Ferroelectrics

Material Properties, Processing, and Microwave Applications

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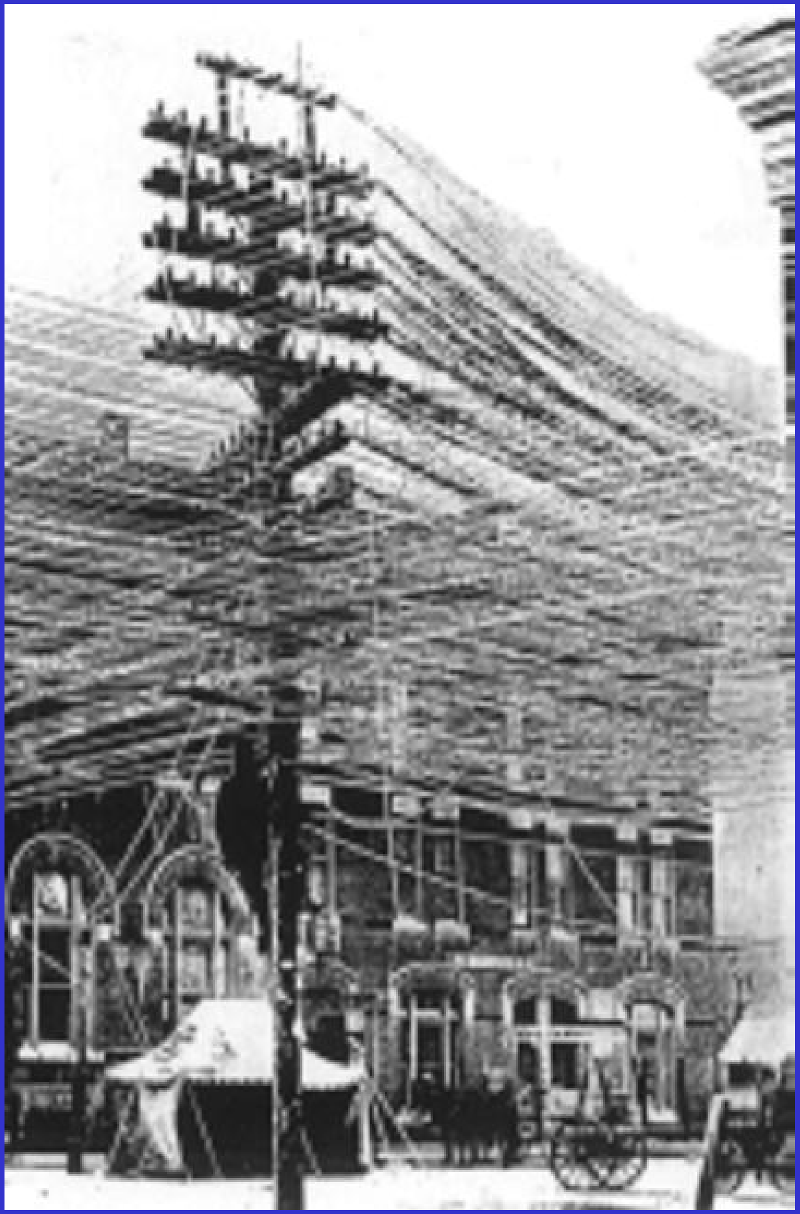
Norwegian IEEE MTT/AP Chapter
SINTEF, Trondheim, March, 2006

CHALMERS

Outline

- ♣*Introduction*
- ♣*Materials (Bulk, Thick and thin Film)*
- ♣*Devices and Circuit Applications*
- ♣*Concluding Remarks: Problems and Perspectives*

What is this about?



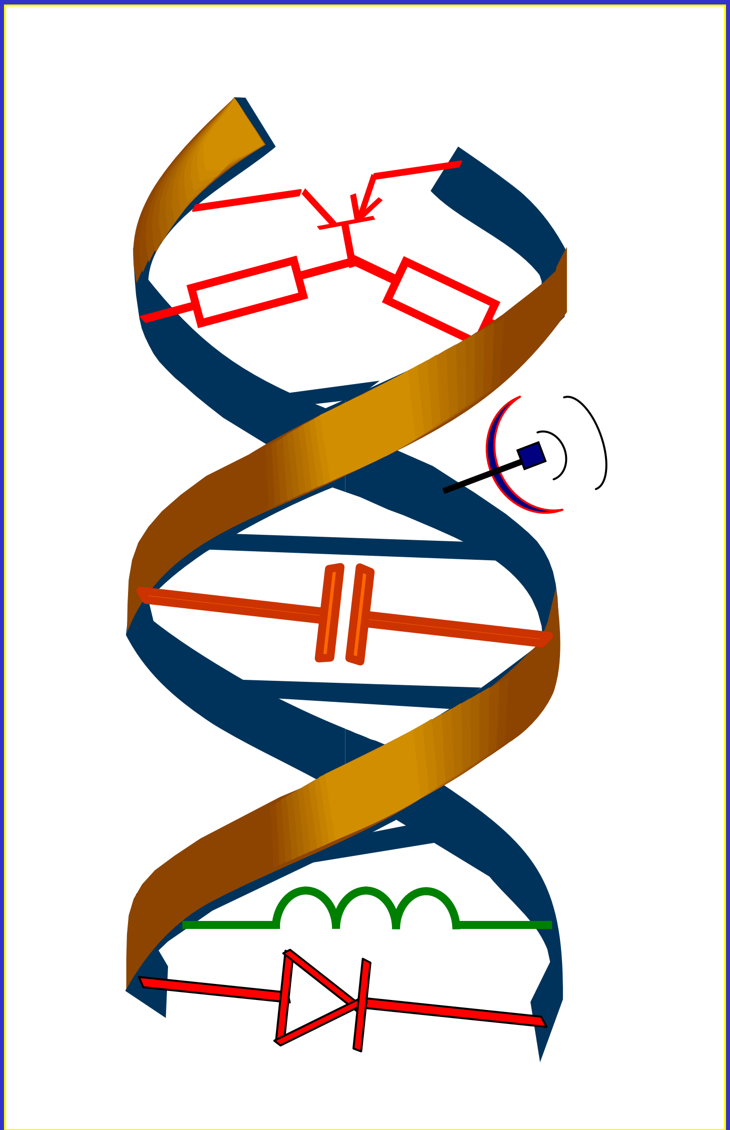
Wired

Communication

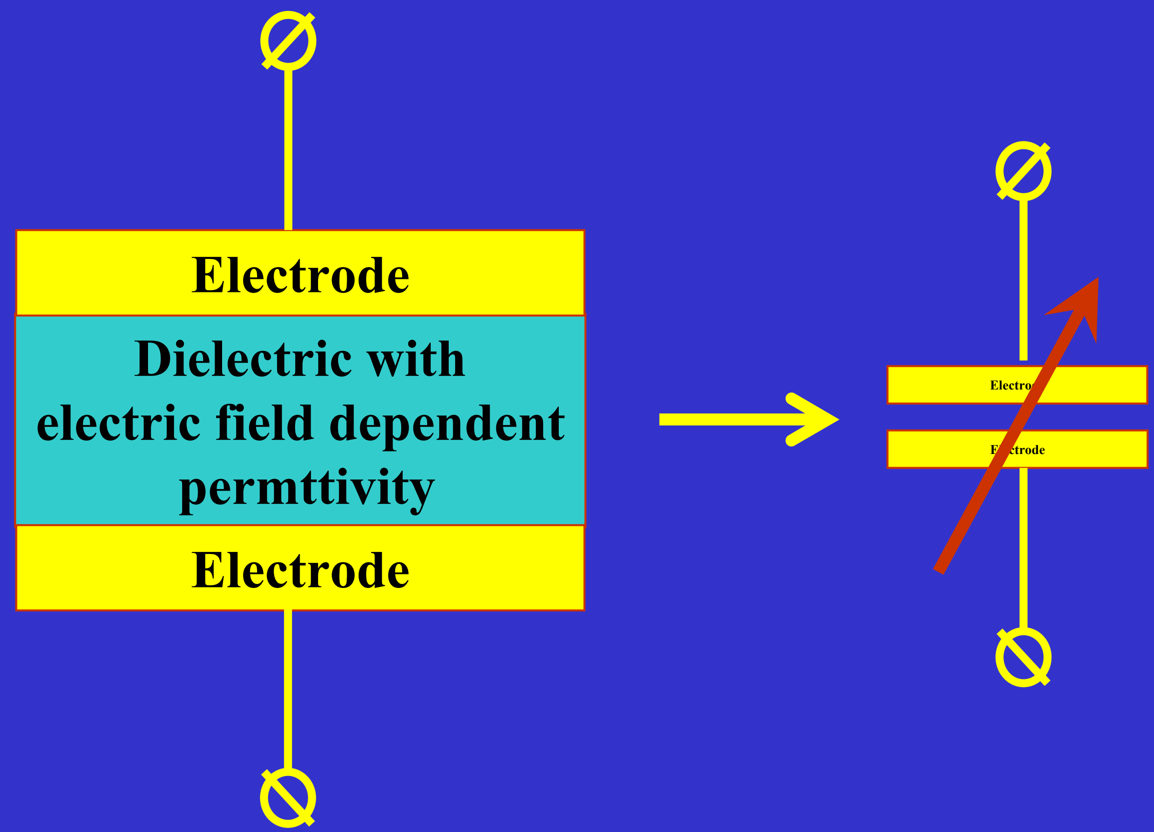
New York 1921

Wireless
Communication
Gothenburg,
Sweden 2001

Electronics DNA: Search for components with enhanced performances



Ferroelectrics: Multifunctional Dielectrics



Ferroelectric Compositions Considered for Microwave Applications

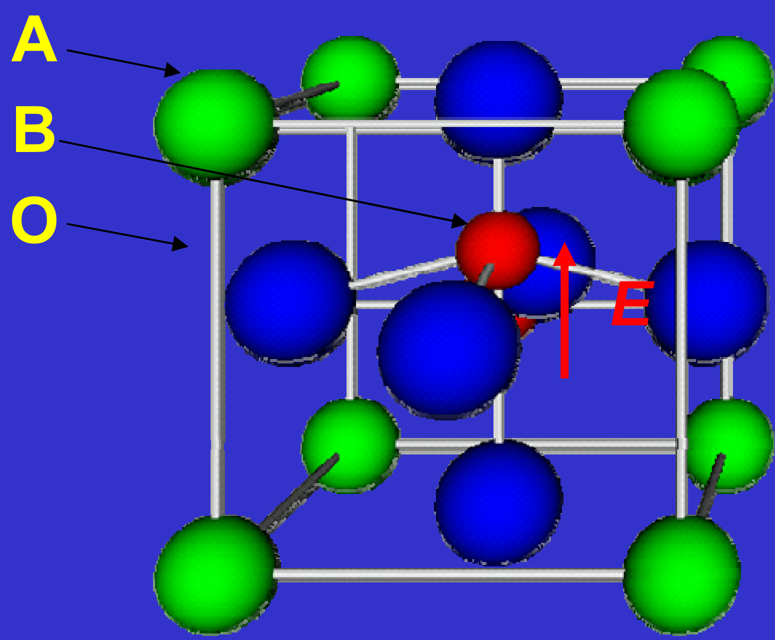
ABO_3 Perovskites:

$Ca_xSr_{1-x}TiO_3$
$K_xLi_{1-x}TaO_3$
$K_xNa_{1-x}NbO_3$
$Pb_xZr_{1-x}TiO3$

→ **$\underline{Ba_xSr_{1-x}TiO_3}$**
x=0 -1

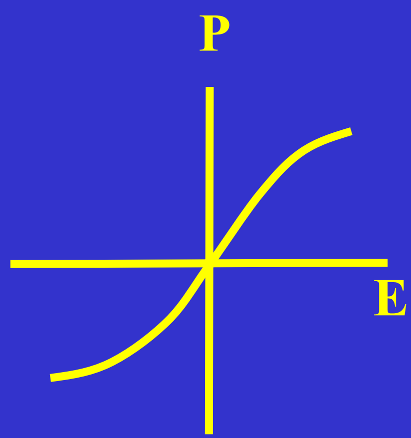
Ferroelectric (polar) and paraelectric phases

Polarization of Paraelectric Perovskites

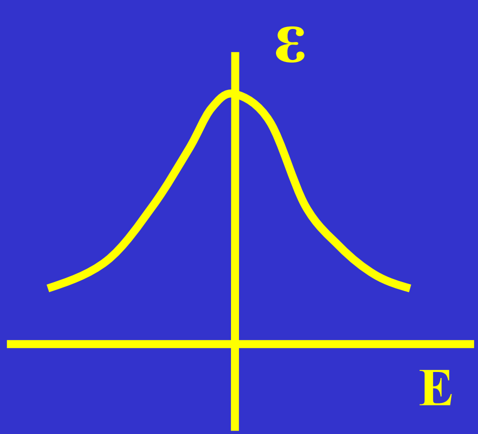


$$T = \frac{\varepsilon(0) - \varepsilon(E)}{\varepsilon(0)}$$

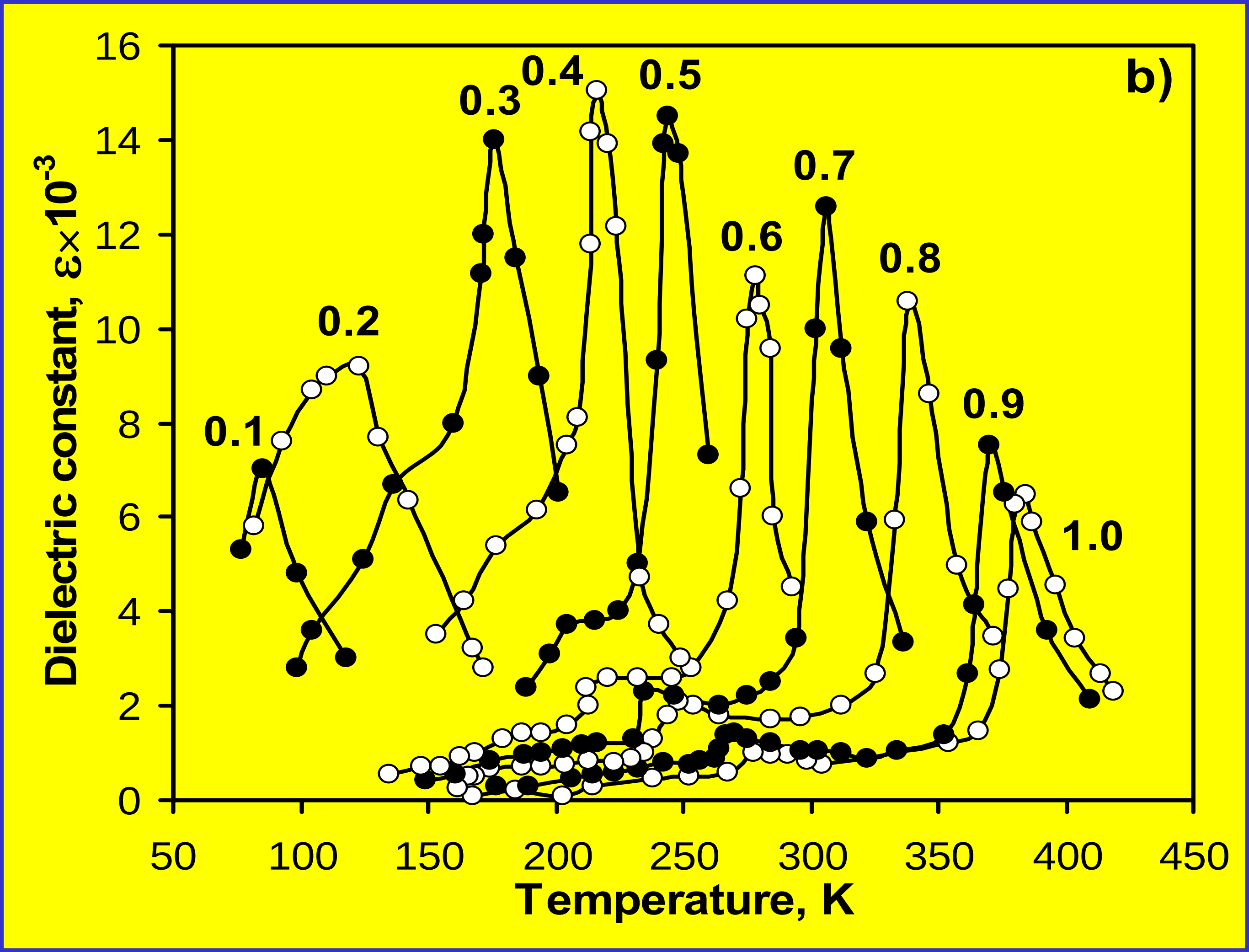
Nonlinear polarization



Field dependent permittivity

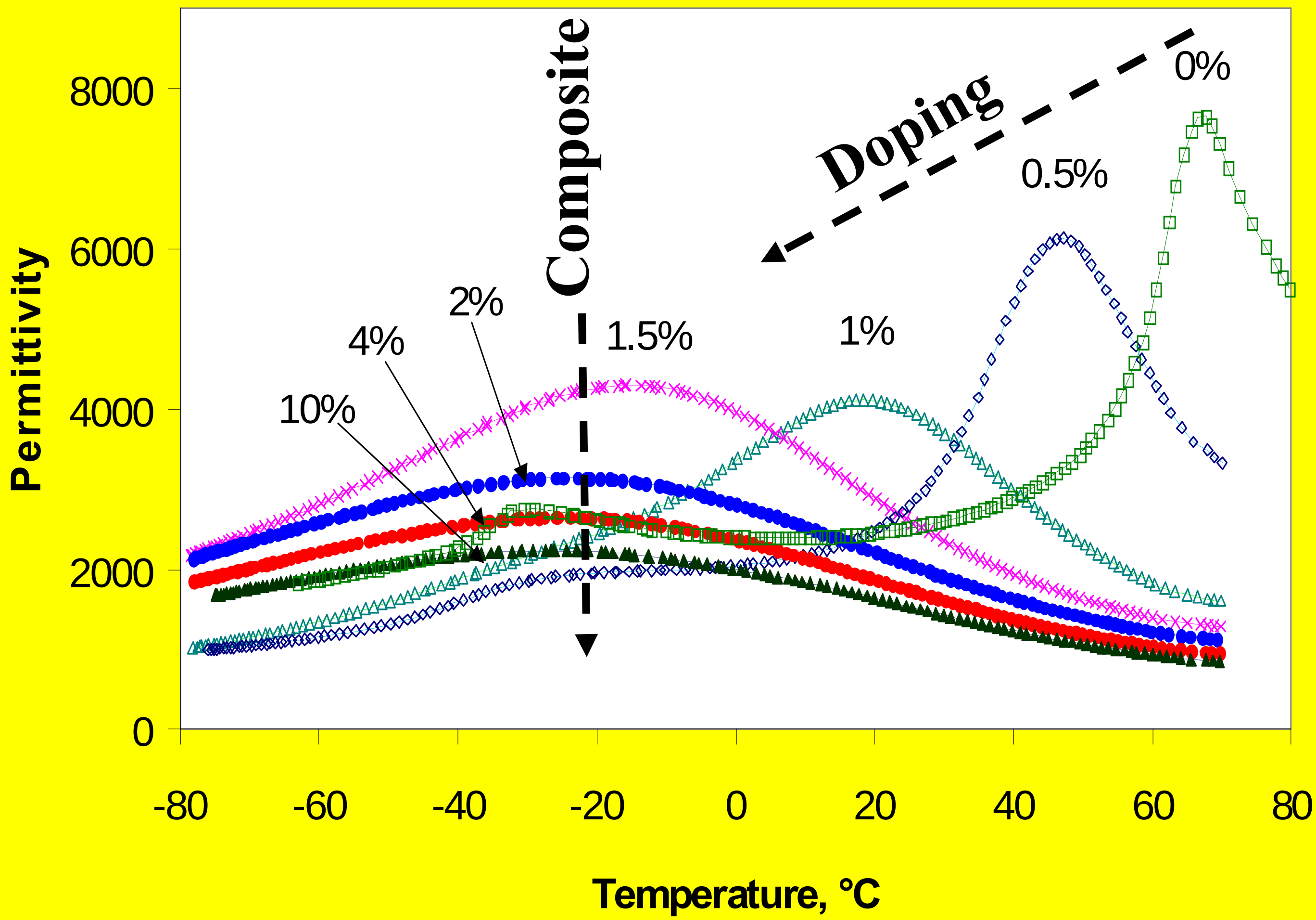


$Ba_xSr_{1-x}TiO_3$(BST) at Room Temperature $x=0.1-1.0$



Smolensky & Isupov (1954)

$Ba_{0.8}Sr_{0.2}TiO_3$+MgO. MgO: 0-10%
From Doping to Composite



Su & Button (2004)

Ferroelectrics- Features Attractive for Microwave Applications-1

Dielectric properties:

Permittivity ε (100-20000) -	**small size devices:**
	Size ~1/ $\sqrt{\varepsilon}$
Electric field dependent -	**tuneable and**
	nonlinear devices
Loss tangent tanδ-	**typically 0.0001-0.05**
Tuning speed-	**< 1.0 ns**

Ferroelectrics- Features Attractive for Microwave Applications-2

Electrical properties:

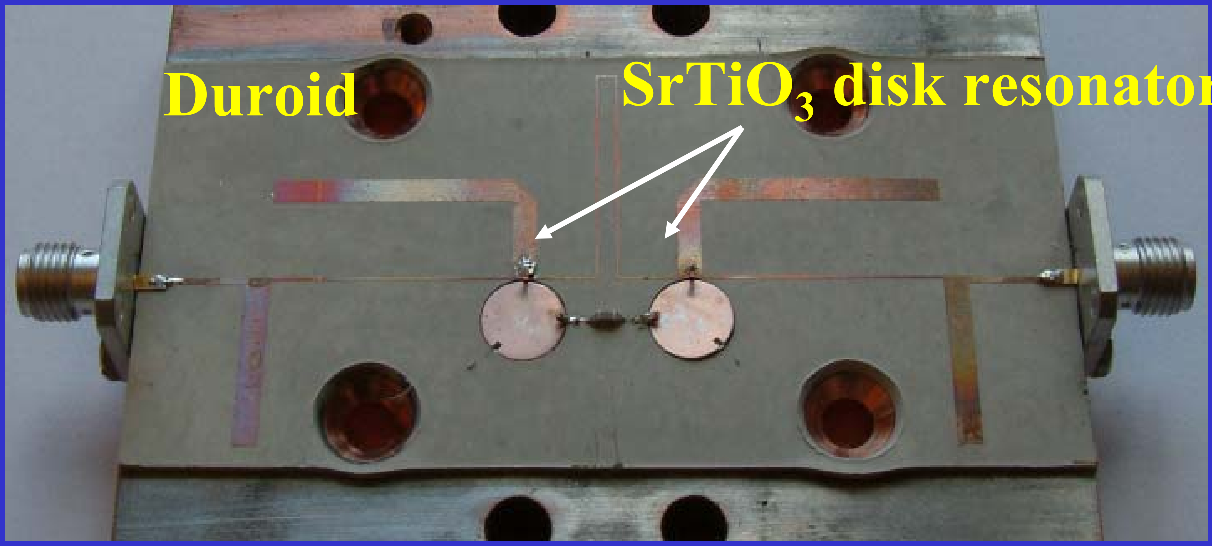
Resistivity-	**undoped >10 $^{8-}$ 10 ^{10} Ohm cm**
Leakage currents-	**extremely low**
Breakedown field-	**>50-100 kV/cm**
Metalic conductivity-	**if highly doped (transparent electrode)**
Bandgap-	**Eg>3.0 eV**
Mobility-	**2D electron gas at low temperature-15000cm^2/Vs**

Ferroelectric Material Technologies Considered for Microwave Device Fabrication

- ♣ Bulk- single crystal and ceramics
- ♣ Thick film- HTCC, LTCC
- ♣ Thin film- single crystal polycrystalline

Bulk Single Crystal ($SrTiO_3$)

Four Pole Tuneable Bandpass Filter Based on $SrTiO_3$ Discs



$SrTiO_3$ disks

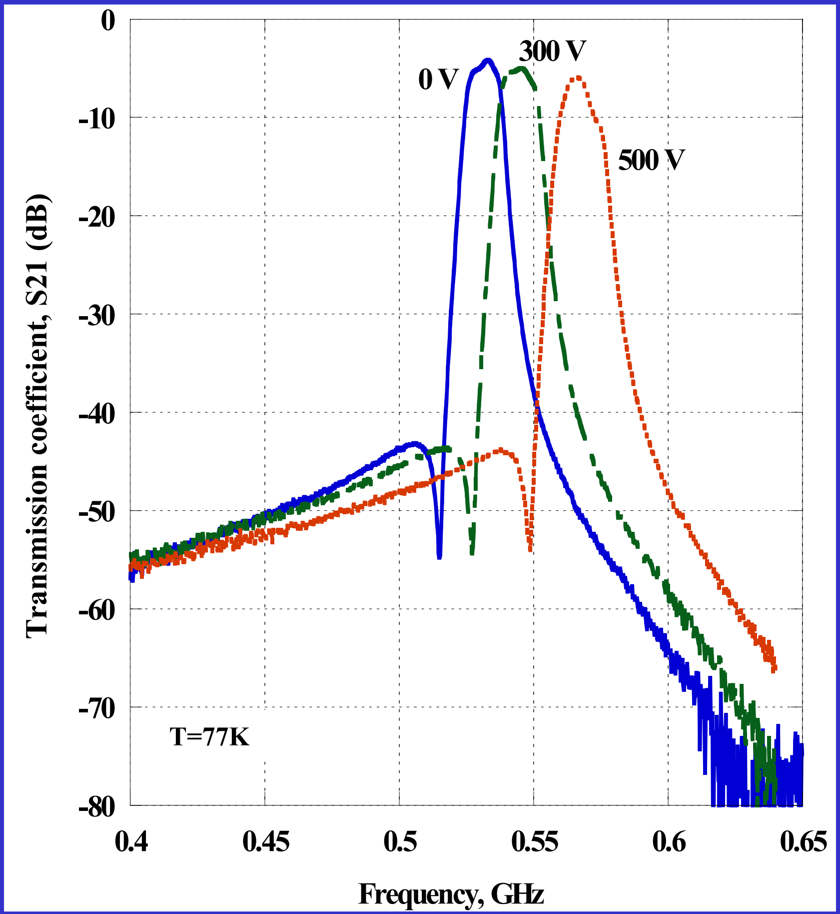
Diameter: 7.0 mm

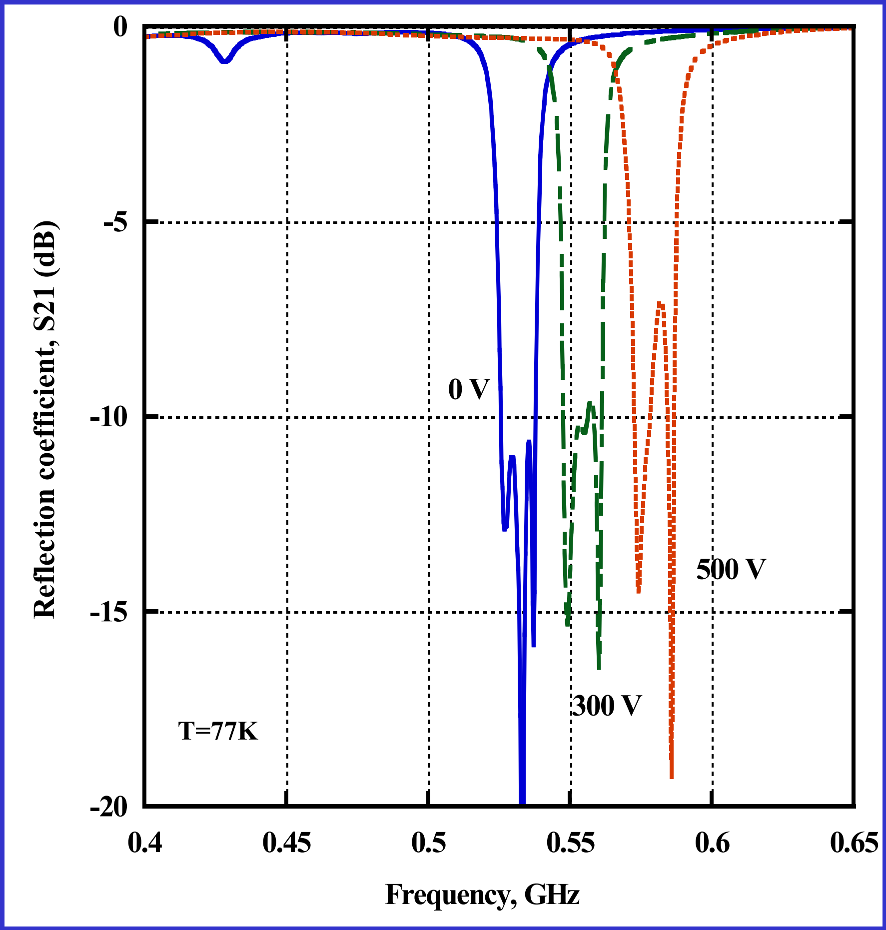
Thickness: 0.5 mm

Plates: Cu/Ti

Deleniv et. al. Proc. EuMC'2002

Four Pole Tuneable Bandpass Filter Based on $SrTiO_3$ Discs





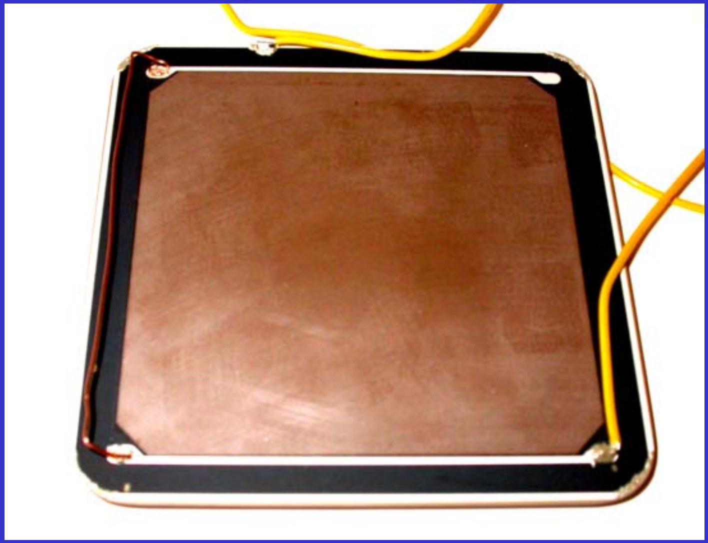
3 dB bandwidth-2.0%;Tuneability-8%; Losses-4.0 dB

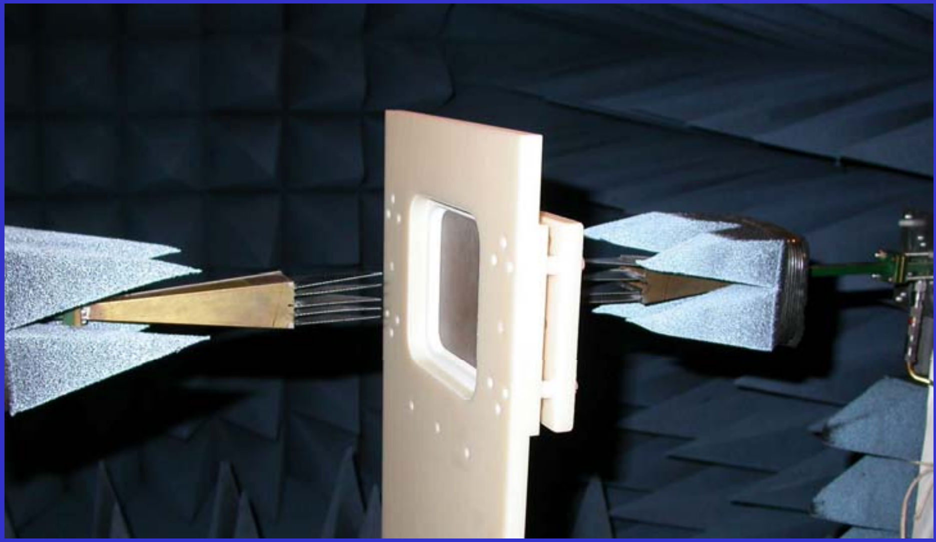
Deleniv et. al. Proc. EuMC'2002

Bulk Ceramic $Ba_xSr_{1-x}TiO_3$

(Project MELODY)

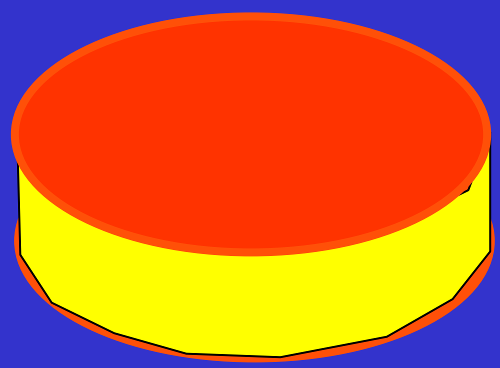
Beam Steering Lens

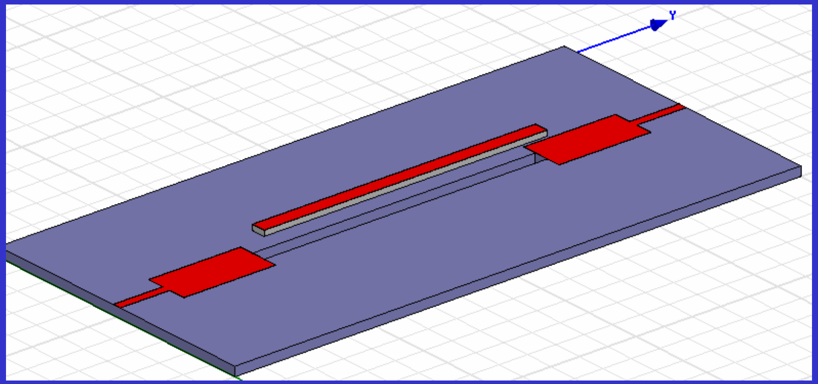


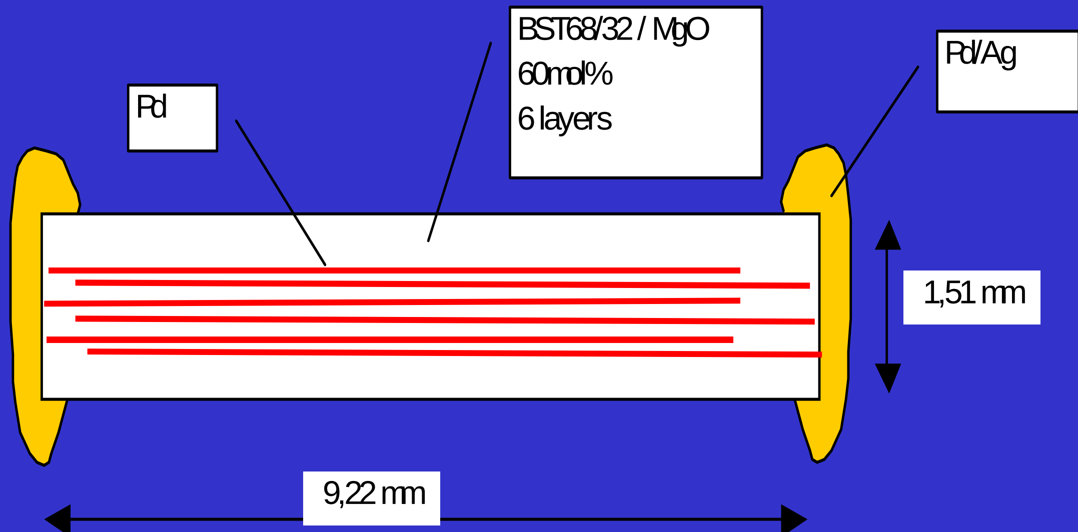


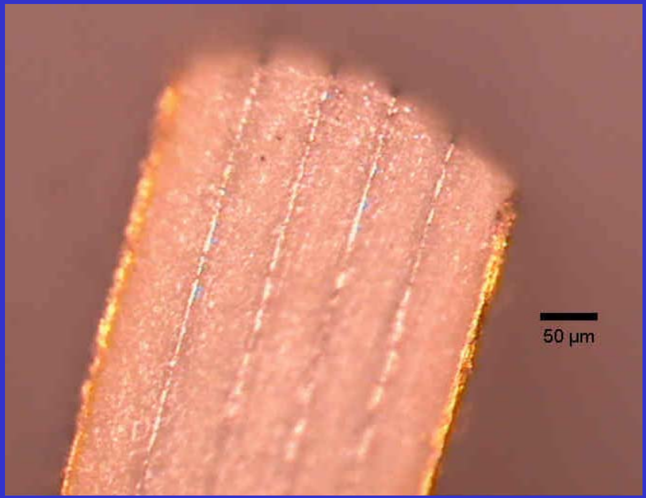
Tageman et. al. Proc. EuMC’2005

Tuneable Chip Components: Resonators Capacitors and Delay Lines





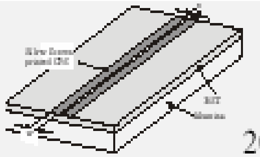
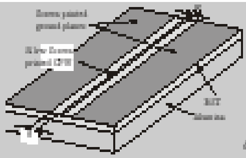
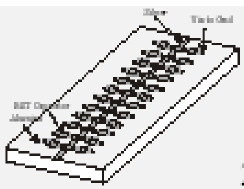
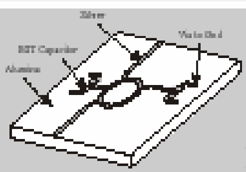
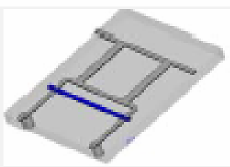




LTCC and HTCC $Ba_xSr_{1-x}TiO_3$

(Project MELODY)

HTCC Phase Shifters in Project MELODY

Phase shifter type	f_0(GHz)	Circuit layout and size(in mm*mm)	Insertion Loss(dB)	$\Delta\Phi$(degree) $\vert_{100V}$	Biasing field(V/µm) $\vert_{100V}$	FOM (degree/dB)	Estimated CQF* of the capacitor
Coupled Strip Line	30GHz	 20*10	-2.5dB (averaged)	20°	1 V/µm	6-7°/dB	1.125(f=30GHz) (with conductor loss)
Coplanar waveguide	26GHz	 40*20	-40dB (averaged)	>400°	2V/µm	12°/dB	3.306(f=26GHz) (with conductor loss)
Microstrip line loaded by BST capacitors	28GHz	 20*15	-15dB (averaged)	125°	1V/µm	6°/dB	0.826(f=28GHz) (with conductor loss)
Reflection type phase shifter 1	26	 10*10	-10dB (averaged)	20°	1V/µm	1.7°/dB	0.092(f=26GHz) (with conductor loss)
Reflection type phase shifter 2	2.5GHz	 25*15	-2.5dB (averaged)	49°	1V/µm	20°/dB	9.1(f=2.5GHz)** (with conductor loss)

LTCC OBJECTIVES

• **Development of tunable ferroelectric LTCC compositions**

Sintering temperature: <950 ^{o}C

ε=100-1000; tanδ < 0.01 at 2-50 GHz; Tunability >10%

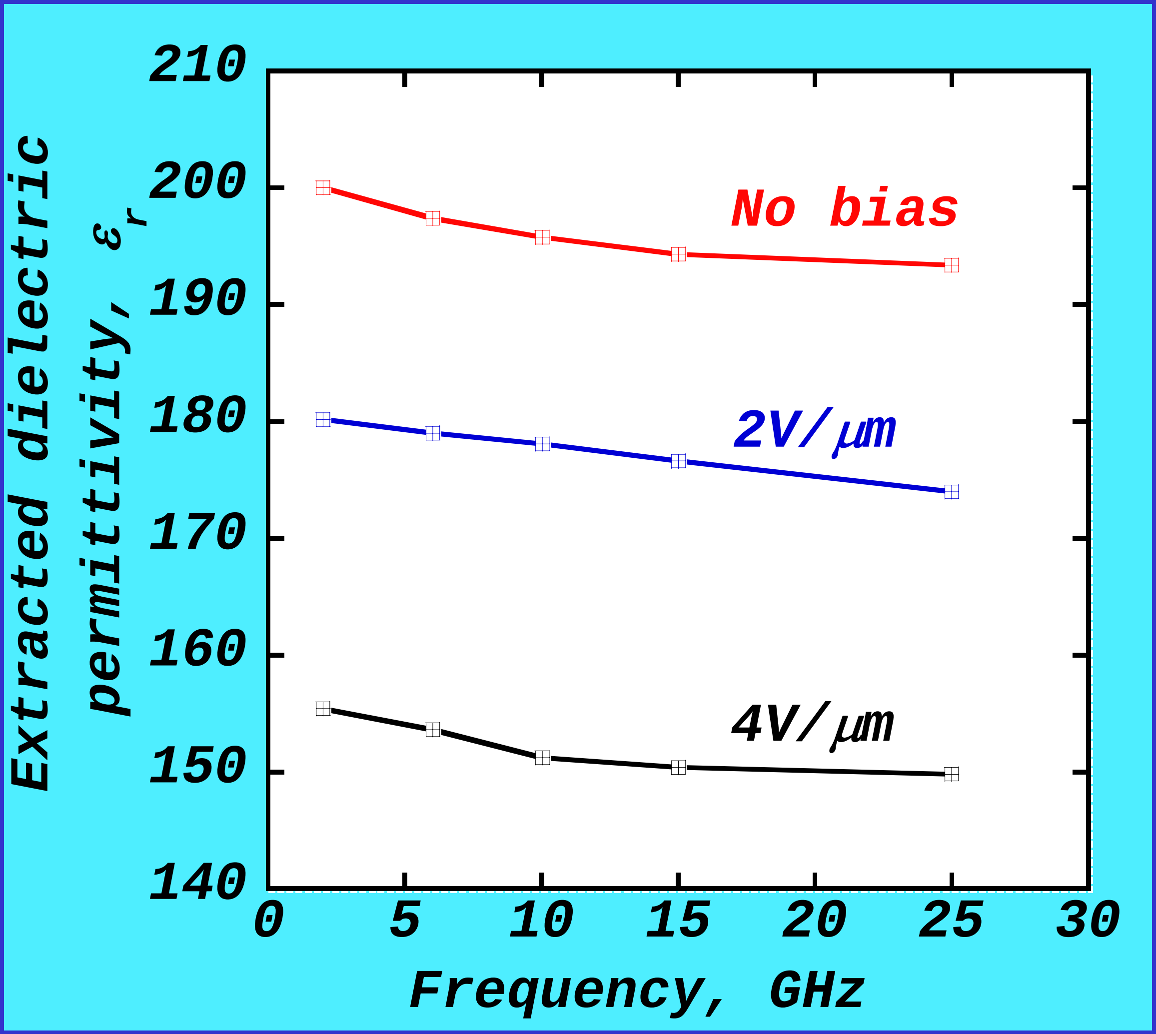
• **Development of processing routes for single and multilayer ferroelectric films with:**

Thickness 5-50 μm; Area 100x100 mm^2

• **Development of fabrication routes for electrodes**

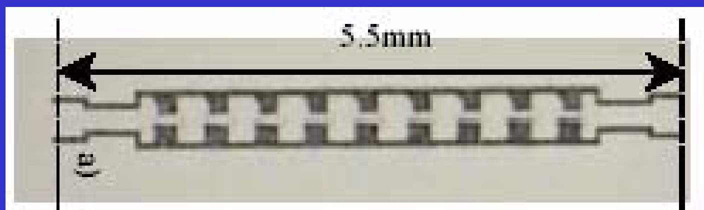
UNIVERSITY of OULU

LTCC BSTO Performance

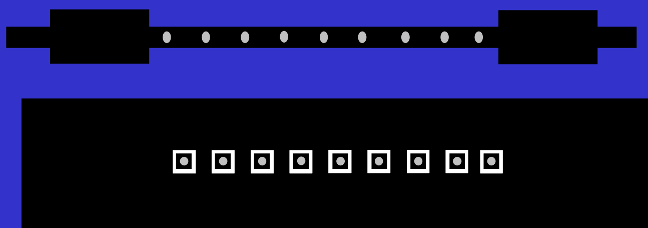


tanδ~f; (~0.12@25GHz)

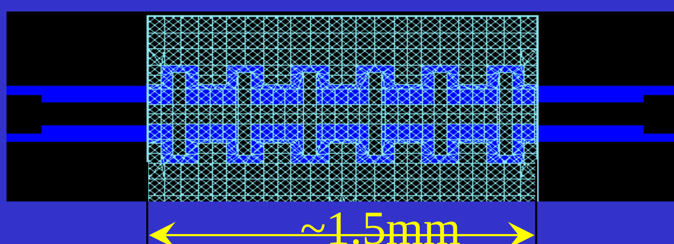
LTCC Phase Shifters in Project MELODY



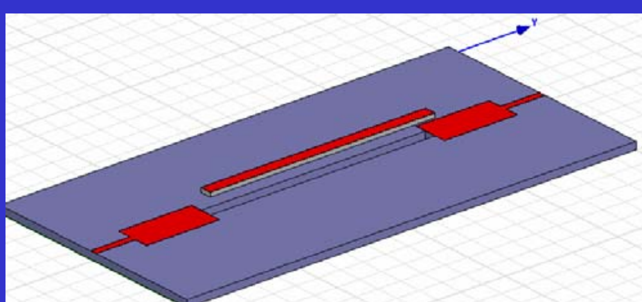
~9deg/dB @25GHz



~20deg/dB @10GHz



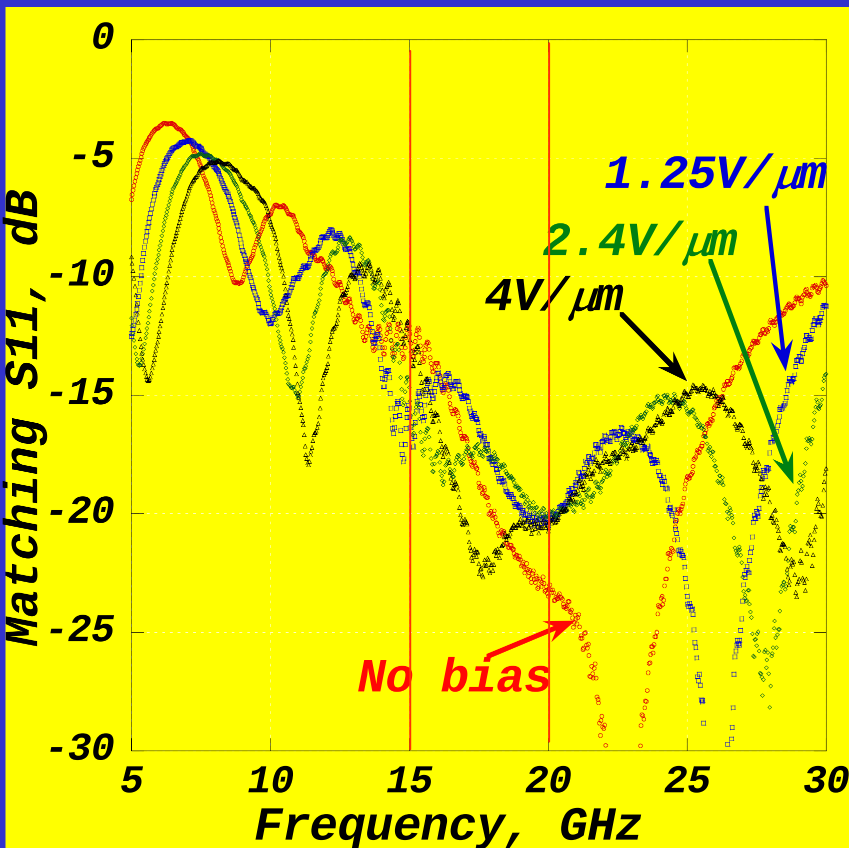
~10deg/dB @25GHz

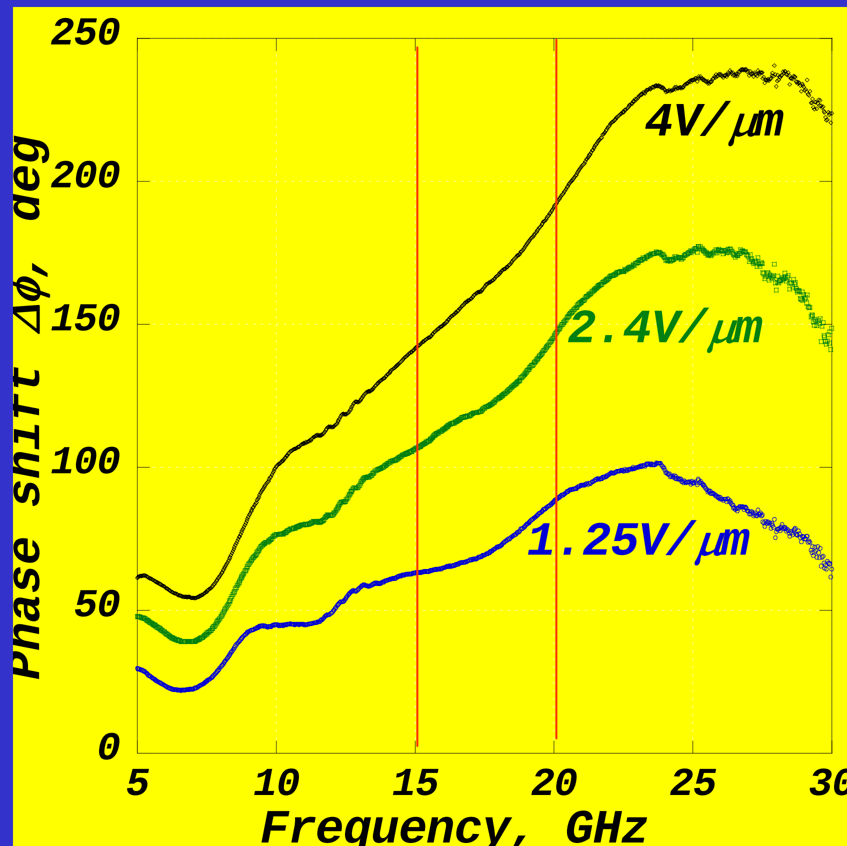


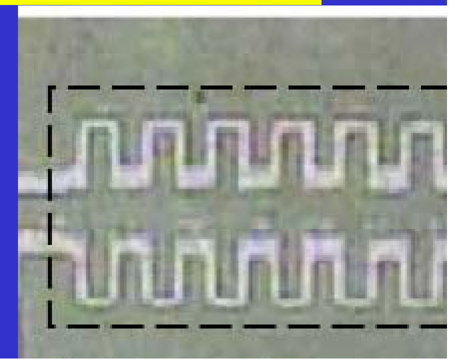
TEMEX

~50deg/dB @3.5GHz

Measured Phase LTCC Shifter Performance

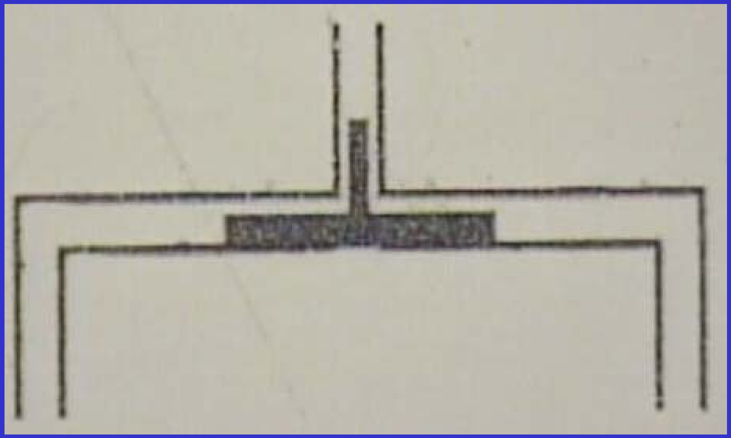




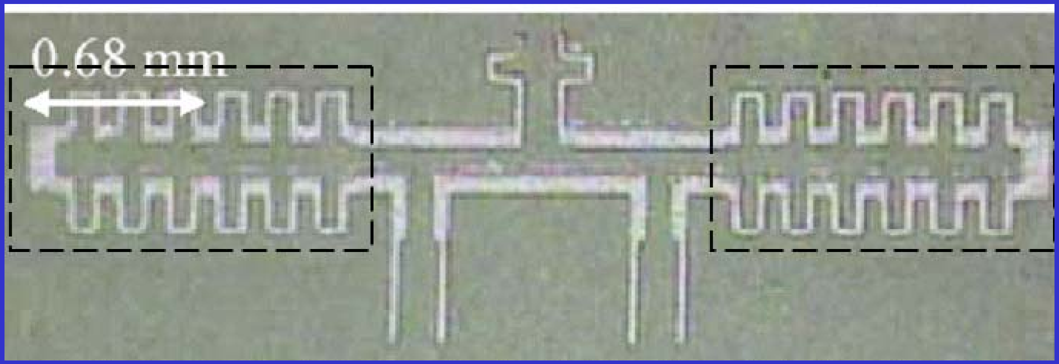


Matching shows
weak dependance on DC biasing!!!

Tuneable Power Splitters

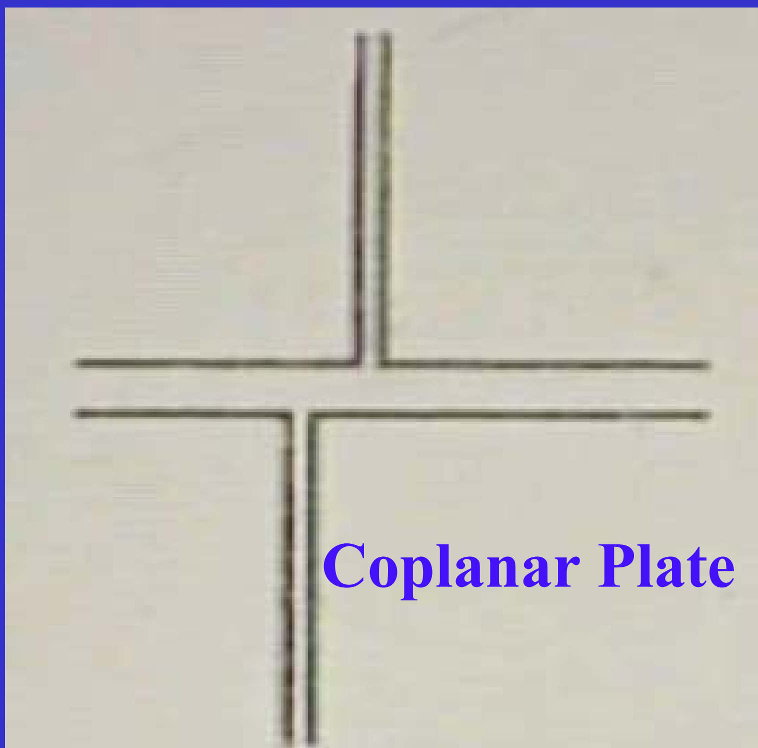


Coplanar Plate (CPS)

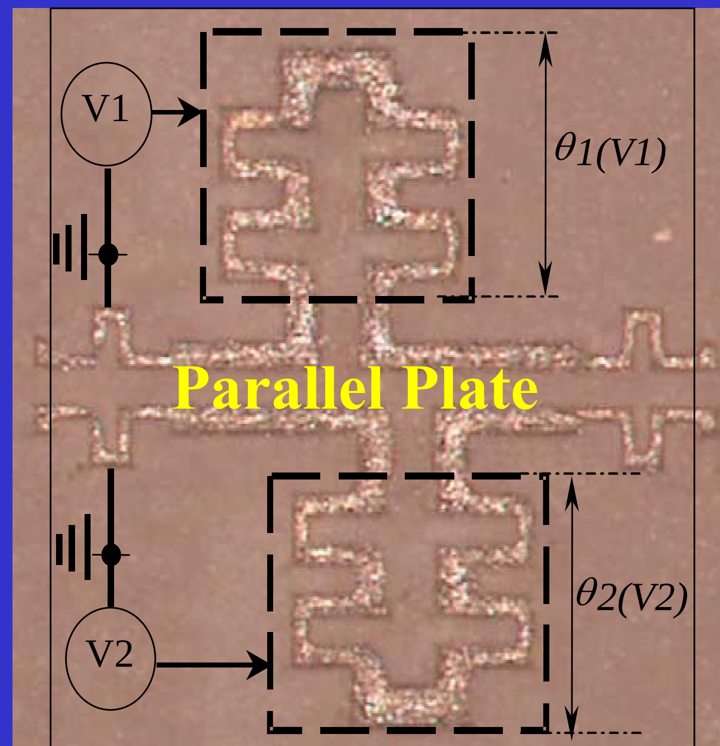


Parallel Plate

Tuneable Matching Networks



Port1



Port2

Thin film $Ba_xSr_{1-x}TiO_3$

(Chalmers)

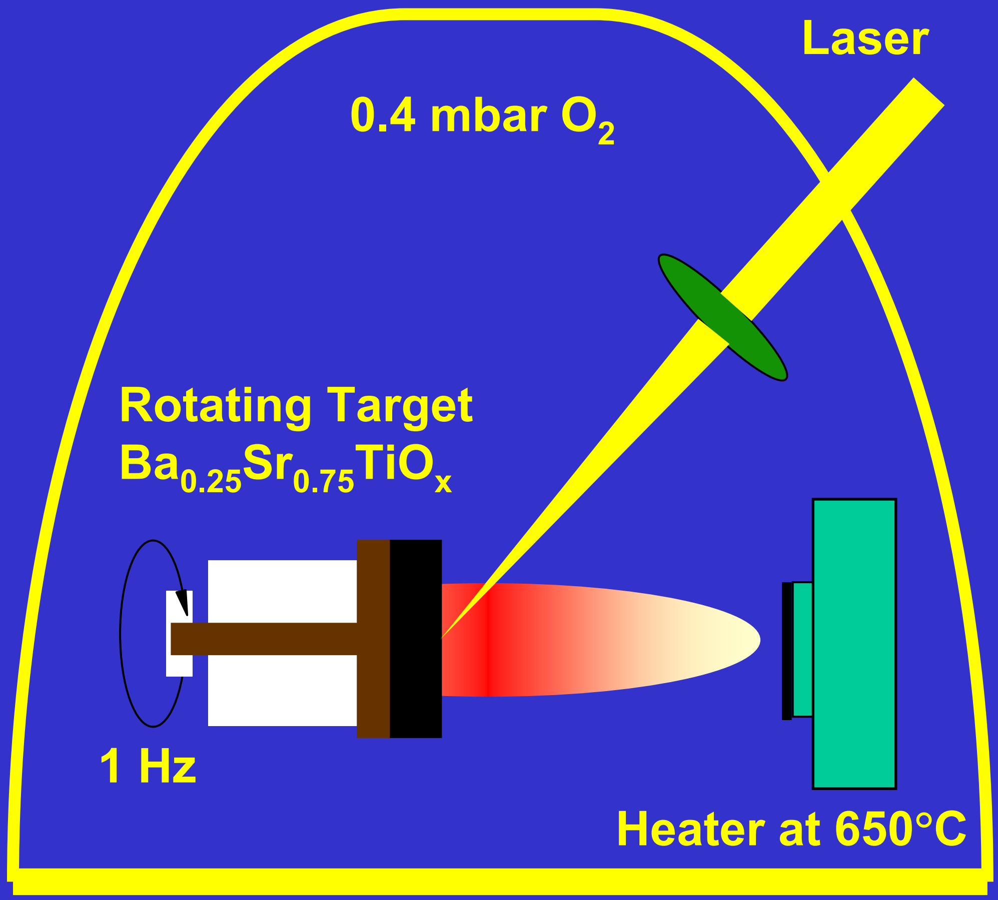
D. Kuylenstierna

M. Norling

A. Vorobiev

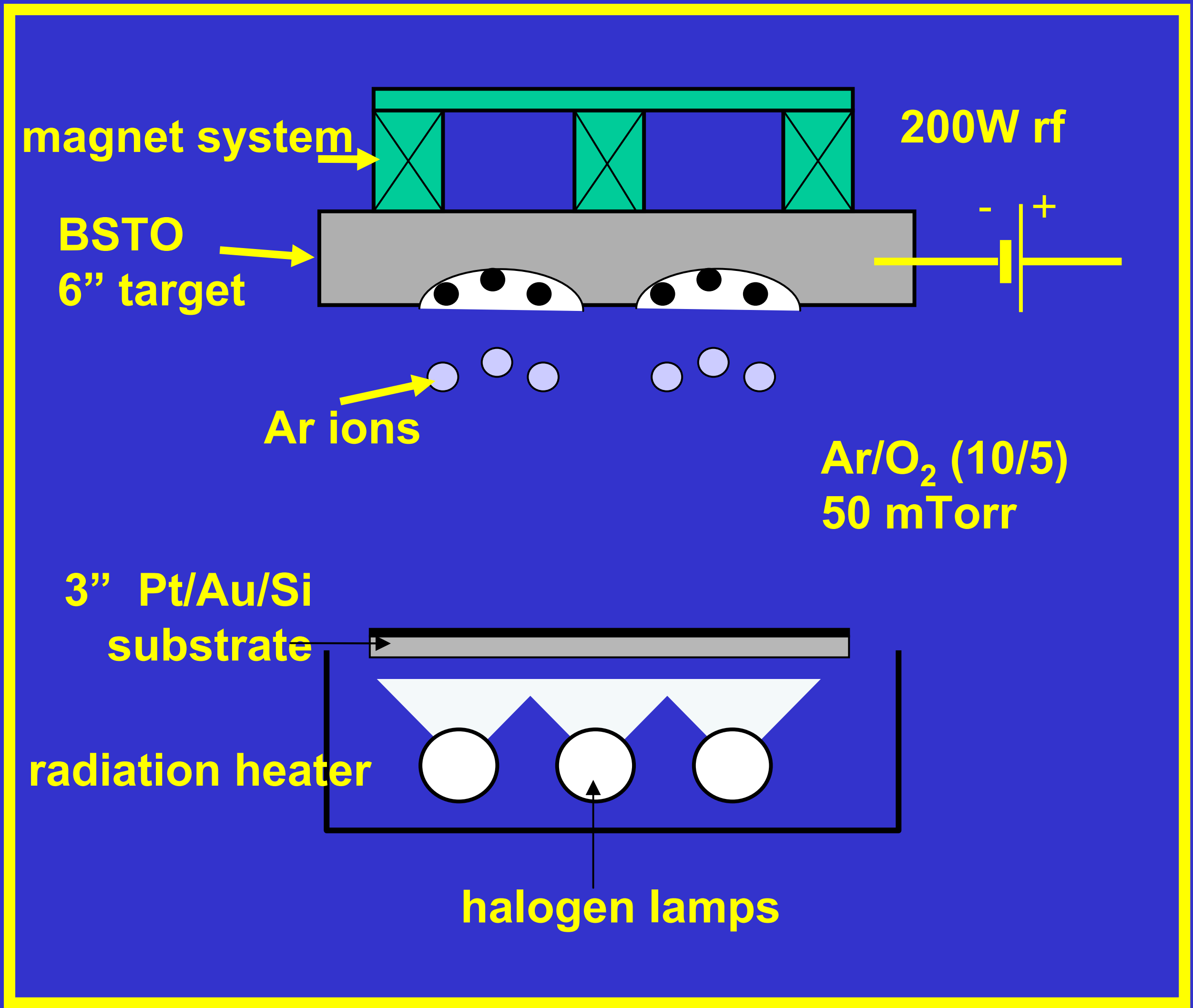
A. Deleniv

Growth of BST films by laser ablation



PLD System -
MC2 Process Lab
Chalmers

Growth of BST films by rf magnetron sputtering



Nordiko 2000 Sputter

Substrates for ferroelectric microwave devices

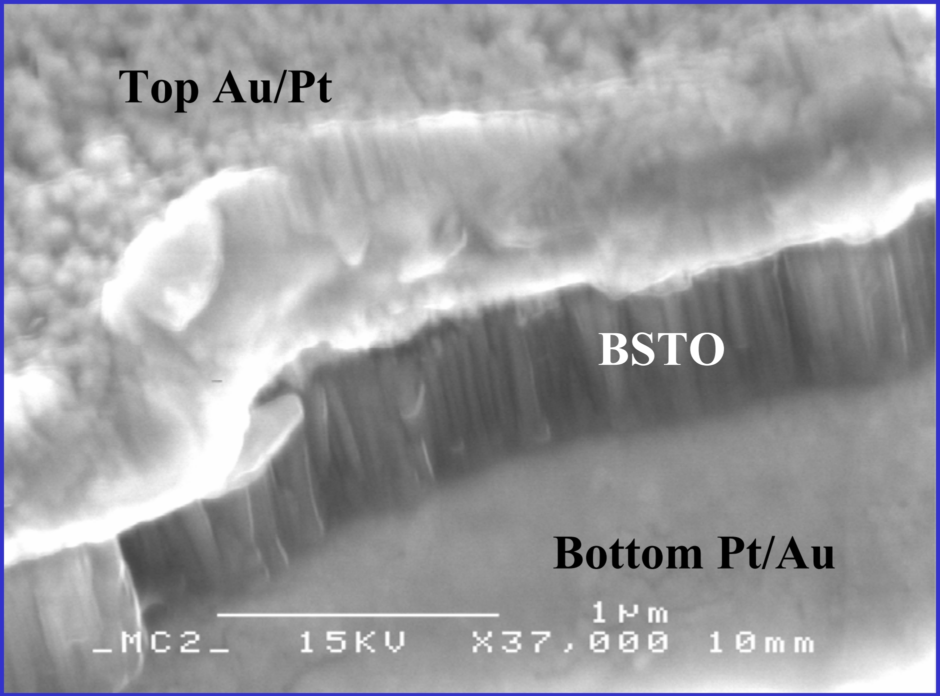
Crystalline: MgO, $LaAlO_3$, Al_2O_3

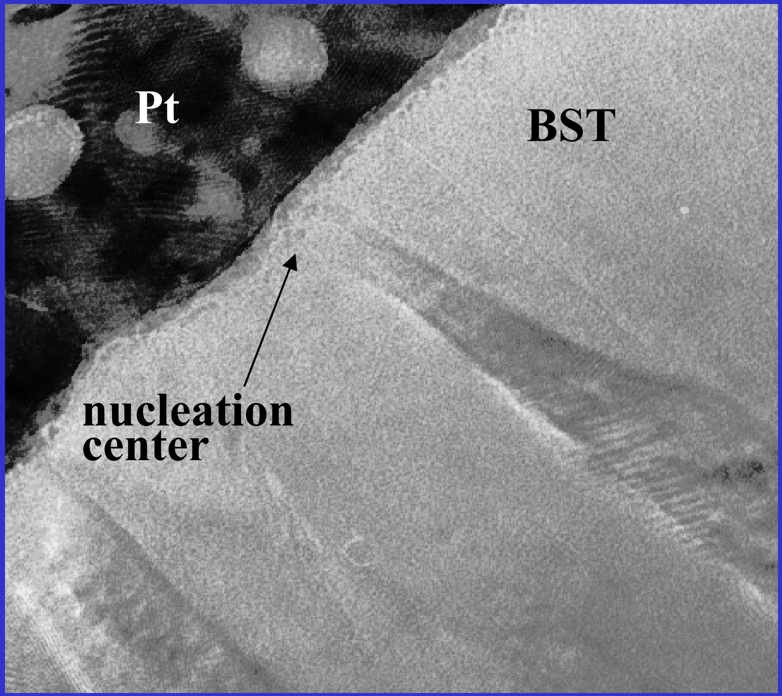
Polycrystalline: Al_2O_3

Amorphous: Oxidized Silicon, Fused Silica

Metal: Pt, Au, Cu (with diffusion stop buffer)

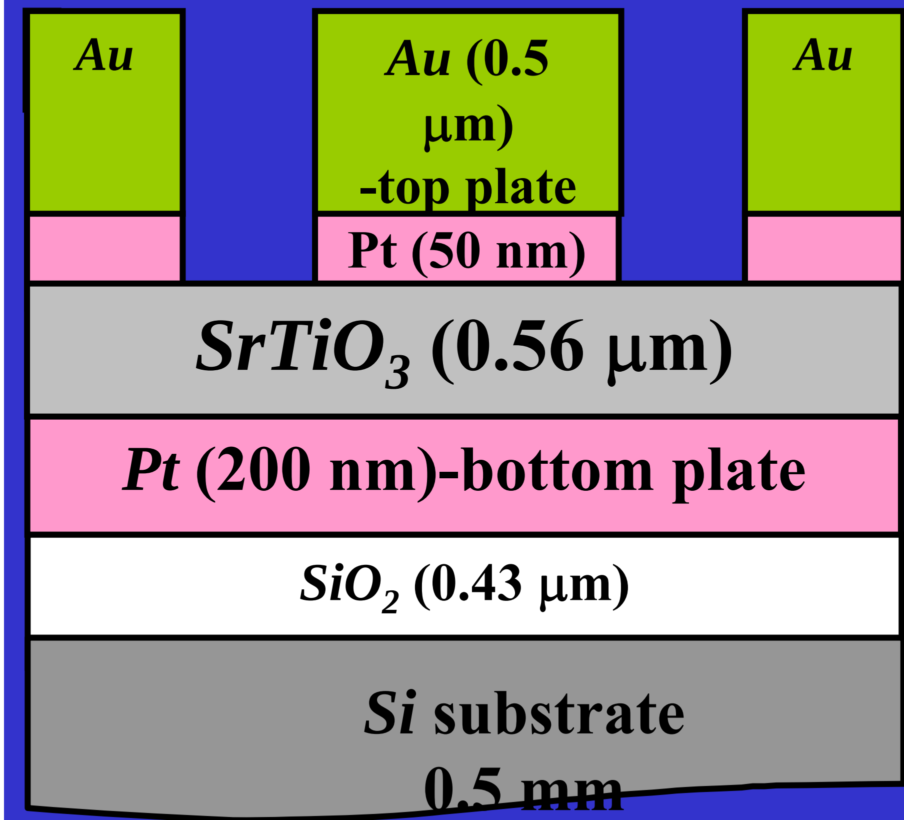
TEM and SEM images of the BSTO films in Thin Film Parallel-Plate Varacotors

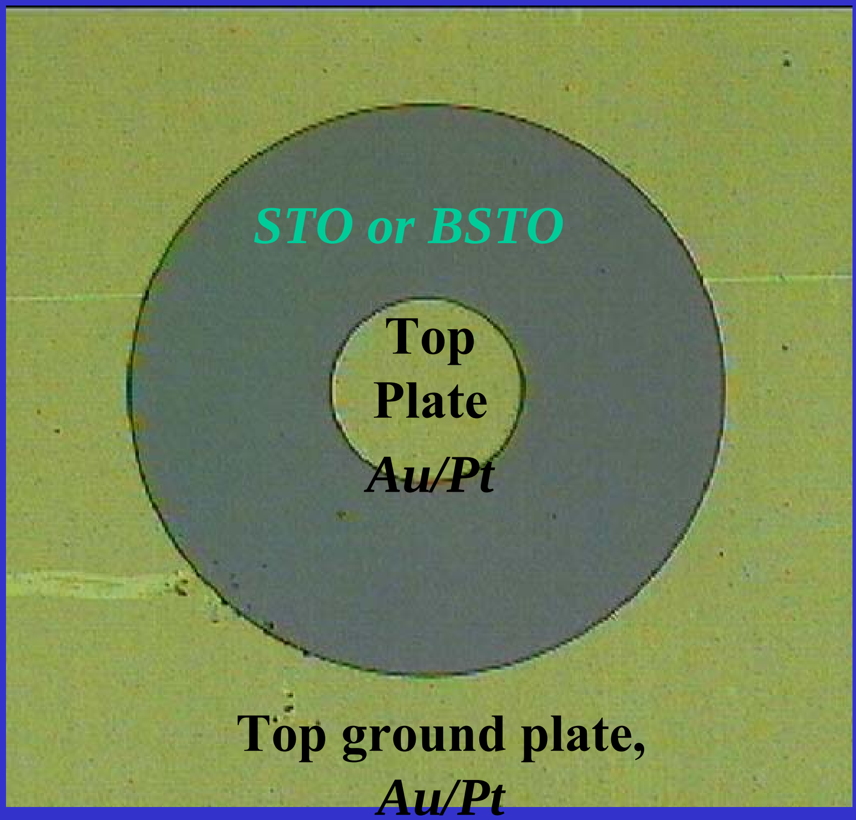




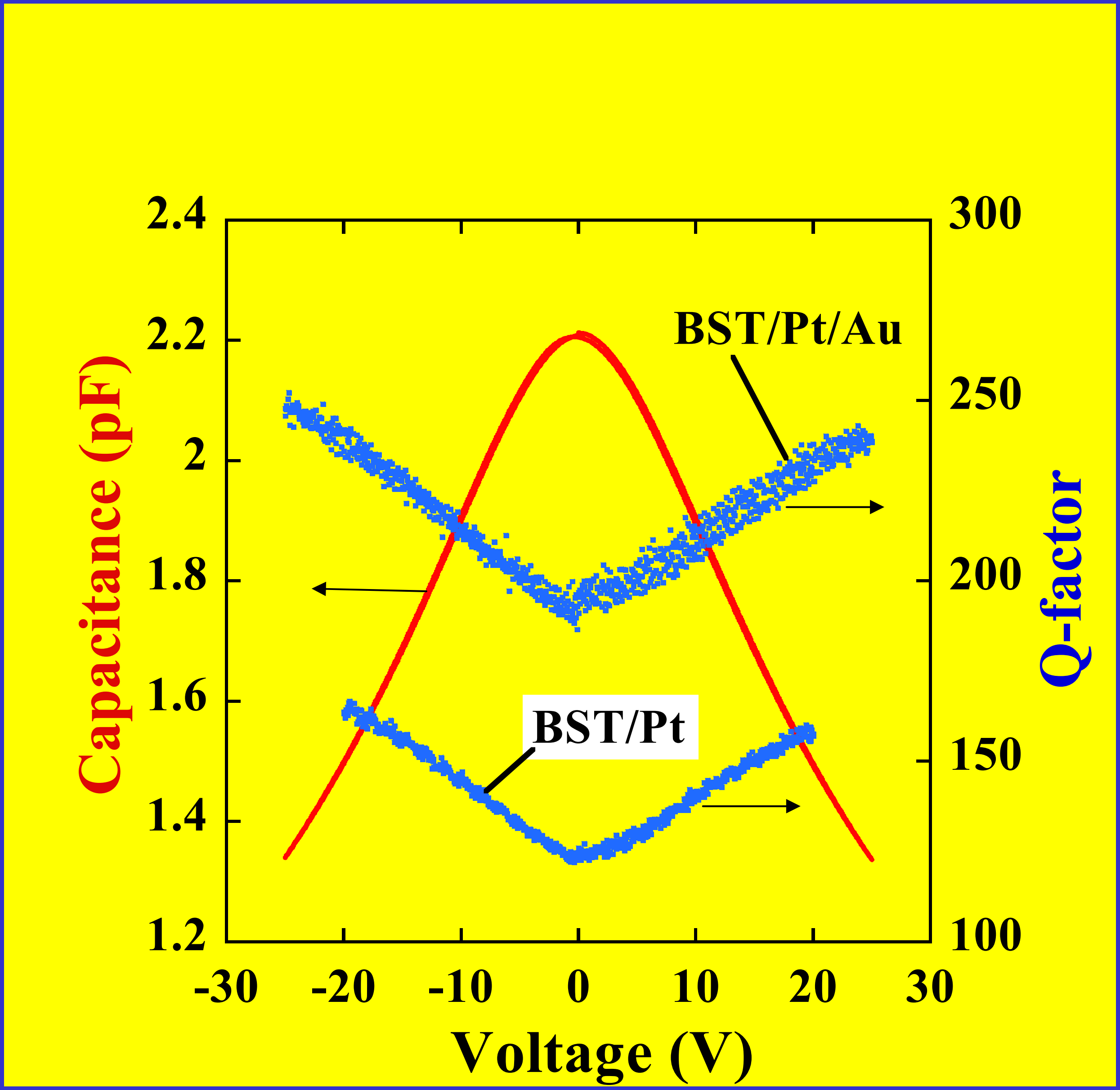
TEM image by Prof. E. Olsson, Chalmers

Test Structure
Cross Section and Top Electrode



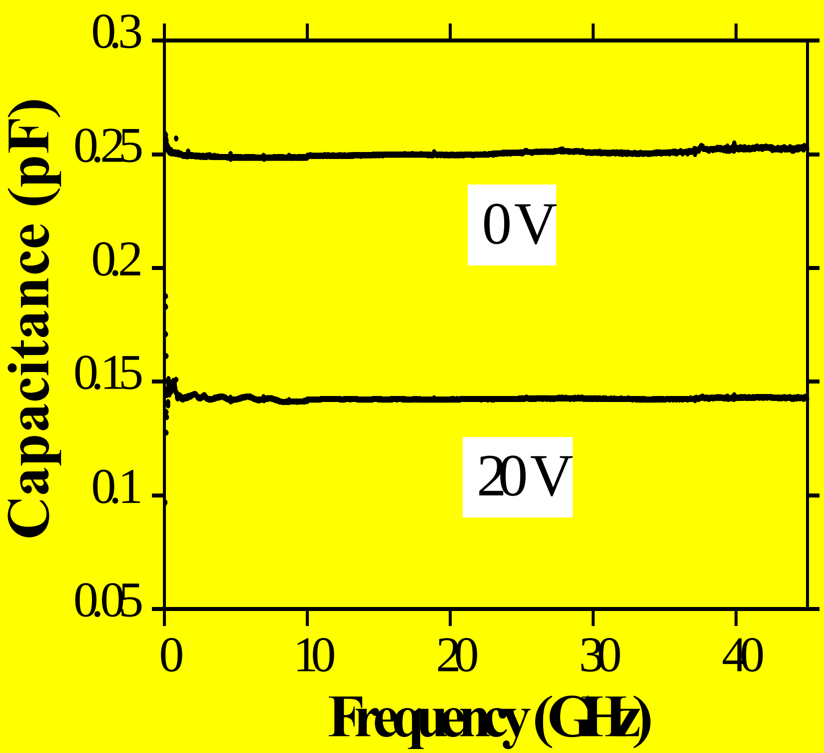


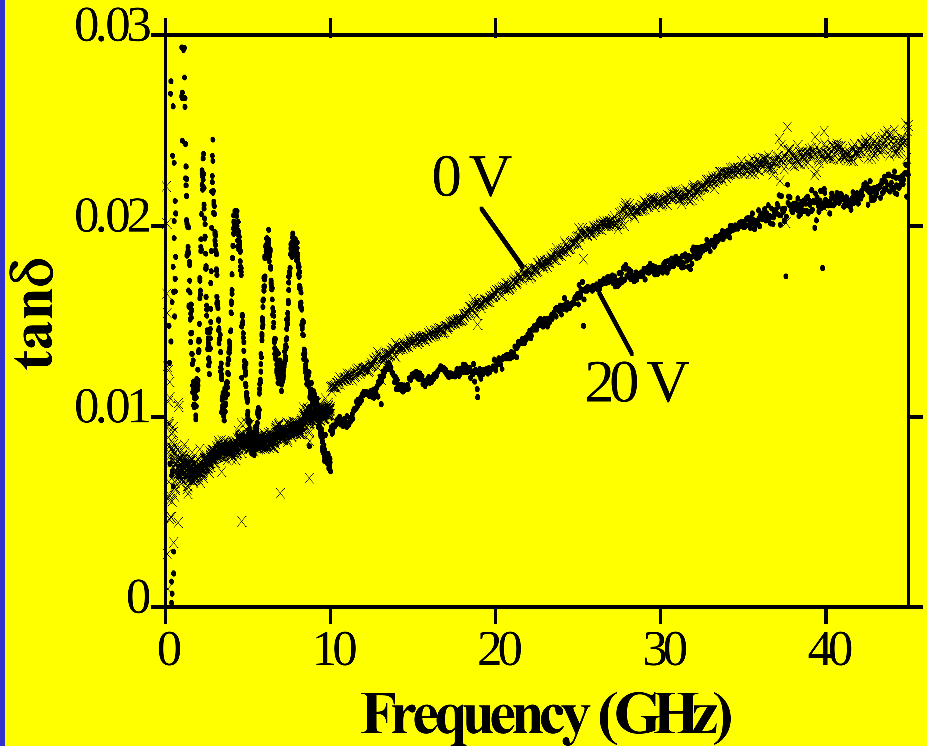
Varactor Performance at 1.0 MHz



A. Vorobiev, P. Rundqvist, K. Khamchane, and S. Gevorgian, *Appl. Phys. Lett.* 83, 3144 (2003)

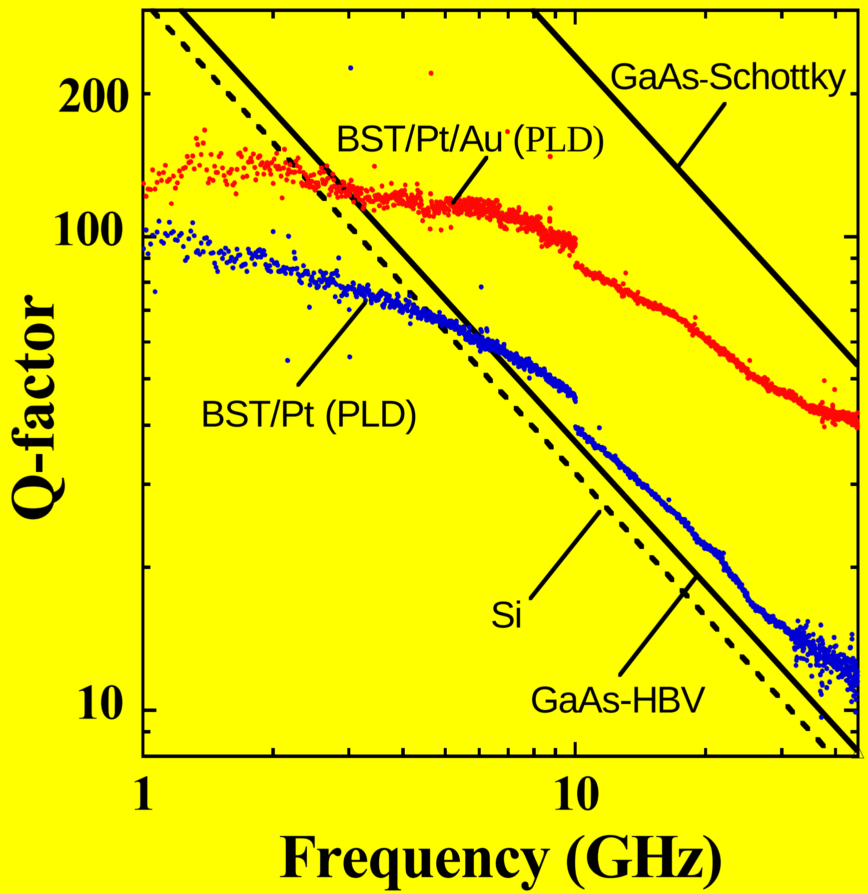
Microwave Performance at V=0 and 20V





- No dispersion in permittivity and tuneability
- Tuneability > 40 %

Technology Comparison. E=0



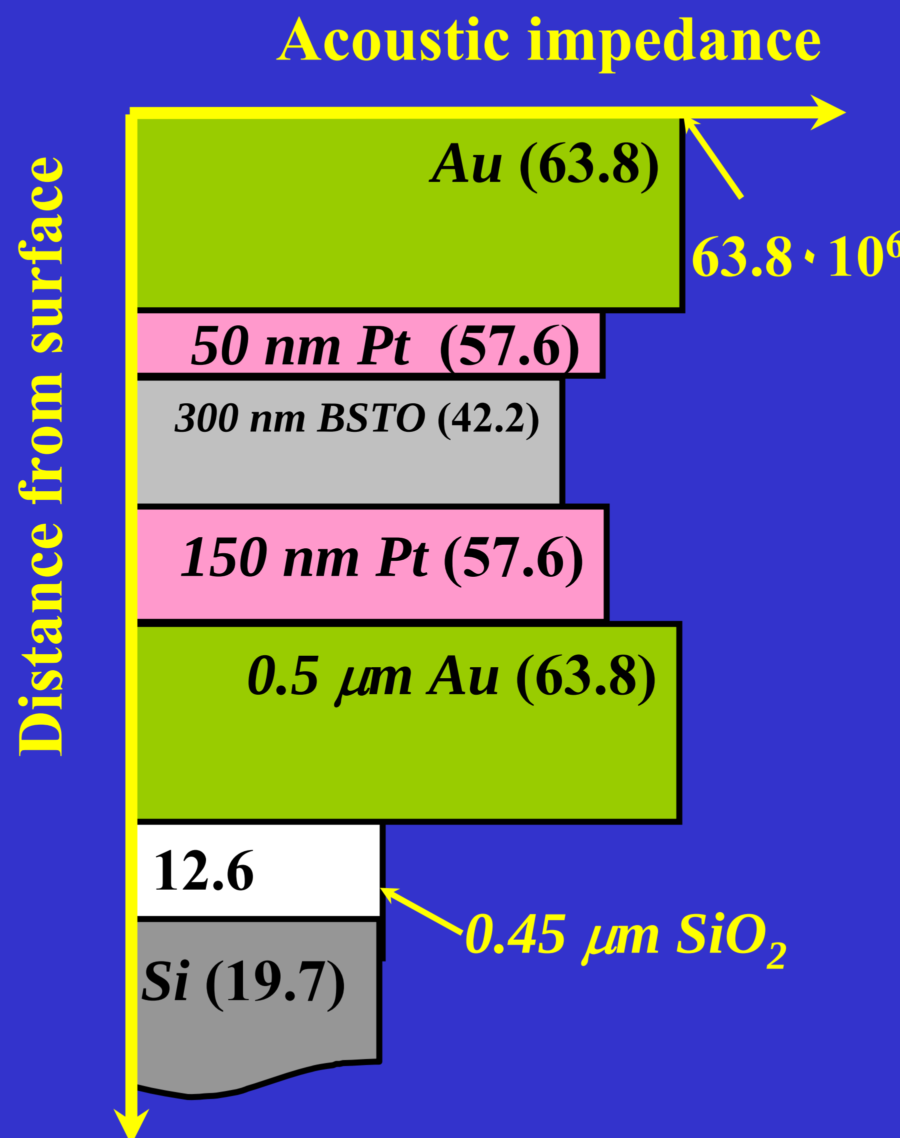
Shown are also:
Si varactor (Metelics, MSV34,060-C12, Q=6500 @ 50 MHz, V=-4V)

GaAs HBV (Darmstadt University of Technology, $f_{cut-off}$=370 GHz)

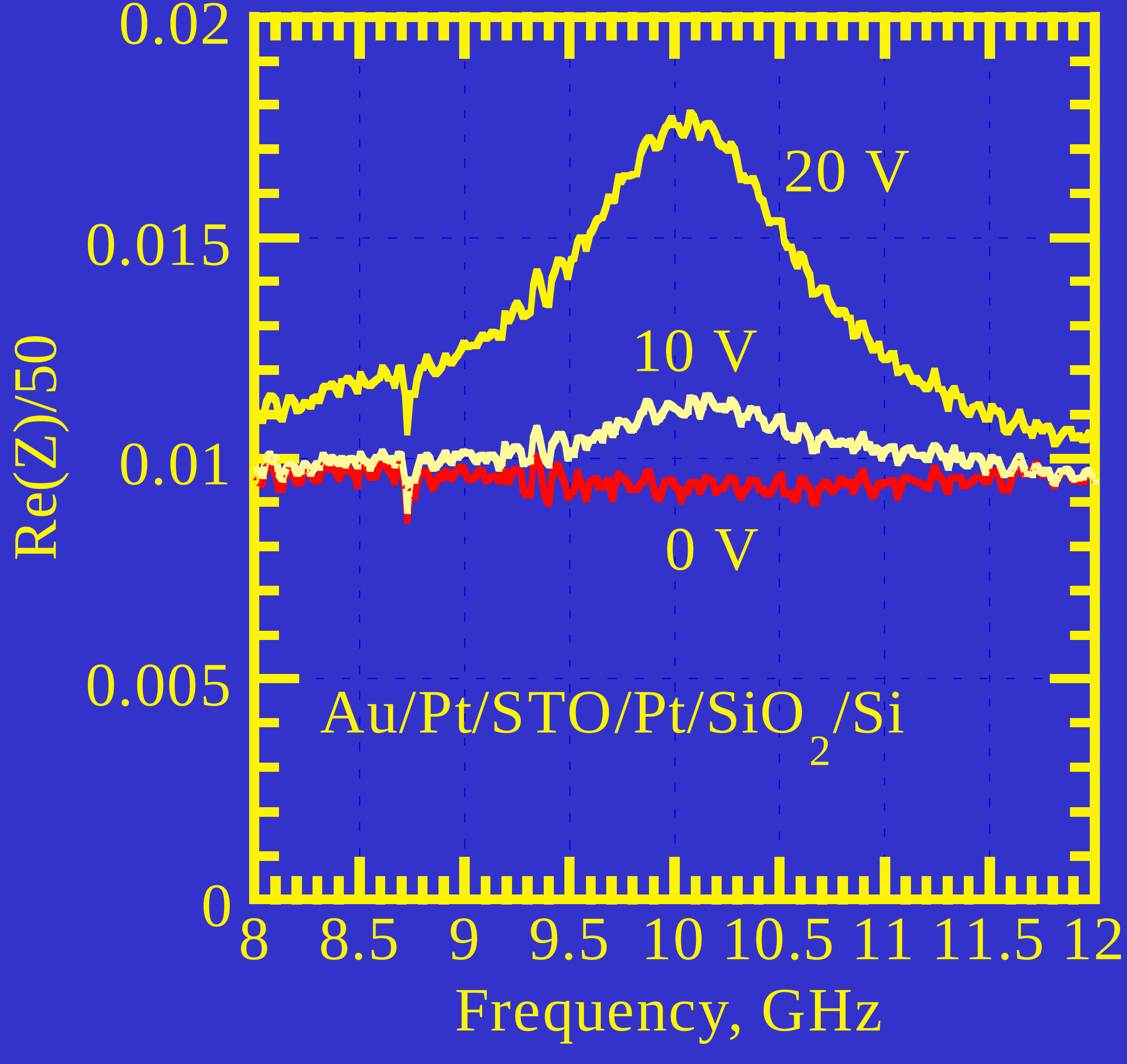
GaAs dual Schottky diode (UMS, DBES105a, $f_{cut-off}$=2.4 THz)

BSTO Potential for Tuneable TFBARs

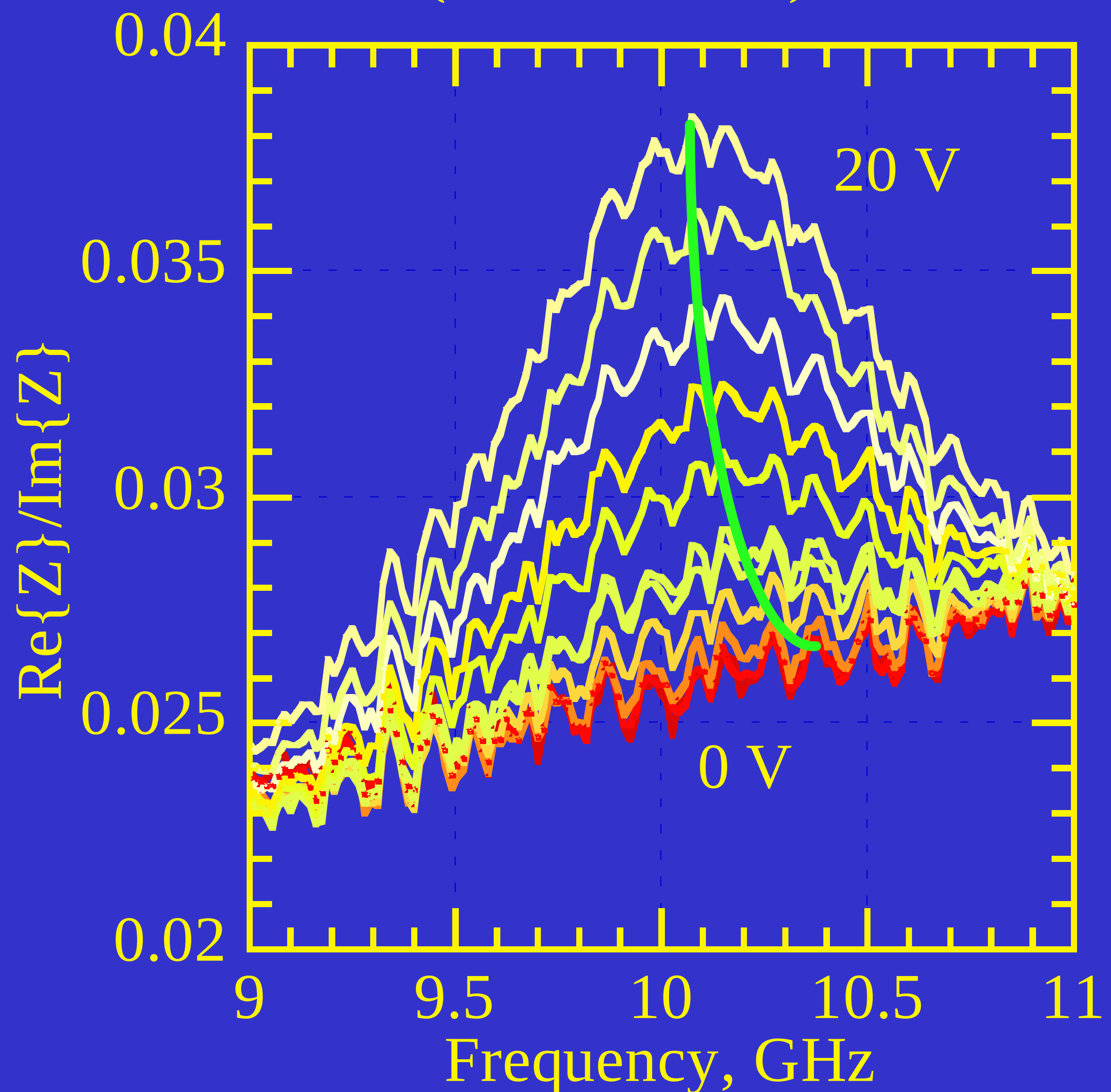
Acoustic Impedances



Real Part of Impedance (Measured)



DC Field Dependent Resonance (Measured)



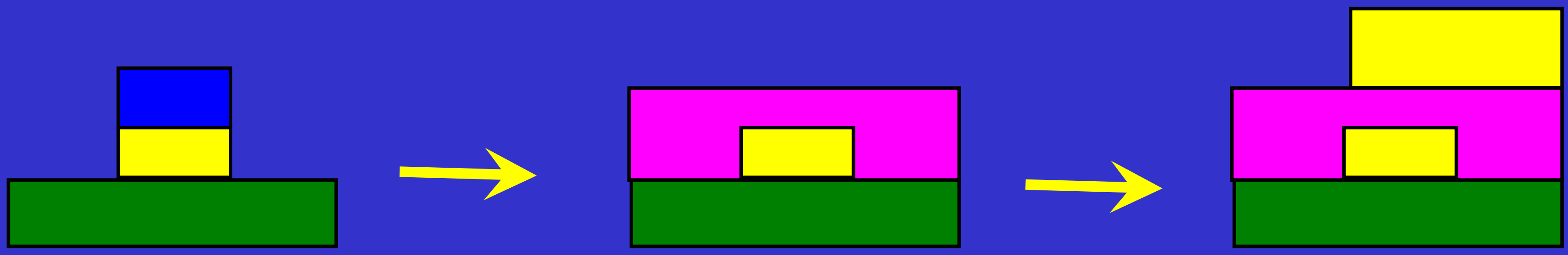
Device Applications

Main Device Fabrication Steps
(Prepatterning of bottom electrode)

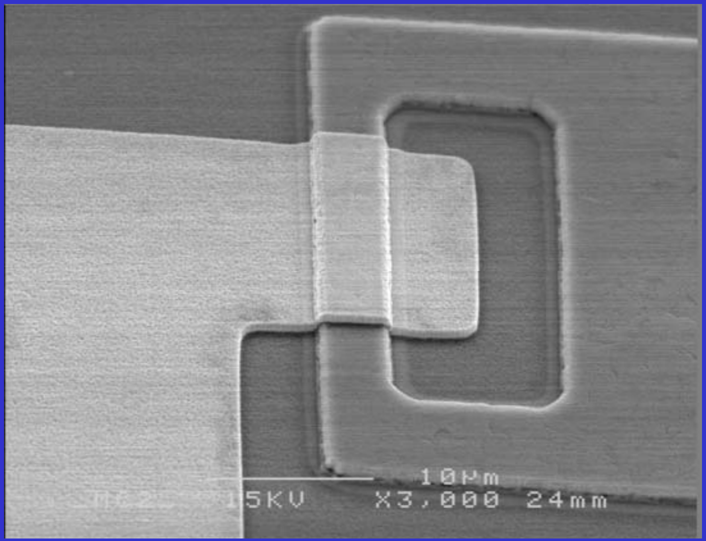
Deposition prepatterning of Pt/Au/Pt (50/500/100nm) bottom electrode

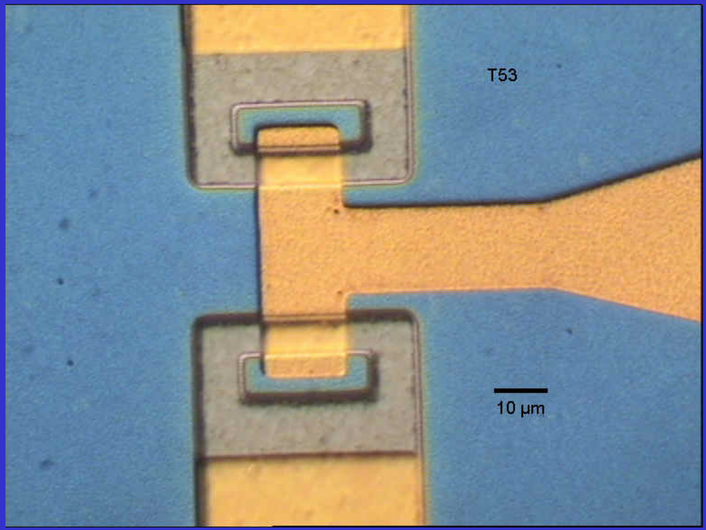
Growth of BST film (300nm) by PLD
650 °C, 0.4 mbar

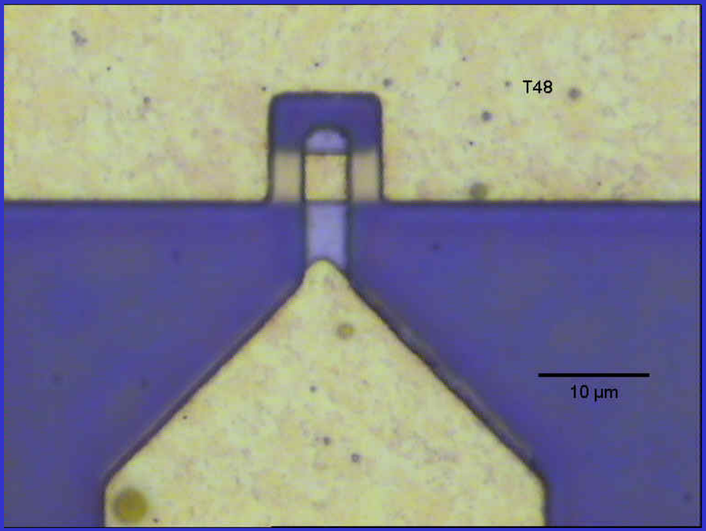
Top electrode formation by lift-off process

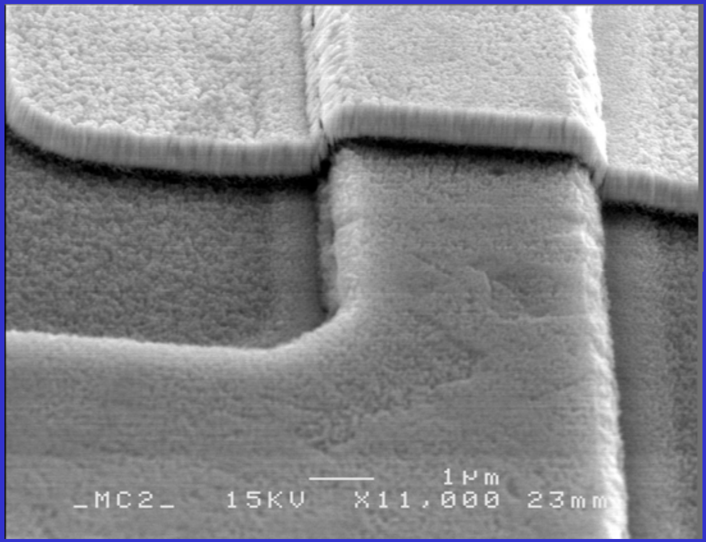


Typical Varactor Structures

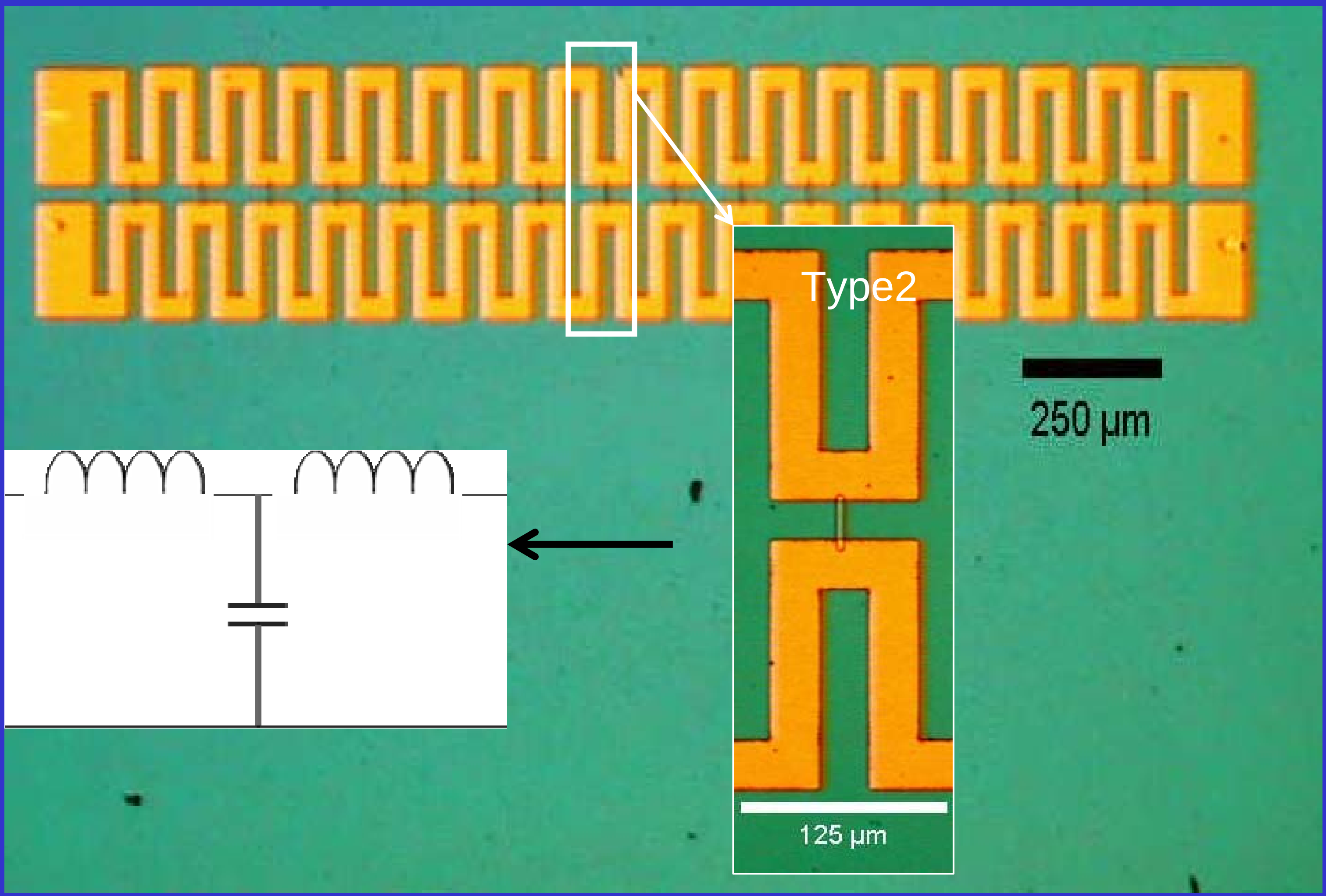




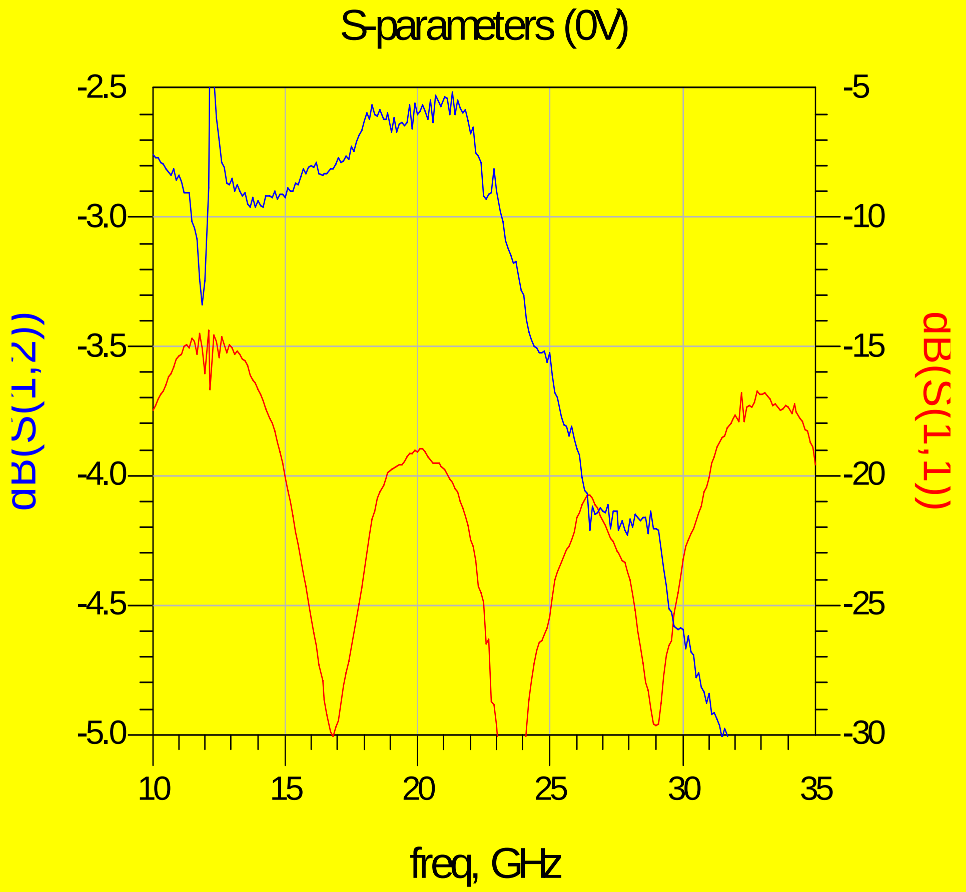


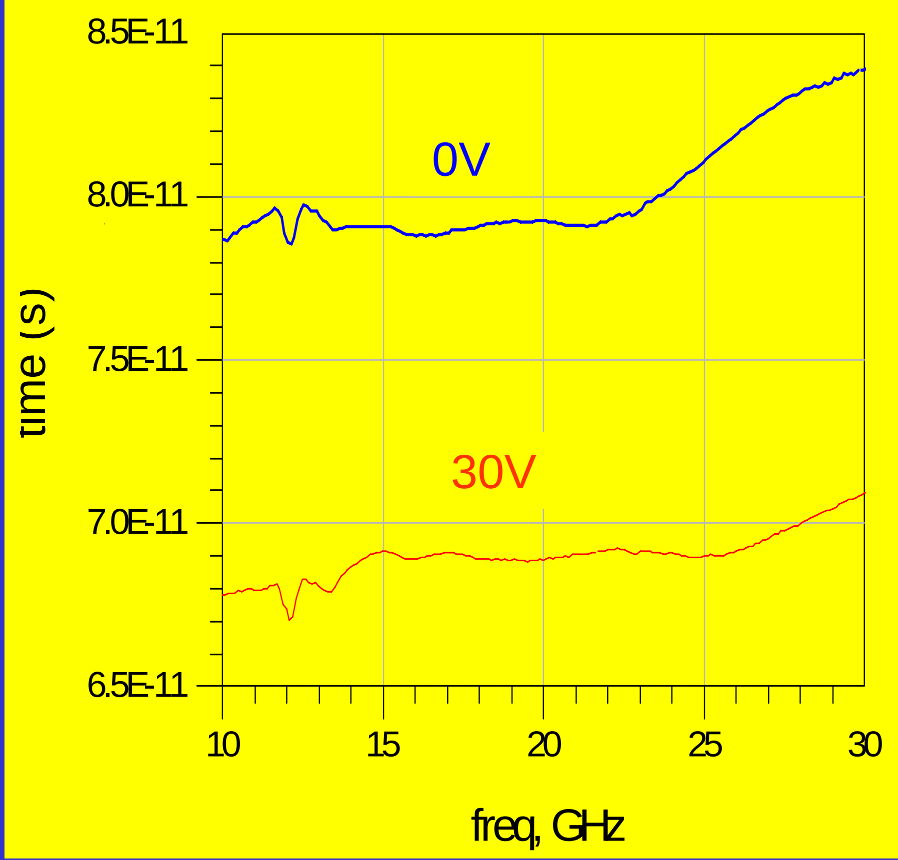


Tuneable Delay Lines



Tuneable Delay Line Performance

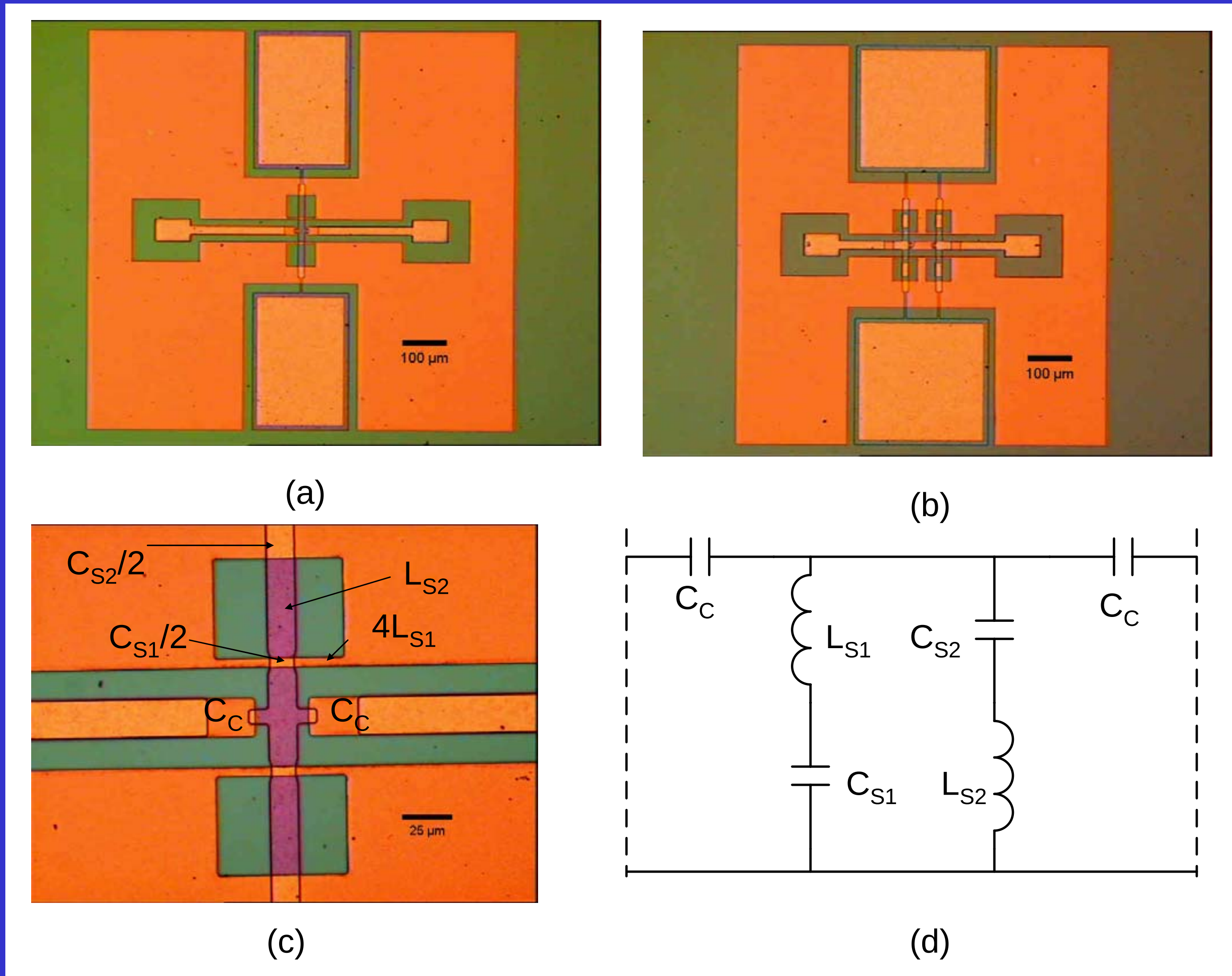




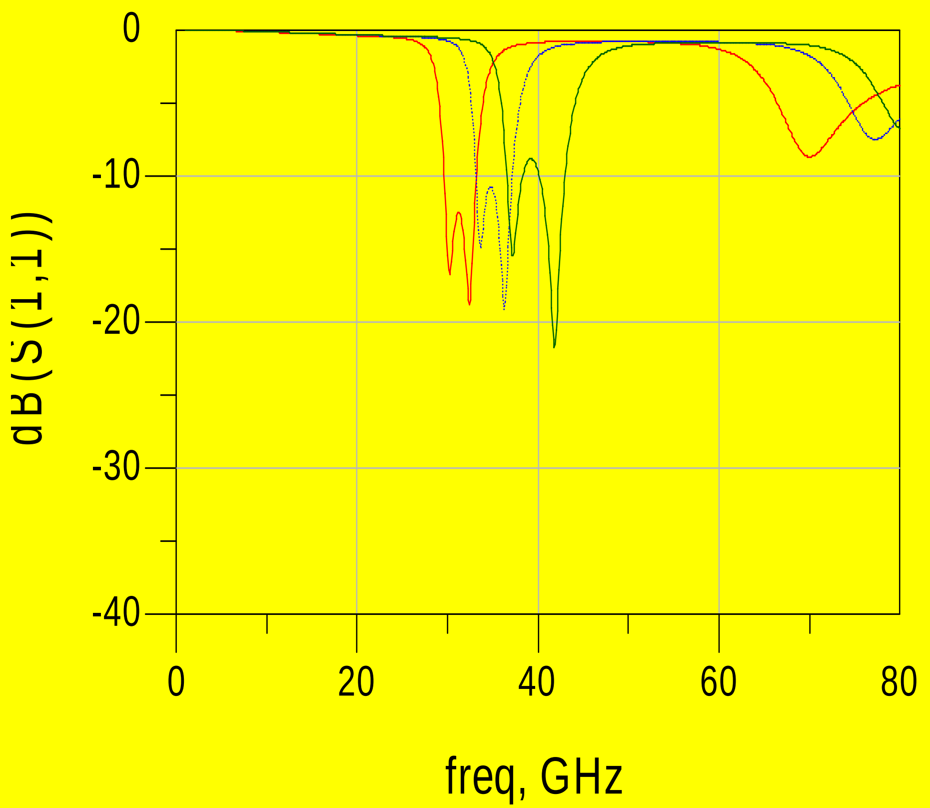
$$\tau = \sqrt{LC(V)}$$

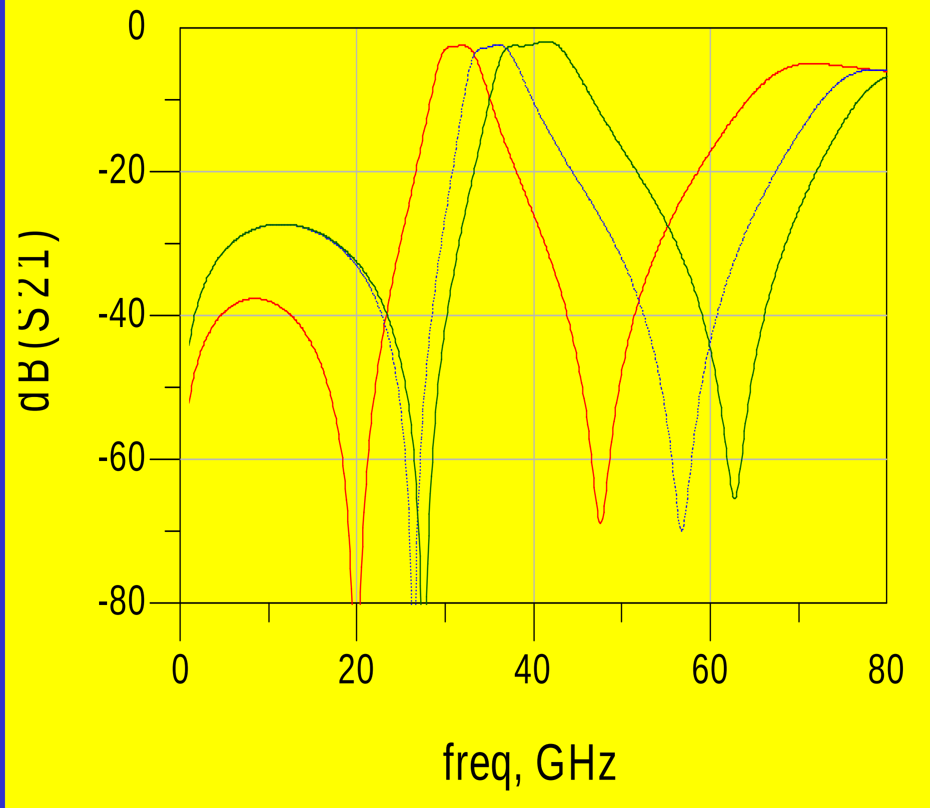
D. Kuylenstierna et. al, EuMC'2004

Lumped Element Tunable Resonators and Filters



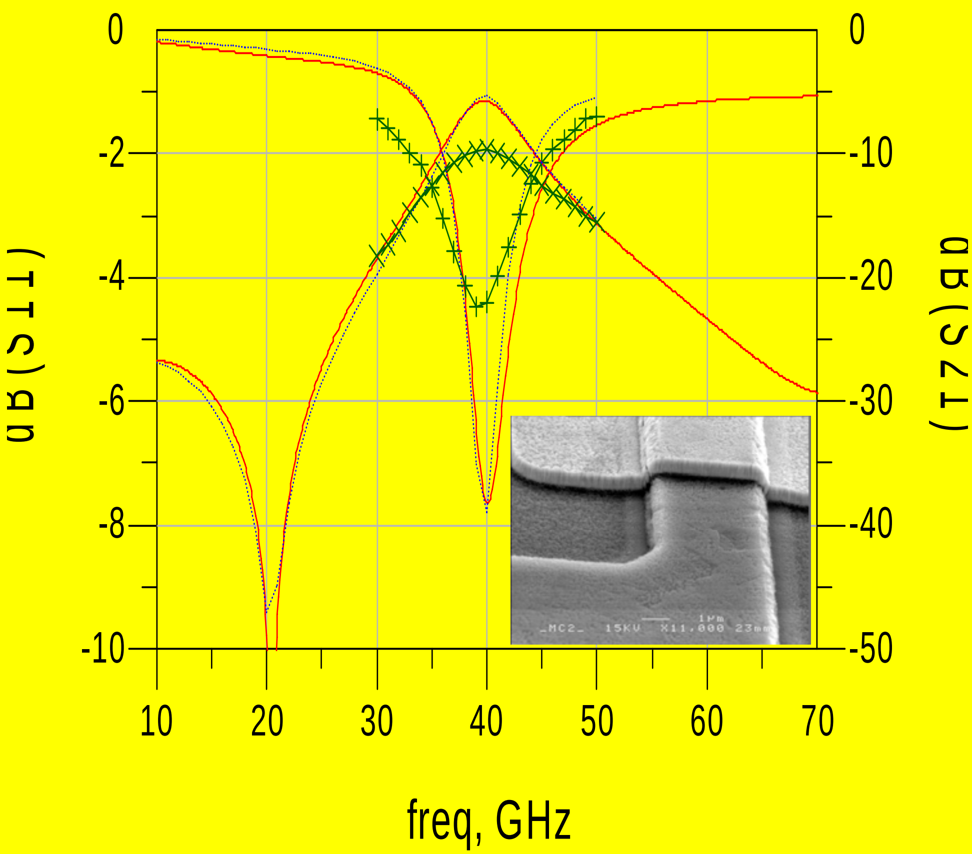
Two-Pole Lumped Element Tunable Filter (simulated)

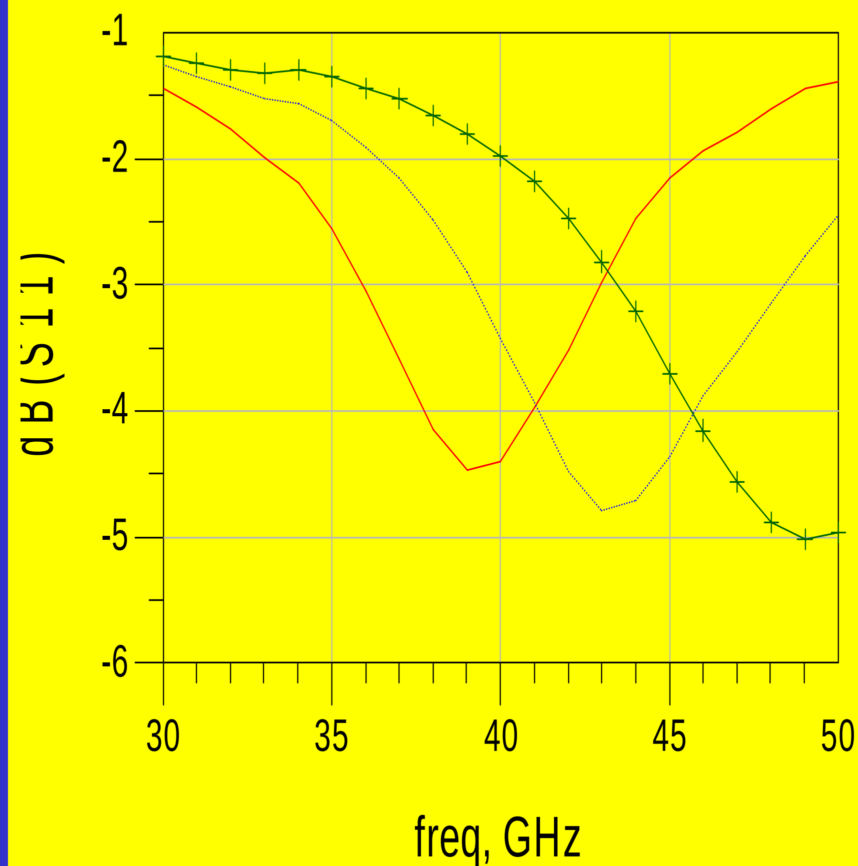




D. Kuylenstierna et. al,Si RFIC'2006

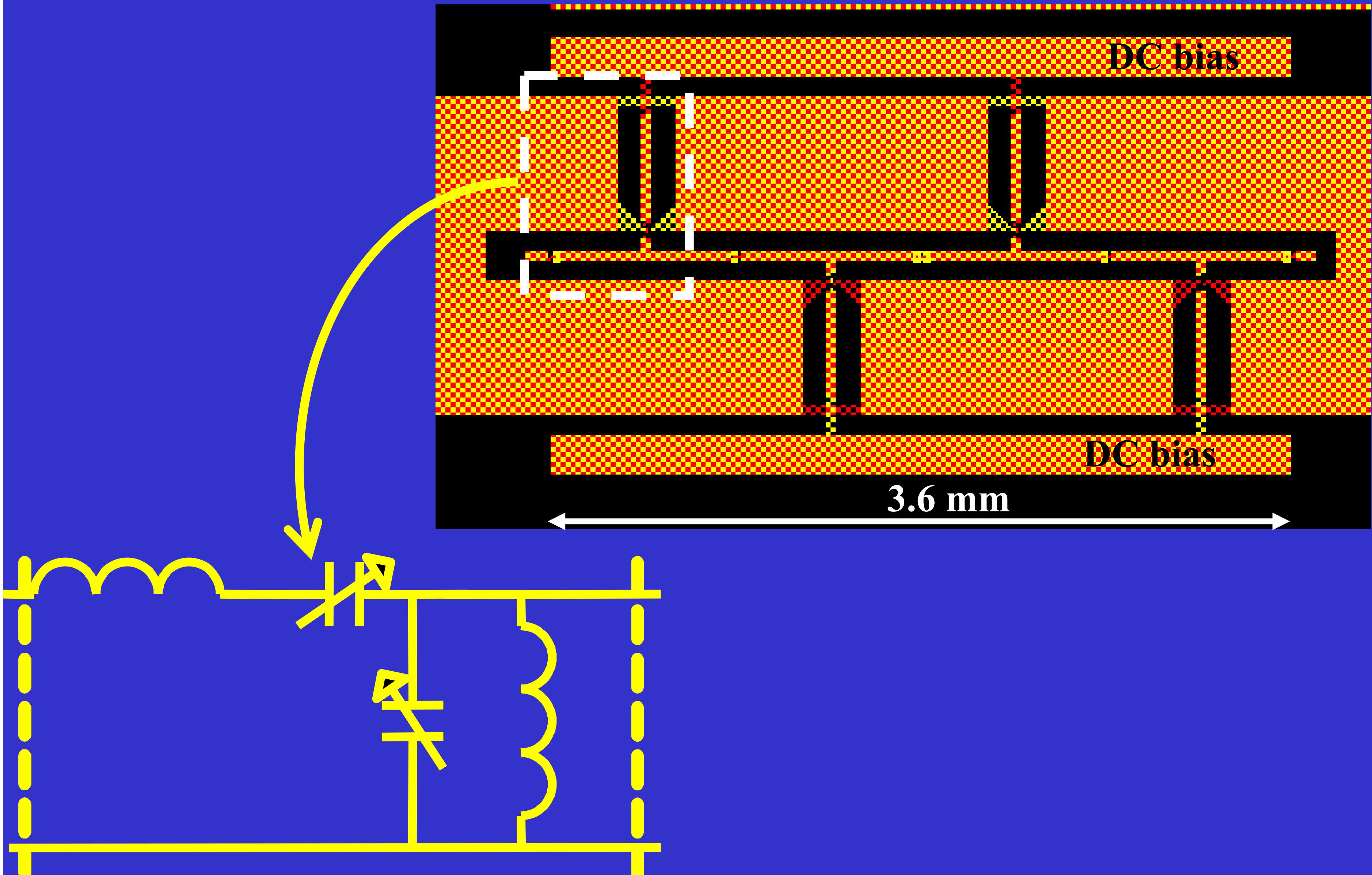
Single –Pole Lumped Element Filter (measured)





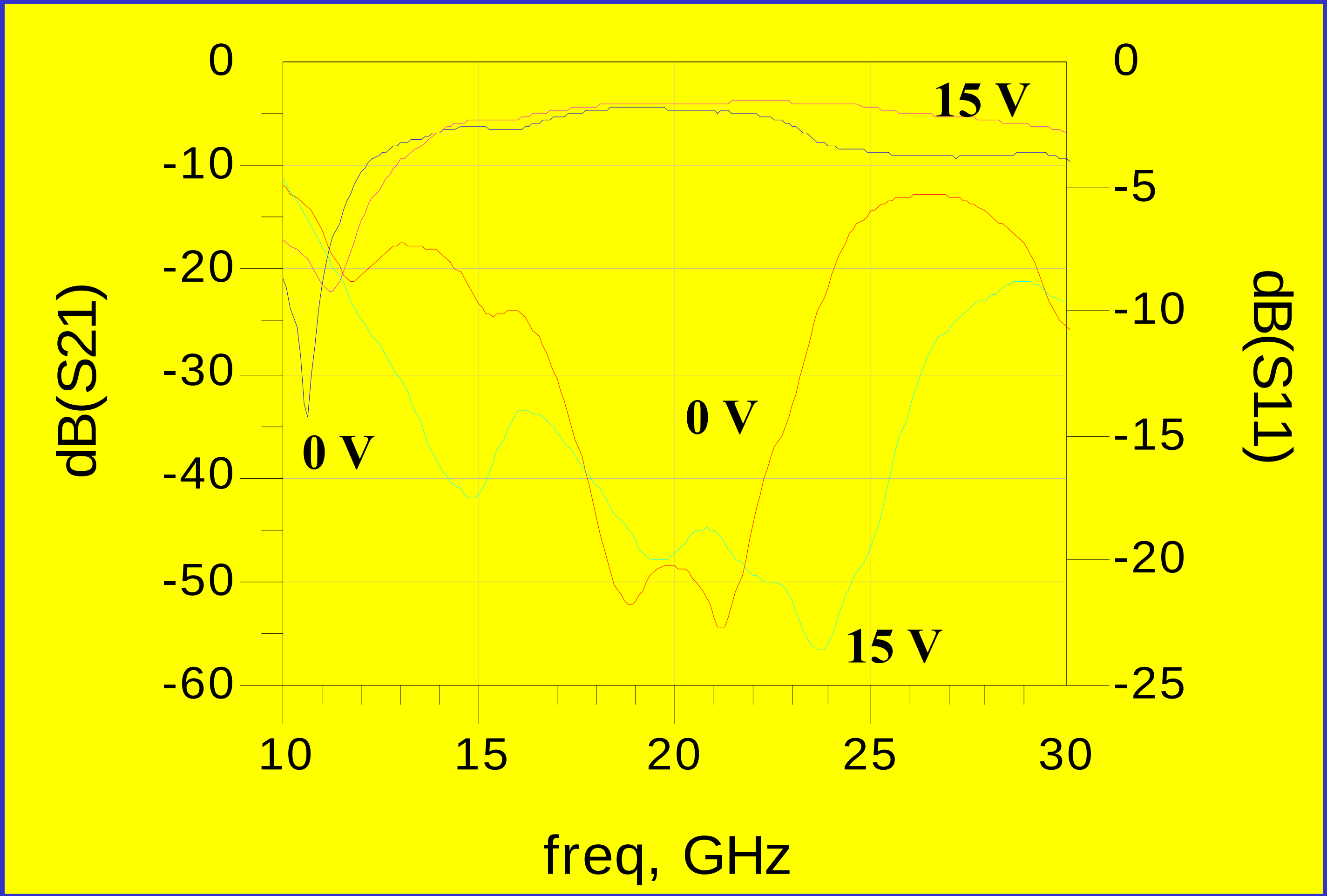
D. Kuylenstierna et. al,Si RFIC'2006

Tuneable Phase Shifters



D. Kuylenstierna et. al, IEEE Micr. Wierless Comp. Letters

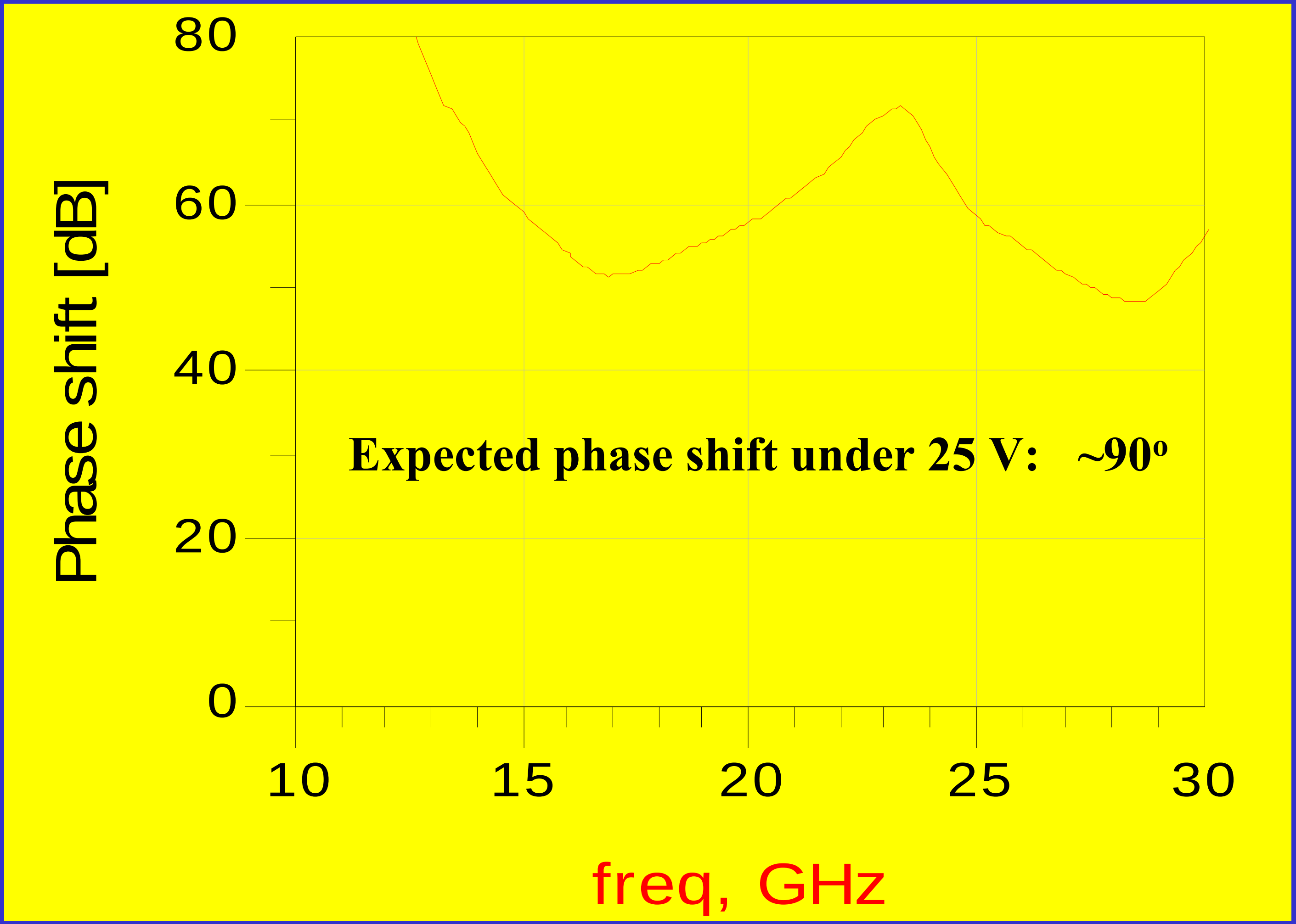
Tuneable Phase Shifters
Mesured S-parameters



Relatively high losses due to steps and surface conductivity of Si

D. Kuylenstierna et. al, IEEE Micr. Wierless Comp. Letters

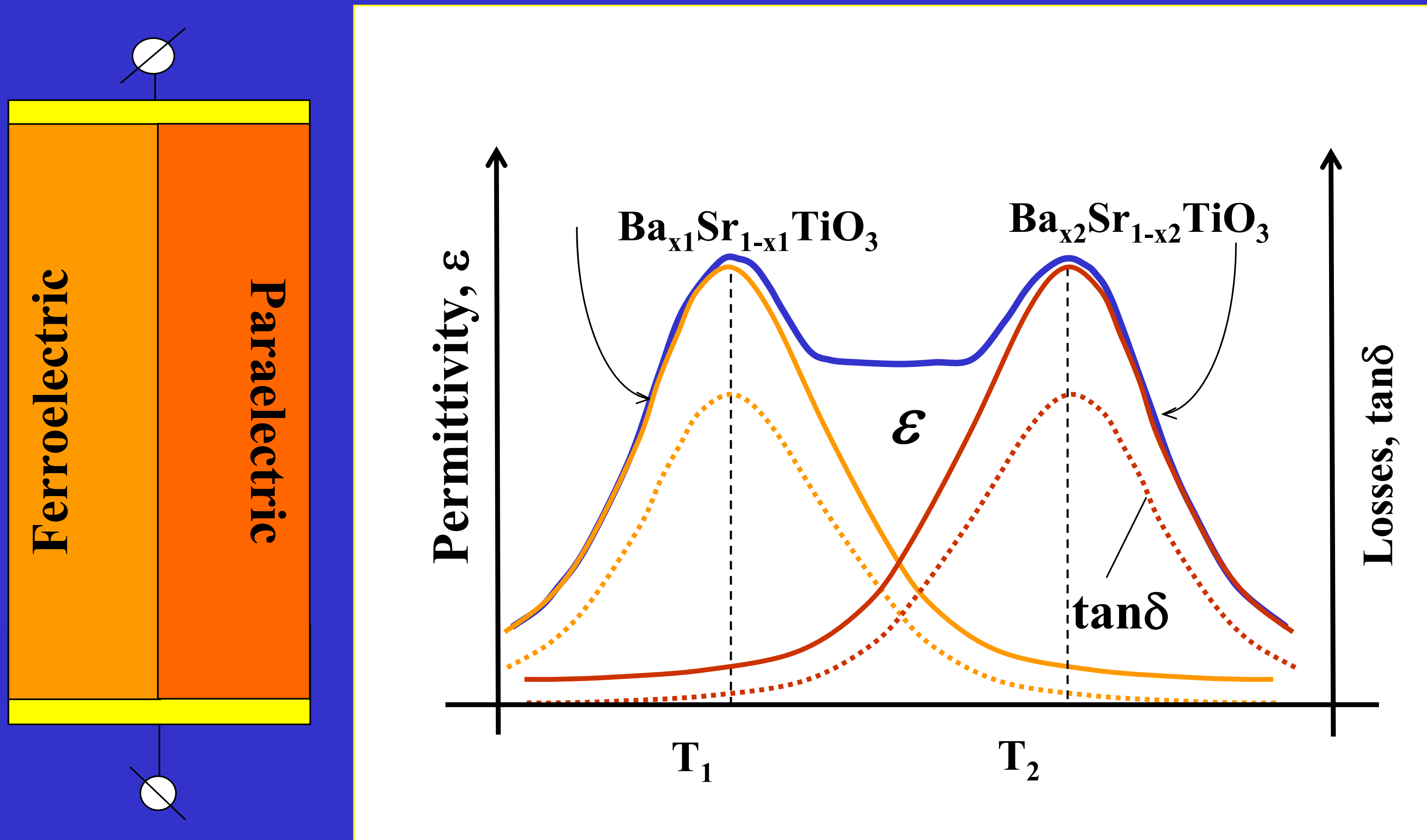
Tuneable Phase Shifters
Mesured Phase Shift Under 15 V



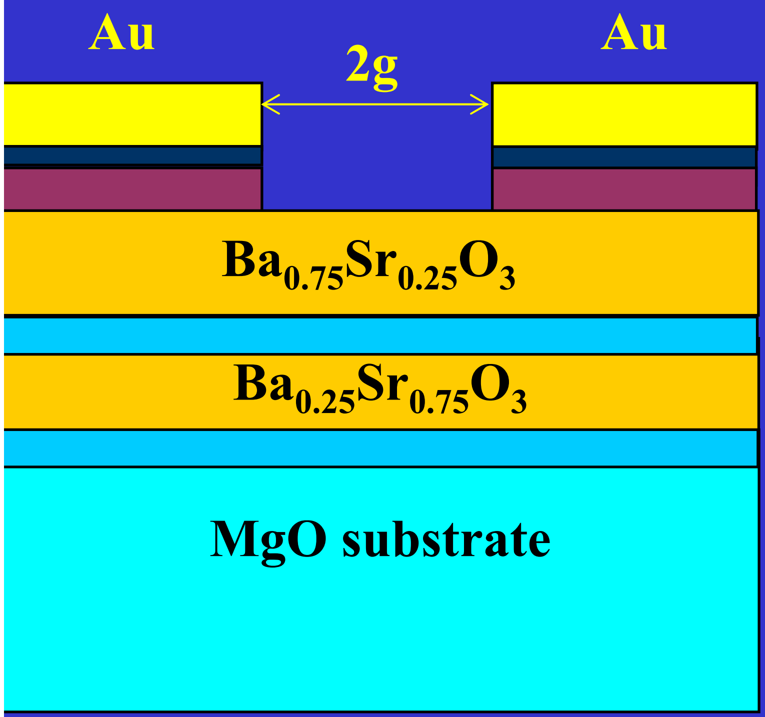
D. Kuylenstierna et. al, IEEE Micr. Wierless Comp. Letters

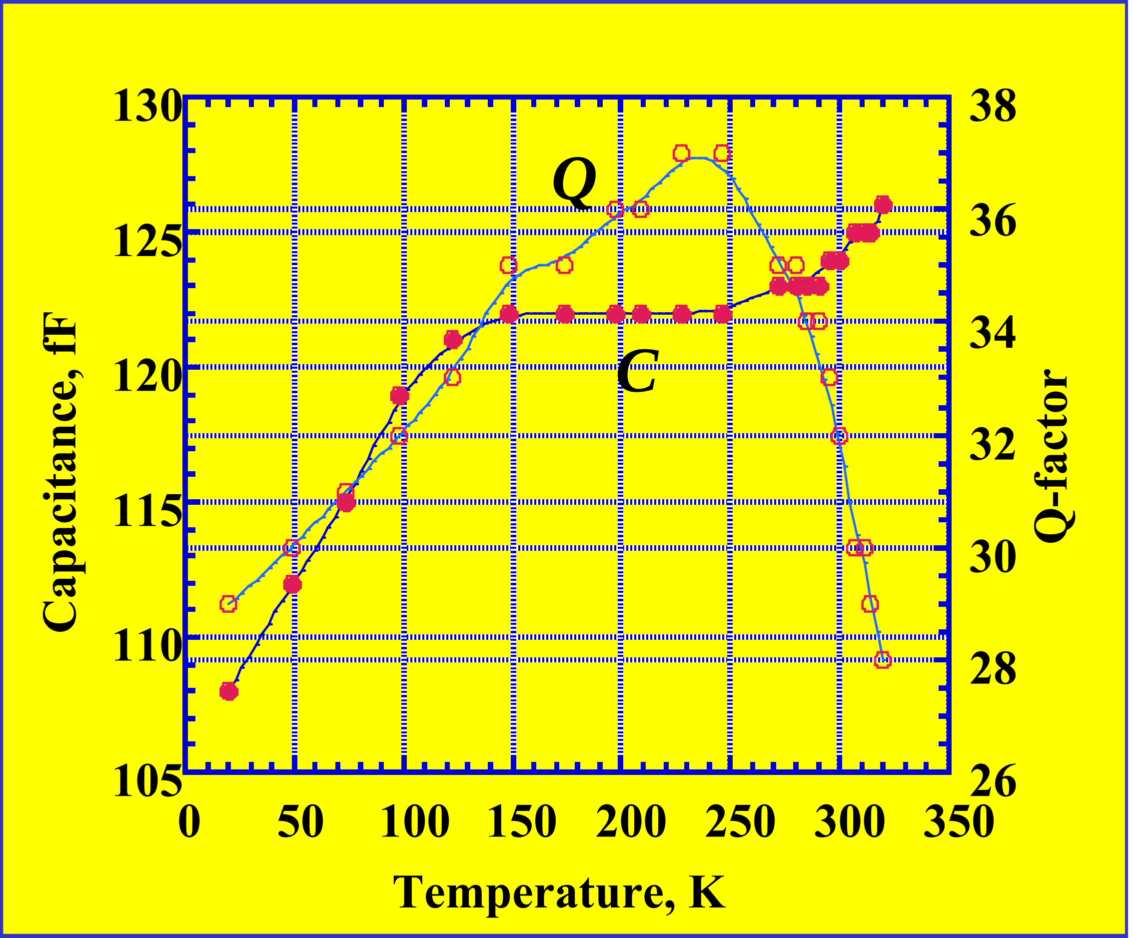
Problems and Perspectives

Temperature Stabilization
(Materials/design based)

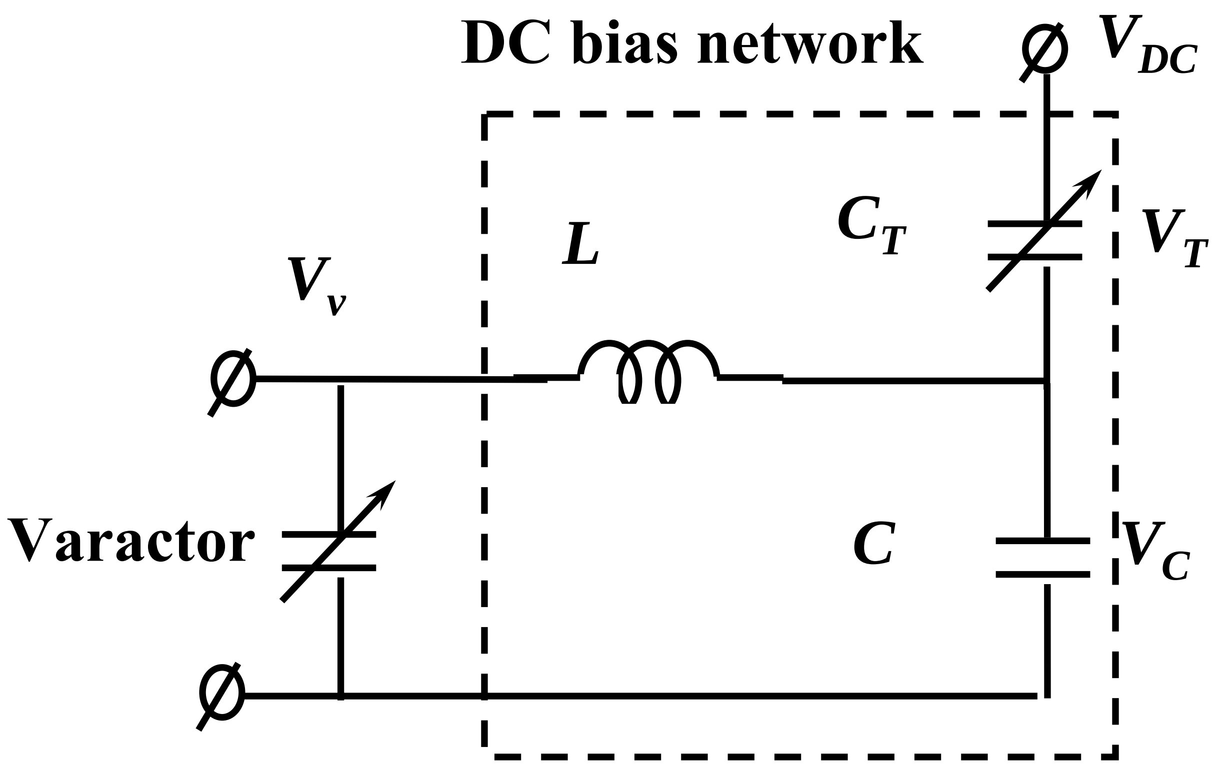


Temperature Dependence (Materials/Design Based- Measured)

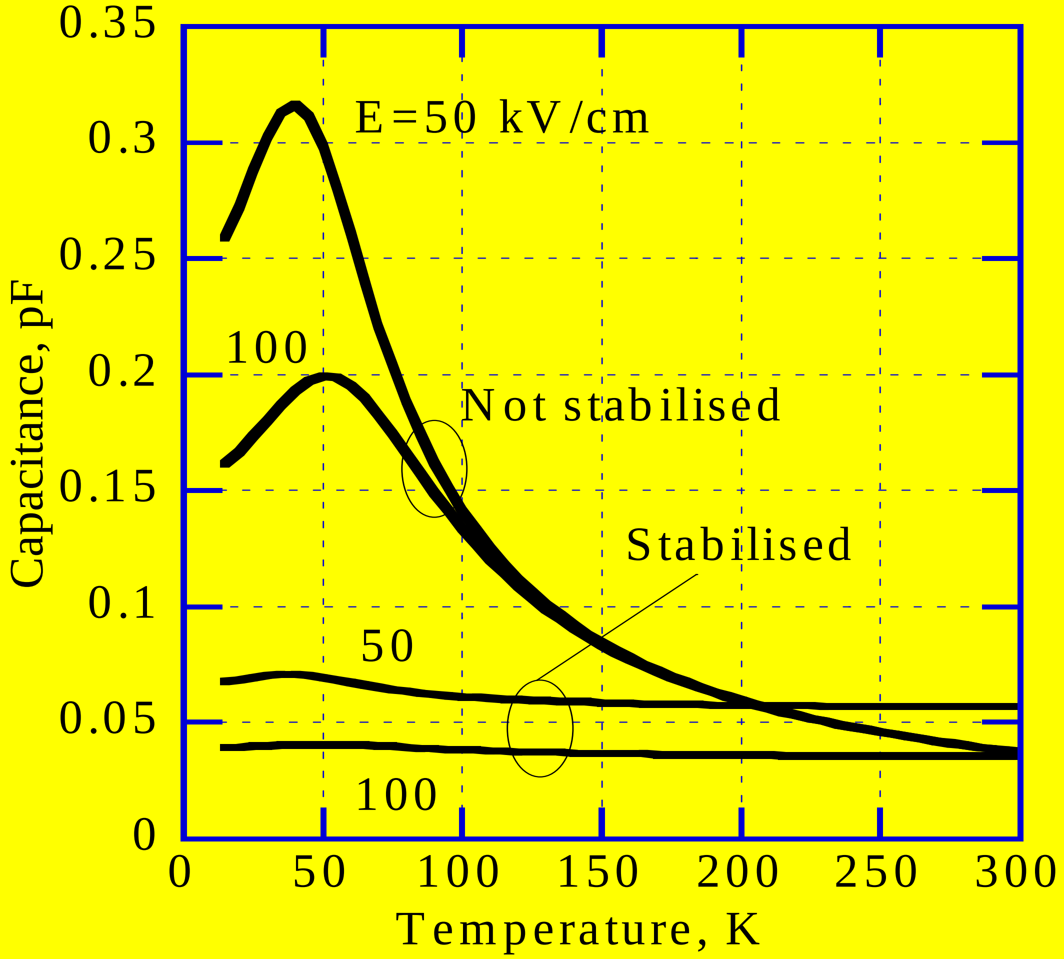




Temperature Stabilization (Circuit Topology Based)



Temperature Stabilization
(Circuit Topology Based-Summation)



Perspective applications :

Project HiMission (EUREKA/MEDEA+/VINNOVA)

- **Phase shifters**
- **Tuneable delay Lines**
- **Tuneable filters**
- **VCO**

Project Nanostar (FP6, EU)

- **Varactors**
- **Tuneable TFBARs**
- **VCOs**

End