Highly reliable and low voltage actuated Ohmic RF MEMS switch with waver level packaging

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- RF MEMS technology
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General failure risks of MEMS Switches

Sticking	Large areas of electrodes or switch capacitance come into intimate physical contact (low roughness) and there is **too low force to separate the contacts**. Welting of α-spot, A-fritting.
Charging	**Dielectric materials in between electrodes accumulate surface charges** or charges are trapped in the material from fabrication (e.g. anodic bonding) or from operation.
Contact wear	Contacts physically destroyed/ deformed because of plastic deformation of **too weak or too thin contact material, inclusions of dielectric residuals into the metal after mechanically breaking the insulating flayers**.
Contamination	**Organic residuals** from fabrication/ packaging, water, oxide or hydrocarbons crack products on contact surface lead to high contact resistance when the contact force is not sufficiently high.
Hermeticity	Un-sufficient hermeticity leads to **increased switch time** (gas damping) and to risk of **contact contamination.**
Overload	Break trough of open contact leads to physical damage of the comparably extreme small sized contact tips. Current overload results in **melting** of contact material, **welding** and generation of alloy (e.g. AuSi) witch **high specific resistance**.
ESD	Driving electrodes and contact may be damaged by **electrostatic discharge** during fabrication (anodic bonding) or while handling.

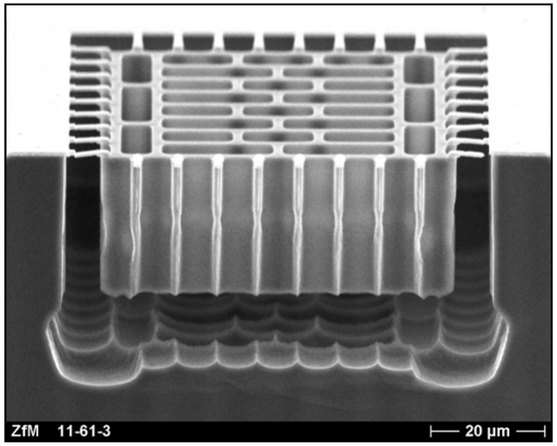
Goals of this Work:

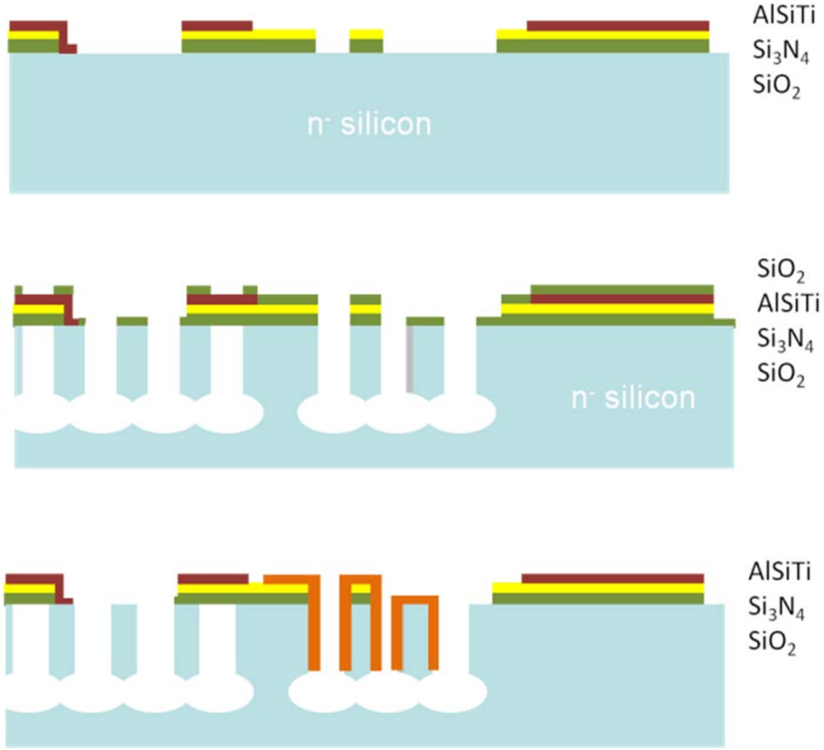
The target is potentially **high reliability of switch devices by novel technology and suitable design**.

1. No dielectric material between movable and fixed structures, **no charging.**
2. Wafer level vacuum encapsulation, and contact material deposition in on of the last fabrication steps, **lowest possible contamination.**
3. High force when closing and when closed, achieve **stable and low contact resistance**.
4. High force for separation, **prevent sticking.**

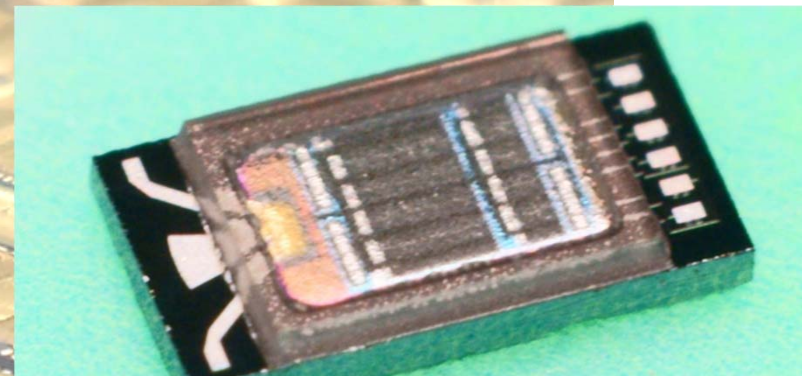
MEMS Technology for RF Applications

- **A**ir gap **I**nsulated **M**icromachining (AIM) Process
- Highly resistive Si-wafers, no SOI-wafer necessary
- 50 µm deep movable structure, large electrode area
- Contact metal sputtering in contact area trough shadow mask

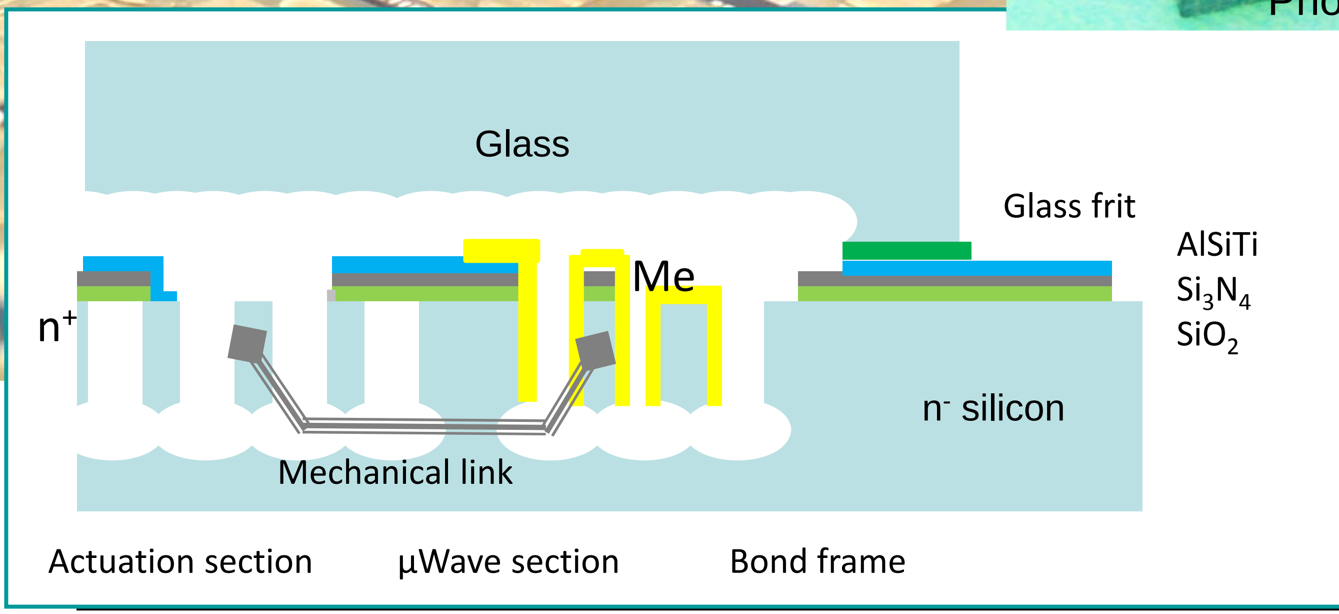




Cost-efficient packaging (0 level) by wafer bonding in vacuum or in inert gas



Photograph of a single chip



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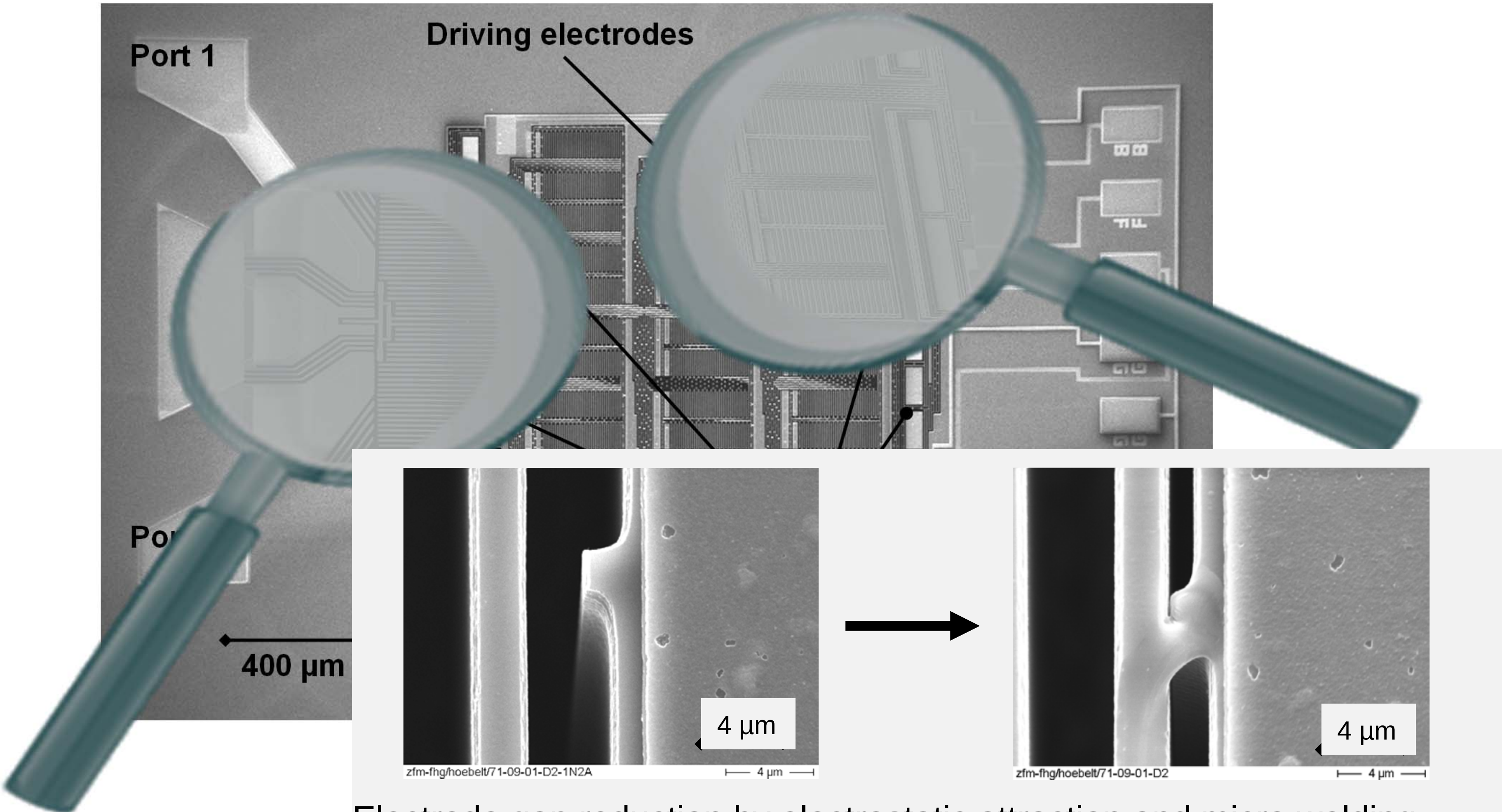
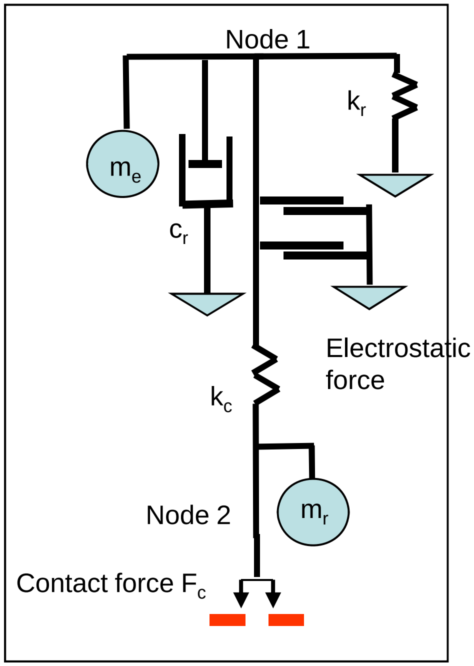
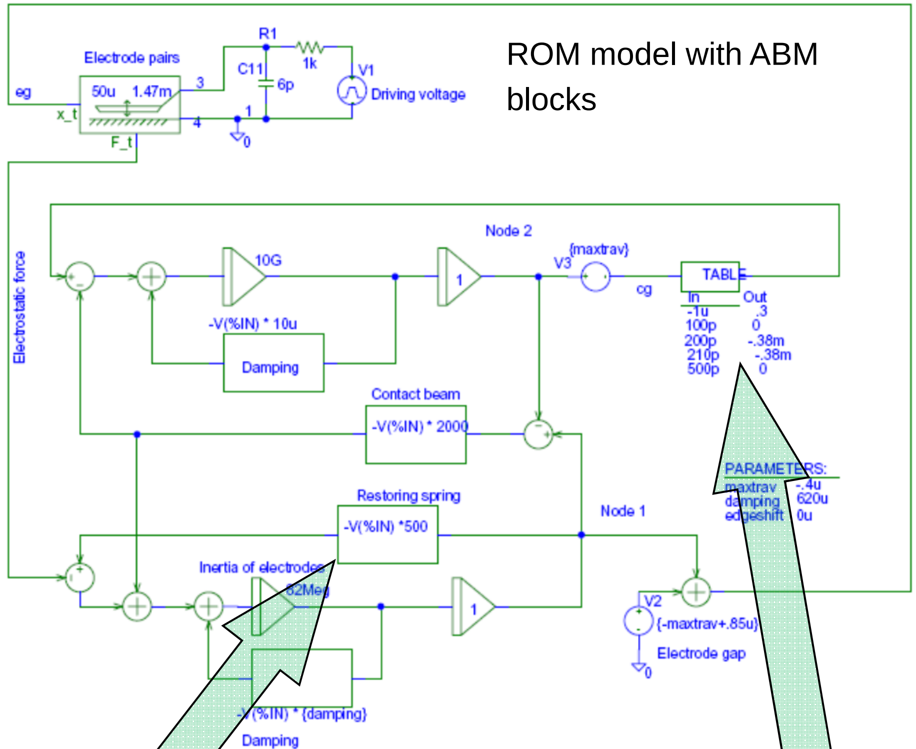
Chip layout and special features

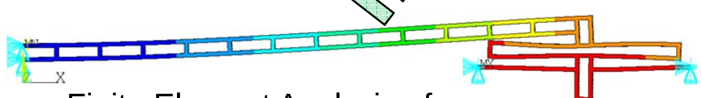


Electrode gap reduction by electrostatic attraction and micro welding

MEMS Model

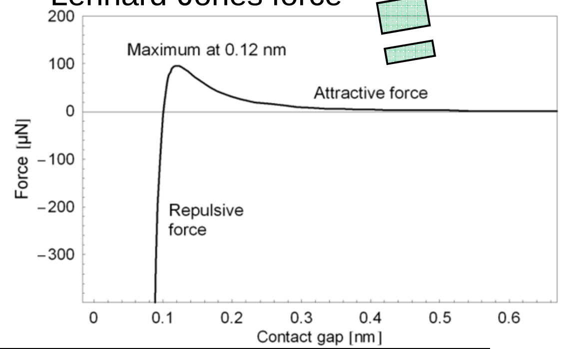






Finite Element Analysis of restoring spring

Lennard-Jones force



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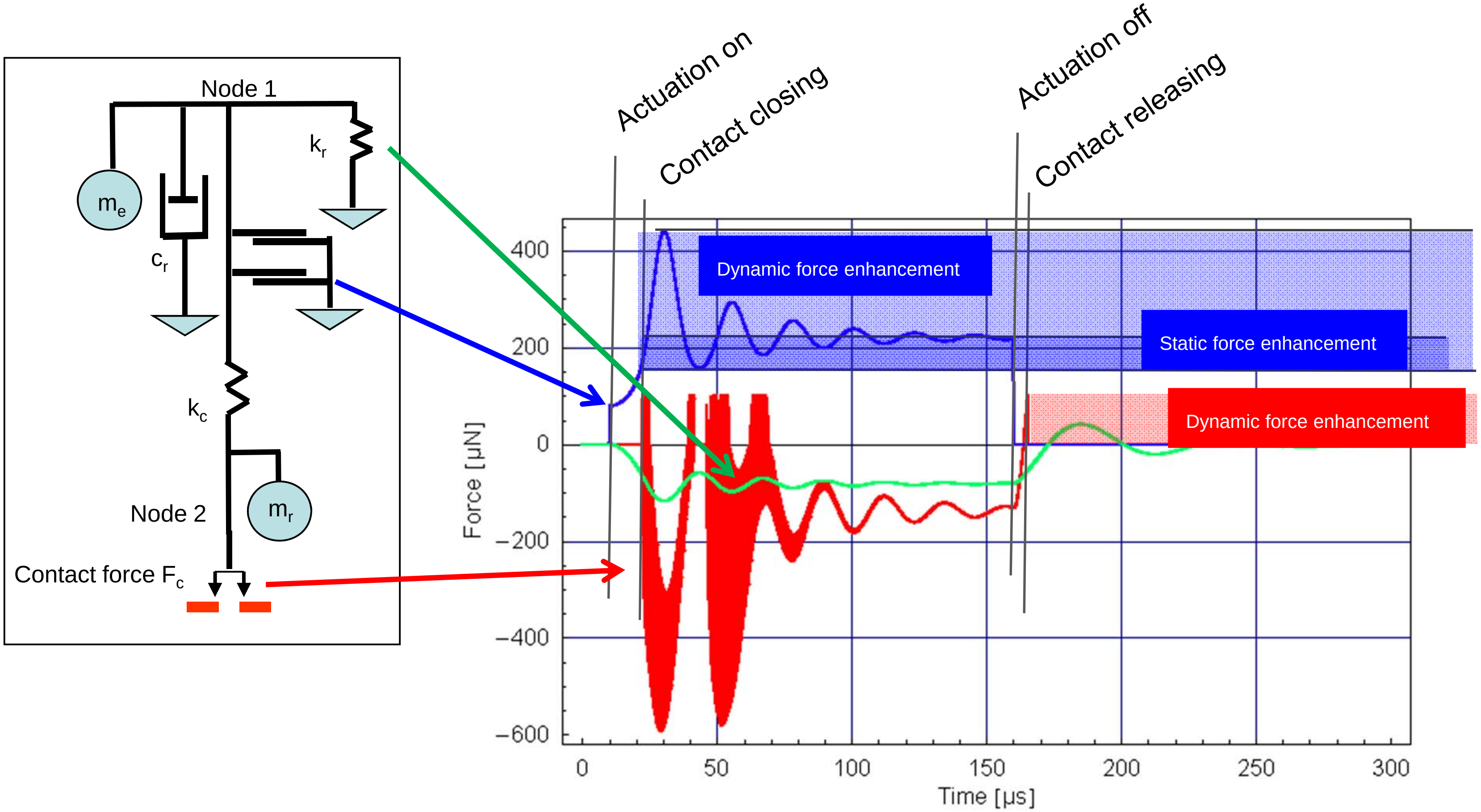
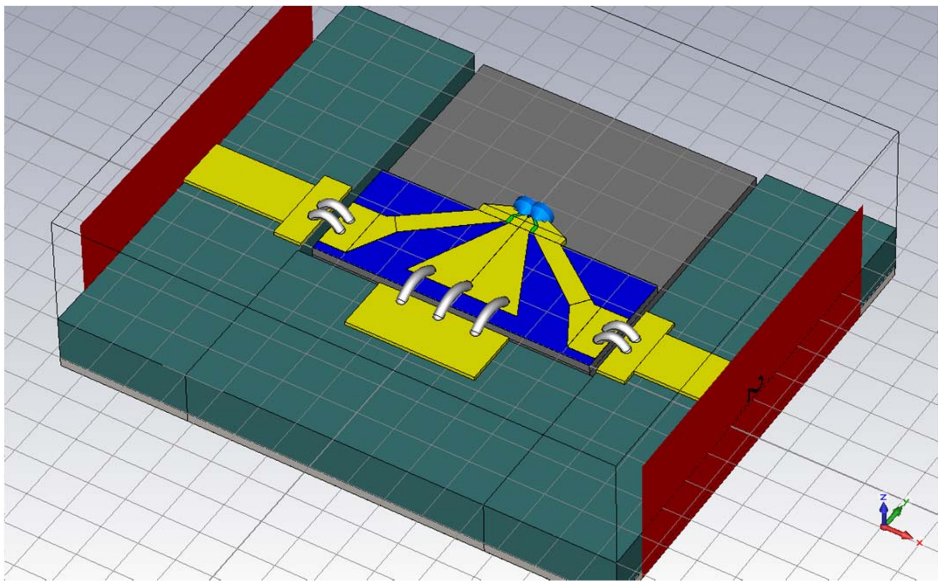
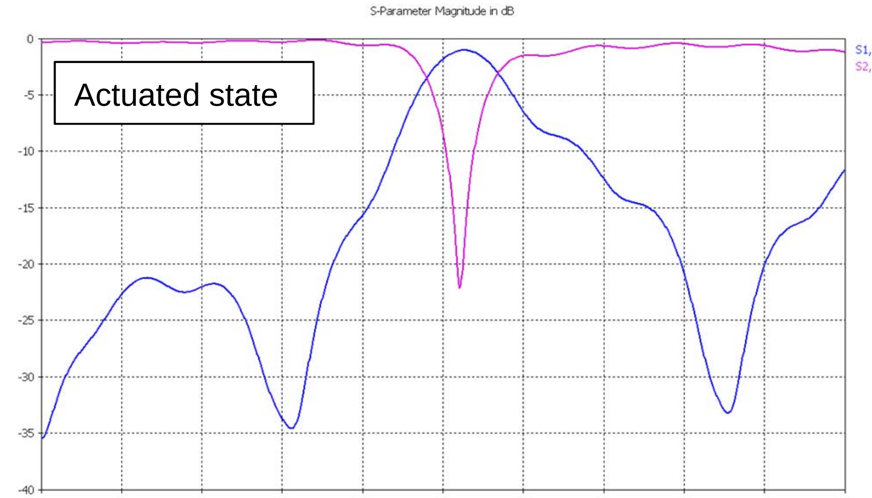
Simulation of Force and Motion

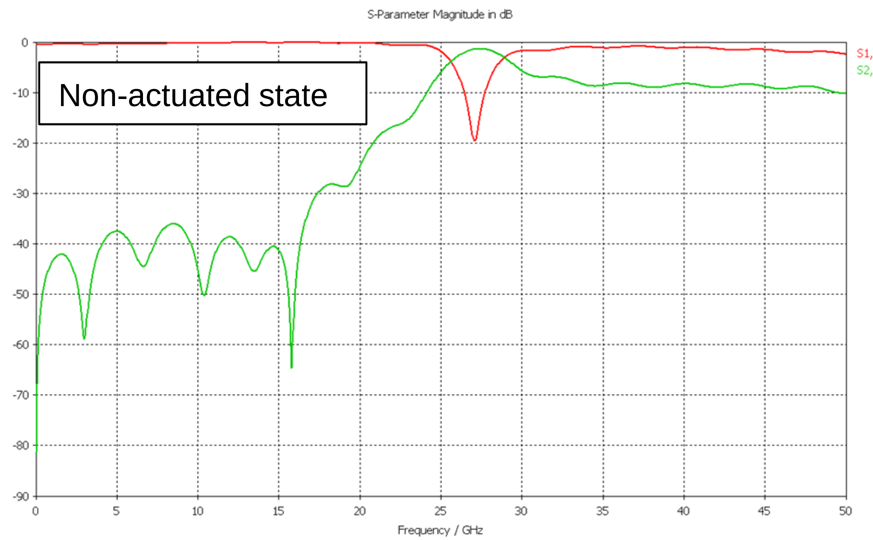


Analysis and optimization by FDTD

Including PCB (Rogers 3006) and bond wires







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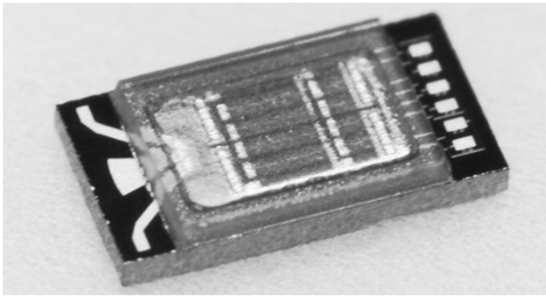
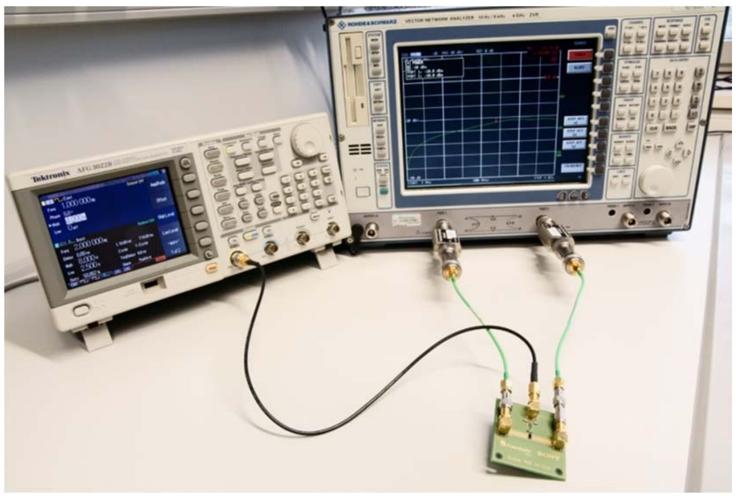
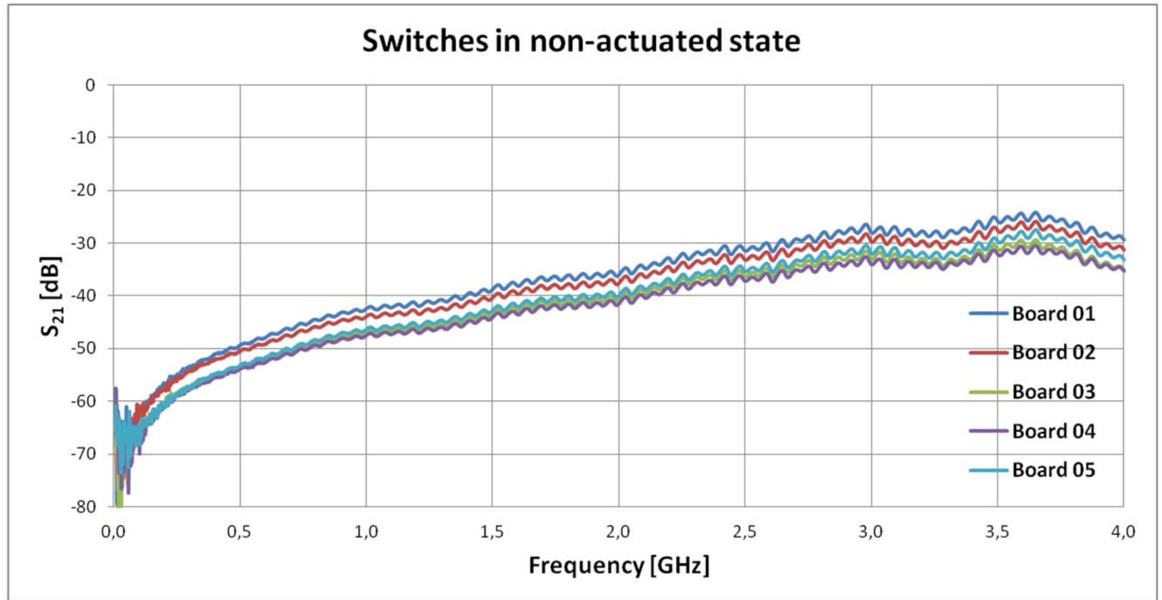
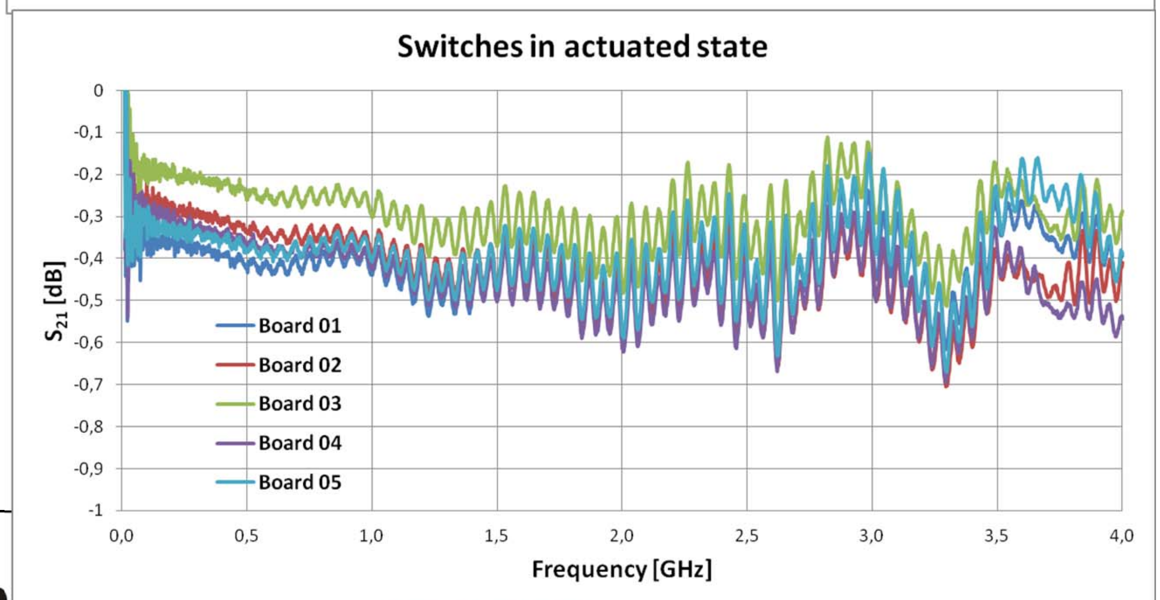
Measurements

4 GHz type





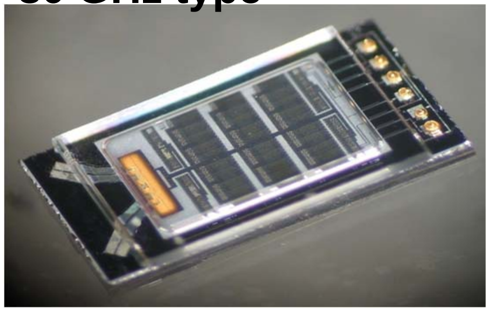


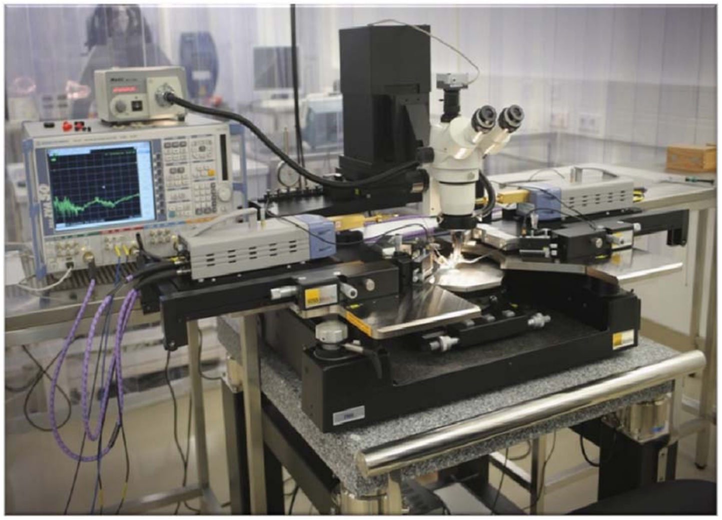


Isolation: -30 dB @ 3 GHz
Max. insertion loss: 0.5 dB
including bond wires

Measurements

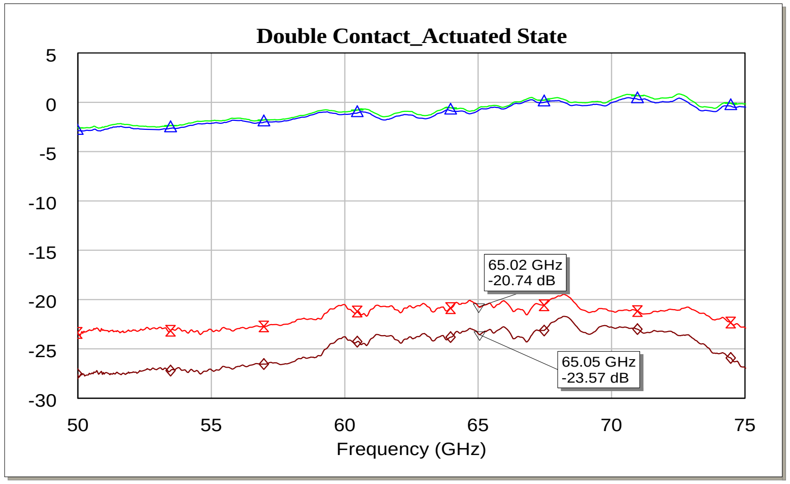
80 GHz type

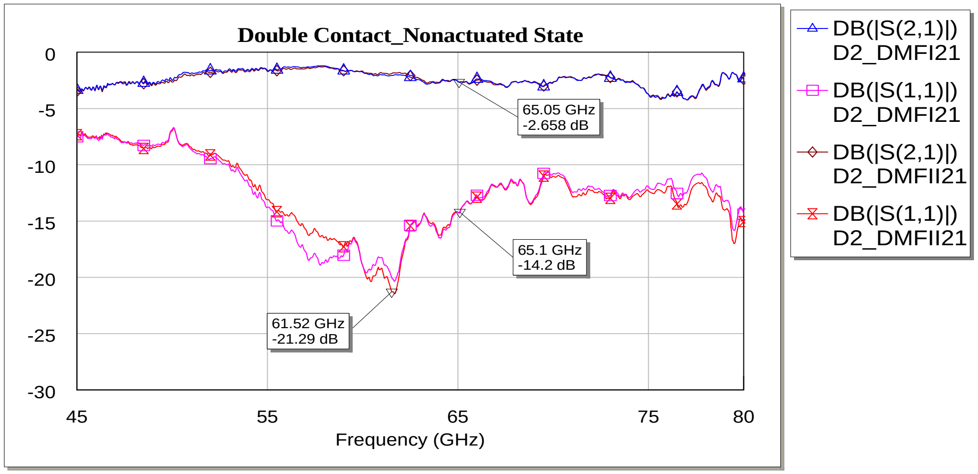




Isolation: -20 dB @ 60 GHz
Max. insertion loss: 2 dB @ 60 GHz

Isolation and reflected power





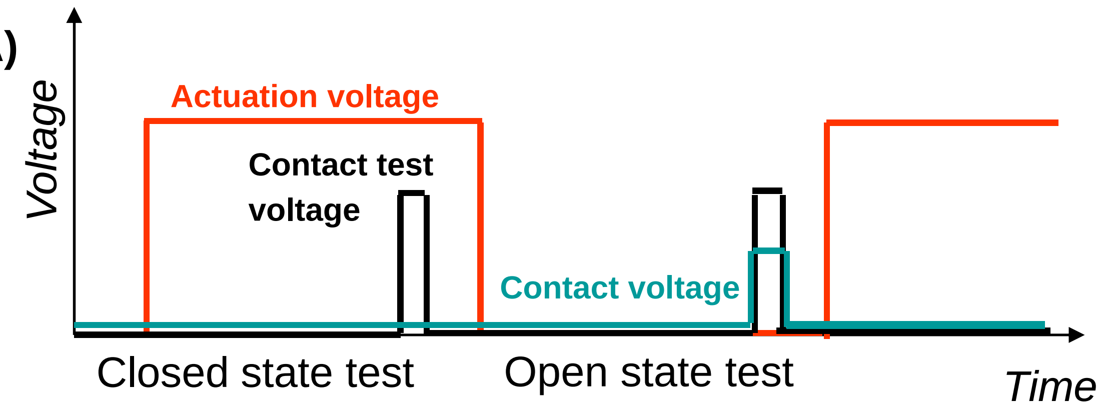
Test sequences for life time test

Cycling test phase (phase A)

with monopolar voltage

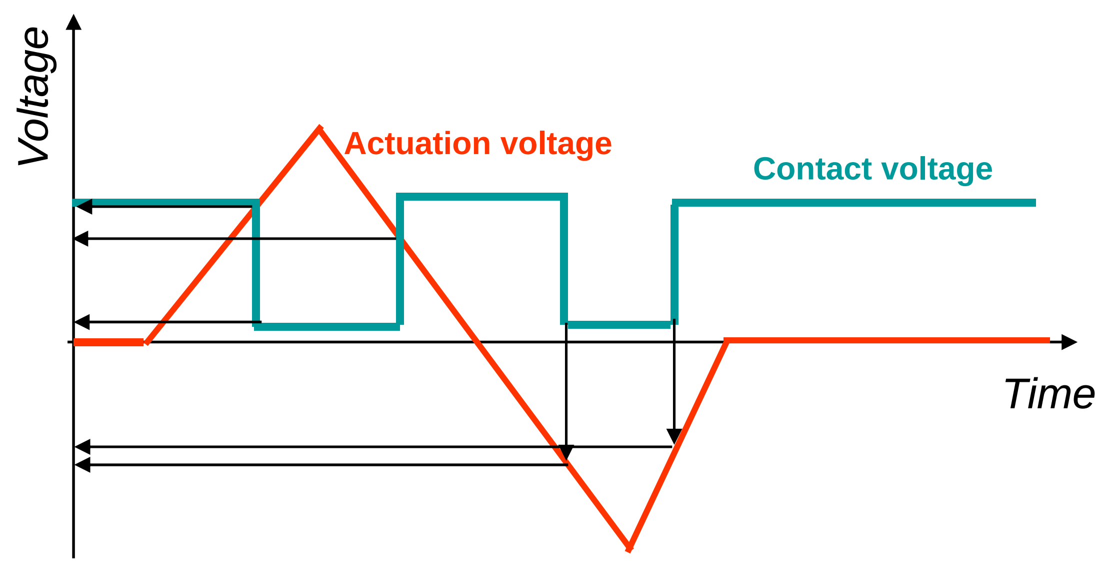
Cold switching test

Yes / No decision!



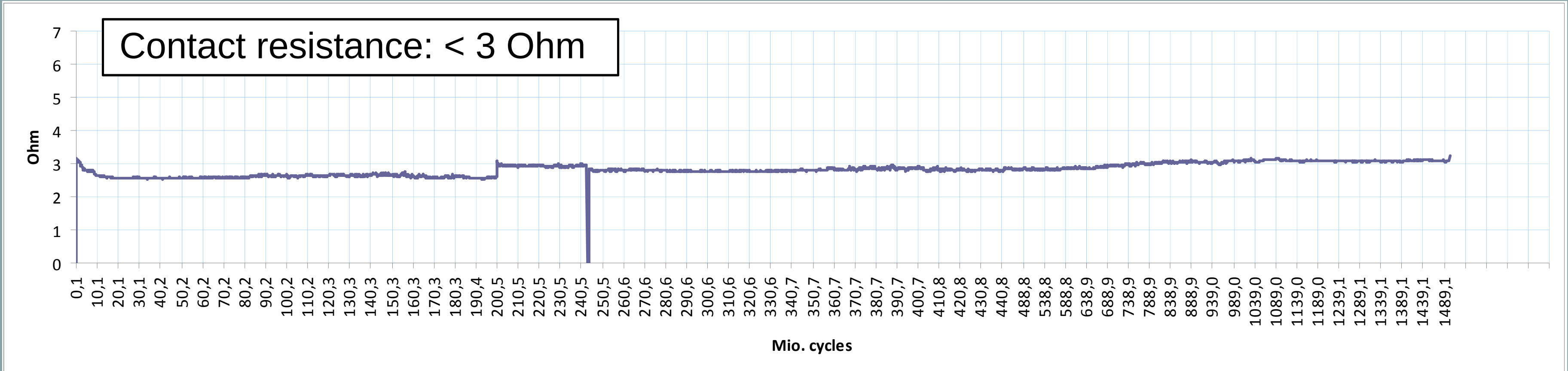
Measurement phase (phase B)

- Minimum pos. and neg. actuation voltages
- Pos. and neg. release voltages
- Contact resistance in on state



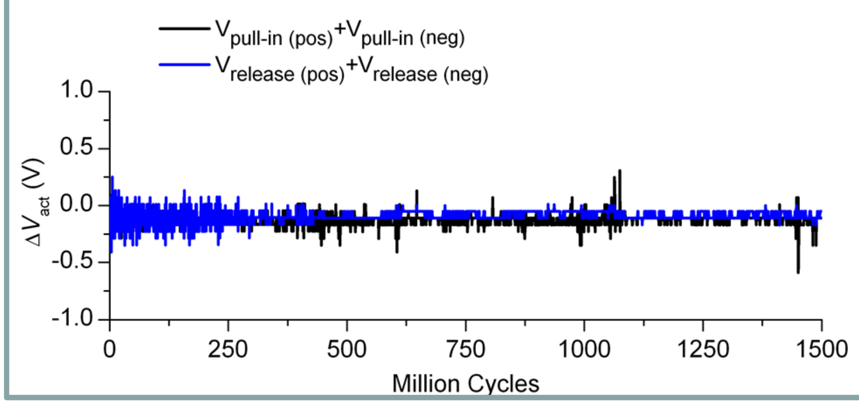
Test phases are consecutively run till manually finishing the test e.g. after 1 Billion cycles.

Life time test results

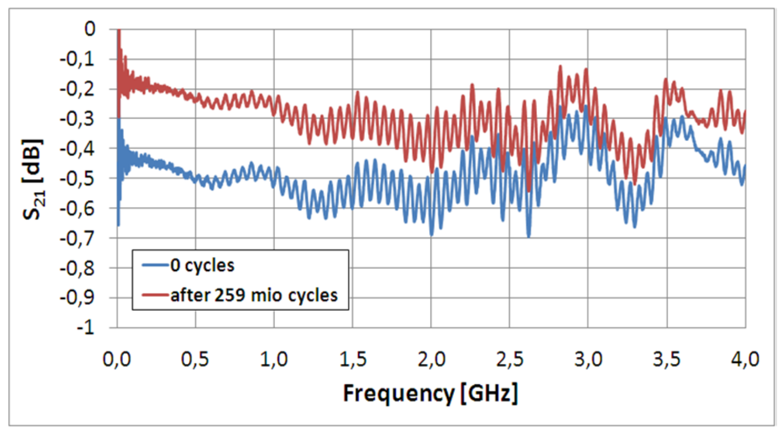


Stable resistance of series switch during life time test

Negligible difference between positive and negative pull in voltage and release voltage: **no charging**



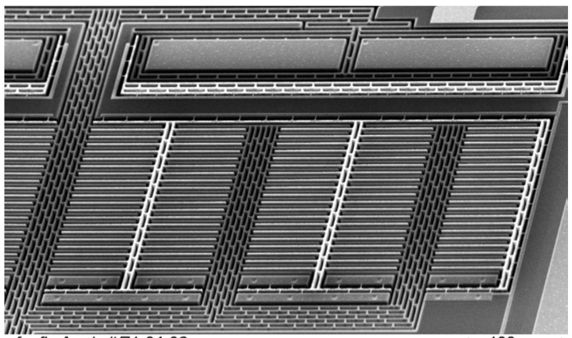
Insertion loss before and after cycling test



Summary, Future Directions

Reliable and proven MEMS technology

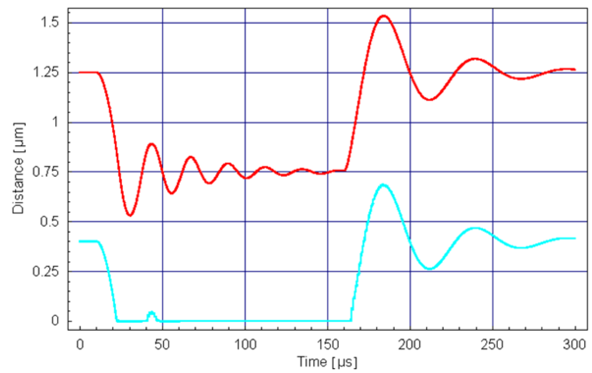
- Large electrode area, high force even at low voltage (>100 µN contact force with <5V and < 30 nA)
- No dielectric material between electrodes
- Wafer level hermetic vacuum package



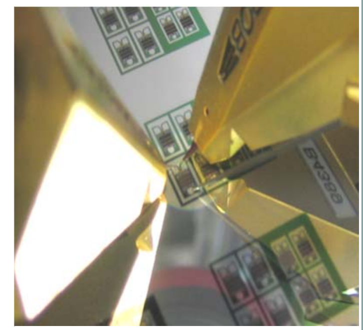
SEM-view of actuation electrodes and mechanics

Design and test

- Mechanical design and simulation
- Optimization of force and switch time
- Analysis of µwave / mm-wave performance
- Reliability test (cold switching)



Result MEMS simulation



S-parameter test of RF MEMS

Future directions

- Improvement of isolation and insertion loss by modified mm-wave line concepts
- Improvement towards maximum power handling capability of 30 dBm
- Non-linearity: IP3 >>60 dBm

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