Metal-Isolator-Metal Varactor Based on Inkjet-Printed Tunable Ceramics

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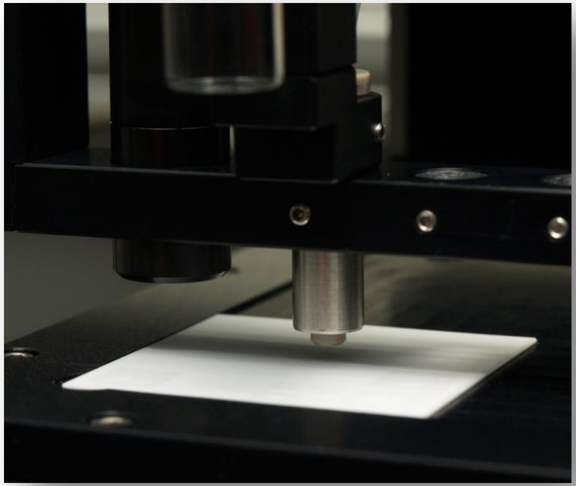
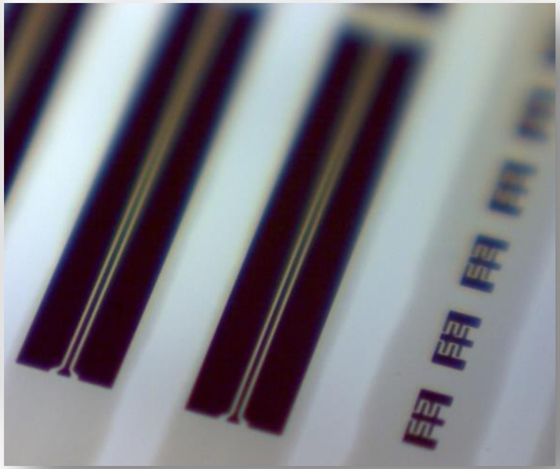
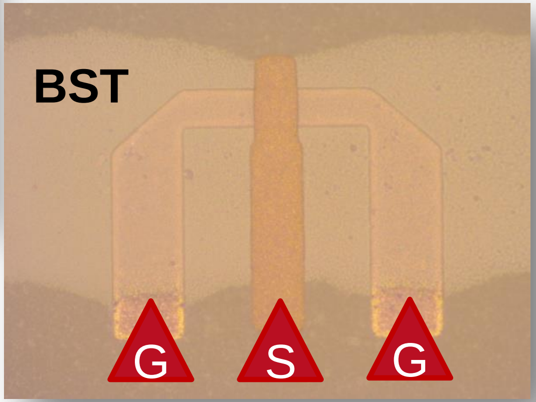
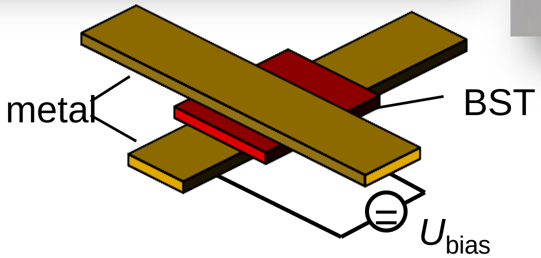
GeMiC German Microwave Conference 10-12 March 2014







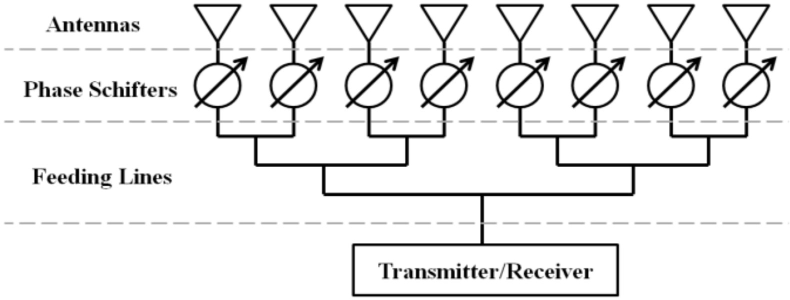


Outline

- ➢ Introduction
- ➢ Inkjet Printing of BST
- ➢ Varactor Fabrication
- ➢ Prototype and Measurement Results
- ➢ Conclusion & Outlook

Introduction

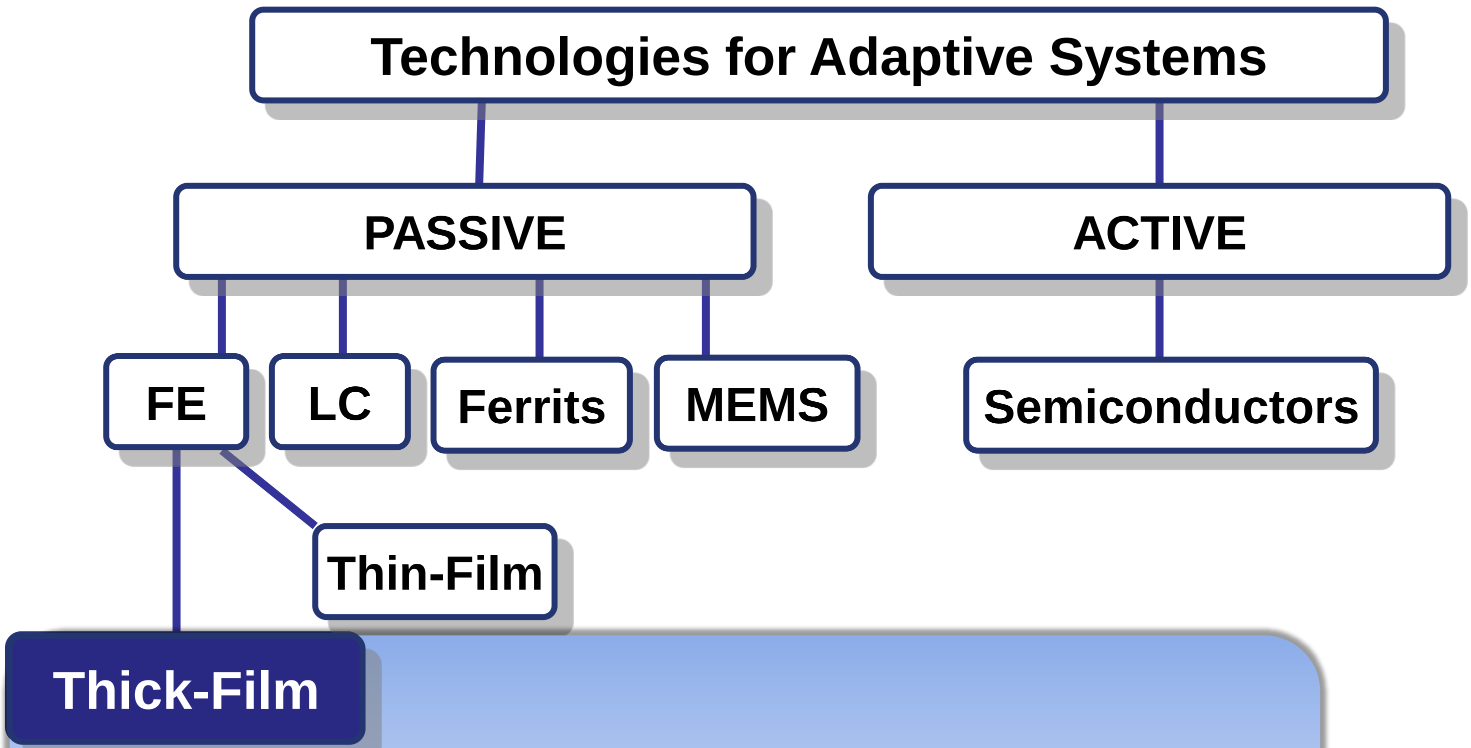
- Multi frequency functionality:
    - Tunable phase shifters
    - Tunable antennas
    - Tunable filters



- A tunable component can reduce
    - Size
    - Complexity
    - power consumption

- The functional components in a tunable circuit are tunable varactors or switches

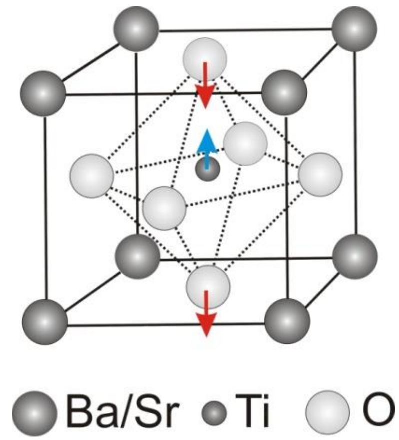
Why BST Thick-Film?

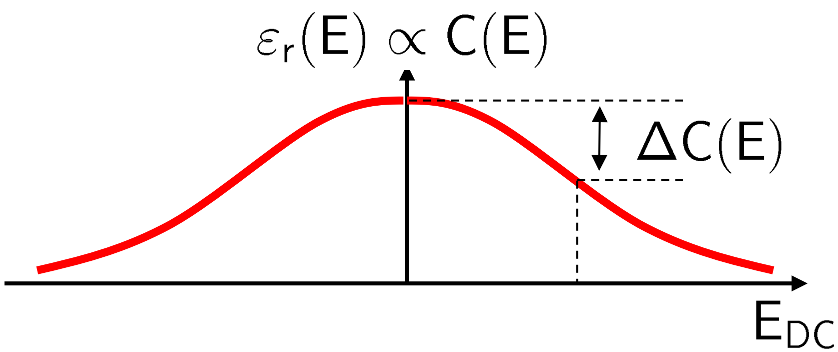


- Screen printing – low cost
- Ceramic based – solid state
- Simple Integration & packaging
- High tuning speed
- High linearity
- Low power consumption

Barium-Strontium-Titanate (BST)
Tunable Dielectric

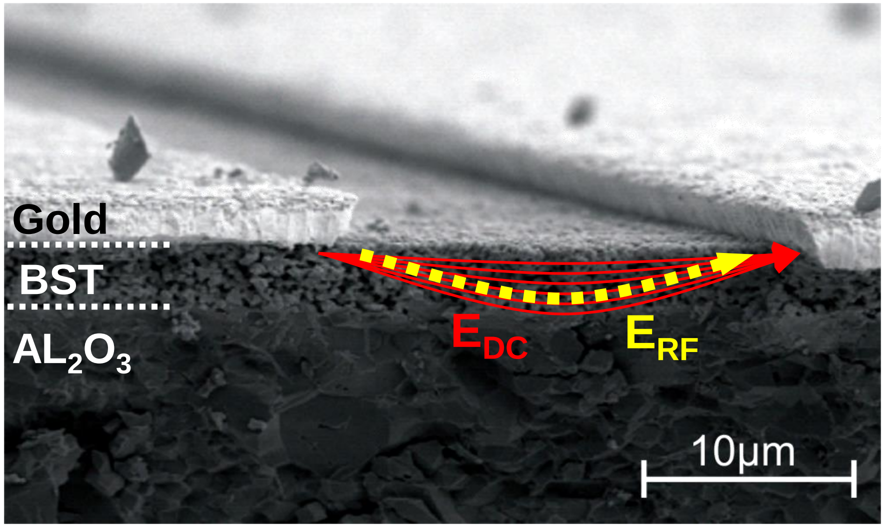
- Permittivity changes by applying an electrostatic field
- Basic tunable component
  - Tunable Interdigital Capacitor (IDC)
  - Minimum gap 10µm





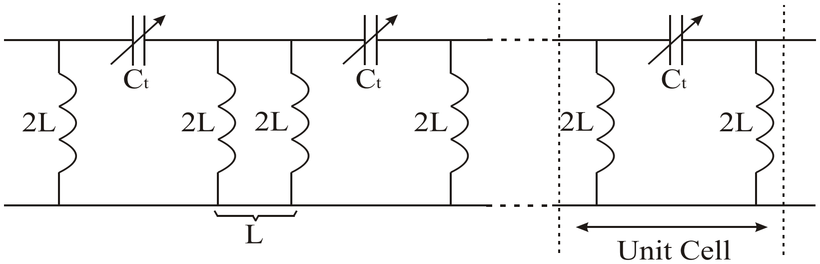
Tunability

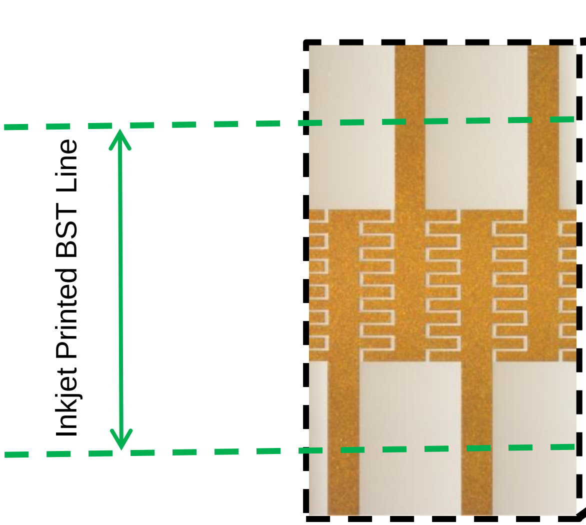
$$\tau_C(E) = \frac{C(0) - C(E)}{C(0)}$$

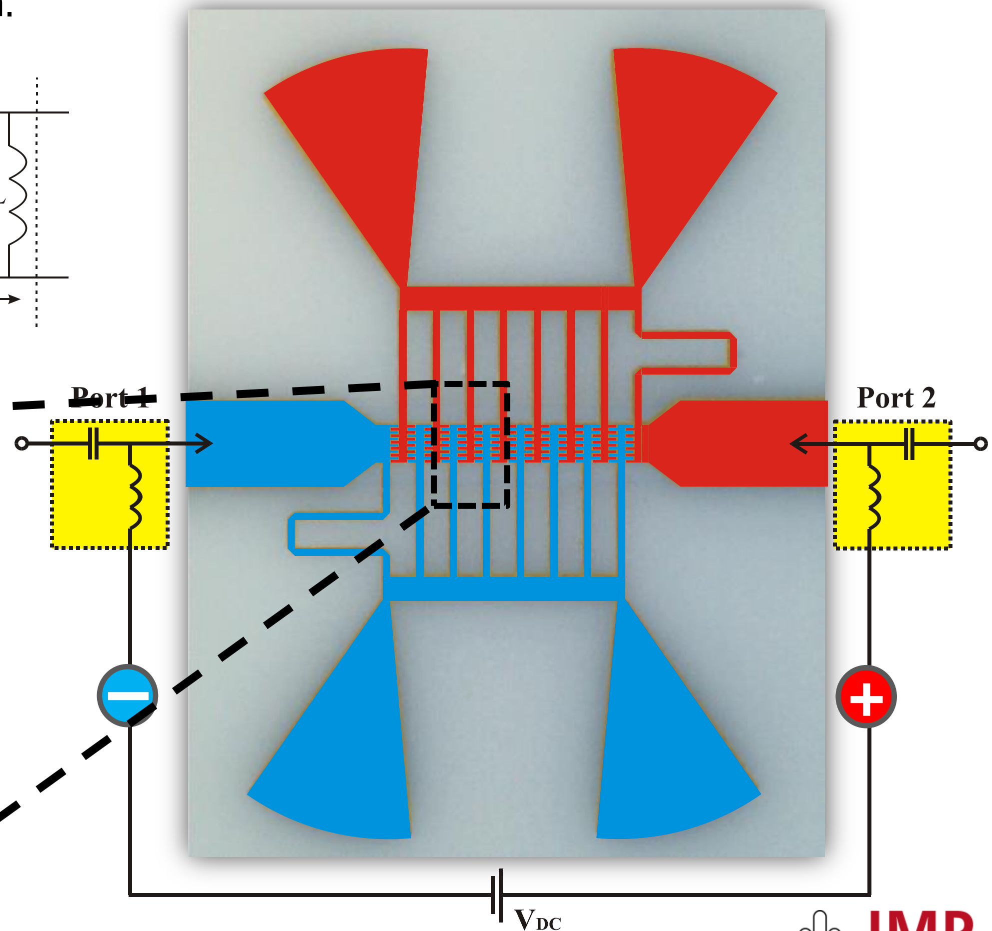


Left-hand Transmission Line Phase Shifter

- Top view of the manufactured tunable phase shifter
  - The BST line is printed in the IDCs region.







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Phase Shifter Measurement Results

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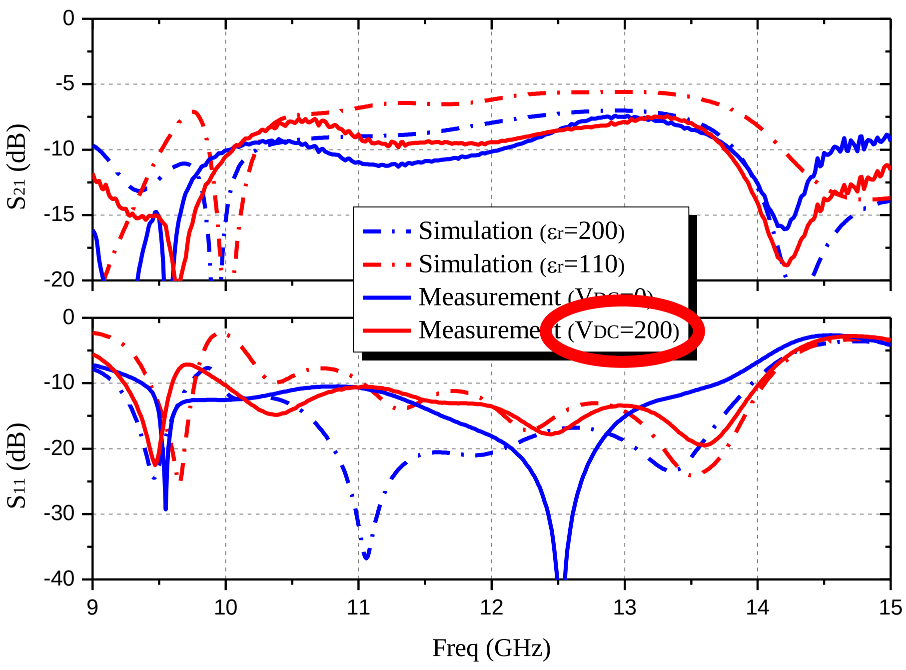
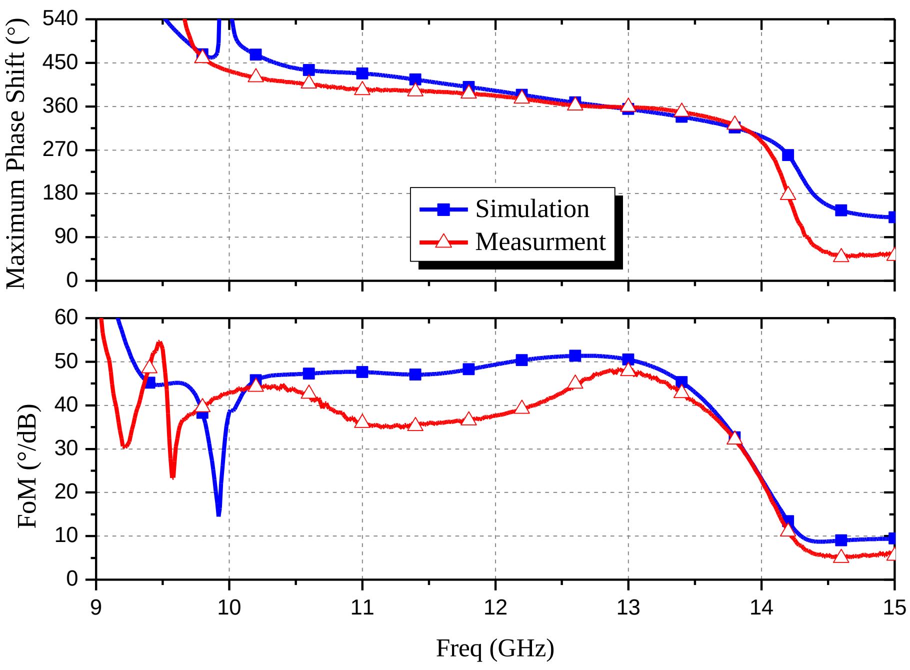
- Simulated and measured s-parameter of the phase shifter
  - The maximum insertion loss is 10dB at 12GHz





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Component Design
Geometry Efficiency

Material Tunability

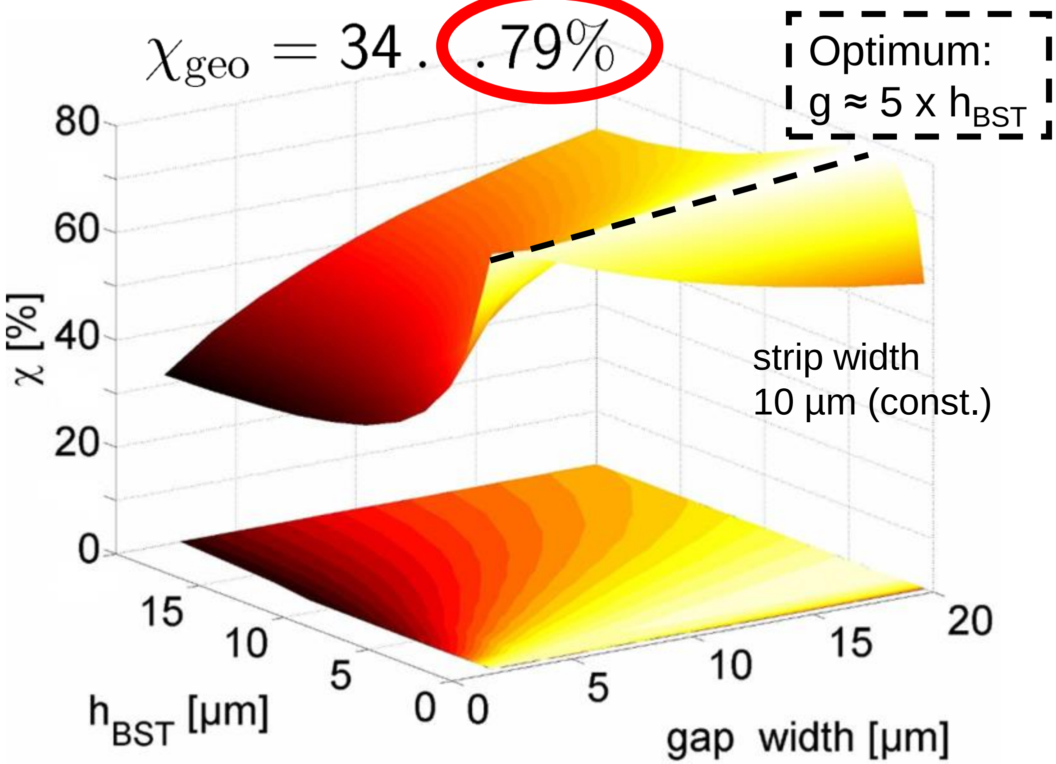
$$\tau_\varepsilon(E) = \frac{\Delta\varepsilon_r(E)}{\varepsilon_r(0)}$$

Component Tunability

$$\tau_C(E_{eff}) = \frac{\Delta C(E_{eff})}{C(0)}$$

Geometry Efficiency

$$\chi_{geo}(E_{eff}) = \frac{\tau_C(E_{eff})}{\tau_\varepsilon(E_{eff})}$$



The component geometry is a critical parameter for the design of tunable components.

Limitation of the technology

	Advantages	Disadvantages
Tunable phase shifters by using BST thick-film	Tuning Speed	High biasing voltage (max 200V)
	Low power consumption	Low FOM
	Compact Size	Frequency limitation
	Compatible with planar structure	Delicate fabrication process

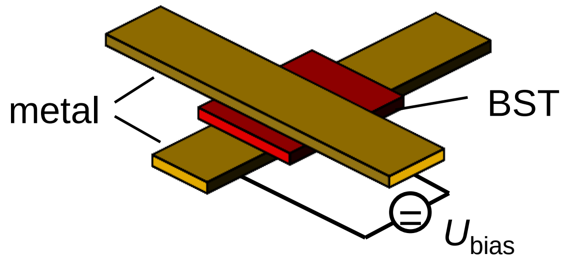
Limitation of the technology

Tunable phase shifters by using BST thick-film	Disadvantages
	High biasing voltage (max 200V)
	Low FOM
	Frequency limitation
	Delicate fabrication process

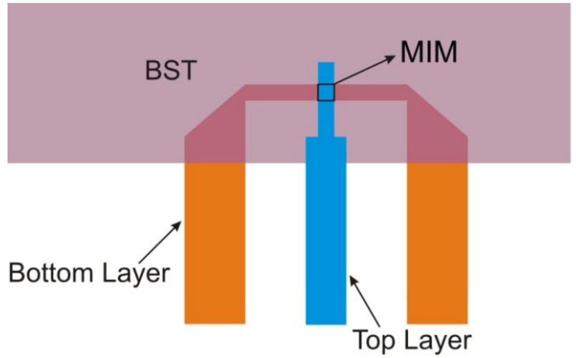
} Metal Isolator Metal Capacitors (MIM)

Limitation of the technology

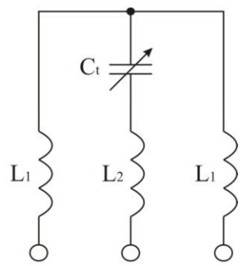
- Metal Isolator Metal Capacitors (MIM):
  - Reduce biasing voltage
  - Increase breaking voltage
  - Increase maximum tunablity
  - Improver Insertion Loss
  - Decrease number of tunable units



- MIM Varactor fabricated by selective printed BST film:
  - Top and bottom conductor layer fabricate by Photolithography process
  - BST layer Printed

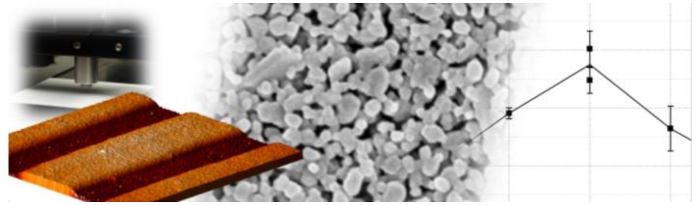


Layout of the MIM varactor



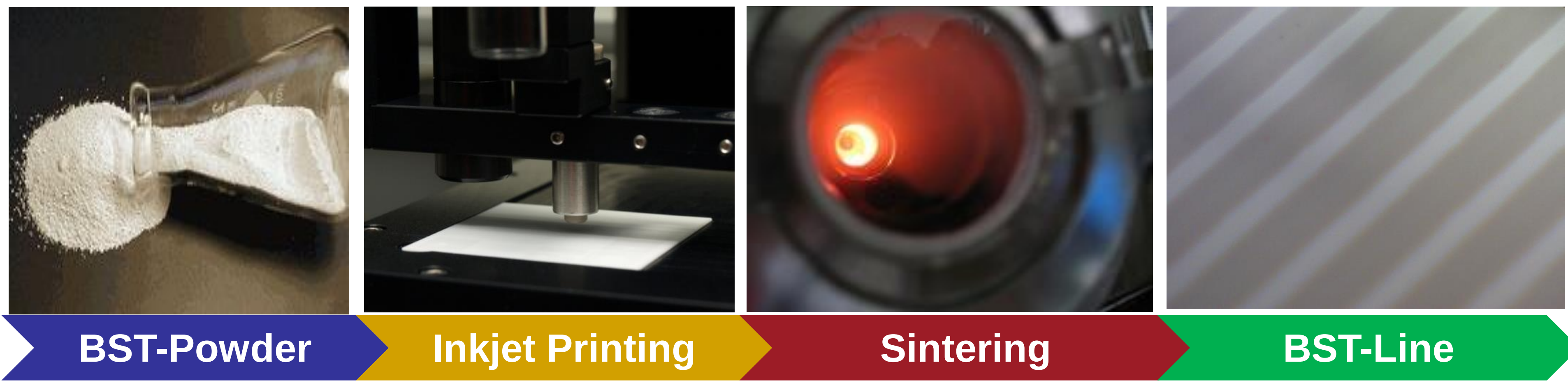
Equivalent circuit of the MIM varactor

Inkjet Printing of BST

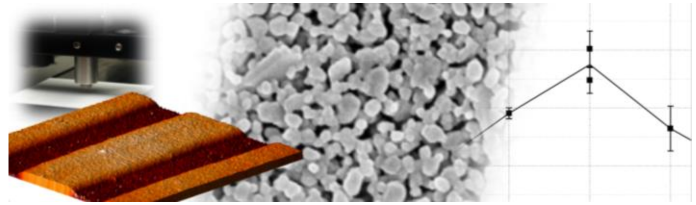


➢The inkjet printing technology:

- Selective BST material printing
- Flexible fabrication process
- Simultaneous multi material printing option
- Single nozzle printhead with 100µm orifice diameter

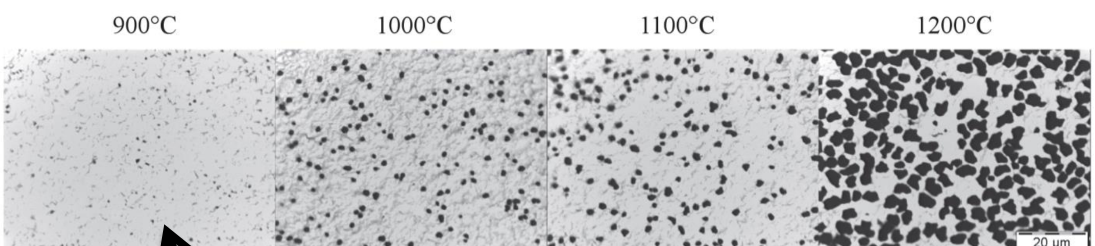


Inkjet Printing of BST

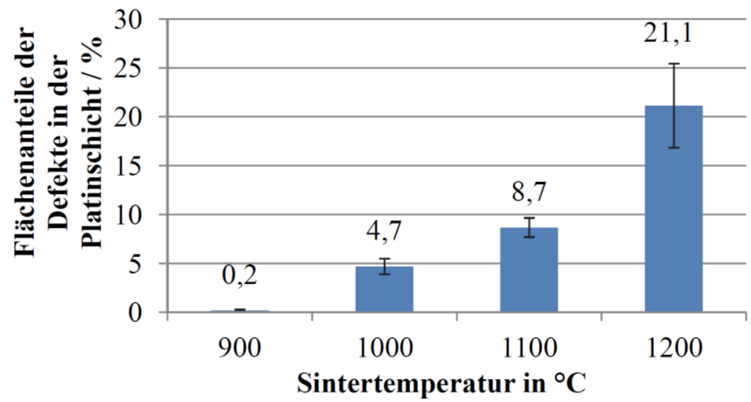


- The inkjet printing technology:
  - Selective BST material printing
  - Flexible fabrication process
  - Simultaneous multi material printing option
  - Single nozzle printhead with 100µm orifice diameter

- Degradation of the platinum layers
  - The increase in the number of defects in the platinum layer (200nm) on top of Al_2O_3 substrates (sintered 1h) at different sintering temperatures.



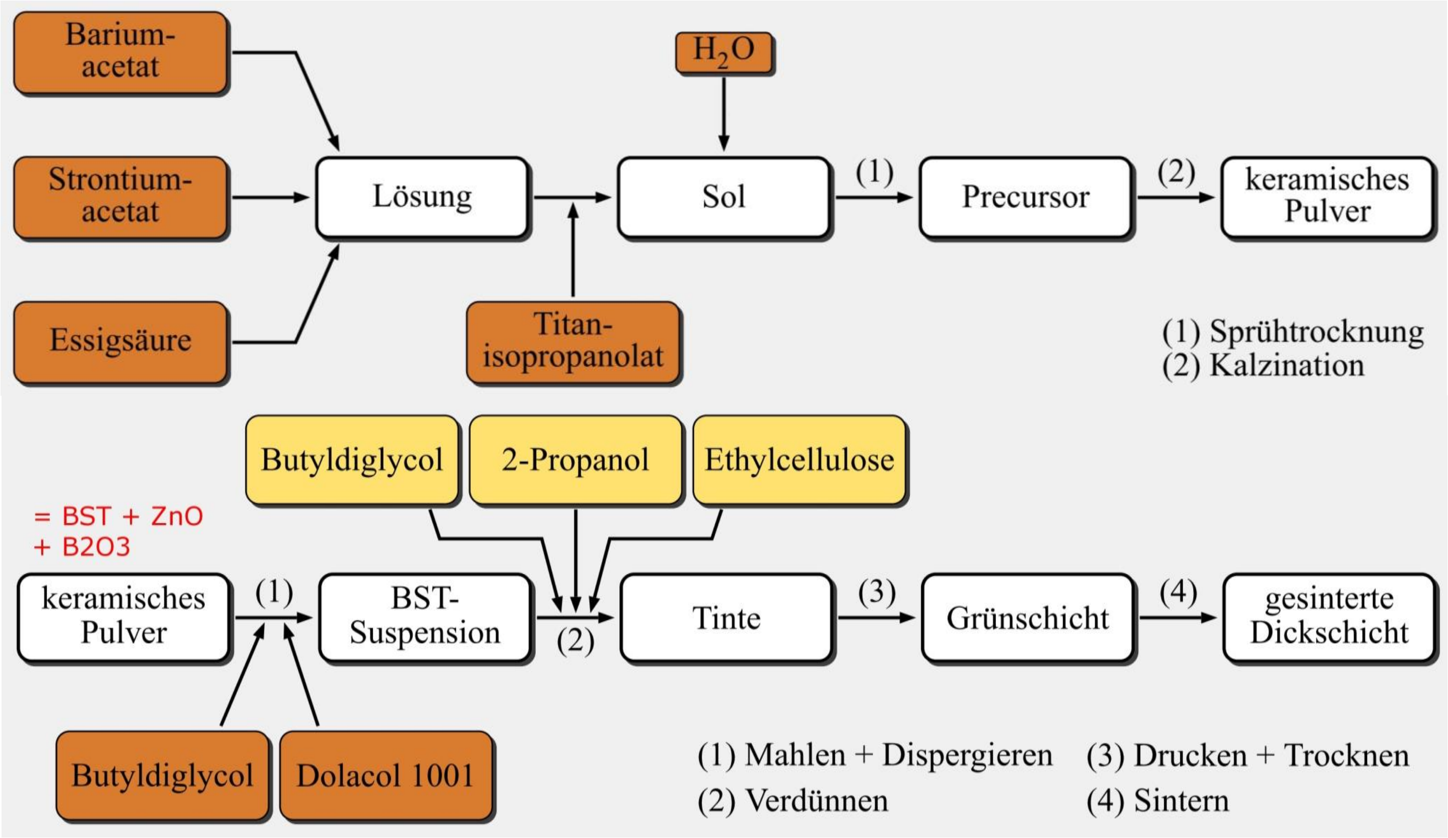
Taken with light microscope at 1000 × magnification



- Goal:
  Reducing BST sintering temperature below 900°C

Inkjet Printing of BST

- Past preparation for low sintering BST thick-film:

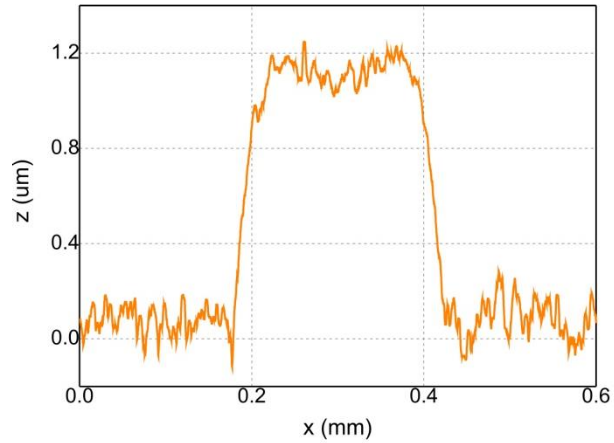


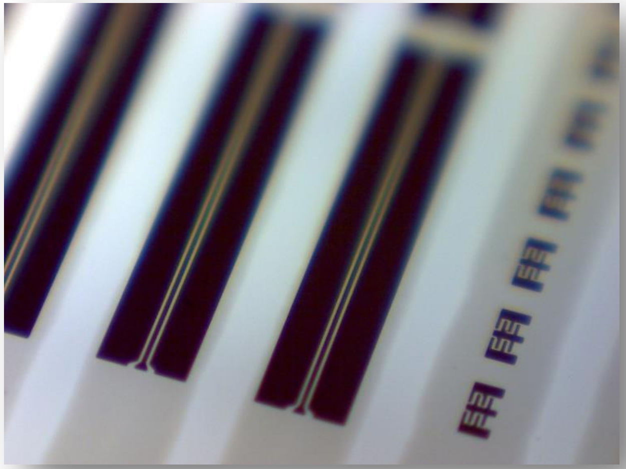
C. Kohler "Effects of ZnO–B_2O_3 Addition on the Microstructure and Microwave Properties of Low-Temperature Sintered Barium Strontium Titanate (BST) Thick Films"

Inkjet Printing of BST

➢ 850°C sintered BST inkjet printed line characterization by IDC:

- Topography of an inkjet printed BST line, dried at T = 50°C and sintered at T = 850°C
- Patterned CPW on top of the printed BST line. The minimum gap of the CPW is 10µm.
- CPW line has been measured by on-wafer probes



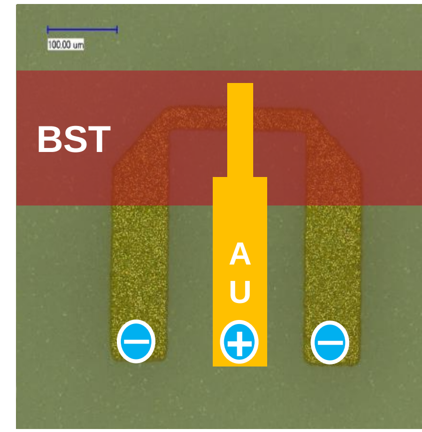


The characteristics of inkjet printed BST film:

Freq	10GHz
Permittivity	133
Tunability	23%(10V/µm)
Loss Tangent	0.07

photolithography process

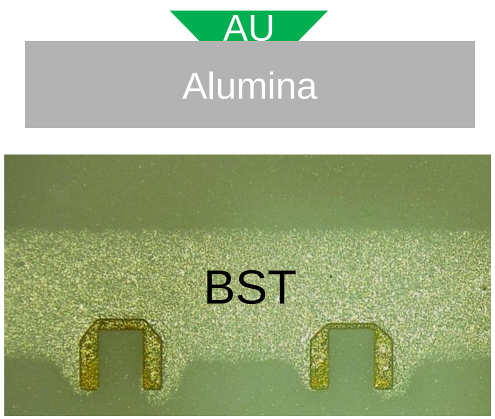
Metal Isolator Metal Capacitors (MIM):

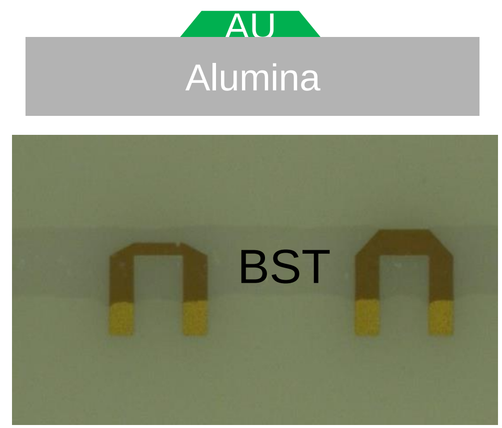


- MIM capacitor by using photolithography process
  - Minimum line wide 10um
  - Cr/Ni as a seed layer because of 850° sintering temperature

    chrome-nickel/gold (20nm/60nm) seed layer

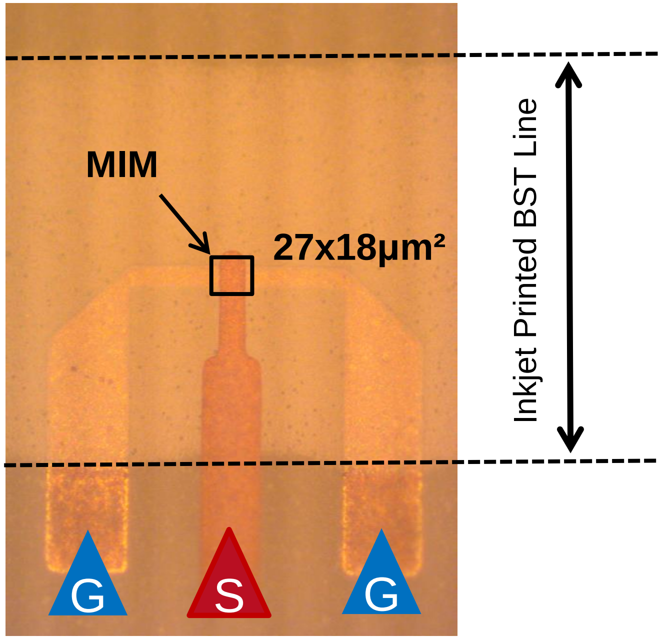
- Bottom electrode edge angle influence:
  - Electroplating by Positive Photoresist
  - Electroplating by Negative Photoresist





Prototype of The MIM Varactor

- Multilayer structure by Metal Isolator Metal (MIM) capacitor
  (1.2um bottom layer)
  - Alignment was done using a fiducial camera system and alignment markers which were applied together with the bottom electrodes
  - GSG with 150µm pitch were used to contact the component



Measurement Results

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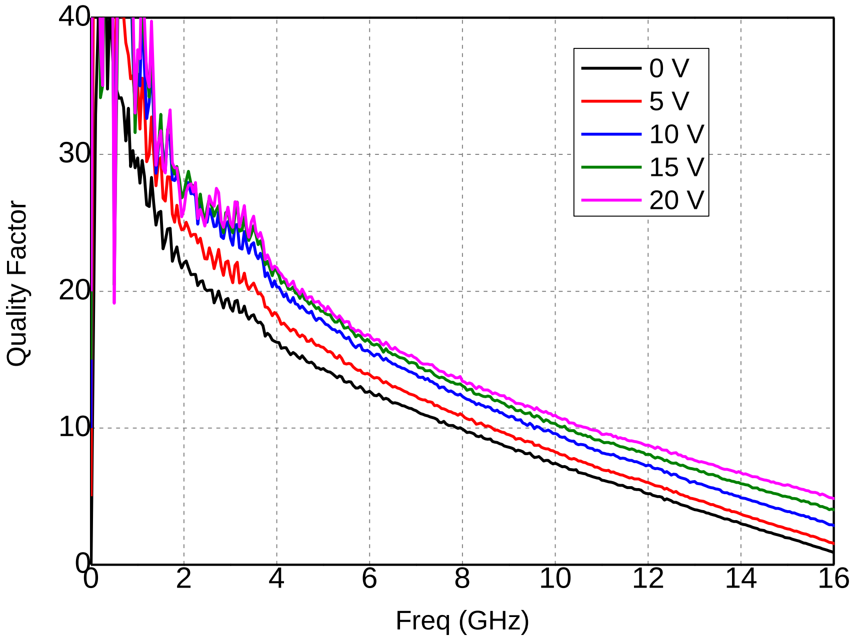
- Measurement result of Multilayer structure by Metal Isolator Metal (MIM) capacitor
  - The biasing voltage has been applied by bias-tee at the RF-port



The Quality factor of the MIM varactor in different biasing voltage

	10GHz
Capacitance	0.75pF
Quality factor	8(Lt 0.12)
Permittivity	200
Tunability	37%(20V/µm)
Maximum Tunability	70%(100V/µm)
Maximum Leakage Current	0.03mA

Biasing voltage significantly reduced

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➢ Conclusion

- The realization and measurements of an inkjet-printed tunable MIM varactor
- The tuning voltage is significantly reduced
- The tunability of 37 % was reached at 20 V biasing voltage (maximum 75%)

➢ Outlook

- The fabricated MIM capacitor demonstrates a simple and flexible preparation
- The quality factor of 8 is achieved at 10GHz which can be increased by reducing conductor and BST layers loss
- Future tunable microwave components based on inkjet printing

Thank you for your attention

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