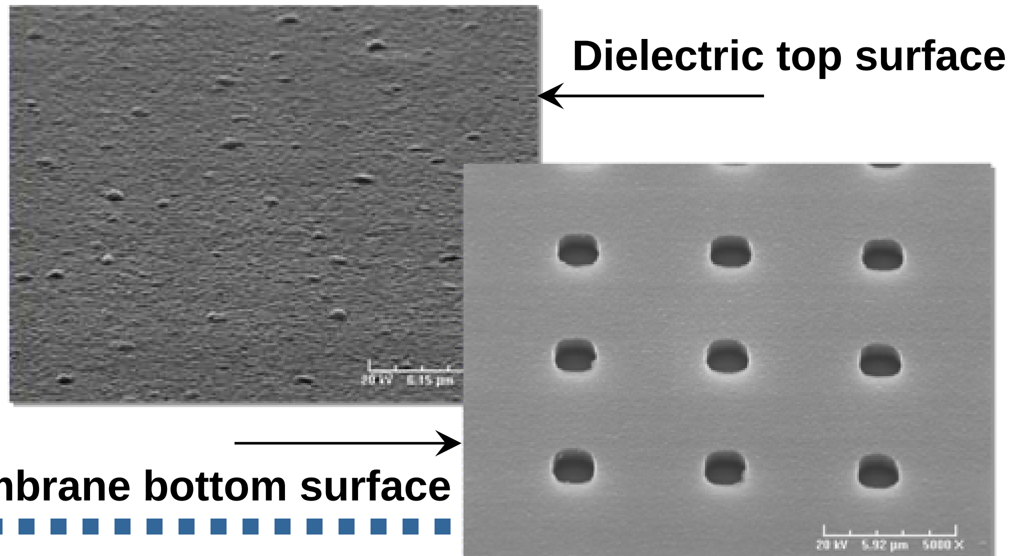


DOWN-state



V = 60 V

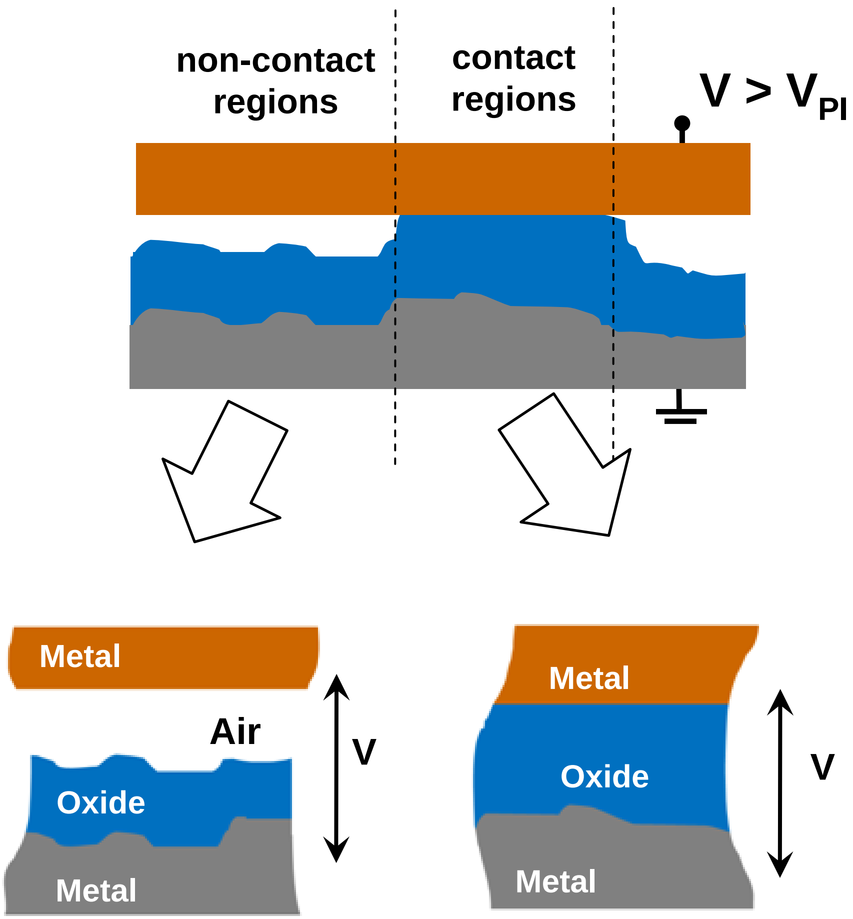


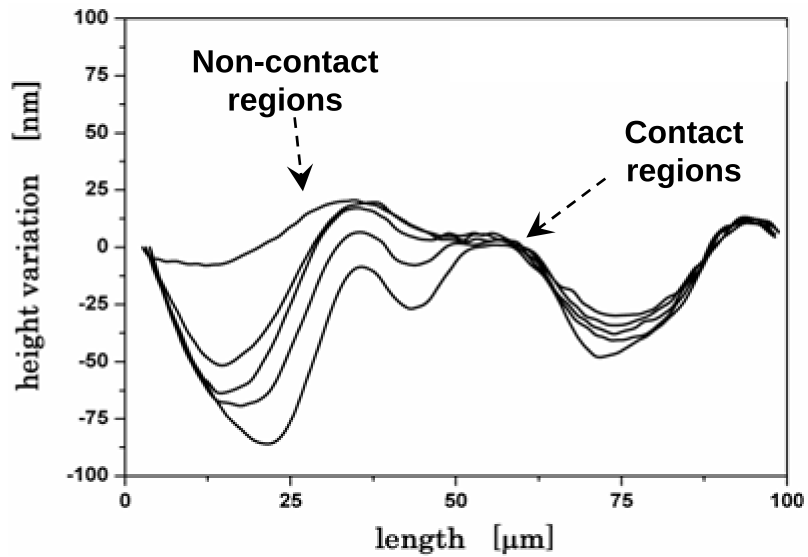


Dielectric top surface

Membrane bottom surface

Physical model of the switch and novel charging concept





- ❑ **Non-uniform bias stress conditions**
- ❑ **New charging concept**
- ➢ non-contact charging mechanism
- ➢ contact charging mechanism

Outline

- ❑ Radio-Frequency (RF) switches and capacitive RF MEMS
- ❑ Reliability problem – “dielectric charging”
- ❑ Physical model of the switch and novel charging concept
- ❑ **Experimental isolation of charging mechanisms**
  - Non-contact charging mechanism
  - Contact charging mechanism
- ❑ Conclusions

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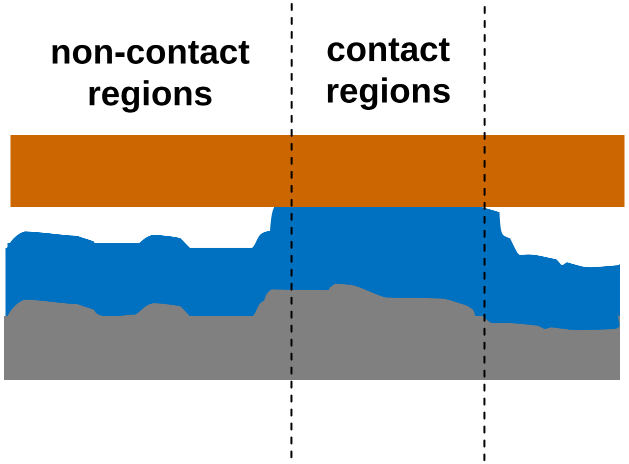
- ❑ **Conclusions**



DOWN-state dc bias stress

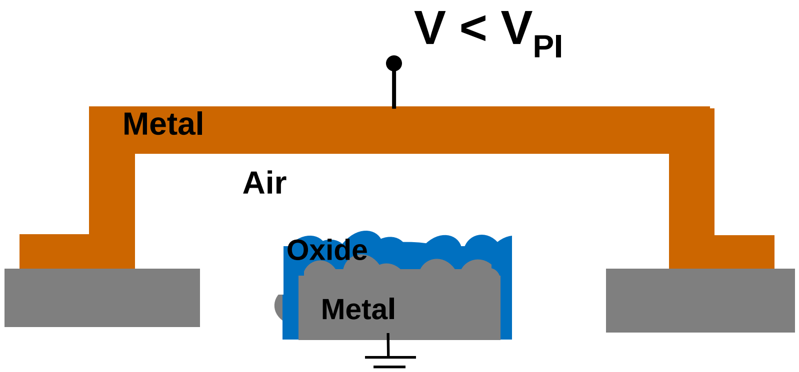
(standard method)

- Two charging mechanisms occur simultaneously
- Mechanical degradation of the membrane can occur

Methodology in this work:

- To isolate the non-contact regions from the contact regions during stress
- To eliminate the influence of mechanical degradation

Non-contact charging mechanism



UP-state bias stress on MEMS

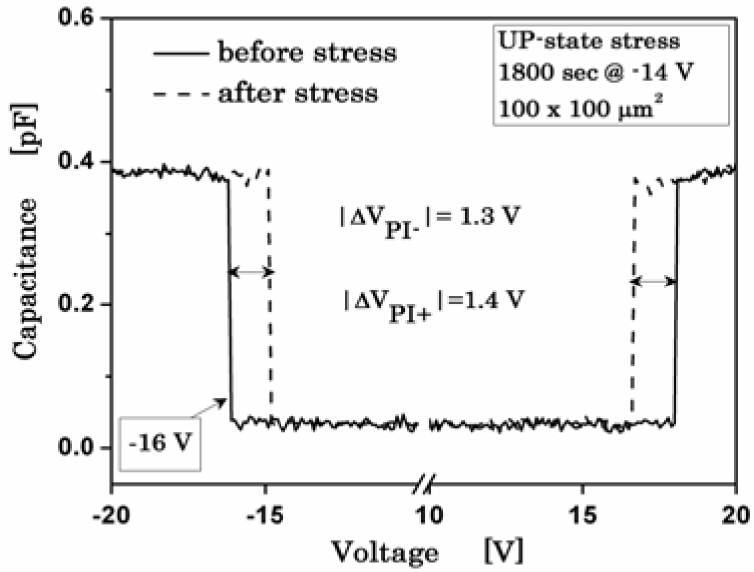
- No charging due to contact bias stress
- No mechanical issues during stress

Measurement procedure:

- V_{PI-} and V_{PI+} - measurement before stress
- Apply Up-state stress
- V_{PI-} and V_{PI+} - measurement after stress
- Analyze change due to charging - ΔV_{PI-} and ΔV_{PI+}

Experimental isolation of charging mechanisms

Non-contact charging mechanism



[*Applied Physics Letters,* 93, 094101 (2008)]

Narrowing effect due to

Non-contact bias stress

Non-contact charging mechanism

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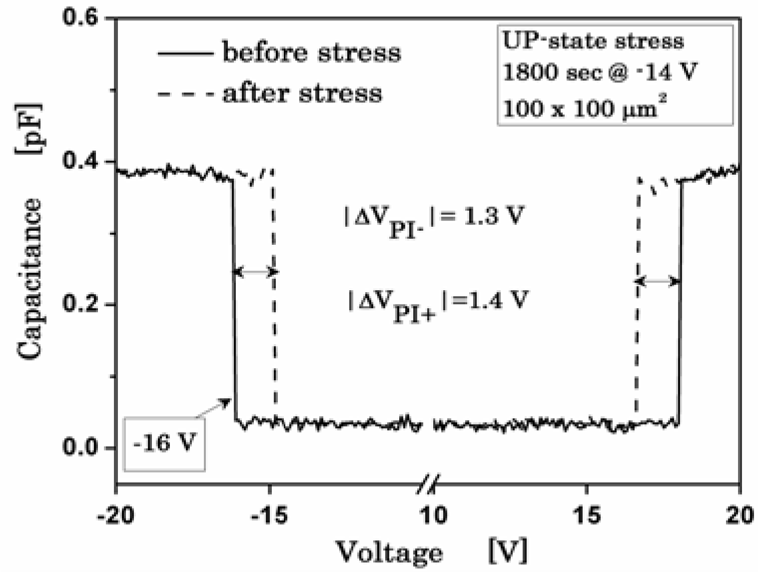

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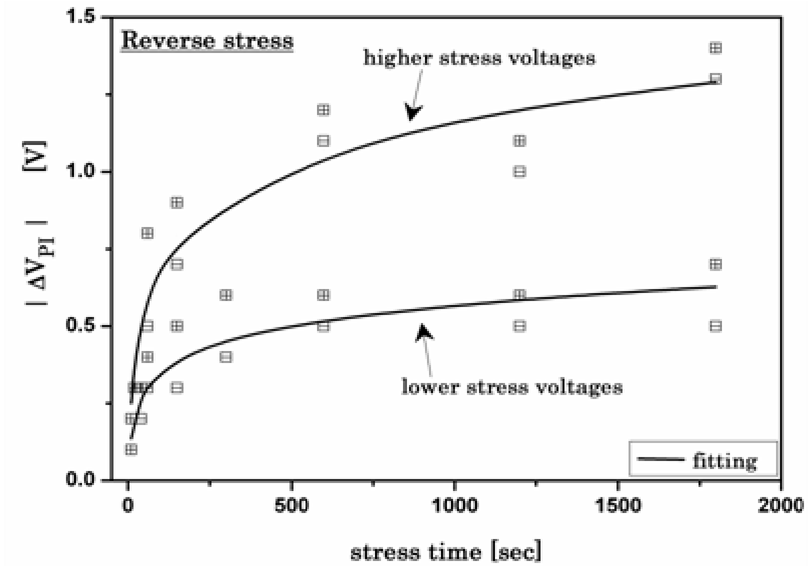
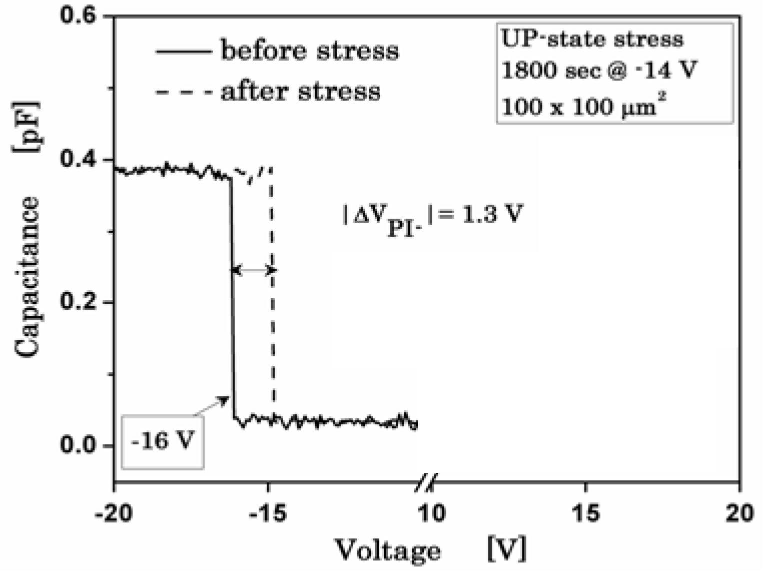


Similar results for the forward stress

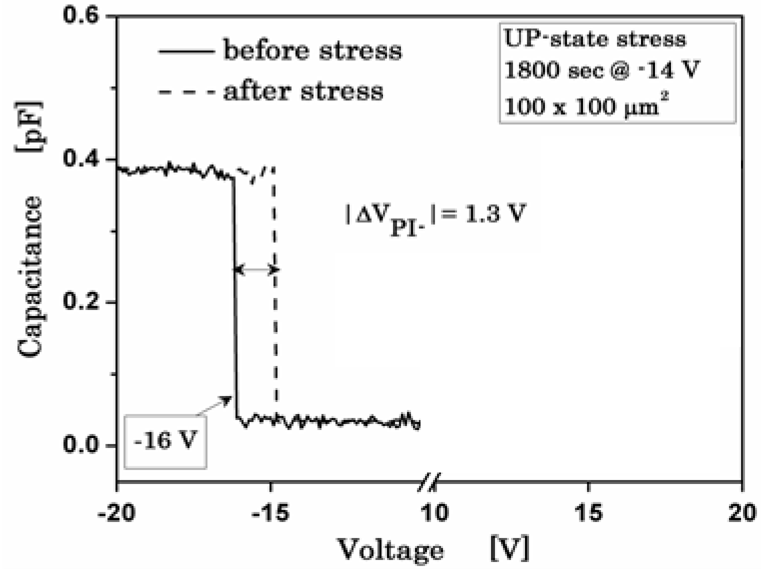
(also symmetrical narrowing effect)

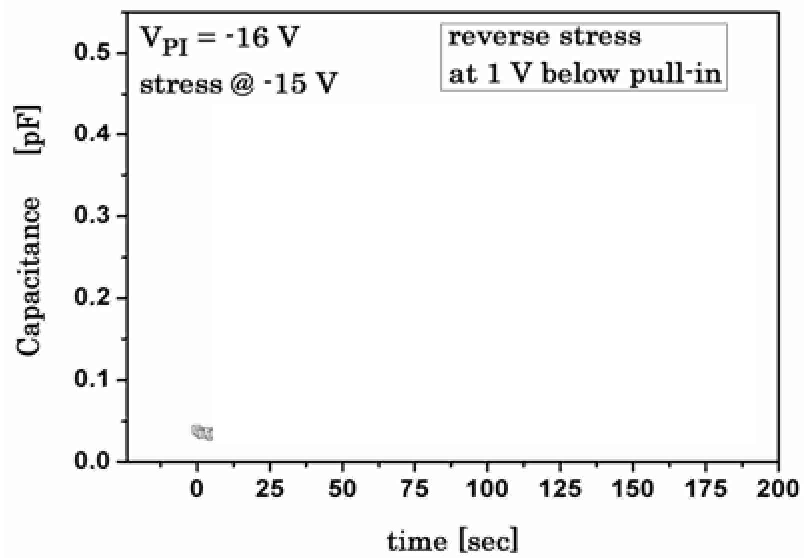
Non-contact charging mechanism



Experimental isolation of charging mechanisms

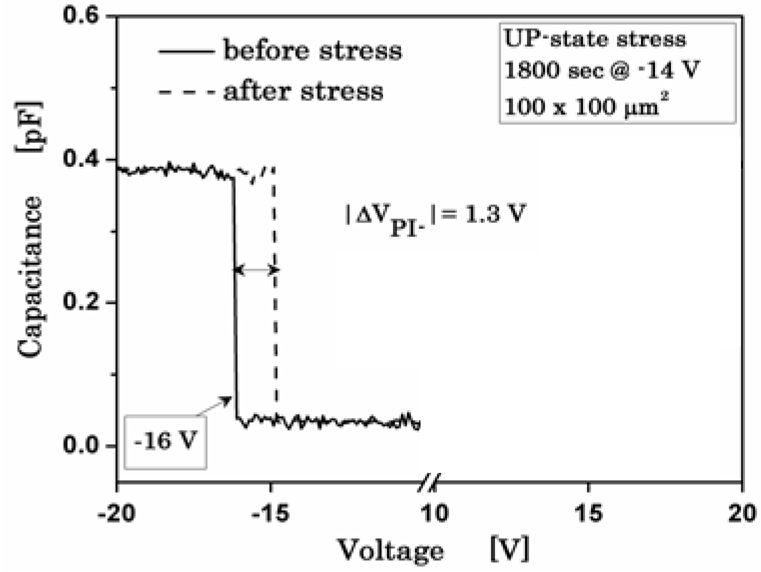
Non-contact charging mechanism

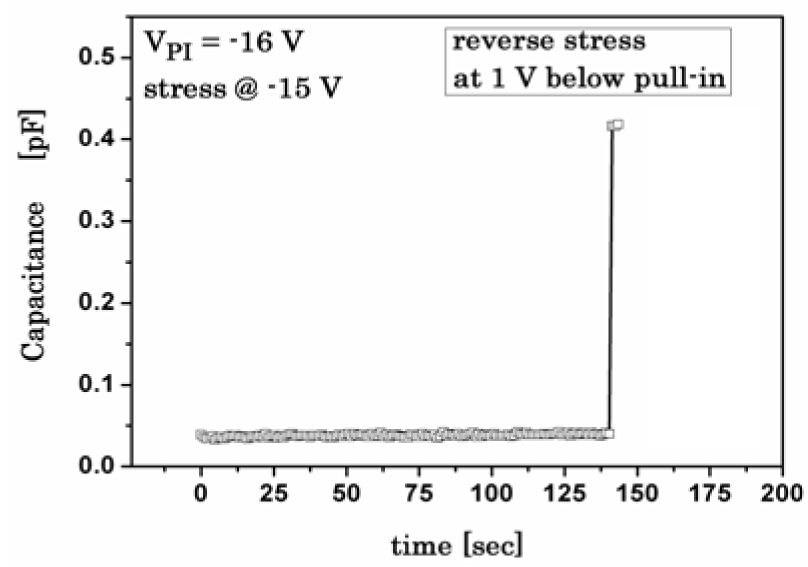




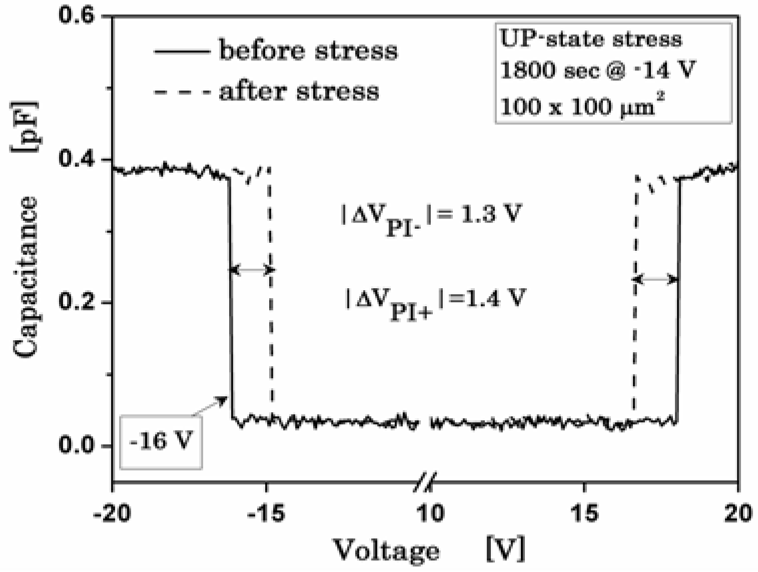
Experimental isolation of charging mechanisms

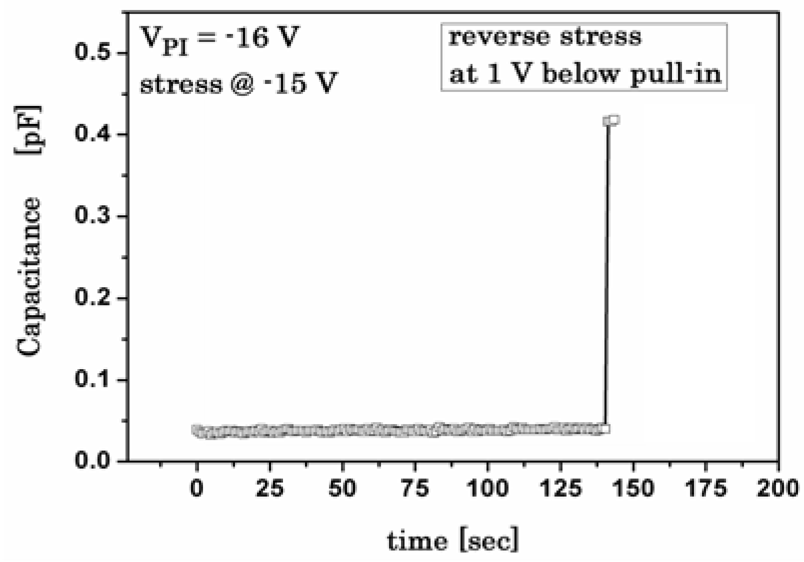
Non-contact charging mechanism



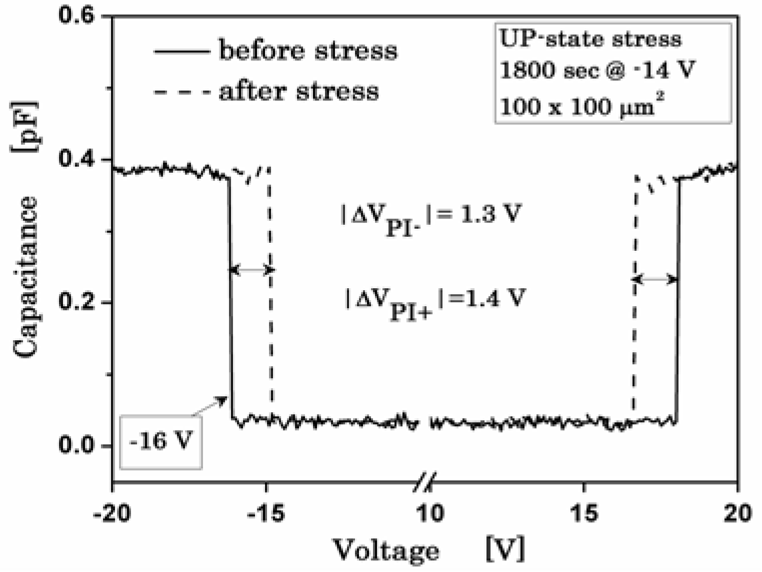


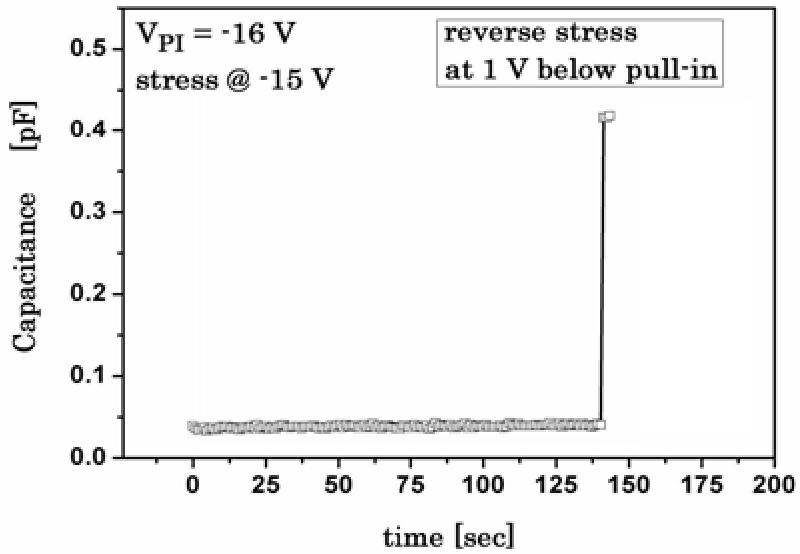
Non-contact charging mechanism

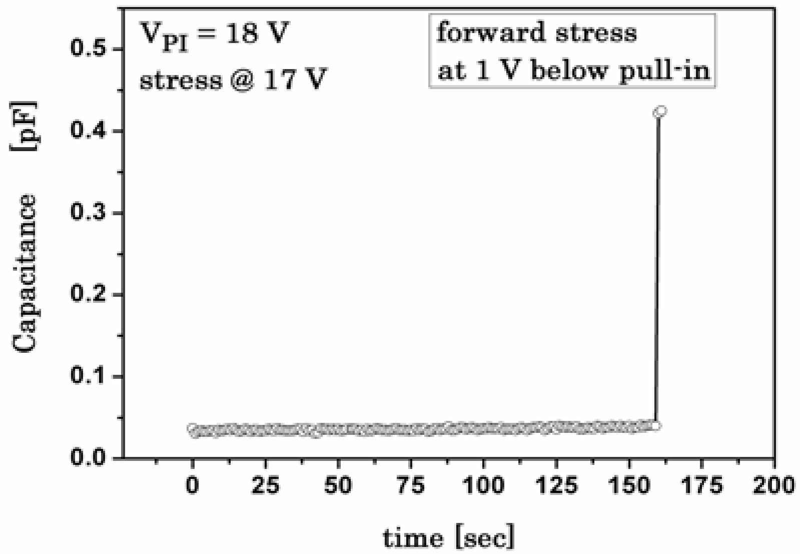




Non-contact charging mechanism

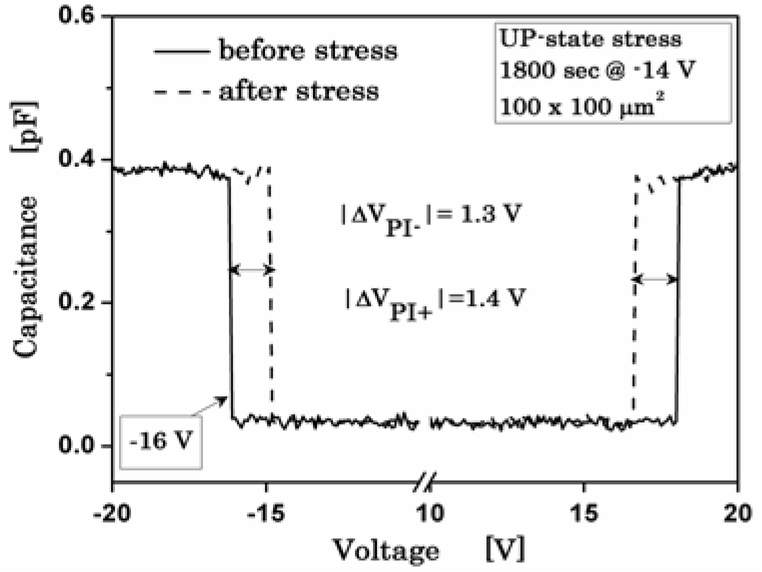


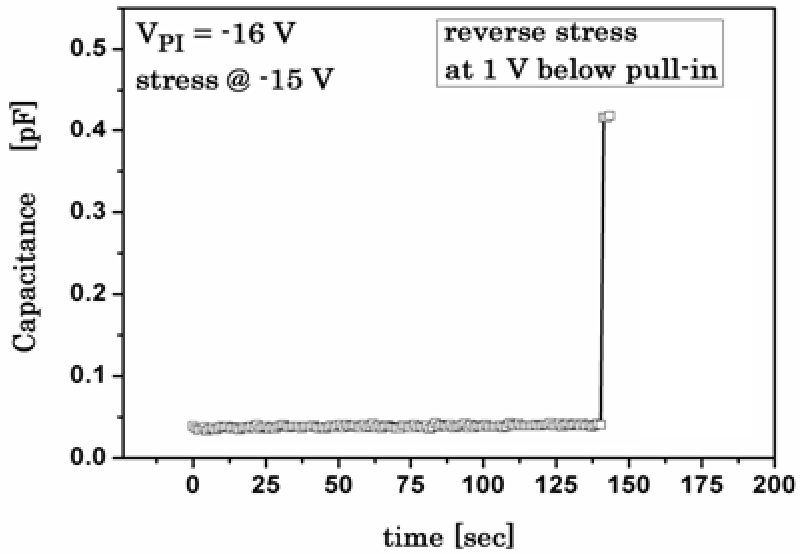


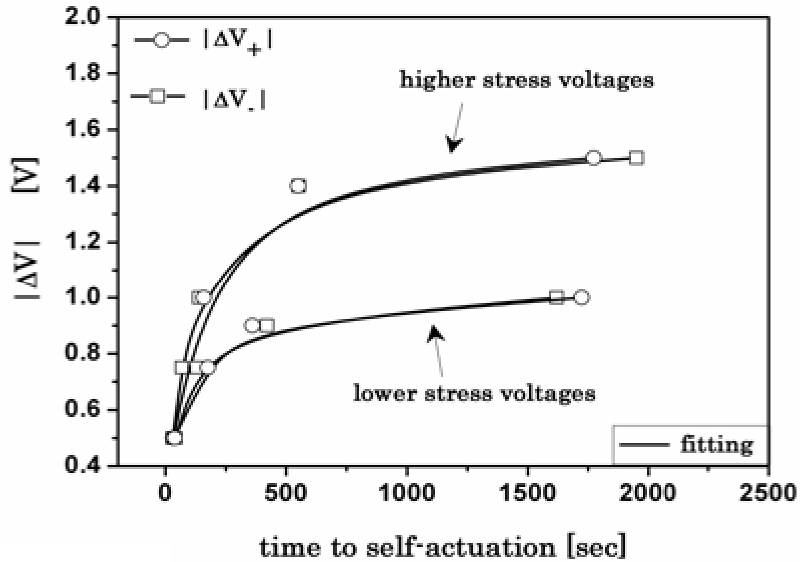


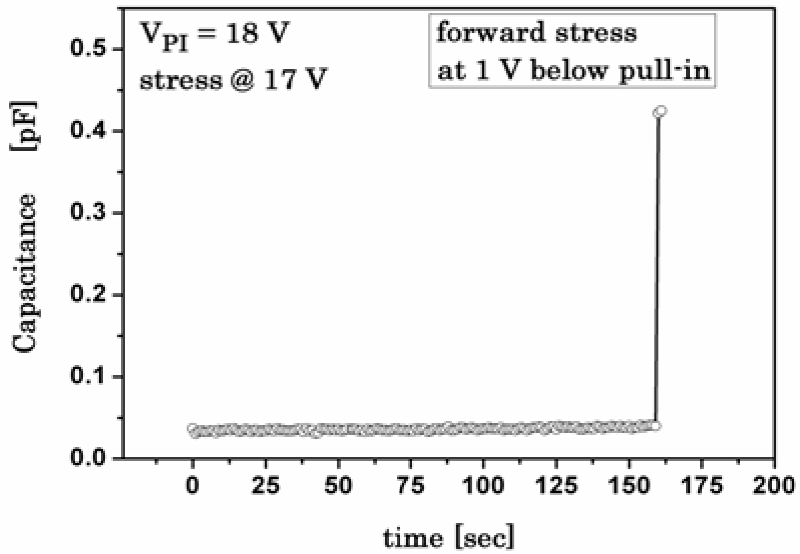
Experimental isolation of charging mechanisms

Non-contact charging mechanism



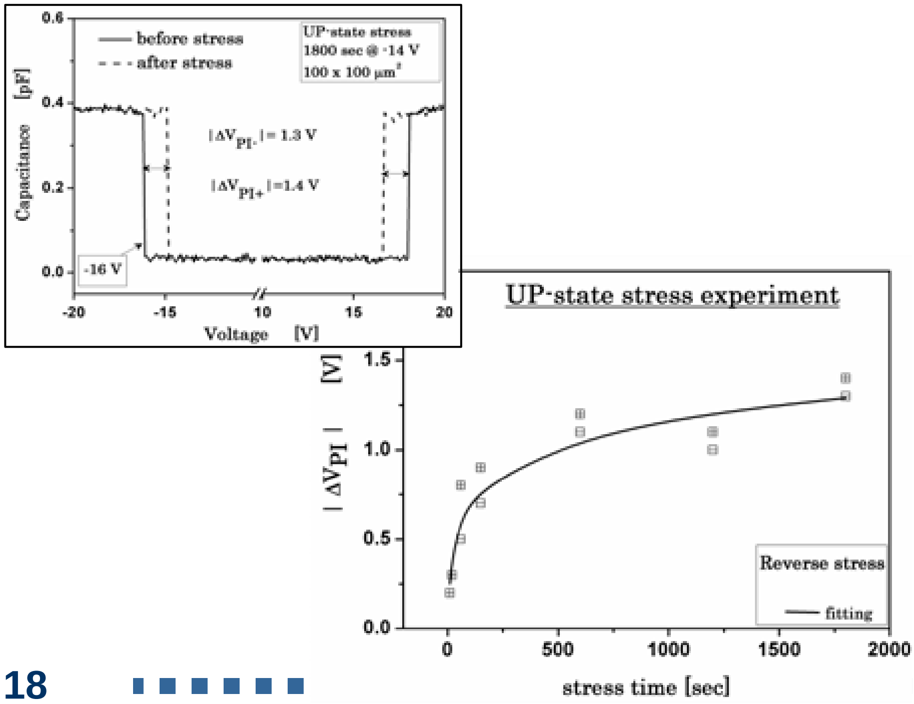


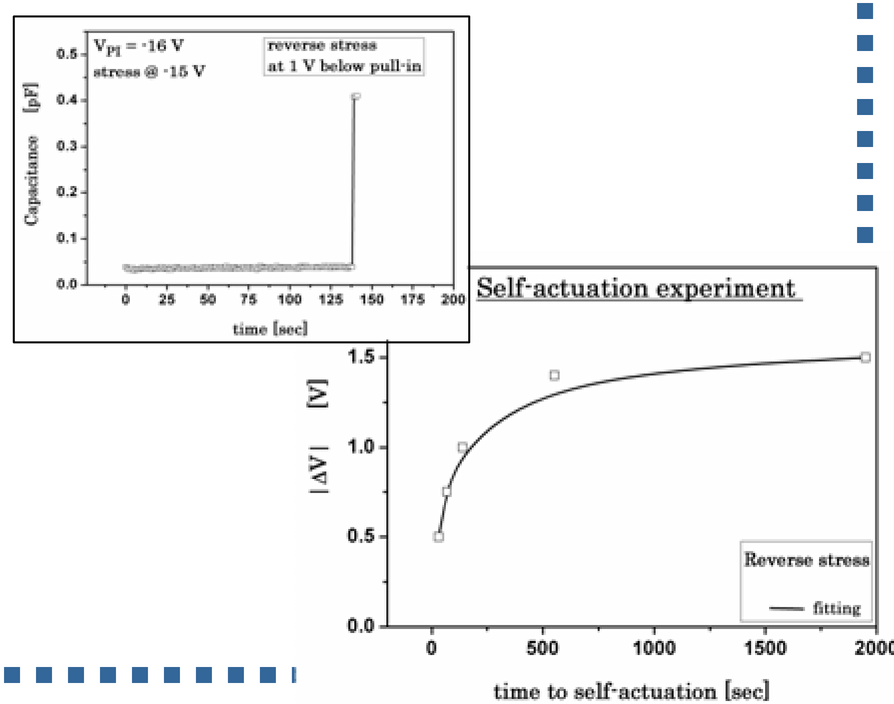




UP-state bias stress and Self-actuation experiments show that:

- dielectric charging due to non-contact bias stress in MEMS can occur
- non-contact bias stress condition can cause the "narrowing" effect





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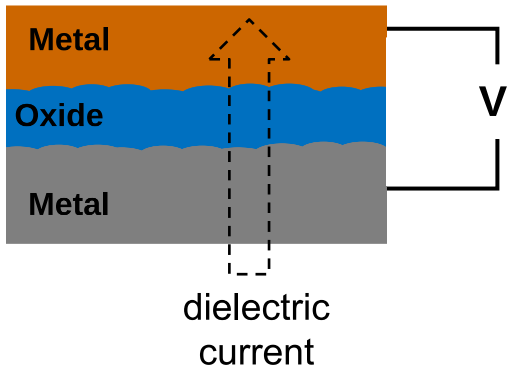
Experimental isolation of charging mechanisms

Contact charging mechanism



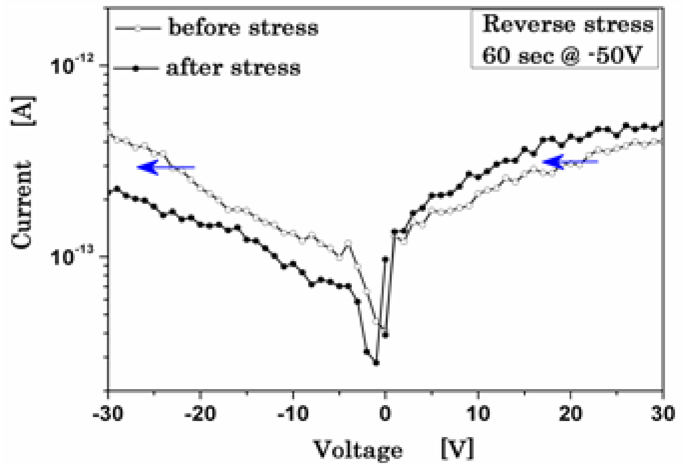
Metal-Insulator-Metal (MIM) capacitors

- No charging due to non-contact bias stress
- No mechanical issues during stress

Measurement procedure:

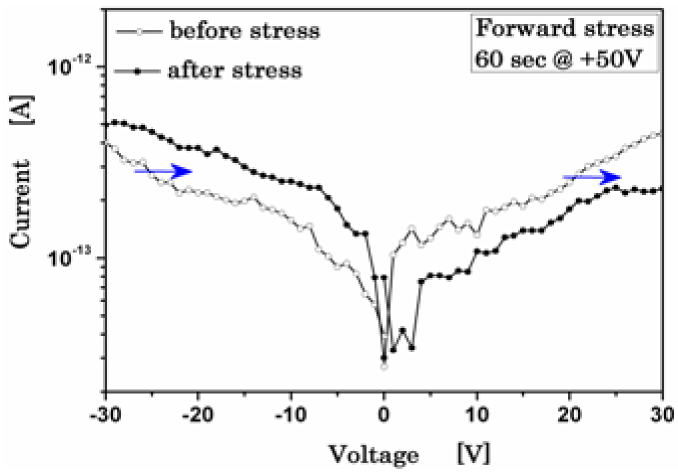
- I-V (forward and reverse) - measurement before stress
- Apply dc bias stress
- I-V (forward and reverse) - measurement after stress
- Analyze change due to charging

Reverse stress



MIM capacitor

Forward stress

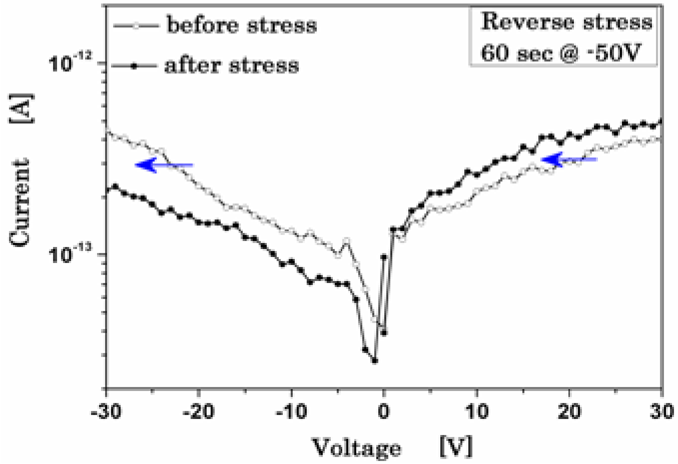


Experimental isolation of charging mechanisms

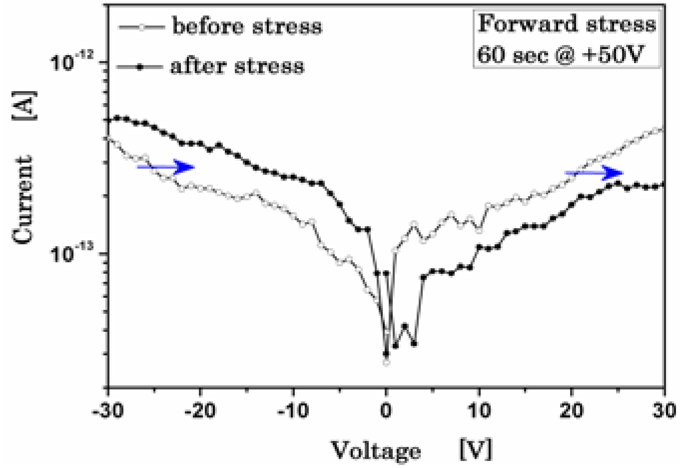
Contact charging mechanism

MIM capacitor

Reverse stress

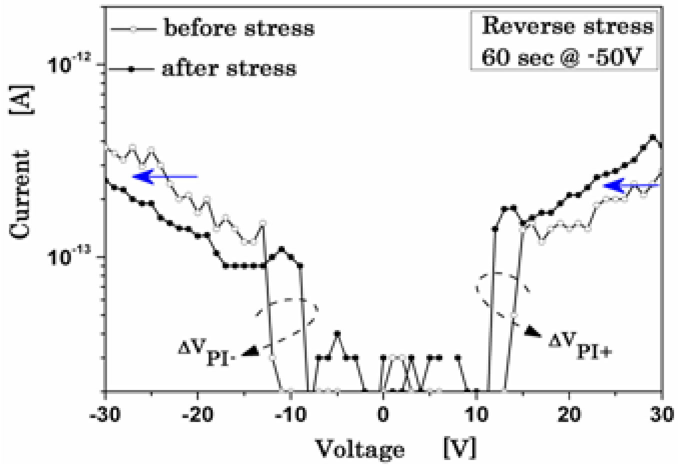


Forward stress

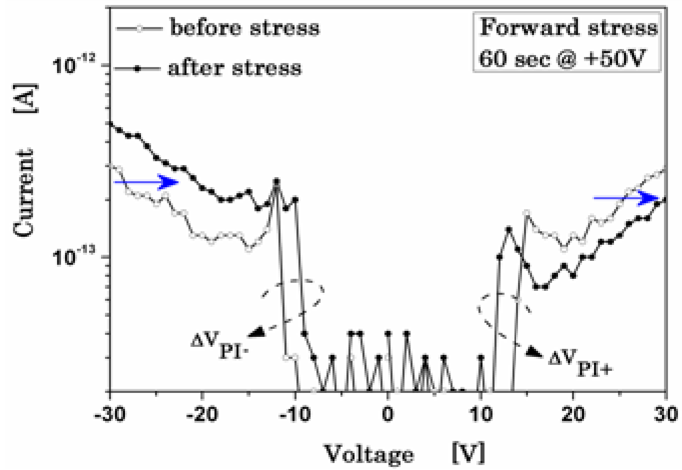


MEMS switch

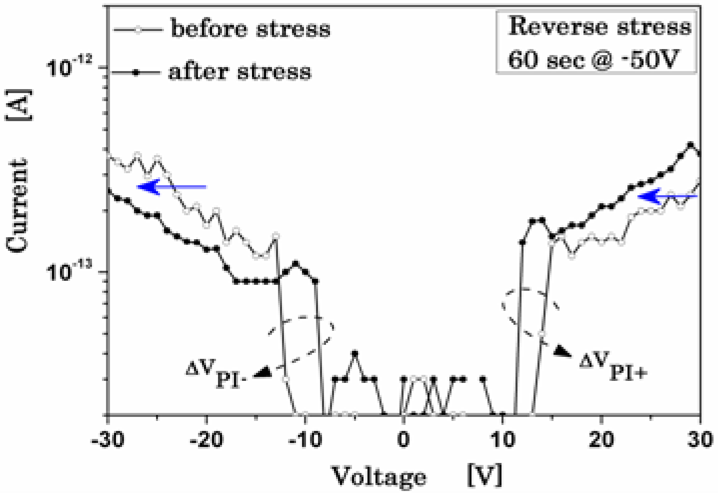
Reverse stress

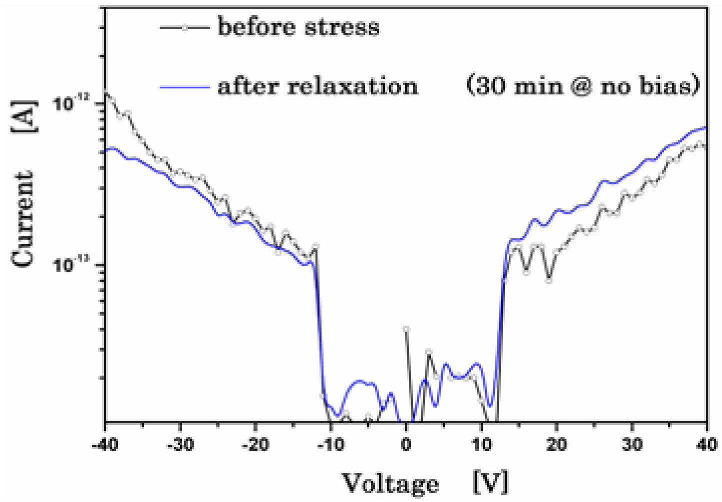


Forward stress



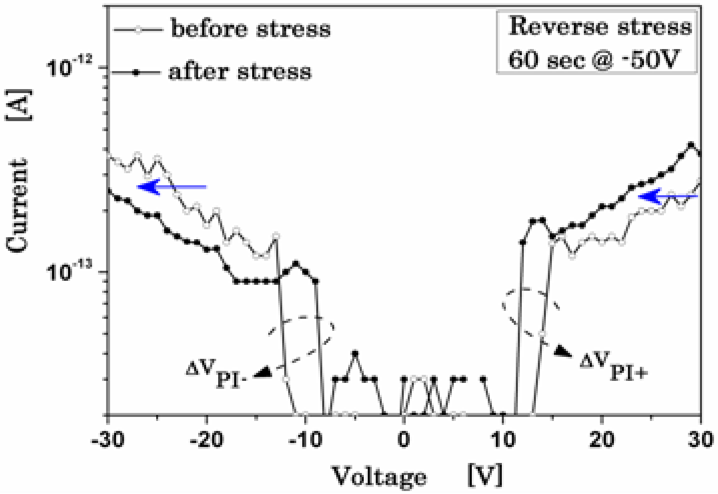
MEMS switch

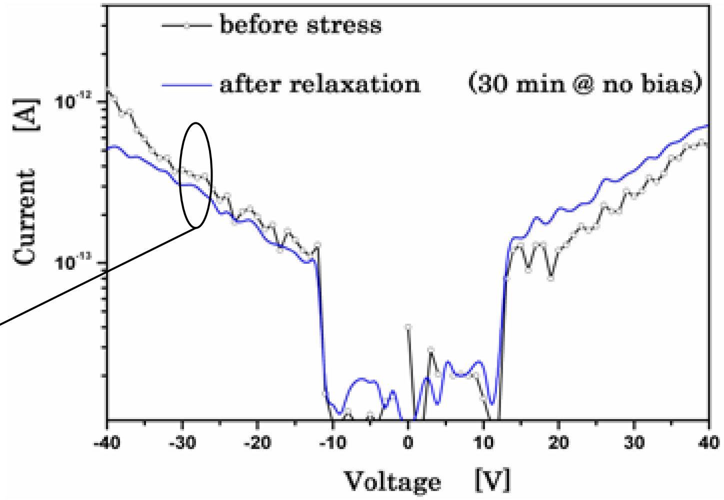

before stress
after stress
Reverse stress
60 sec @ -50V
Current [A]
Voltage [V]
ΔV PI-
ΔV PI+


before stress
after relaxation
(30 min @ no bias)
Current [A]
Voltage [V]

Contact and Non-contact charging mechanism

MEMS switch

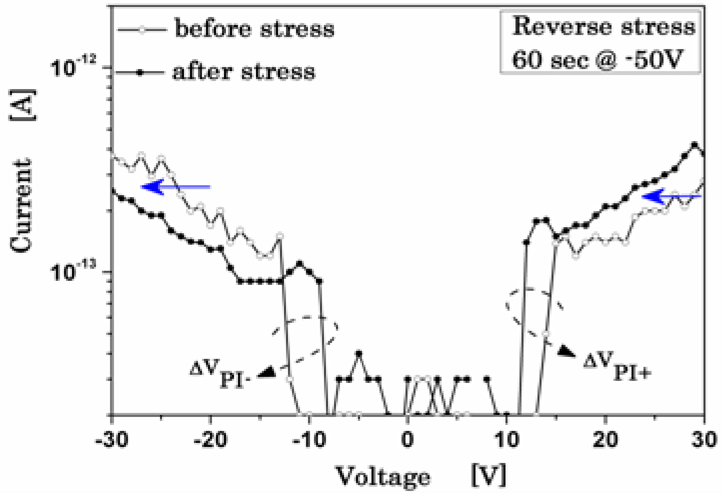


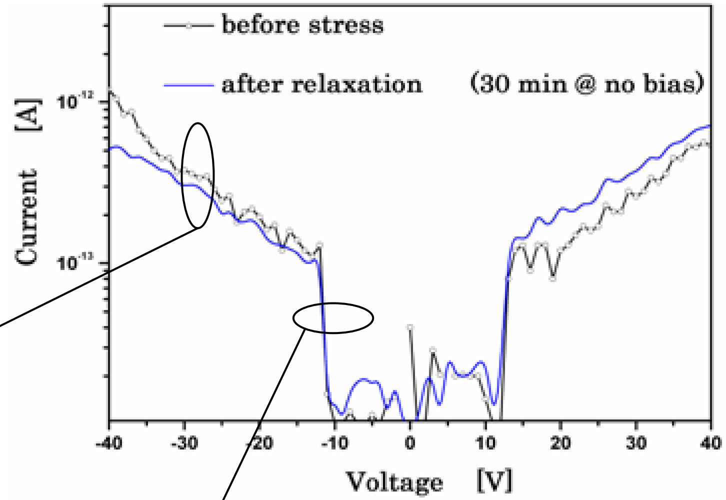


Charge due to contact bias stress does not decay from the dielectric over 30 minutes at no bias

Contact and Non-contact charging mechanism

MEMS switch





Charge due to contact bias stress does not decay from the dielectric over 30 minutes at no bias

Charge due to non-contact bias stress decays from the dielectric

Experimental isolation of charging mechanisms

Summary

- **New charging concept in capacitive MEMS has been described (roughness-based model):**

- Experimental evidences of charging due to non-contact bias stress (non-contact regions),

- Experimental evidences of charging due to contact bias stress (contact regions).

- **Current and Future work:**

- **Physical mechanisms responsible for charging,**

non-contact charging: charge accumulation at the dielectric-air interface due to Maxwell-Wagner mechanism (e.g. two dielectric system with different conductivities)

contact charging: charge trapping in the dielectric close to top and bottom interface with metal electrodes,

- **Effect of radiation on charging mechanisms.**