NAP12: MEMS Variable Capacitors – From Concept to Company

Martin Hill[1]

Conor O'Mahony[2]

[1]Cork Institute of Technology
martin.hill@cit.ie

[2]Tyndall National Institute
conor.omahony@tyndall.ie

Outline

- Applications for variable capacitors
- MEMS variable capacitors
- NAP12 Objectives
- Technical Accomplishments
- Outputs

Multiband Mobile Phones

Connectivity (iPhone 3GS)

- Wi-Fi
- Bluetooth 2.0+EDR
- Quad band GSM 850/900/1800/1900MHz
- GPRS/EDGE
- A-GPS
- Tri band UMTS/HSDPA 850/1900/2100MHz
- 7.2 Mbps HSDPA

MultiBand RF Transceivers

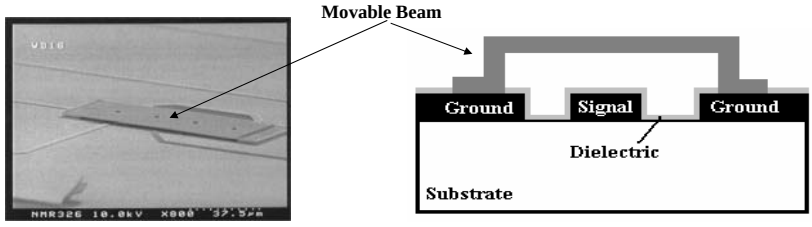
- **Mobile phones operate using many standards and frequency bands (>80) with a separate receiver for each supported band**
- **80% of components in a phone are discrete passives – these are expensive, bulky and power-hungry!**
- **Could replace these discrete receiver circuits with a single, software-controlled tunable circuit that would :**
  - Match circuit impedance to that of the antenna
  - Tune centre frequency and frequency bandwidth
  - Switch frequency bands as required
- **Can be achieved with a tunable capacitor (varactor)**
- **Requirements: tuning range = 200%, operating voltage < 10V, quality factor (Measure of energy loss) > 100**

RF Variable Capacitor Review

- **Main parameters**
  - Base capacitance
  - Tuning ratio
  - Quality factor (Q)
  - Linearity
- **Currently, the most common element is a varactor diode with TR ≈30%, Q<20, poor linearity**
- **MEMS can have high TR (>100%) and Q factor (>30)**
- **Application in frequency selection, tunable filters and impedance matching**
- **Huge worldwide research effort in MEMS R&D for telecommunications**

MEMS Variable Capacitors

- **Microelectromechanical systems: range of micron-scale movable components used in many applications**
- **MEMS varactors modify capacitance by changing gap between movable beam and signal line**

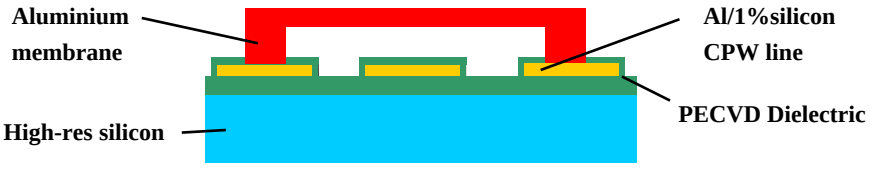


! **Electromechanical laws say that the beam range of travel is limited to 33% of initial gap by 'pull-in effect' (beam snaps down).**

- **This works looks at solutions to overcome this limitation**

Process Details

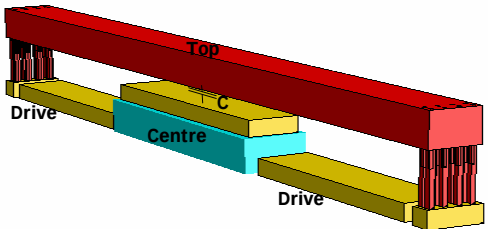
- CPW lines: aluminium/1%-silicon
- Dielectric: 200 nm PECVD material
- Structural metal: cold-sputtered aluminium
- Sacrificial layer: PI 2545 polyimide
- Resulting airgap: 1-2 μm (design dependent)

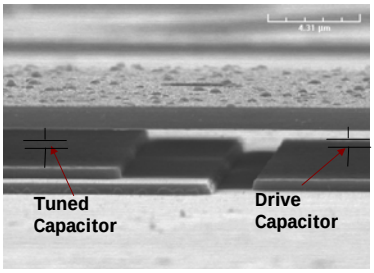


NAP12 Objectives

1. Evaluate new devices to extend the range of travel for high tuning ratio, i.e. avoid/limit the pull-in effect
2. Design on co-planar waveguides (CPW) for RF measurements
3. Investigate thin film packaging to protect these fragile devices

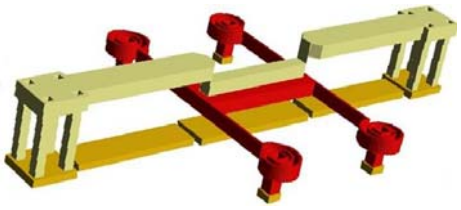
Two Gap UpGap Capacitor

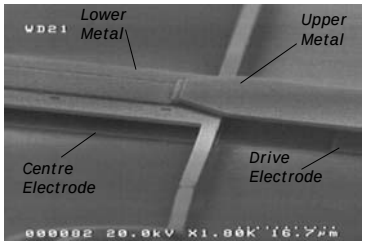




- Drive gap is twice as large as centre gap
- Drive on outer electrodes (TR>150%)
- Requires planarisation of top layer – work in progress
- Functioning as expected

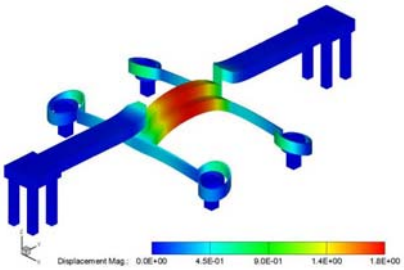
Two Gap DownGap Capacitor

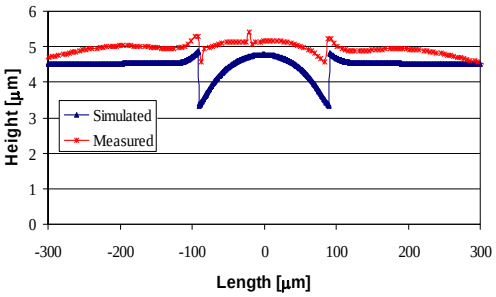




- Drive gap is twice as large as centre gap
- Drive on outer electrodes (TR>150%)
- Requires two sacrificial and mechanical layers
- Problem with distortion due to stress

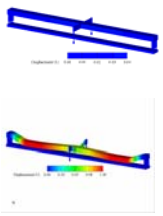
Two Gap DownGap Capacitor





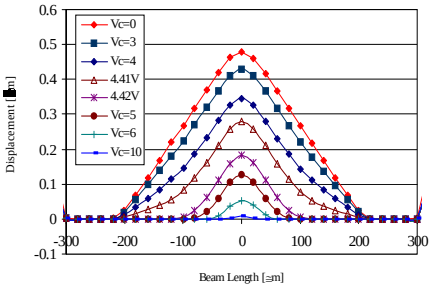
- Initial problems arose due to deformation of beam due to process internal stress and temperature effects
- Improved design demonstrated in second phase of project

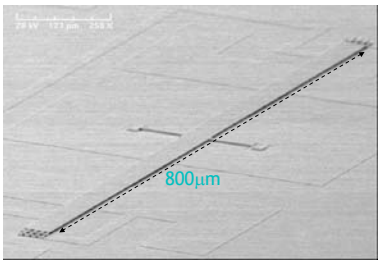
Hill-Shaped Zipup Capacitor

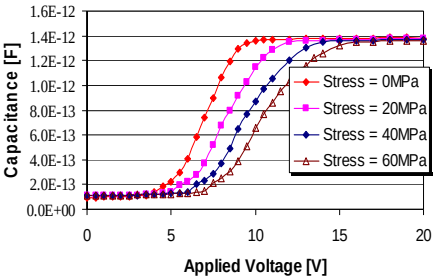


- Patented device based on zip-up operation of a beam partially in contact with the substrate
- Two phases of operation
  - Actuation to hill-shape
  - Tuning

Hill-Shaped Zipup Capacitor



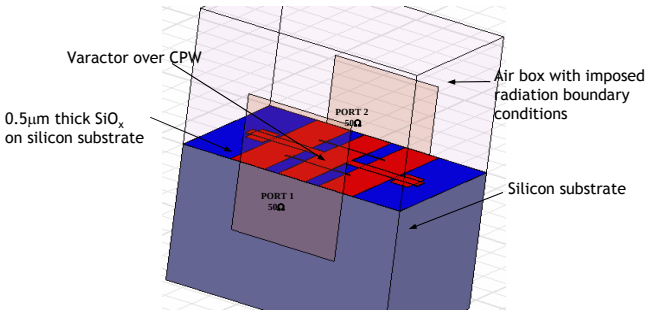




- **Base capacitance 0.15pF**
- **Potential tuning Range >500%**
- **Tuning voltage <20V**

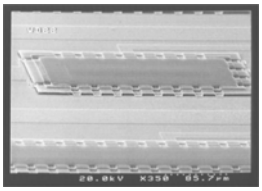
Design for RF Characterisaton

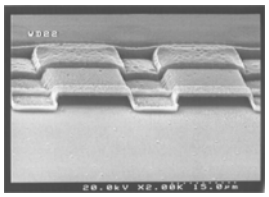
- **At RF frequencies, interconnect impedance dominates measurements**
- **Put capacitor on coplanar waveguide (CPW) to improve measurements**

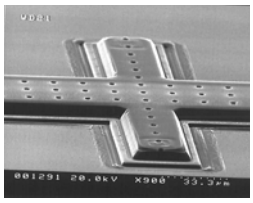


Thin film packaging

- MEMS packaging essential for high reliability
- Packaging can account for 75% of total cost
- This work also investigated 'wafer level' thin film packaging
- MEMS packaging tested with oxide and metal lids
- Devices can be actuated with lid in place
- Process for sealing etch holes still being tested







Conclusions

- Verified operation of different devices with improved performance
- HZC device has very promising performance and has been patented
- Company to develop technology
- New packaging technology demonstrated
- Outputs:
  - 1 patent
  - 2 journal publications
  - 9 conference publications

Benefits to CIT

- Involvement in IP generation
- Opportunities to develop collaboration with two external companies
- Publications
- Establishment of a research activity
- Support for five postgraduate research projects
- Basis for joint developments with Tyndall

Acknowledgements

- Science Foundation Ireland
- NAP Programme Coordinators
- Tyndall/UCC Technology Transfer Office
- Tyndall Central Fabrication Facility