Th3A-319-GL413

Silicon-Micromachined Liquid Crystal Variable Capacitors for Tunable RF Devices

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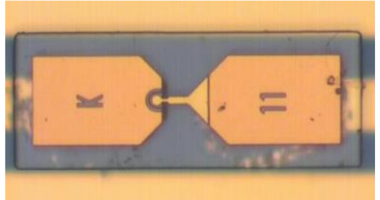
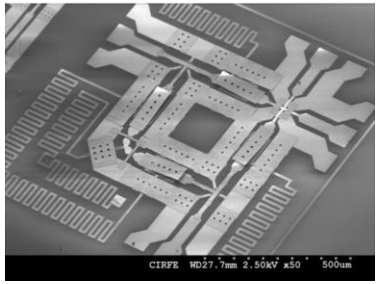
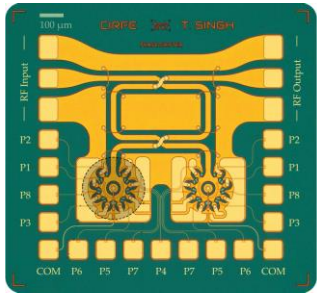
Presentation Overview

- Introduction
- Fabrication Requirement
- Adopted methods
- Fabrication Process
- Simulation and Measurement Results
- Conclusion
- References

Technologies for Tunable RF devices

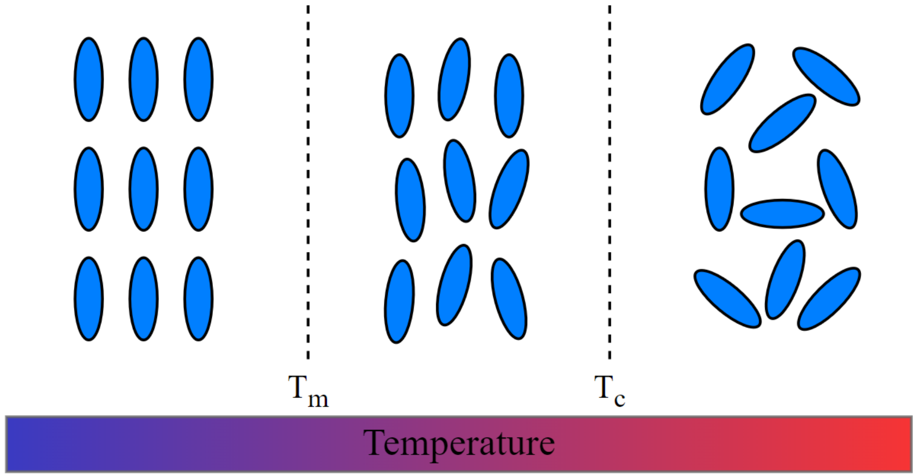






	Semiconductor	MEMS	Liquid Crystal	PCM	BST
Operation principal	Modulation of depletion zone	Change in geometry	Alignment of molecules	Formation change	Ionic Polarization
Tunability	High	Medium	Medium	High	High
Speed	Very Fast	Fast	Slow	Very Fast	Very Fast
Tuning voltage	Small	Medium	Medium	Medium	High
Linearity	Poor	Good	Good	Good	Very good
Pro/Con	Technological effort	Long term stability	Liquid state	Long term stability	Solid state ceramic

Liquid Crystal

- LC materials are anisotropic in certain temperatures between melting point and clear point ($T_m < T < T_c$) .

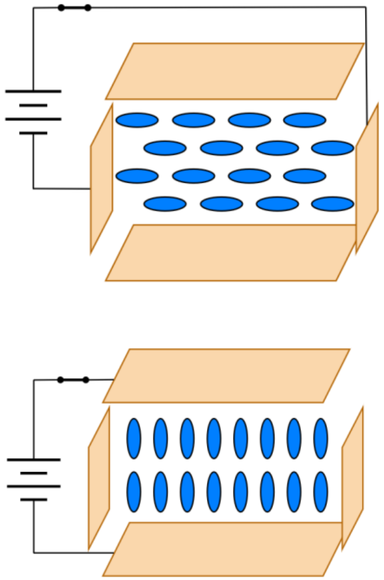


- Electromagnetic properties are variable in nematic phase
  - $\varepsilon_{\perp} < \varepsilon_r < \varepsilon_{||}$ & $Tan\delta_{||} < Tan\delta < Tan\delta_{\perp}$

LC Alignment Methods

Electric field

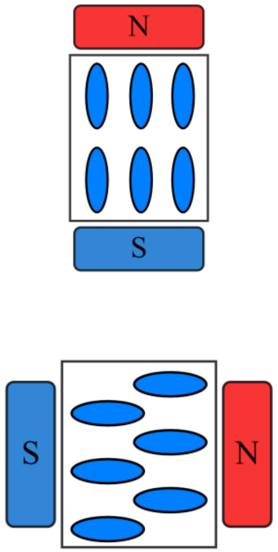
LC molecules align along electric field



Used in planar and dielectric waveguide applications

Magnetic Field

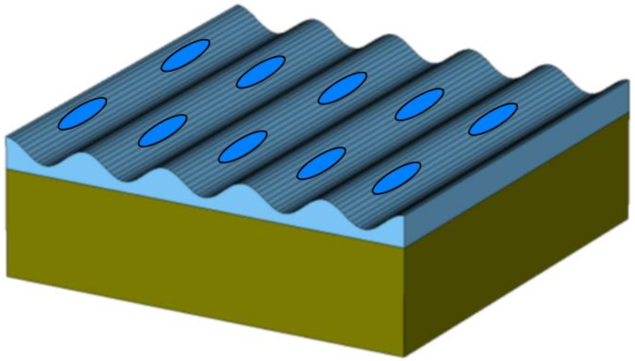
LC molecules align along magnetic field



Can be used in waveguide application

Surface Anchoring

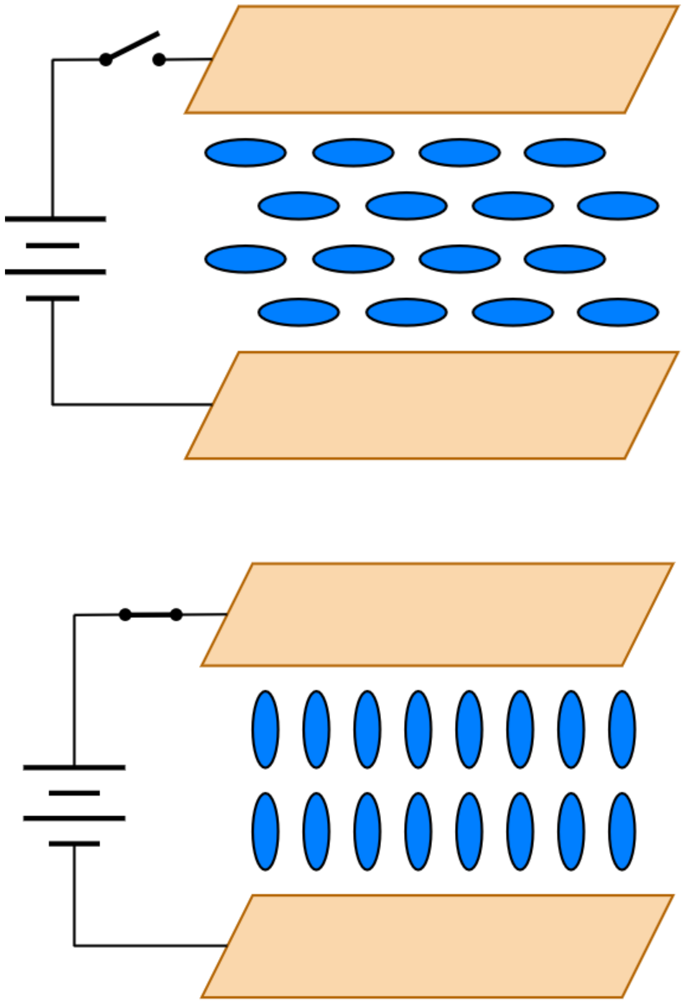
LC molecules align along polyimide’s surface grooves



Used for pre-alignment state in planar devices

Control Mechanism

- This work utilize combination of two method to change LC state.
- State I
  - – Surface anchoring force
    - Treated polyimide layer
- State II
  - – Electric field
    - Parallel plates create static electric field



Variable Capacitor

- Key component in tunable RF devices:
  - Filters
  - Phase Shifters
  - Impedance tuners
  - Beam steering antennas
- Important aspects of a variable capacitor:
  - Quality factor
  - Available states (Analog or switched)
  - Range of variation

Variable Capacitor

Higher Quality factor → Lower Loss → Higher frequency, Higher efficiency

More available states → Precise tuning → Better matching, Higher efficiency

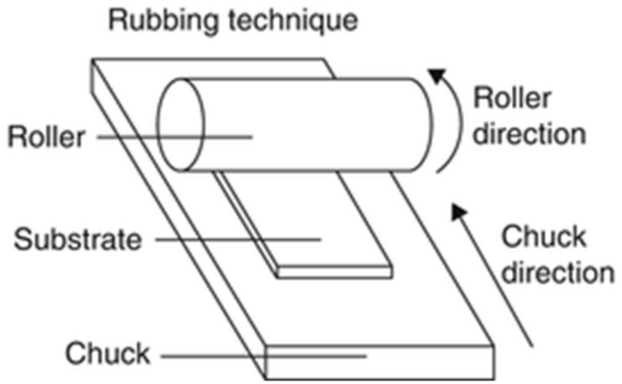
Broader tuning capability → Wider tunning range → Spectrum efficient

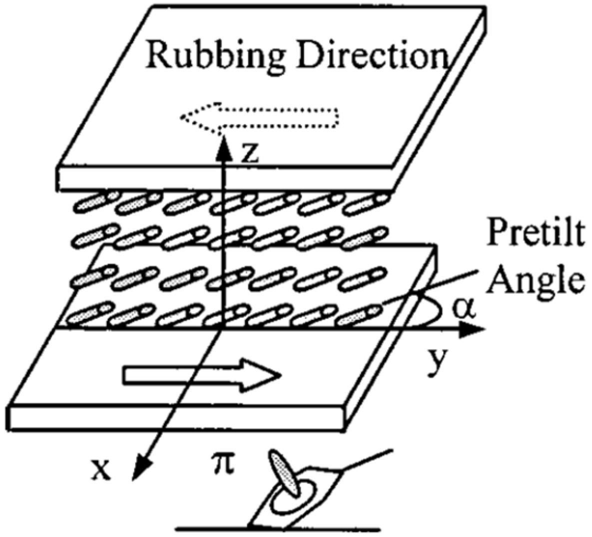
Fabrication Requirement

- Fabrication process require
  - Creating trench for LC → **DRIE**
  - Creating parallel plates → **Sputtering and lift off**
  - Coating and curing of PI layer → **Spin-coater & hotplate**
  - Nano-scale treatment of PI layer → **Ion Beam Irradiation system**
  - Packaging and filling process → **Die bonder and vacuum chamber**

Surface Treatment

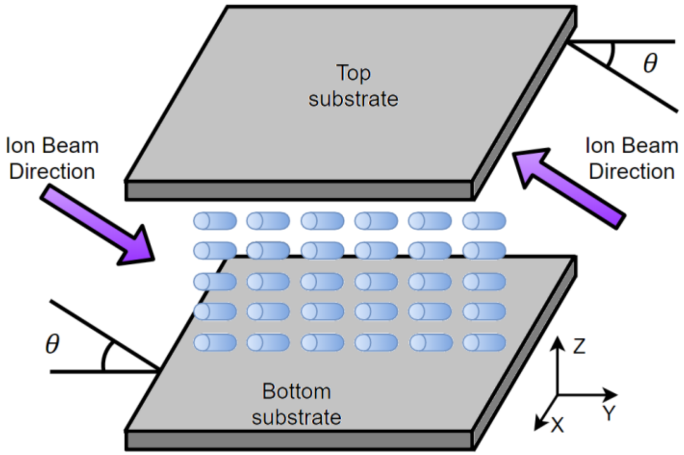
- Traditionally, rubbing machine is used to create micro grooves.
- A roller covered with velvet cloth rubs the polyimide coated surface.
- Problems using it in our work:
  - – Only applicable to flat surfaces
  - – Suitable for large structures





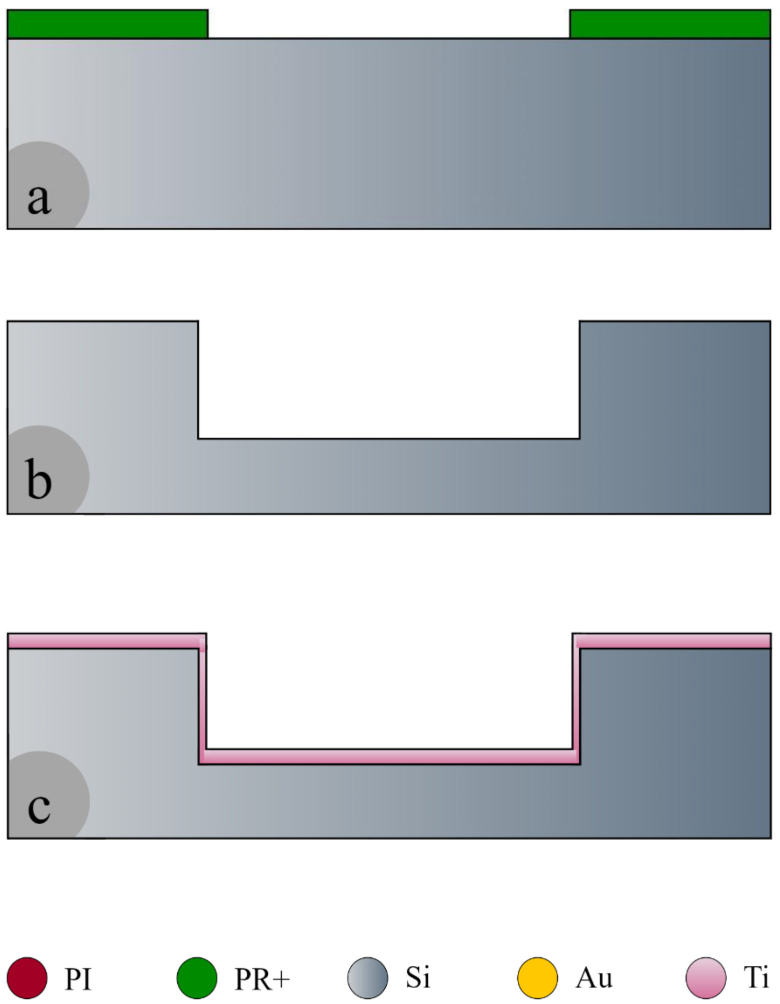
Surface Treatment

- Multi-level surface require special treatment
- Pre-Alignment layer preparation:
  - Thin polyimide layer coating
  - Hard bake and curing process
  - Exposure to Ion-Beam-Milling system for short time and low power



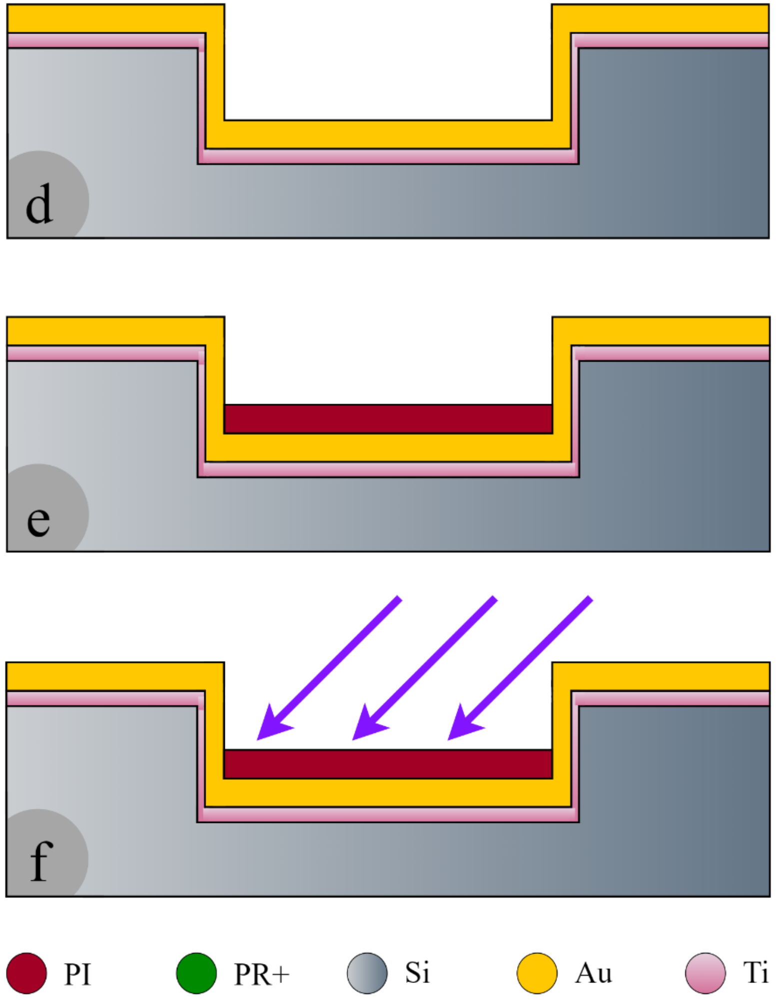
Fabrication Process

- Step (a)
  - spin coating, photolithography, and development of positive photoresist
- Step (b)
  - Dry etch using Deep Reactive Ion Etching (DRIE) for 100um.
- Step (c)
  - Plasma clean and sputtering of Ti as adhesion layer of gold



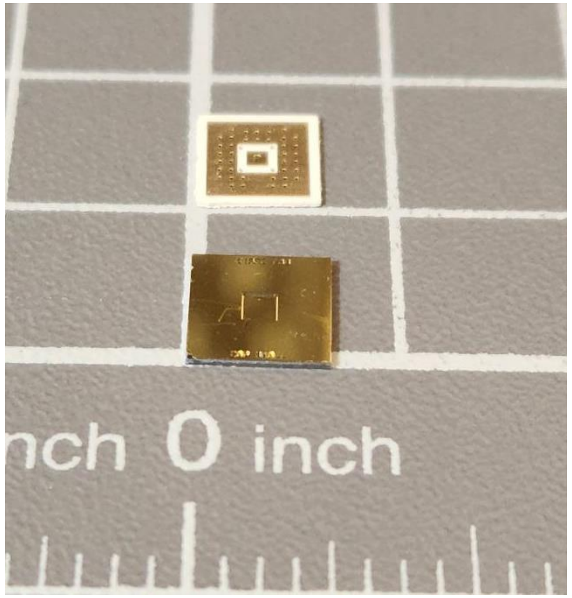
Fabrication Process

- Step (d)
  - Au sputtering as seed layer
  - Electroplating
- Step (e)
  - Polyimide coating
  - Polyimide curing
- Step (f)
  - PI exposure to IBI system

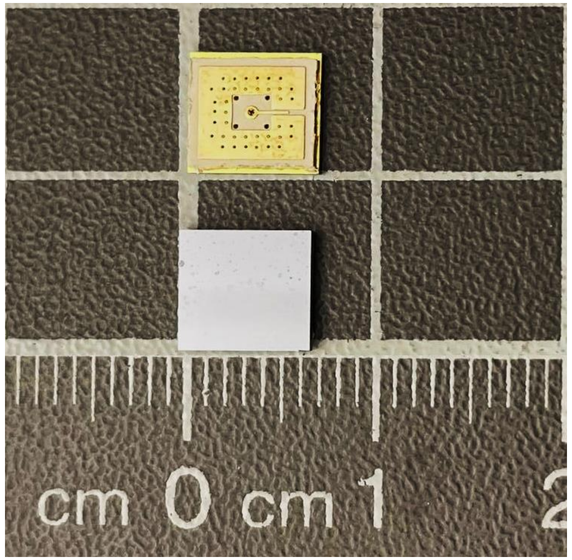


Fabrication Process

- Packaging
  - Die bonding machine
  - Low temperature bonding agent
  - Specific pressure and time
- LC Filling process
  - Fill with micro-syringe
  - Vacuum chamber to remove air
  - Repeat multiple time



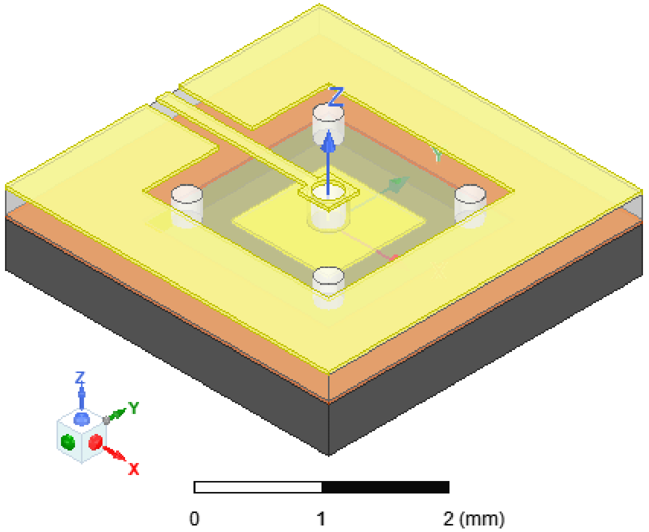
Top and bottom part of the capacitor before packaging



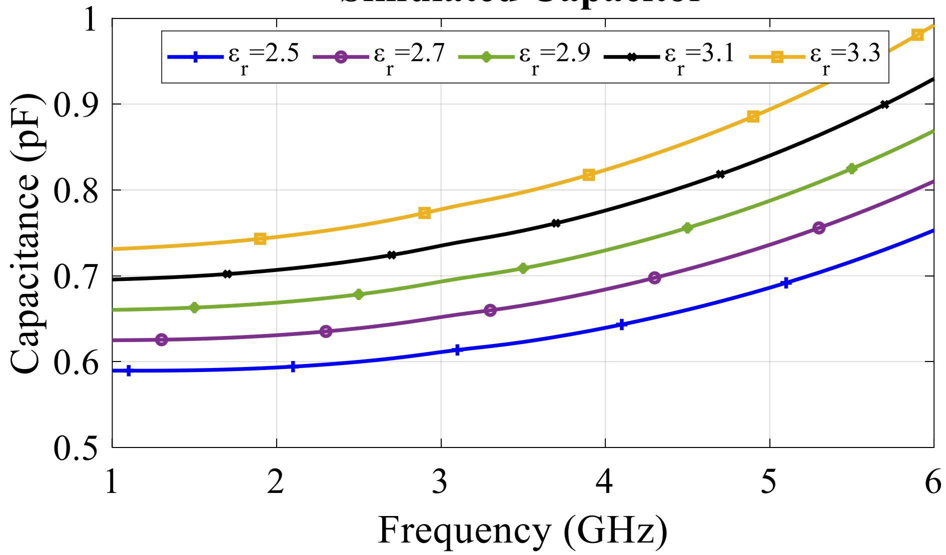
Two packaged capacitor looking from top and bottom

Simulation Result

- Simulation details:
  - Completed in Ansys EM (HFSS)
  - Dielectric constant defined as tensor
  - Loss tangent defined as tensor
- Simulation results:
  - Capacitance of 0.59 pF to 0.73 pF
  - Quality factor of 65 to 150
  - 24% shift in capacity

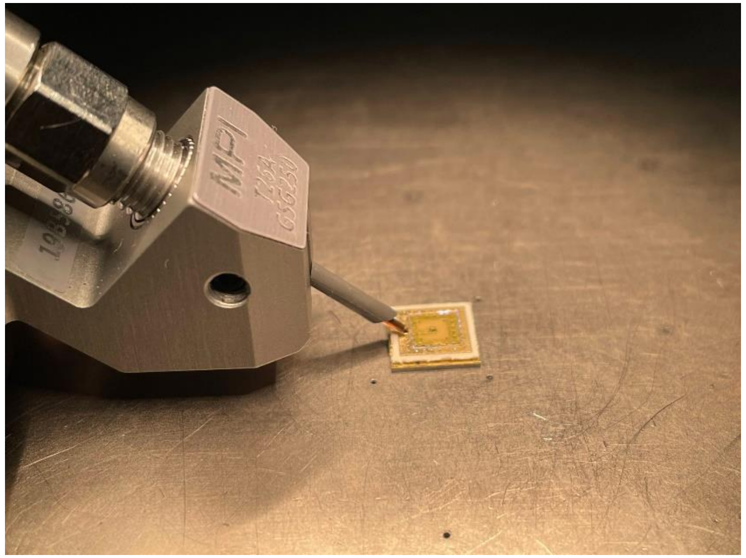


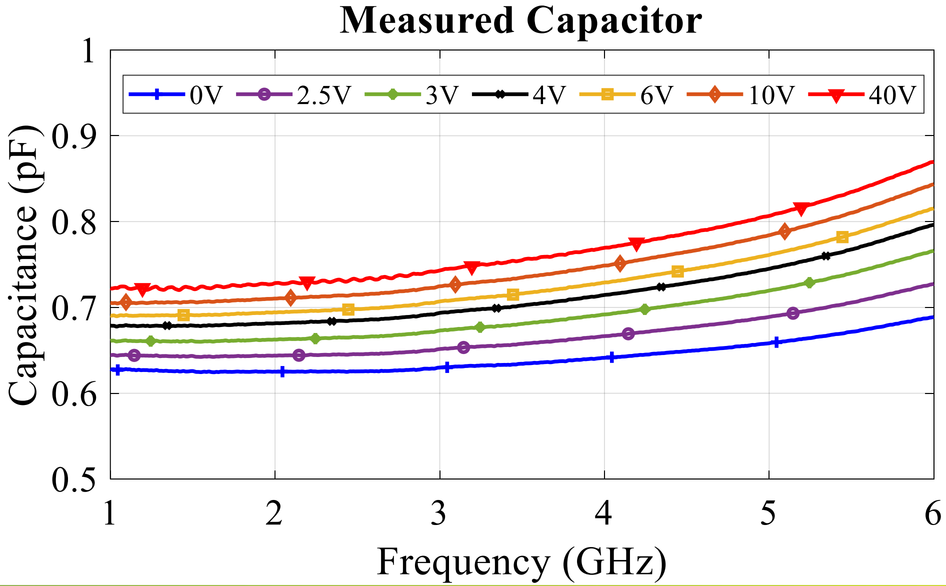
Simulated Capacitor



Measurement Result

- Measurement setup:
  - 67GHz Keysight PNA
  - 250um pitch GSG probes and probes station
  - Bias tee and 40GHz cables
- Measurement results:
  - Capacitance of 0.62 pF to 0.73 pF
  - Quality factor of 44 to 123
  - 18% shift in capacitance





Conclusion

- Feasibility of fabricating LC integrated chip capacitor has been demonstrated.
- An ion beam milling technique is devised to deal with critical pre-alignment layer in a multi level and small surface area of a chip capacitor.
- Simulation results has been validated with fabrication and measurement.
- Capacitance change of 18% and quality factor of 44 to 123 has been measured with analog tuning.
- Power consumption is almost zero as there is no bias current.
- The results are promising as it can eventually replace other technologies including semiconductors.

References

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Questions?

Thank you!