Advanced Integration of High Permittivity Oxide for RF-Modules by Layer Transfer Method

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MOTIVATION

- The development of thin film varactor structures using high ε_r oxide (e.g. $Ba_xSr_{(1-x)}TiO_3$ or $Pb_xSr_{(1-x)}TiO_3$) for miniaturized RF-module devices
- High electrode conductivity is required to reduce RF-losses!
- Deposition of high ε_r layers:
  - At elevated temperatures ($\geq$ 650 °C)
  - In oxygen atmosphere
  - → Metallic electrode is heavily attacked during oxide growth
  - Oxidation of electrode
  - Grain growth → Poor oxide and electrode quality!
- Options for electrode configuration:

I. Highly conducting noble metals (e.g. Ag, Al, Au, Cu)
  - Not thermodynamically stable during deposition

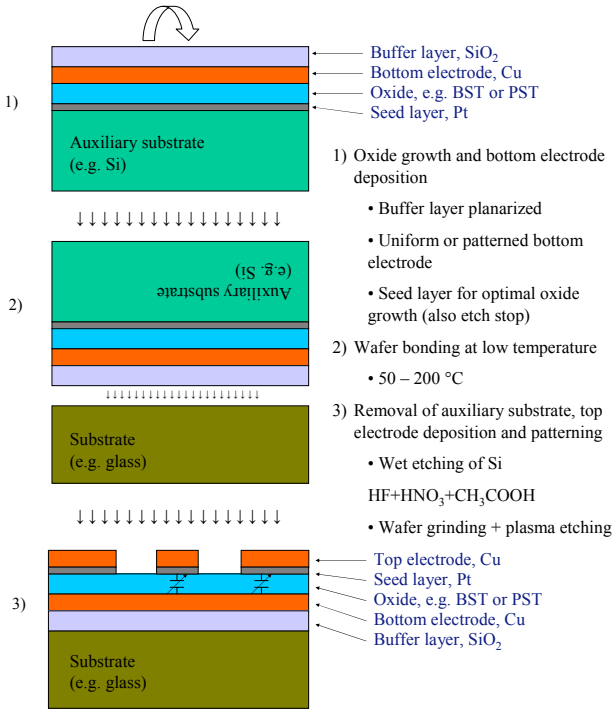
II. Refractory metals (e.g. Mo, W)
  - Endure high temperature, but are prone to oxidation

III. Refractory metals with diffusion barrier
  - Parasitic effects arise for well-protective layer

IV. Conducting oxides
  - Too resistive for RF-applications

- State-of-the-art: Pt
  - Low conductivity ρ = 6 x ρ of Cu
  - Grain growth and hillock formation
  - Good seed layer for BST growth

LAYER TRANSFER



1) Oxide growth and bottom electrode deposition
  - Buffer layer planarized
  - Uniform or patterned bottom electrode
  - Seed layer for optimal oxide growth (also etch stop)

2) Wafer bonding at low temperature
  - 50 – 200 °C

3) Removal of auxiliary substrate, top electrode deposition and patterning
  - Wet etching of Si

  $HF+HNO_3+CH_3COOH$

  - Wafer grinding + plasma etching

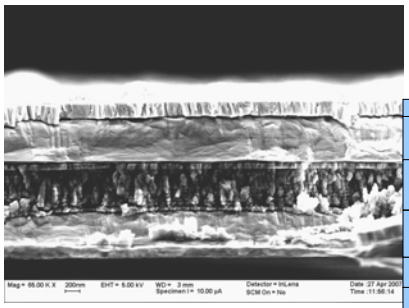
→ Both electrodes are deposited at room temperature after oxide growth:

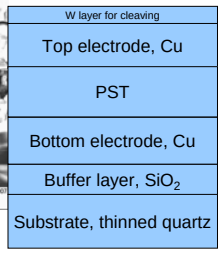
+ Oxide growth under optimal conditions: in oxygen ambient at high temperature

+ Electrode metal can be freely chosen, e.g. Cu

SAMPLES

- Substrates: Si/SiO_2 and quartz wafers 100 mm diameter
- Oxide: sol-gel PST ($Pb_xSr_{(1-x)}TiO_3$) onto Ti/Pt seed layer
  - Annealing 15 min @ 650 °C
- SiO_2 and quartz bonding at room temperature
  - Bond strengthening; two hours at 200 °C

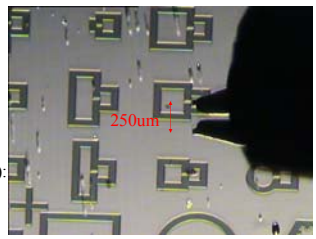




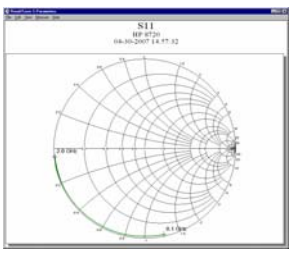
→ Poor adhesion at Pt/PST interface: No Pt in varactor structure!

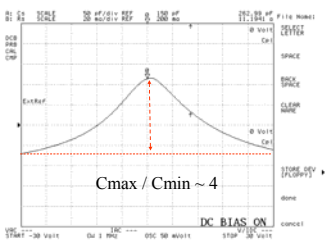
ELECTRICAL PROPERTIES

Low frequency measurement (1 MHz):
- Large tuning range ~ 4
- 70 V/µm breakdown field
- Relative permittivity ~ 330



High frequency measurement (0,1 – 2 GHz):
- Preliminary result:
  Q-value ~ 20 @ 1 GHz





CONCLUSIONS

- Degradation of low resistivity electrode is problem when depositing high ε_r films for RF-applications
- The problem can be solved by transferring of the high ε_r layer to another substrate
  - → Oxide growth under optimal conditions
  - → Electrode material can be chosen freely: high conductivity and large thickness
  - → Substrate that is compatible with RF-applications can be selected
- As a demonstration, sol-gel PST successfully transferred: large tuning range ~ 4 with relative permittivity of 330

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