Properties of $Ba_{0.6}Sr_{0.4}TiO_3$ based Coplanar and MIM Varactors

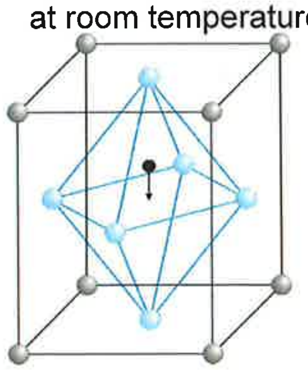
E-MRS 2012 Fall Meeting / Warsaw

H. C. Elsenheimer, F. Paul, M. Sazegar, F. Stemme, J. R. Binder, R. Jakoby, T. Hanemann
Laboratory for Materials Processing
Department of Microsystems Engineering - IMTEK
University of Freiburg, Germany

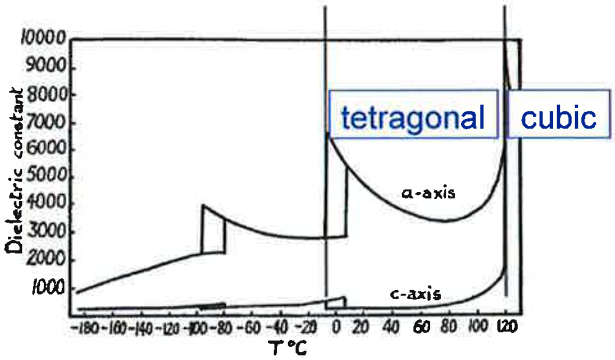
Varactors – motivation / theory

- **Barium-titanium-oxide (BT)**
  - Perovskite structure
  - general formula ABO_3

unit cell of $BaTiO_3$ at room temperature



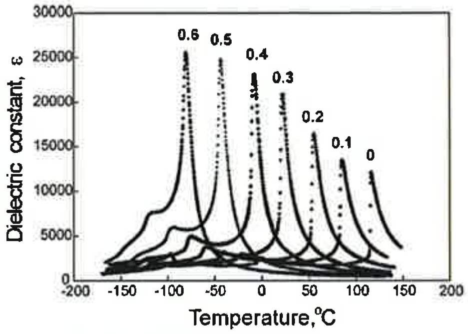
- A ion (Ba^{2+})
- B ion (Ti^{4+})
- oxygen ion (O^{2-})



Devonshire, Philosophical Magazine Series 7, 40, (1949)

Varactors – motivation / theory

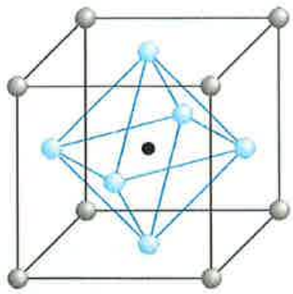
- **Barium-titanium-oxide (BT)**
  - Perovskite structure
  - general formula ABO_3



Jeon, Journal of the European Ceramic Society, 24, 6 (2004)

unit cell of $Ba_{0.6}Sr_{0.4}TiO_3$

at room temperature



A ion (**Ba^{2+} / Sr^{2+}**)
B ion (**Ti^{4+}**)
oxygen ion (**O^{2-}**)

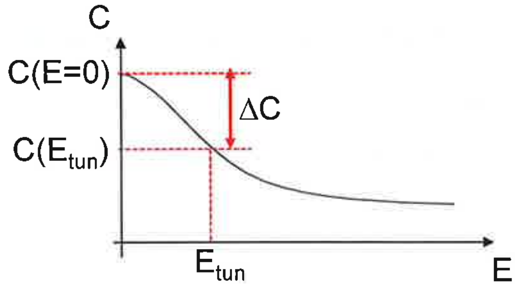
BST ($Ba_{1-x}Sr_xTiO_3$)

- substitution of Ba^{2+} by Sr^{2+}
- $SrTiO_3$ completely miscible in $BaTiO_3$
  → shift of the phase transition

Varactors – motivation / theory

- **BST as tunable dielectric**
  - tuning of capacitance/permittivity by an electrical field

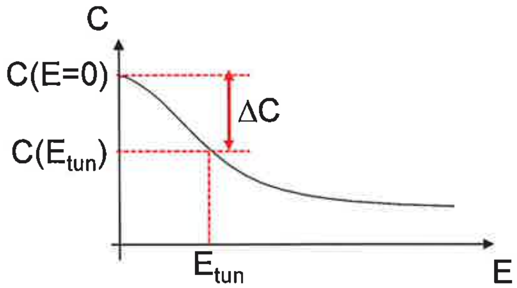
$$\tau = \frac{\Delta C}{C(E=0)} = \frac{\left(C(E=0) - C(E_{tun})\right)}{C(E=0)}$$



Varactors – motivation / theory

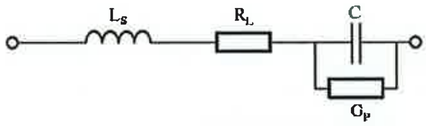
- **BST as tunable dielectric**
  - tuning of capacitance/permittivity by an electrical field

$$\tau = \frac{\Delta C}{C(E=0)} = \frac{(C(E=0) - C(E_{tun}))}{C(E=0)}$$



  - loss factor of varactor

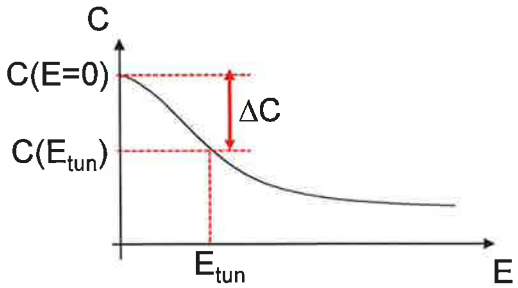
$$\frac{1}{Q} = \tan\delta$$



Varactors – motivation / theory

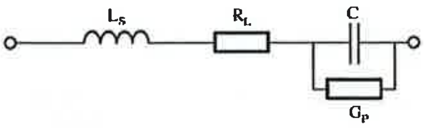
- **BST as tunable dielectric**
  - tuning of capacitance/permittivity by an electrical field

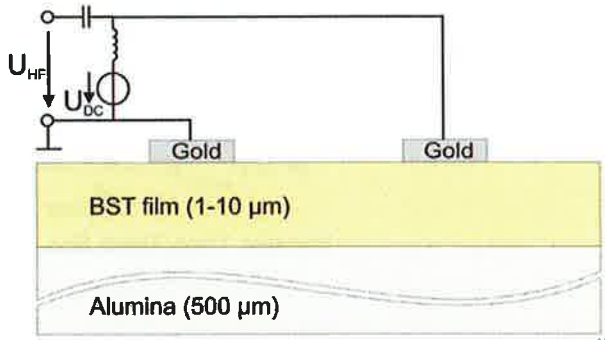
$$\tau = \frac{\Delta C}{C(E=0)} = \frac{(C(E=0) - C(E_{tun}))}{C(E=0)}$$



  - loss factor of varactor

$$\frac{1}{Q} = \tan\delta$$



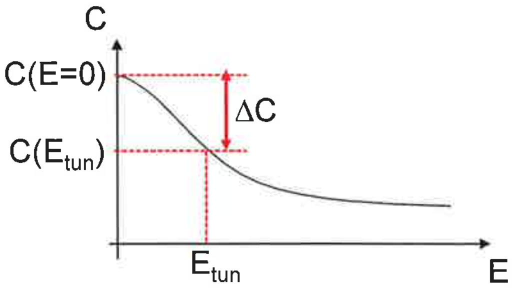


coplanar IDC varactor

Varactors – motivation / theory

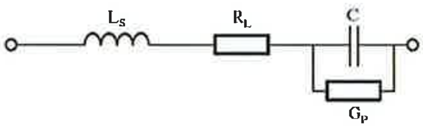
- **BST as tunable dielectric**
  - tuning of capacitance/permittivity by an electrical field

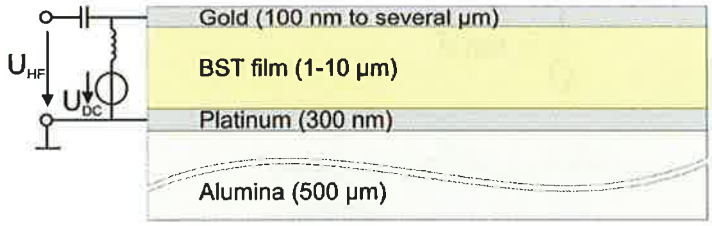
$$\tau = \frac{\Delta C}{C(E=0)} = \frac{(C(E=0) - C(E_{tun}))}{C(E=0)}$$



  - loss factor of varactor

$$\frac{1}{Q} = \tan\delta$$

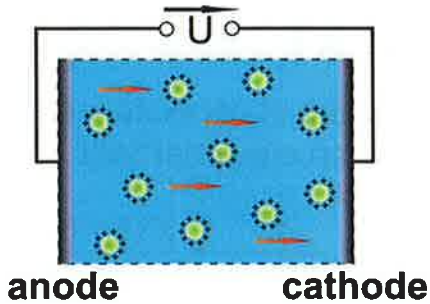




MIM-varactor

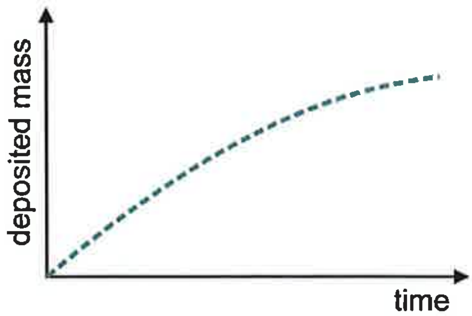
EPD – motivation / theory

- **Characteristics**
  - films derived from suspensions
  - deposition enforced by electrical field
  - high homogeneity of green body
  - predictable thickness of films



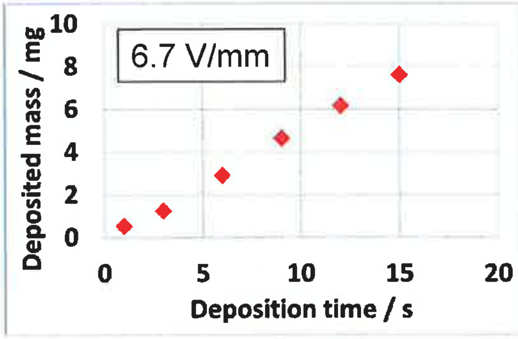
$$m = c_{solid}\,\mu \cdot \frac{A_{electr} U \cdot t}{d_{electr}}$$

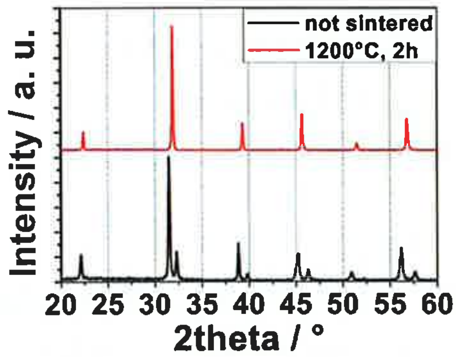
Hamaker, Trans. Farad. Soc., (1940)



Experimental results - processing of films

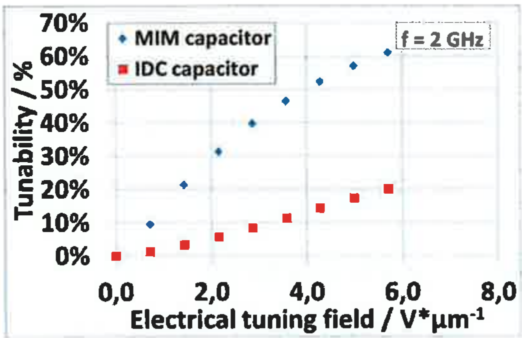
- **Film thickness specified by**
  - electrical field
  - deposition time
- **Cofiring**
  - powder mixture (60 % $BaTiO_3$, 40 % $SrTiO_3$)
  - 2 h @ 1200°C
  - BST formed by interdiffusion of $BaTiO_3$ and $SrTiO_3$

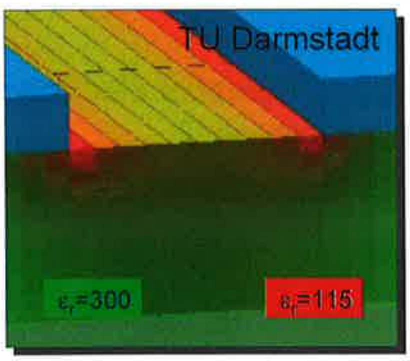




Experimental results - MIM varactors vs. IDC varactors

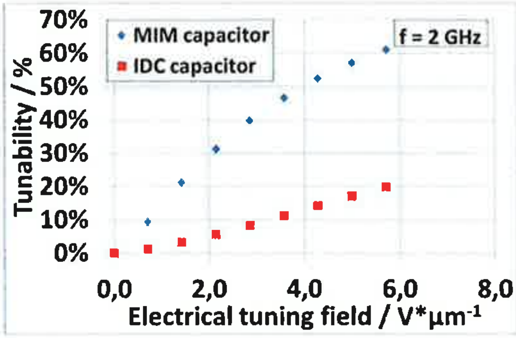
- **Tuning field**
  - IDCs: Inhomogenous field distribution
  - MIMs: Homogenous field distribution
- **Tunability**
  - up to 60 % at 5 V/µm for MIMs
  - good linearity
  - MIMs homogeneously tuned
  - MIMs superior to IDCs

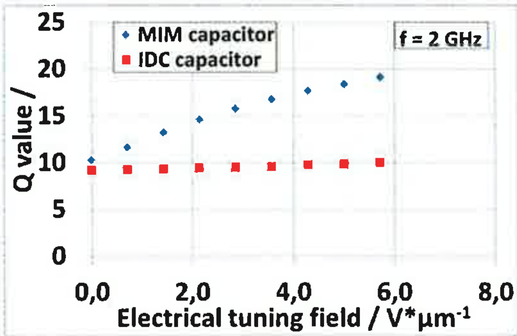




Experimental results - MIM varactors vs. IDC varactors

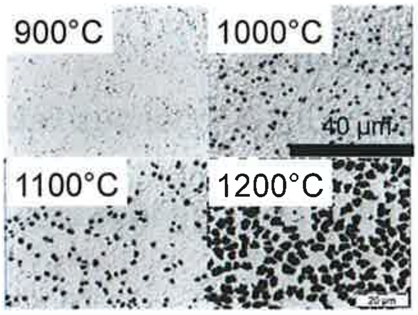
- **Tuning field**
  - IDCs: Inhomogenous field distribution
  - MIMs: Homogenous field distribution
- **Tunability**
  - up to 60 % at 5 V/µm for MIMs
  - good linearity
  - MIMs superior to IDCs
- Q value
  - about 10 without tuning field
  - increase with tuning field (MIMs)

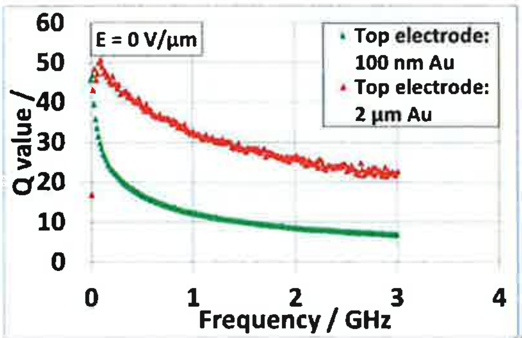




Experimental results - MIMs: Electrodes

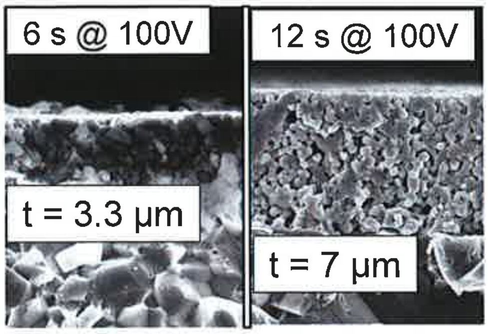
- **Bottom electrode**
  - 300 nm platinum
  - degradation during sintering
- **Top electrode**
  - galvanically reinforced
  - increase of Q from 8 to 26 at 2 GHz
  - strong impact of electrode thickness on Q

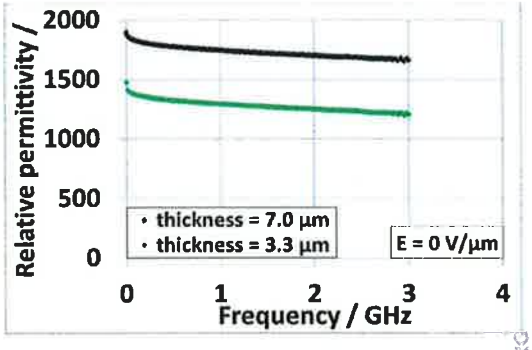




Experimental results - MIMs: Film thickness of BST

- **Permittivity**
  - decreases slightly with frequency
  - decreases with decreased film thickness
  - defects in platinum electrode: Reaction between BST and substrate





Conclusions

- **BST is a promising tunable dielectric**
- **Preparation of BST thick films (1 – 10 µm) via EPD codeposition and cofiring process of $BaTiO_3$ and $SrTiO_3$**
- **MIM structures superior to IDC structures**
- **Degradation of the bottom electrode (thermal budget)**
- **Strong influence of electrodes on dielectric properties**

Acknowledgement

- DFG for funding

  grant no.: HA2571/9-1

- In cooperation between
  - University of Freiburg / IMTEK - WPT
  - Karlsruhe Institute of Technology (KIT – IAM)
  - Technical University of Darmstadt (TU Darmstadt – IMP)

Thank you for your attention