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SMARTIS

RF MEMS – Single Switch Element

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NOVA MEMS

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Outline

- Introduction
- Mathematical-Physical Model of the Electro-Mechanical Transducer
- Simulation Results
  - Switching Time
  - Contact Bouncing and free Oscillation
  - Re-feeded Bias Power and Cross-Actuation
  - Energy transferred to contacts
- **Fabrication**
  - **Development history**
  - **Process follow-up**
  - **Project Outlook**

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Advantages of RF MEMSwitches

- High isolation in the off-state
- Low insertion loss in the on-state
- Low power consumption
- High cut-off frequency
- High linearity (IP2)
- High intermodulation performance (IP3)

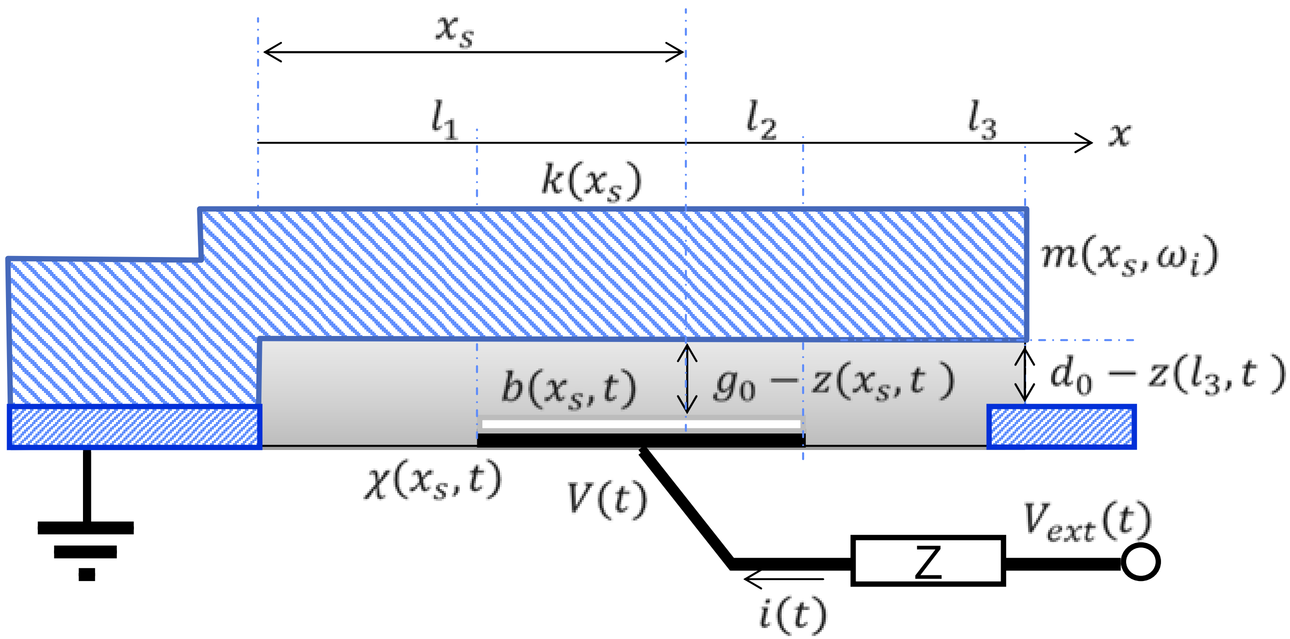
Challenges of RF MEMSwitches

- Short switching time
- Low actuation voltage
- Robust contact materials
- High power handling
- Robust packaging
- High reliability

Mathematical-Physical Model

Electro-mechanical Transducer

- Generalized arrangement of a capacitive coupled EMT
- Electrical Subsystem: Bias line circuitry
- Mechanical Subsystem: resonating cantilever incl. squeeze-film damping



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Electro-mechanical Transducer

- Description of mechanical Part including (non-harmonic parametric values) to reproduce bouncing, energy transferred to the contact.

$$m(x_s,\omega_1)\ddot{z}(x_s,t)+b(x_s,t)\dot{z}(x_s,t)+k(x_s)z(x_s,t)=F_{ext}(x_s,t)$$

$$z(x_s,t=0)=0 \qquad z(x_s,t=t_c^i)=z_c(x_s)$$

$$\dot{z}(x_s,t=0)=0 \qquad \dot{z}(x_s,t=t_c^i)=-\kappa\dot{z}(x_s,t=t_c^i)$$

- Description of electrical Part including the backward coupling by the capacitance and current respectively.

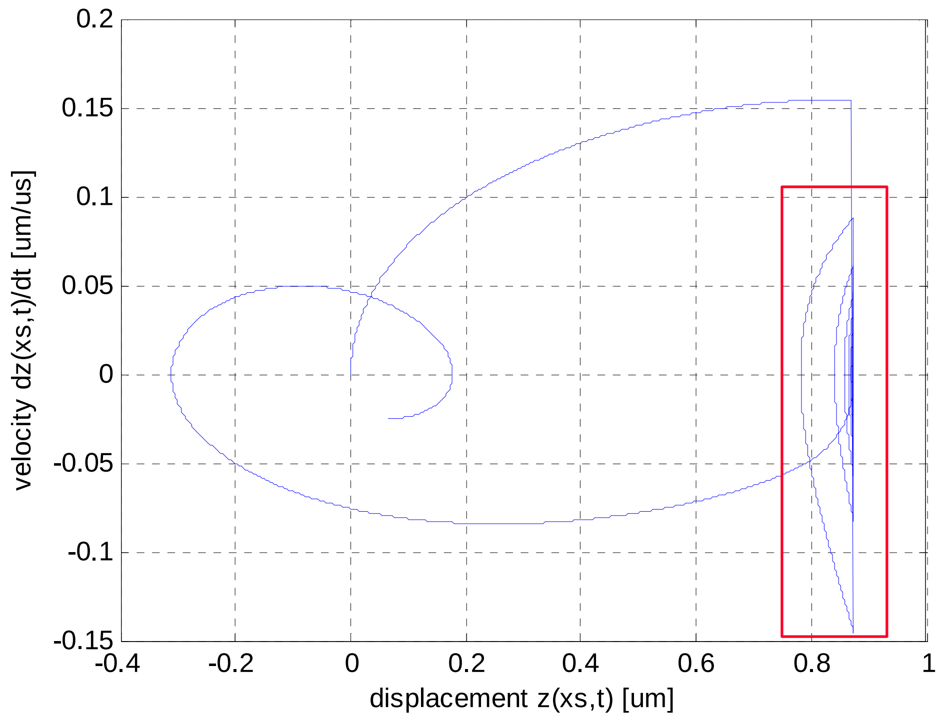
$$\ddot{V}(t)=\frac{1}{R_sC_sC(t)}\begin{bmatrix}C_s\dot{V}_{ext}(t)- \\ \left(\dot{C}(t)+R_sC_s\ddot{C}(t)\right)V(t)- \\ \left(C_s+C(t)+2R_sC_s\dot{C}(t)\right)\dot{V}(t)\end{bmatrix}$$

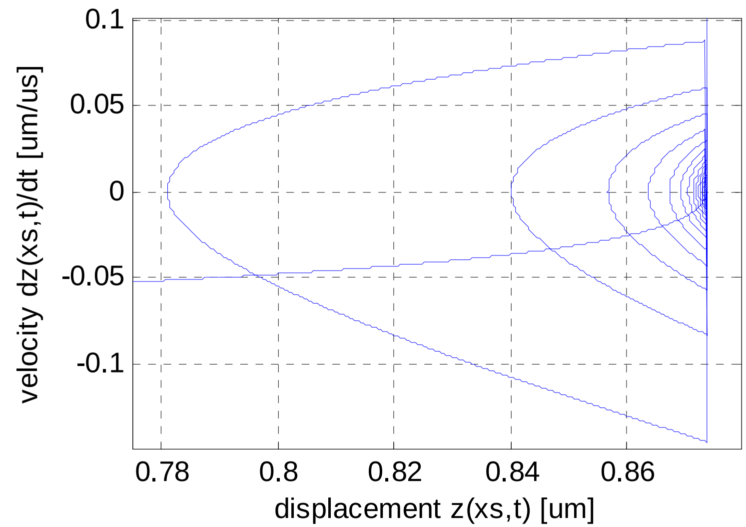
$$i(t)=\frac{dQ(t)}{dt}=\frac{d(VC)}{dt}=V\dot{C}+C\dot{V}$$

Simulation Results

Dynamics of the RF Switch

- Two resonant modes at different states: off-state / on-state
- State space trajectory of the of the cantilever tip





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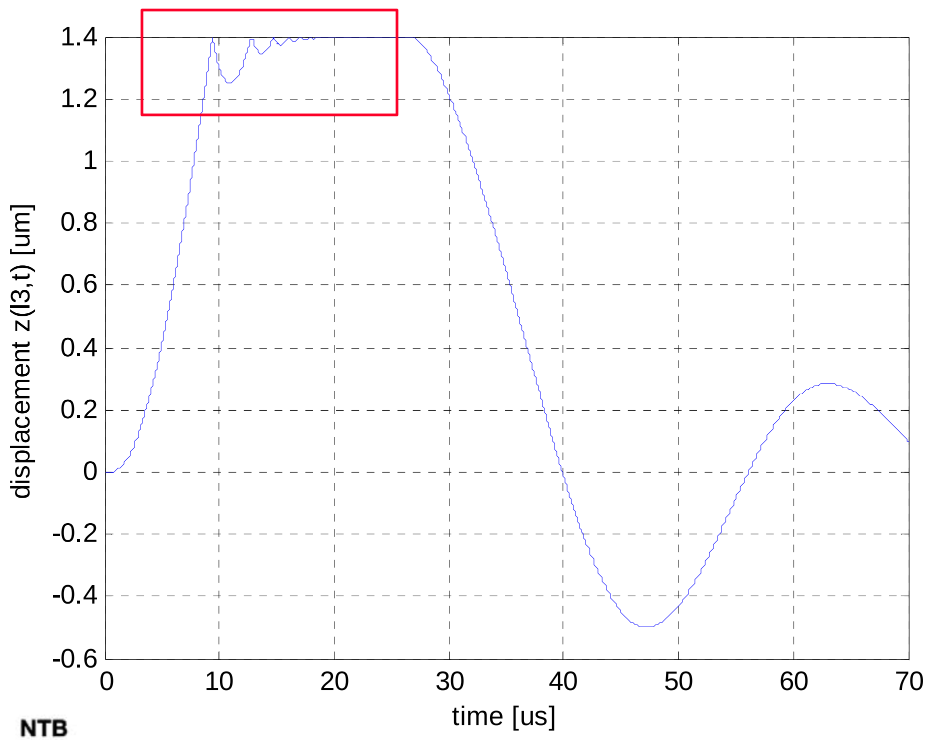
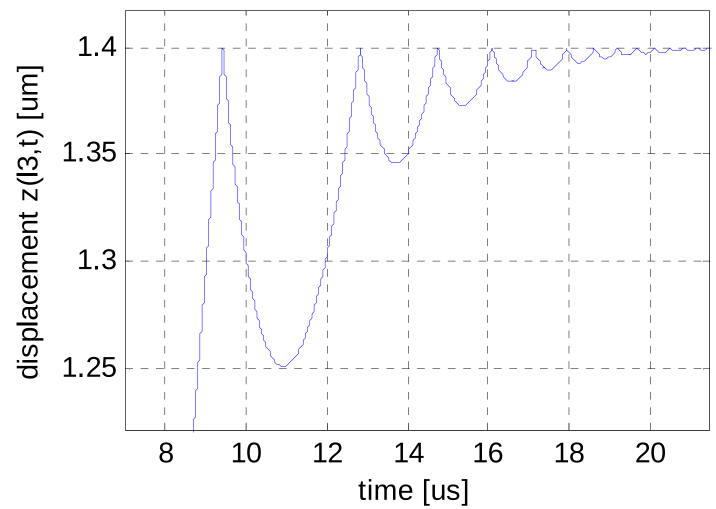
Switching Time and Contact Bouncing

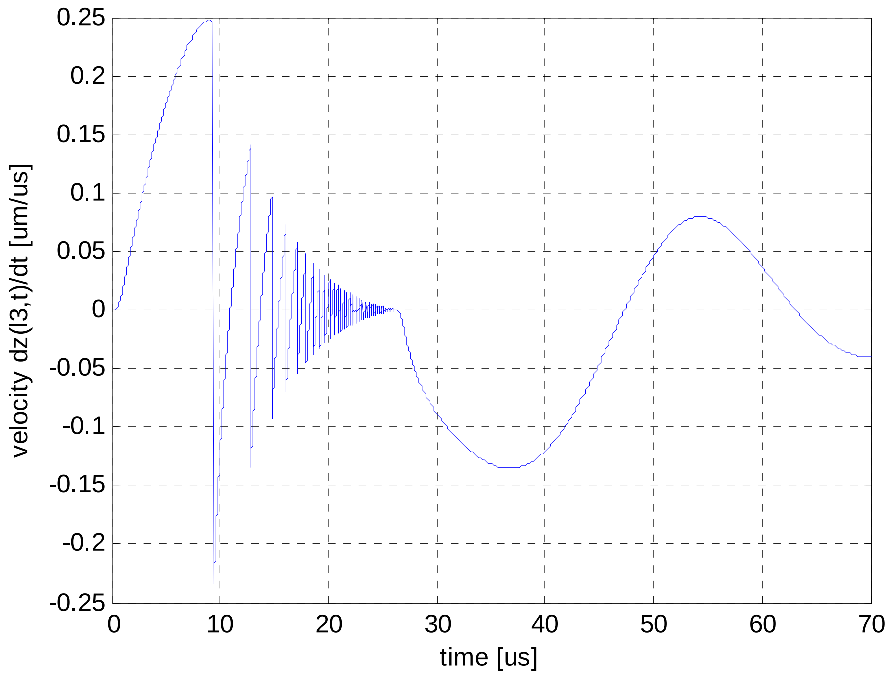
- The switching time of 9µs corresponds to a 50V actuation signal with 50V/1µs rising edge and a momentum absorption coefficient for the contact of 5%.
- The resonant mode in the off-state is strongly dependent of the squeeze-film damping

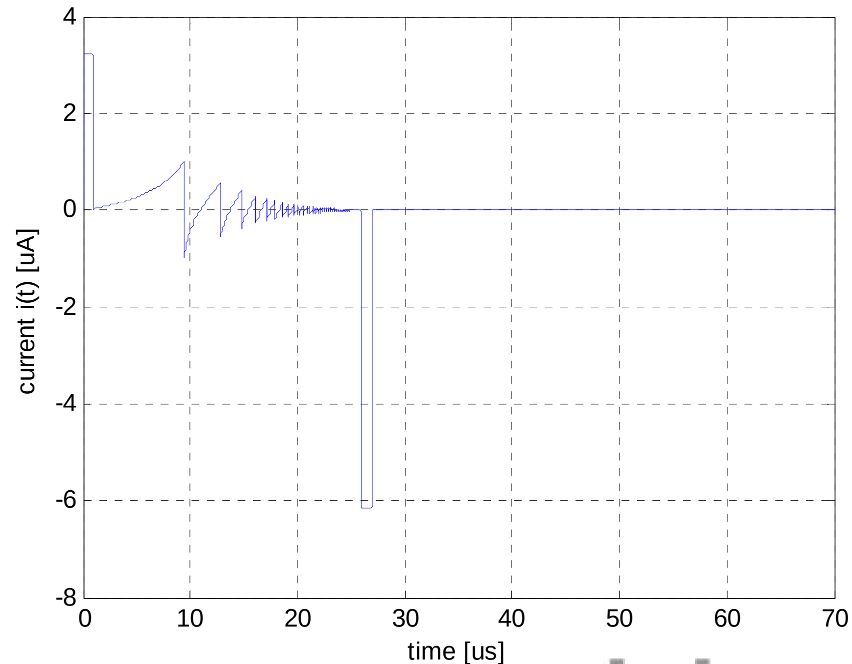




EM Coupling

- The decreasing velocity in the on-state is caused by the non-linear squeeze-film damping
- The oscillating current is coupled from the resonating cantilever at a given voltage.





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Contact Conditions

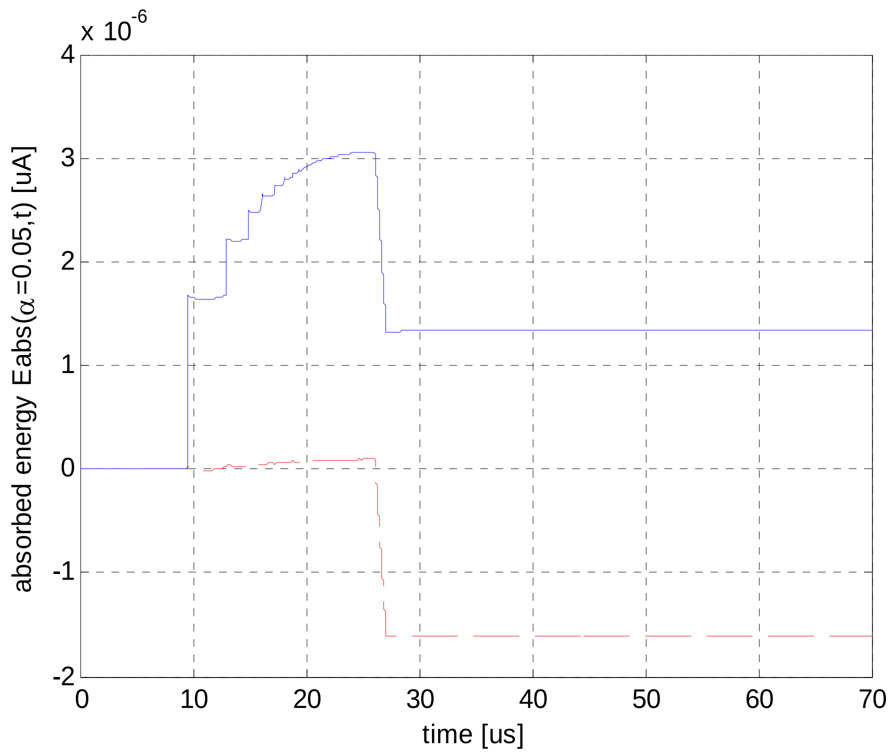
- The energy balance is solved for E_{abs} assuming a momentum absorption coefficient of α=5%

$$E_{ext} = E_{kin} + E_{pot} + E_{damp} + E_{abs} + E_{cap} + E_{Rs} + E_{Cs}$$

- Transferred energy calculated via energy balance (blue line) blanked by the absolute error at α=0% (red line).

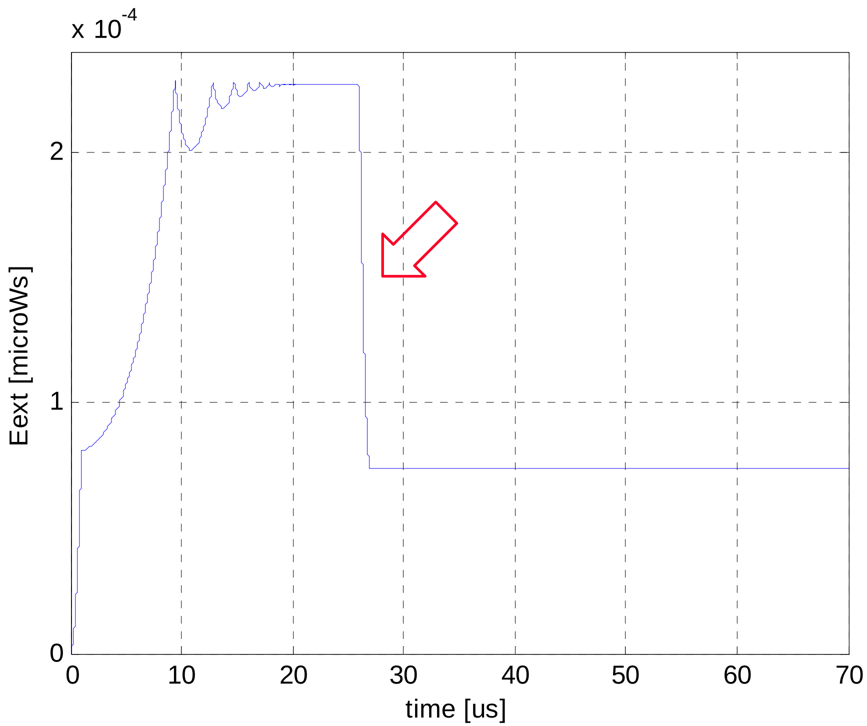
$$E_{abs} = \int \alpha \frac{dp(t)}{dt} v dt$$

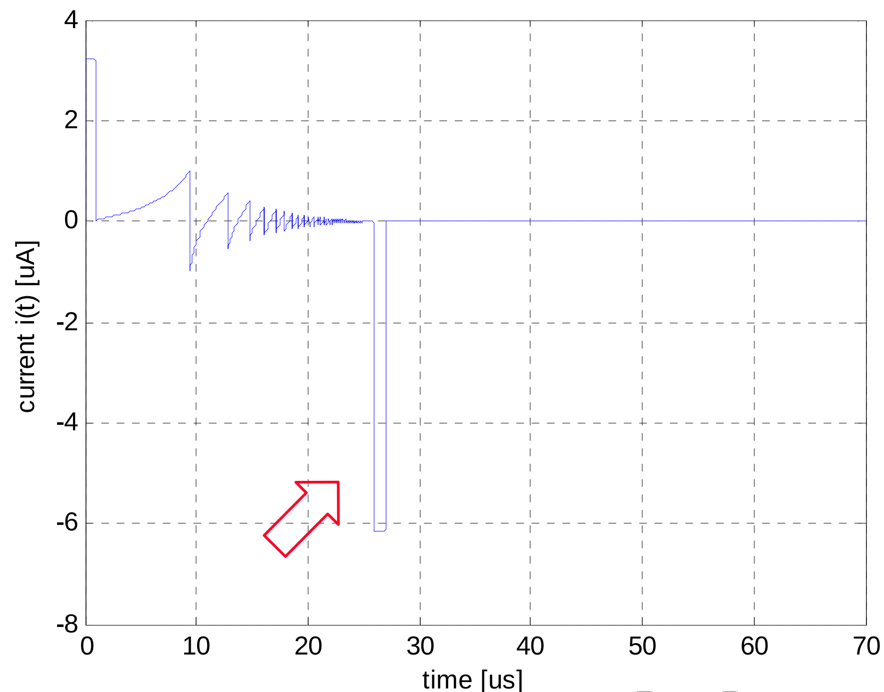
- The energy transferred at the first bounce is 1.6µWµs



Re-feeded Power

- A comparable high energy is stored in the deflected cantilever, which is released within very short time, as soon the voltage is switched off (trailing edge -50V/1μs).

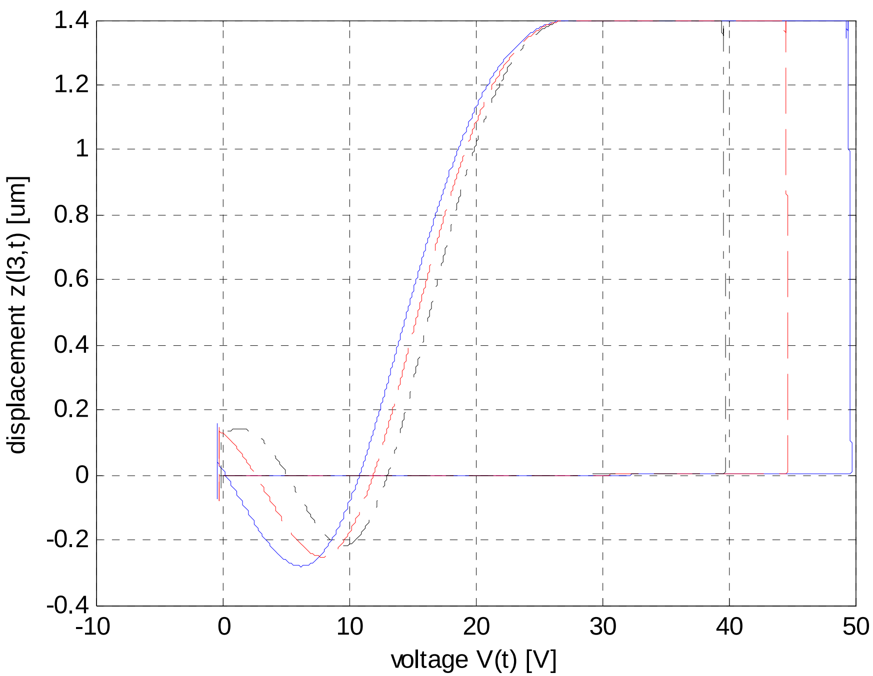


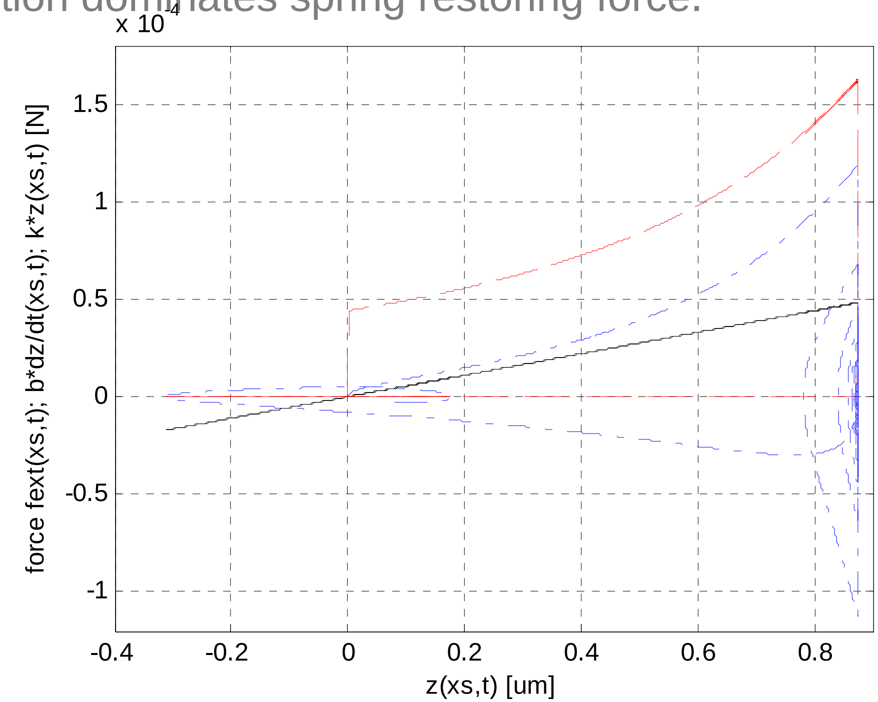


Simulation Results

♦ Pull-In / Release Voltage

- The pull-in Voltage lies is expected to be within 35-40V
- The more system specific response, the release voltage is around 27V.
- Forces aren‘t in equilibrium, damping action dominates spring restoring force.





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♦ Development History

- Initiating Industrial Partner: Thales Alenia Space (TAS) (2005)
- Development of first switches at the NTB (2005-2006)
- European Eurimus (EM95) Project SMARTIS (2007-2010)
  - Project partners: TAS, Xlim, CNES, Novamems, Armines
- CTI Project to focus on Packaging Technology (2010-2013)

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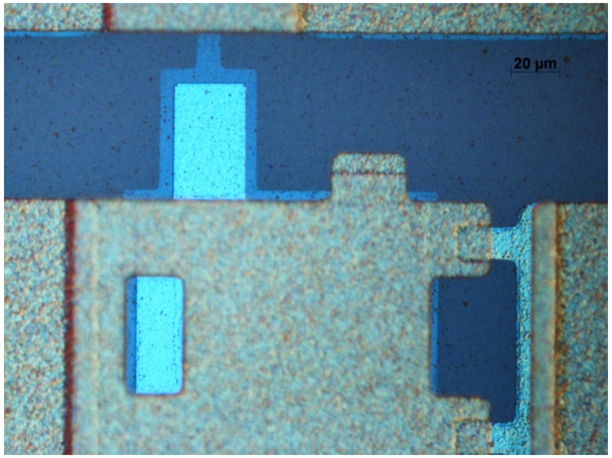
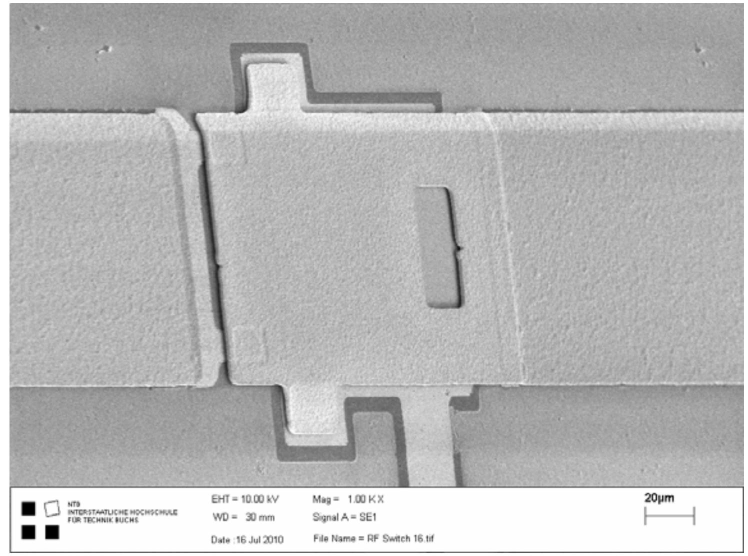
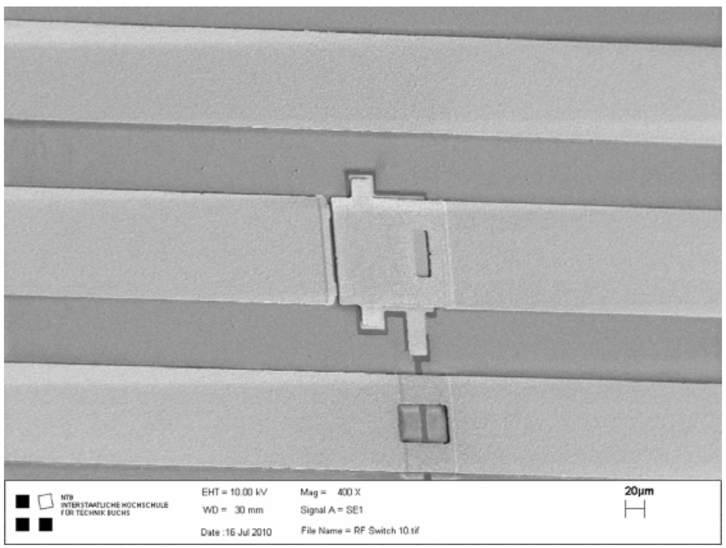
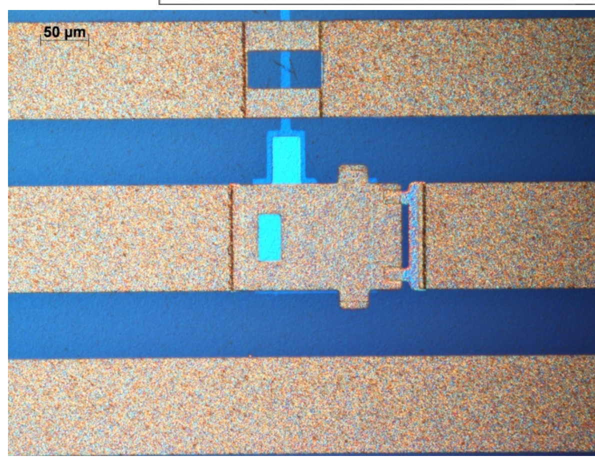
Actual Status – Single Switch Element









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