A Novel Robust RF-MEMS Varactor Design with Extended Tuning Range

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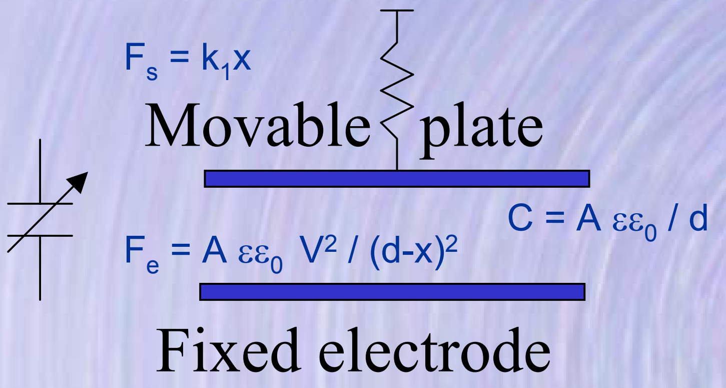
WHAT'S NEXT. AND NEXT. AND NEXT.

Presentation contents

- Varactor concept
- Requirements
- Design overview
- Simulations
- Preliminary experimental results
- Conclusions

General varactor concept

- Varactors can be built in MEMS technology as:
  - A capacitor where the gap distance is controlled by the motion of one of the parallel plates
  - Electrostatic actuation will be considered, as it does not require any static current consumption



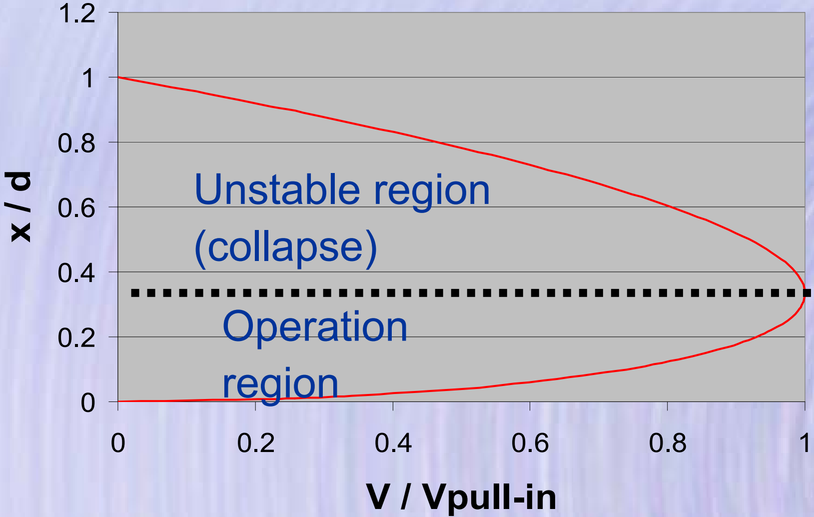
F_s – restitution force
k_1 – linear spring coefficient
x – displacement
A – capacitor area
V – Voltage across the capacitor
d – airgap distance

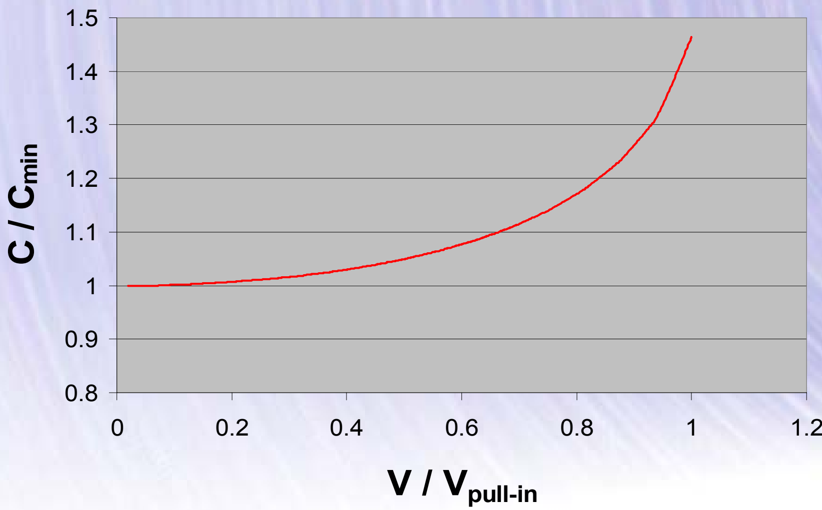
Plate collapse (pull-in)

- In linear electro-mechanical systems, equilibrium can only be reached for values

  x < d/3, the plate collapses after this value has been reached

- This limitation restricts the controllable capacitance change
  - Maximum ratio is < 1.5



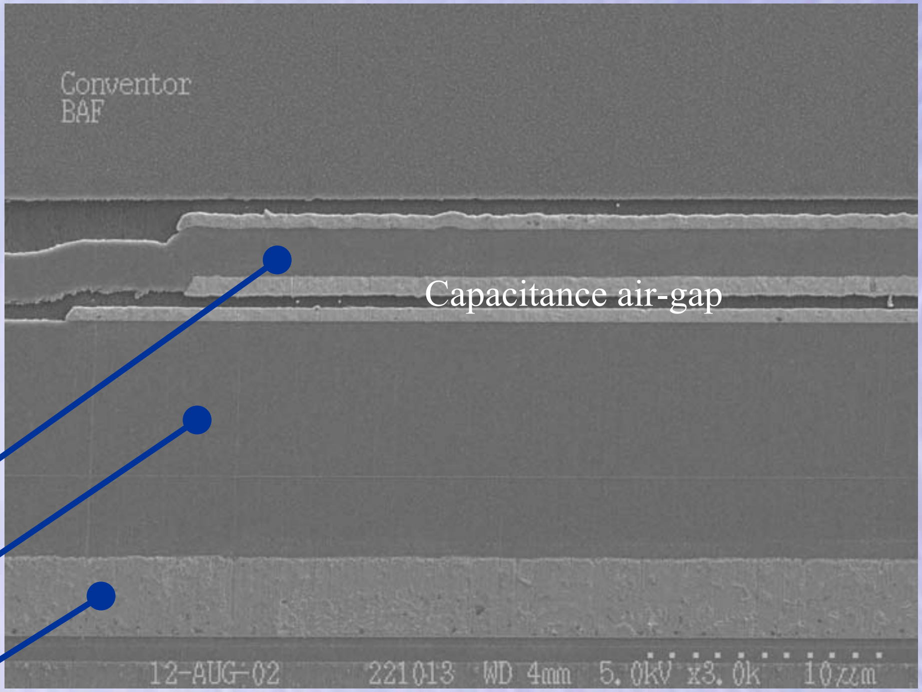


Requirements

- Process compatibility with Coventor RF-MEMS switch platform
- Design robust against fabrication tolerances
- Large capacitance tuning range
- Functional under normal operation conditions (temperature, acceleration, …)
- Full electrical isolation between control- and RF- signals

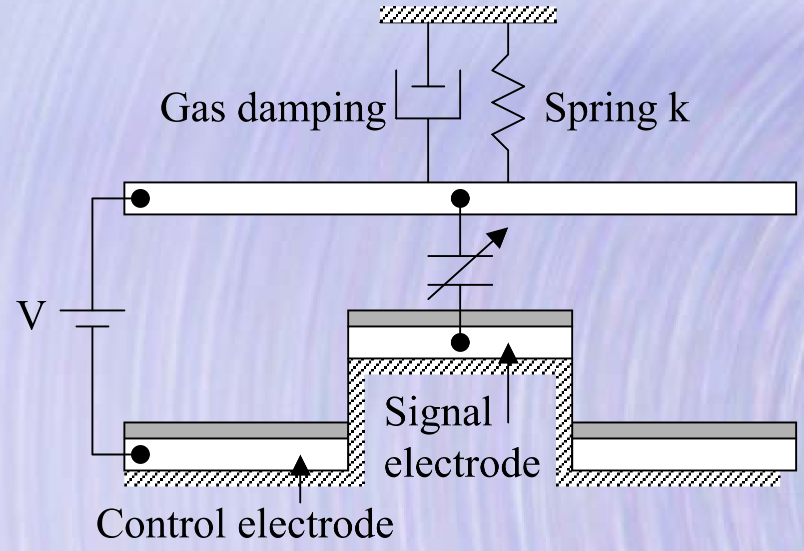
Coventor switch process

- Varactor design should be compatible with our mature RF-MEMS switch process which includes:
  - A movable triple layer (metal-dielectric-metal)
  - Thick dielectric
  - Metal interconnection layers



How to extend the displacement range ?

- If signal voltage << control voltage, a dual-gap approach can be used:
  - Actuator air-gap should be > 3 times the capacitor air-gap

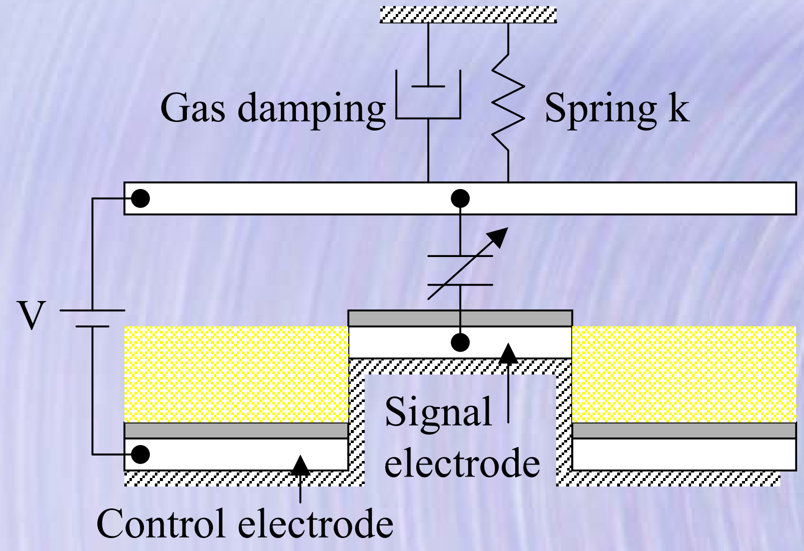


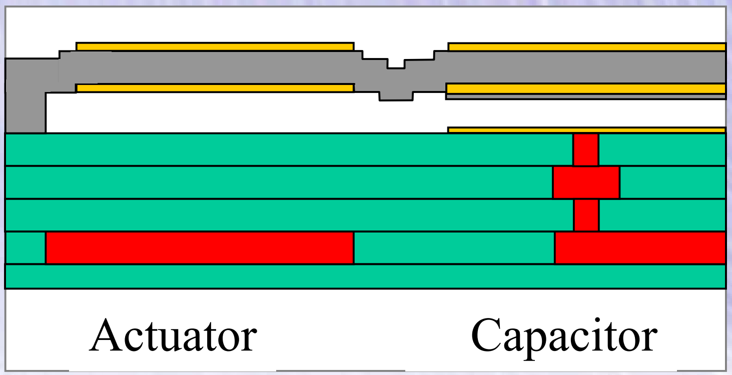
"Microelectromechanical capacitors for RF applications",
H Nieminen, V Ermolov, K Nybergh, S Silanto and T Ryhänen,
J. Micromech. Microeng. **12** (2002) 177–186

Quasi dual-gap

- If signal voltage << control voltage, a dual-gap approach can be used:
  - Actuator air-gap should be > 3 times the capacitor air-gap

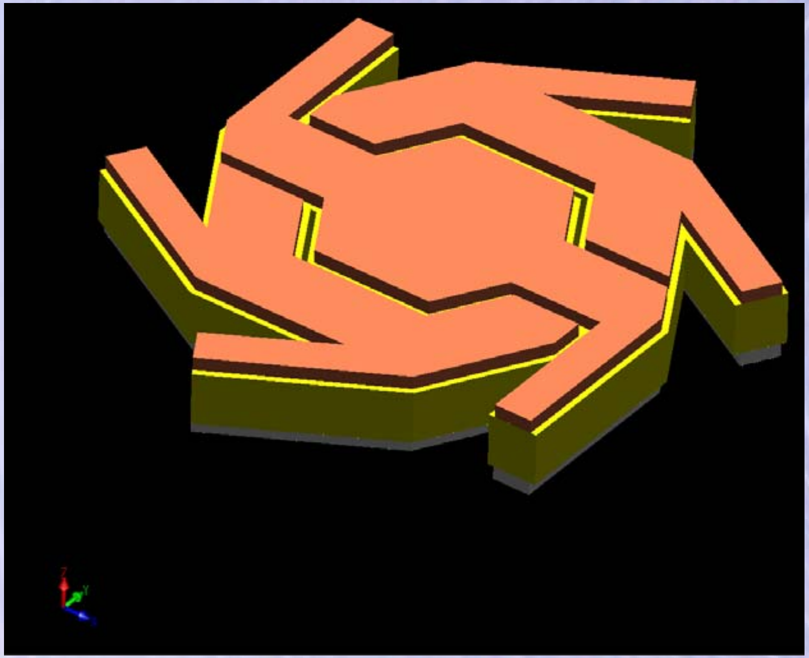
- Quasi- dual approach is equivalent, with a thick dielectric in the actuator gap





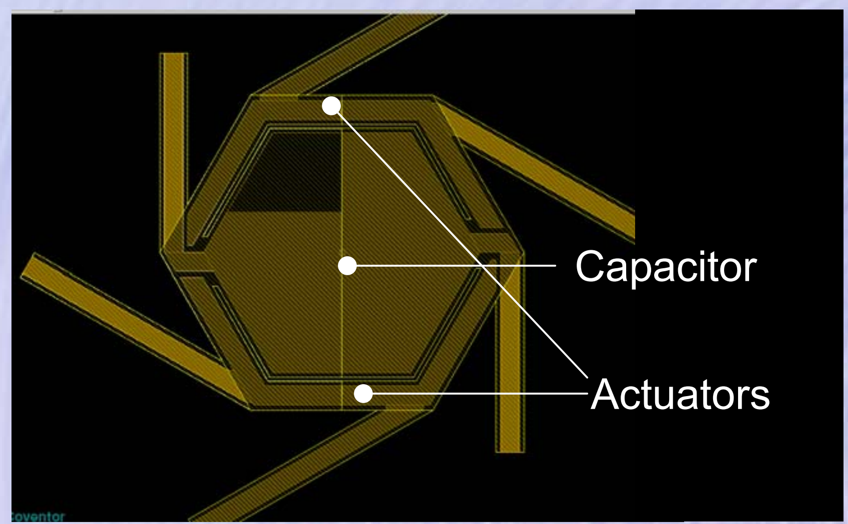
Design Overview

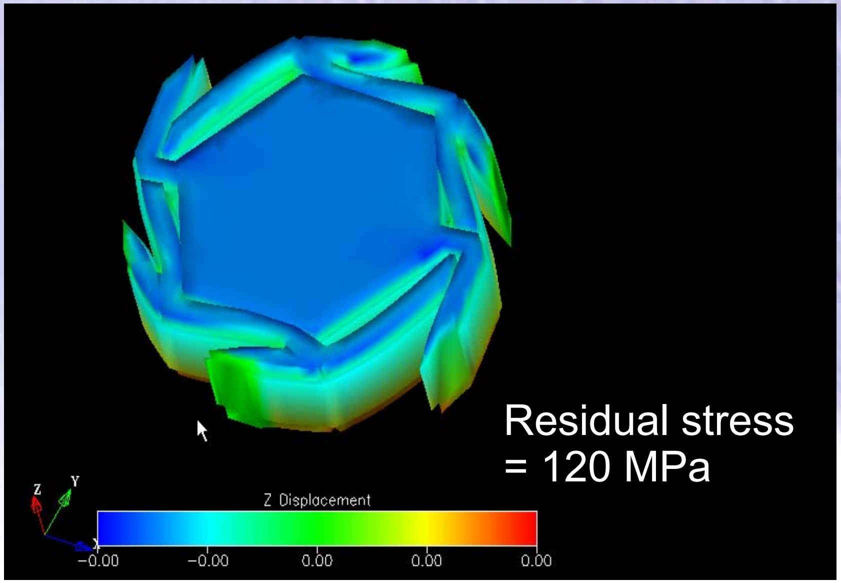
- A hexagonal shape was chosen for symmetry reasons.
- Separation of the signal capacitor and the actuator electrodes.
- Some mechanical isolation is provided by suspending the capacitor inside the actuated peripheral frame.
- The angle between the membranes and the tethers minimizes residual stress effects



Advantages of the hexagonal design

- The electrostatic force is well-distributed around the central capacitance plate
- Residual and thermal stresses have little influence on the z-position of the plate





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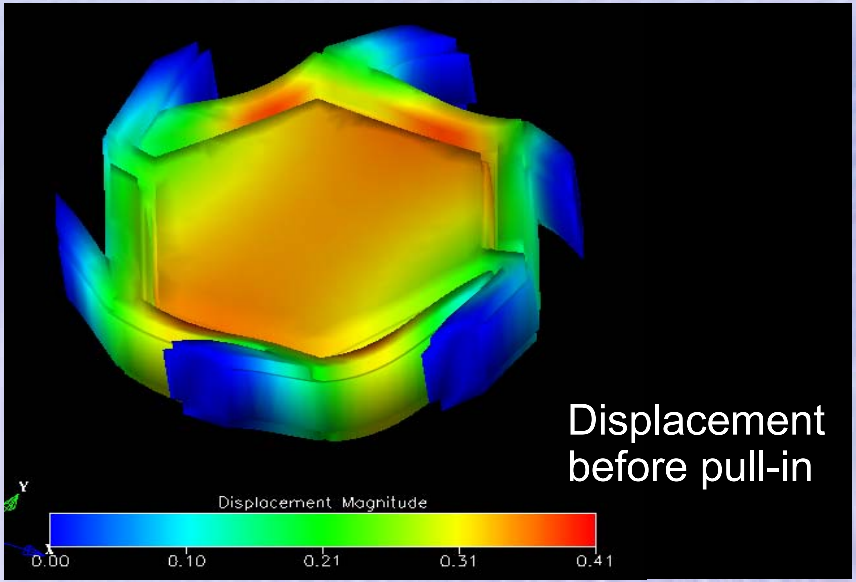
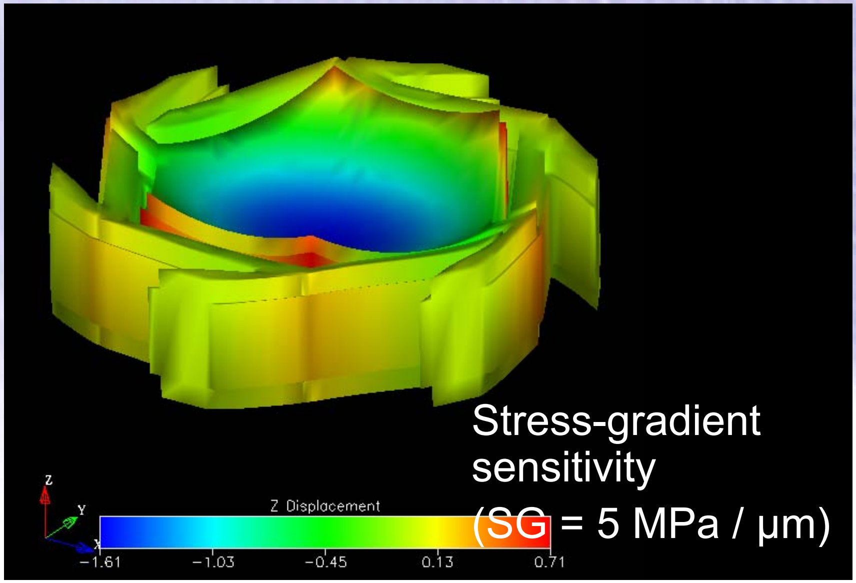
Issues related to large areas

- Large structures (for increased capacitance) are too compliant for a proper 'parallel-plate' behavior
  - The capacitance area is deflected by almost half of the total displacement

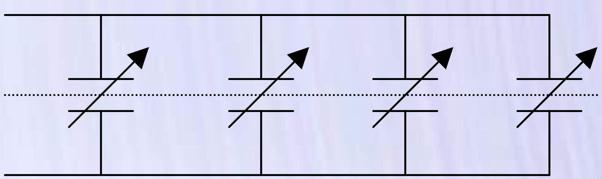
- The large area also makes difficult to have flat structures in presence of stress-gradients

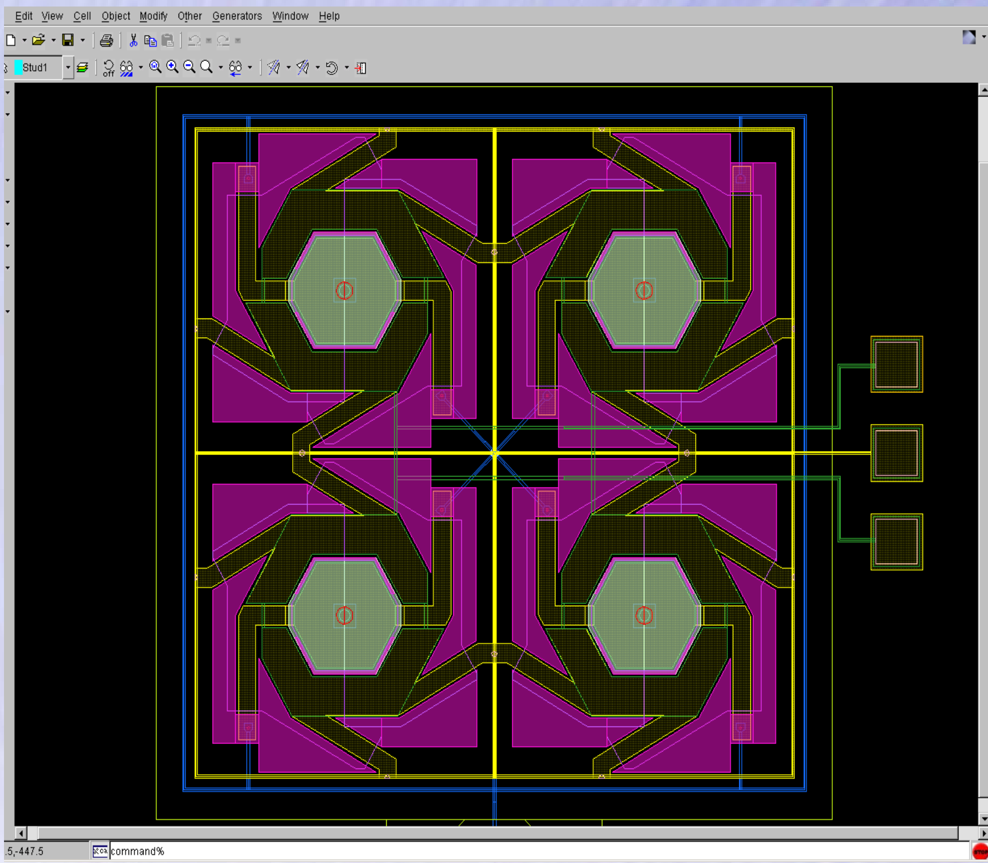




How to minimize area-related effects ?

- A given capacitance value can be reached by using arrays of identical smaller capacitors

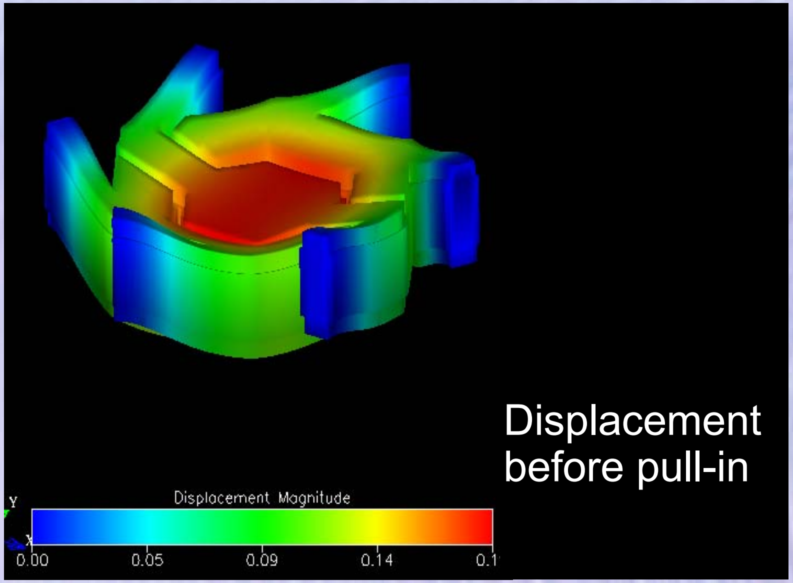


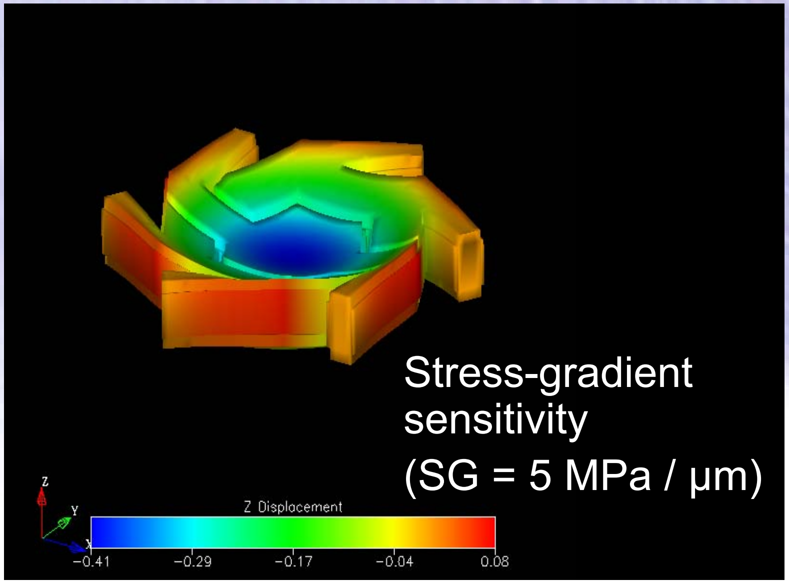


Area related-effects

- A flatter capacitor is obtained for a smaller device
  - The capacitance plate distorts only slightly

- The structure is also less-sensitive to stress-gradients





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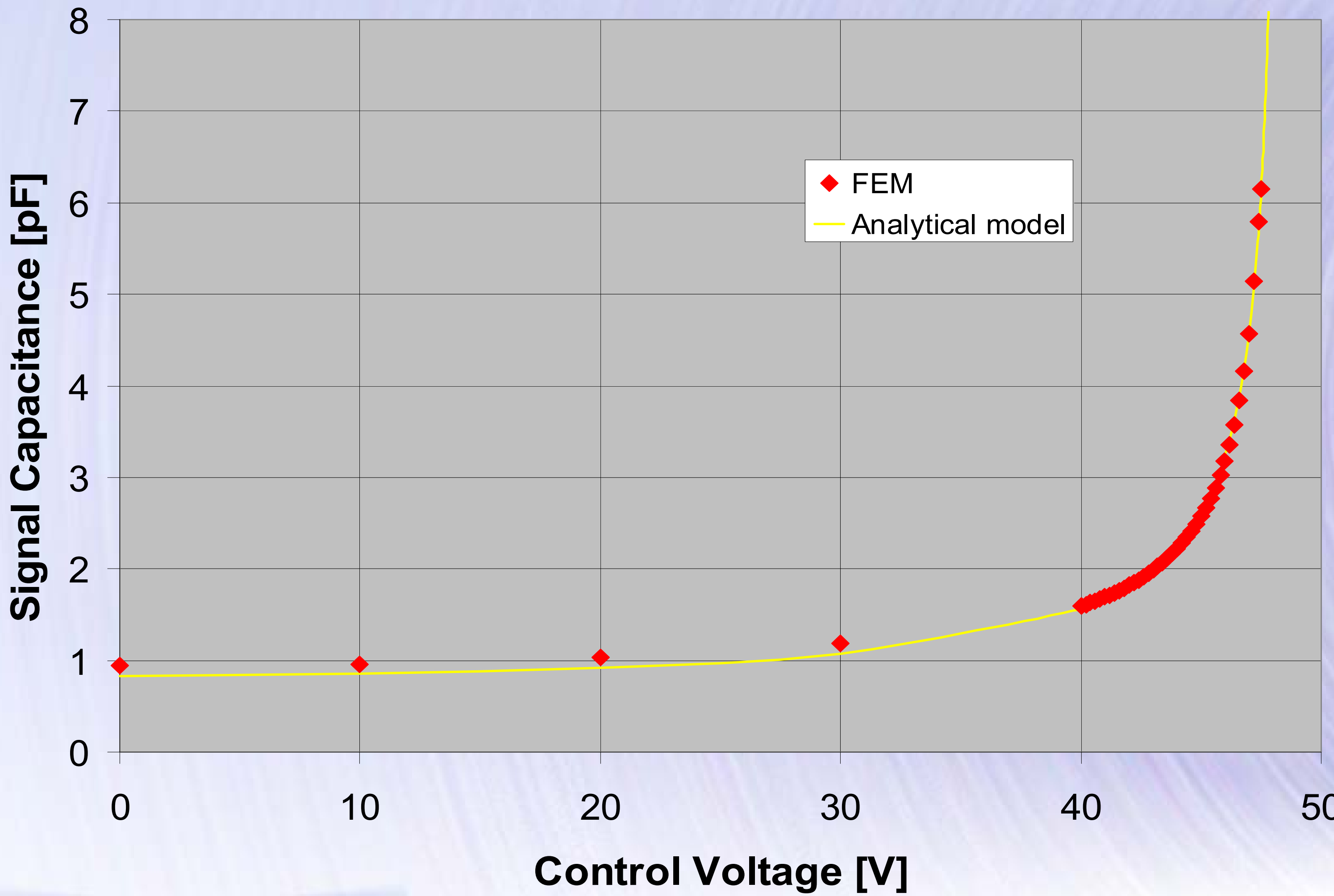
Simulated C(V) curve



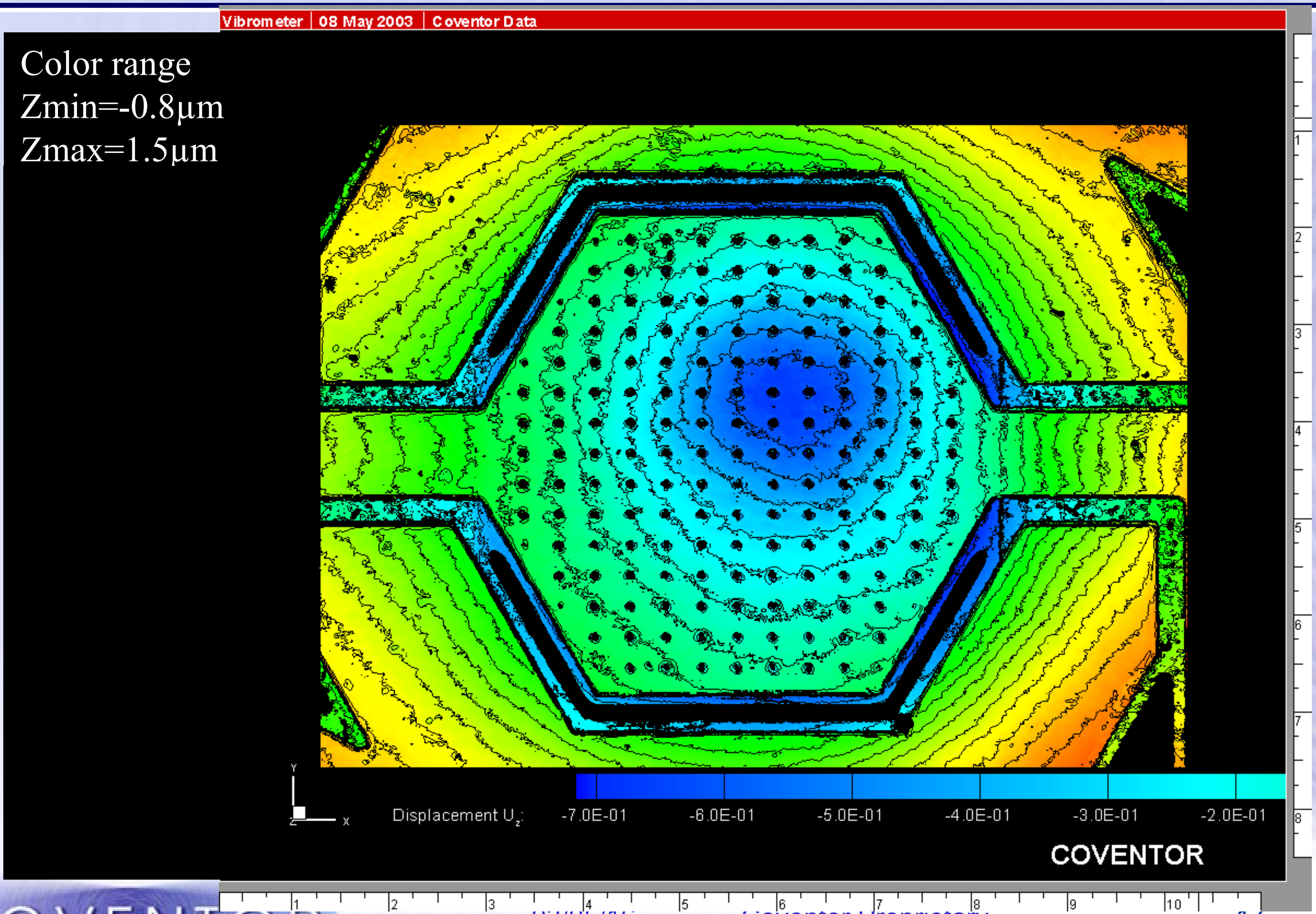
Simulation results

Characteristics	Value
C_{min}	0.9 pF
Capacitance ratio	> 1:5
Maximum Control Voltage	50 V
Mechanical resonance frequency	22 kHz
Vibration sensitivity	< 0.5% / g
Stress sensitivity (related to operating temperature)	negligible

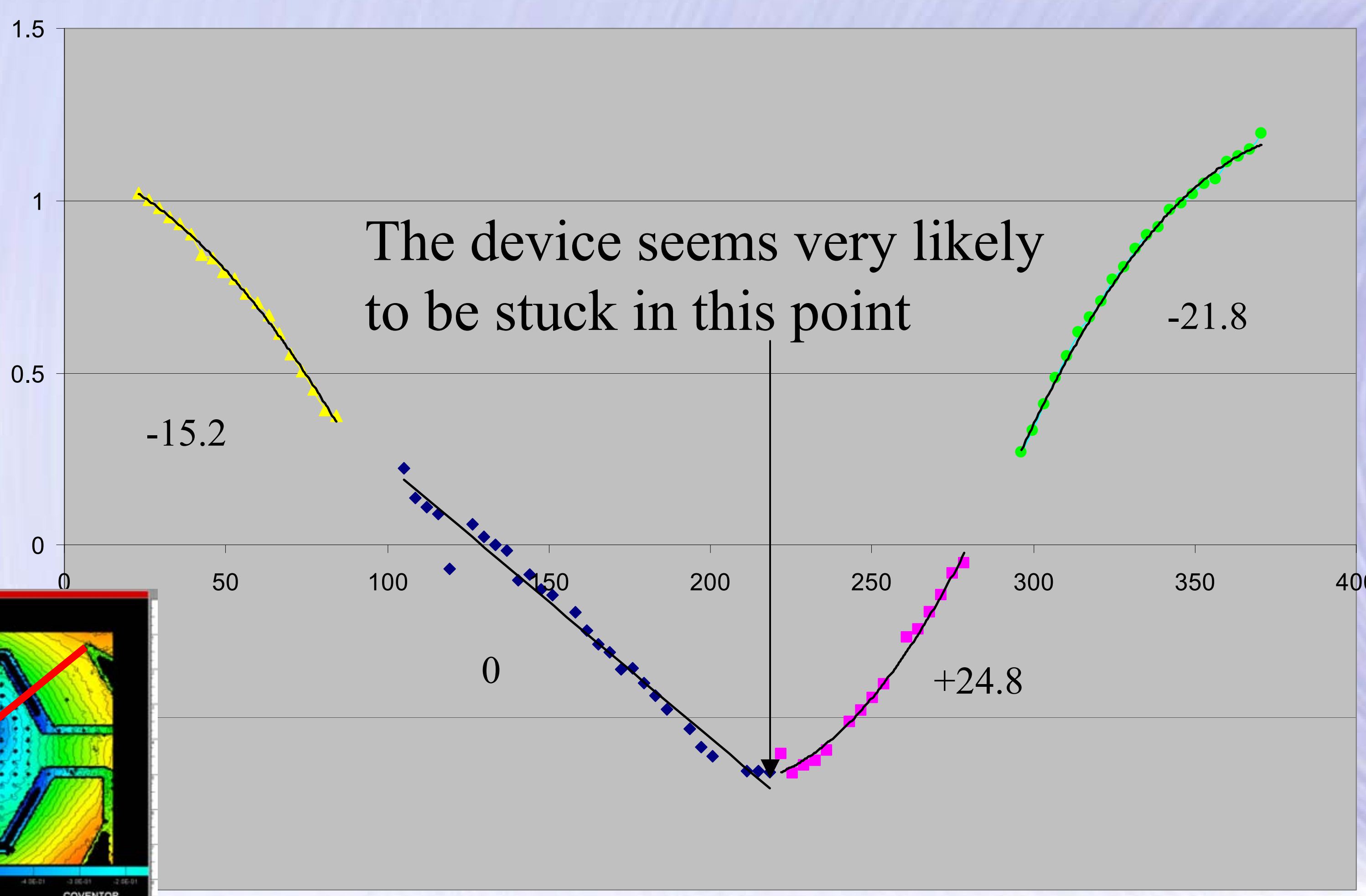
Preliminary experimental results

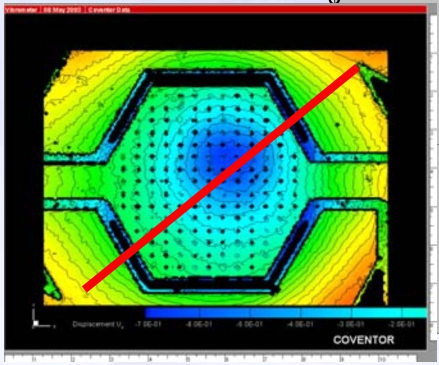
- Diced samples show stiction
- Undiced samples are released and are currently being measured

3D-Interferometry on a diced sample



Cutline (four sections)





Conclusions

- A concept and detailed design for a high-performance RF-MEMS varactor was presented
- The varactor has been fabricated in Coventor's RF-MEMS switch process
  - Dicing step is being currently improved
  - Measurements on un-diced samples are currently being completed