PZT thin films for capacitive RF-MEMS

Objective : assessment of integration of PZT thin film in RF MEMS

Key words : MEMS, pulsed laser deposition, functional oxide thin films, RF measurements, electrical measurements

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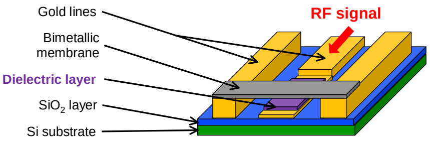
RF switch



Up position
RF signal transmitted

Down position
RF signal not transmitted

Dielectric layer :

❖ Control of the main performances (isolation, insertion losses) → **high dielectric constant**

Up position : lowest insertion loss → lowest C_{down} $\quad C_{up} = \frac{\varepsilon_0 . A}{d + \left(\frac{d_r}{\varepsilon_r}\right)}$

Down position : highest isolation → highest C_{up} $\quad C_{down} = \frac{\varepsilon_0 . \varepsilon_r . A}{d_r}$

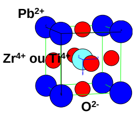
High C_{down}/C_{up} for good performances

d = distance between the two metal plates – A = active capacitive area – d_r = thickness of the dielectric layer – ε_0 = permittivity of free space – ε_r = permittivity of the dielectric layer

❖ Reliability of the device → **charges evacuation**
→ **resistance degradation and breakdown**

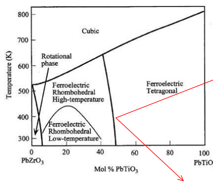
PZT layer for having high dielectric constant

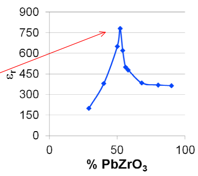
$PbZr_xTi_{1-x}O_3$ (PZT)



Solid solution : $PbZrO_3$-$PbTiO_3$

Perovskite structure





$PbZr_{0.52}Ti_{0.48}O_3$

Morphotropic phase boundary → **highest ε_r**

Typical permittivity : ε_{11} = 650 – ε_{33} = 560

PZT layer on Pt substrate

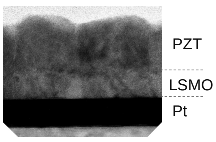
❖ model substrate : **epitaxial (111) Pt** on sapphire

❖ deposition technique : **PLD**

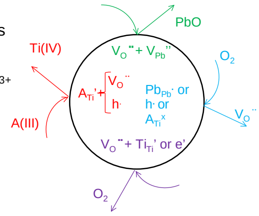
❖ **oxide buffer layer** ($La_{2/3}Sr_{1/3}MnO_3$) to control crystalline phase and texture of the PZT layer

➡ **Polycrystalline PZT with columnar structure**
Texture : 80-90% (100) and 10-20% (101)
Epitaxy of PZT grains on LSMO grains on Pt

TEM image



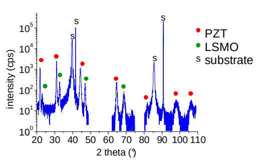
❖**defect chemistry :**
- oxygen and lead vacancies
- acceptor impurities
- oxidation of Pb^{2+} to Pb^{3+}
- reduction of Ti/Zr^{4+} to Ti/Zr^{3+}
- extended defects : grain boundaries, dislocations



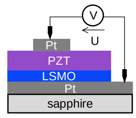
❖ chemical analysis :

➡ **$Pb_{0.92-0.96}Zr_{0.56}Ti_{0.44}O_x$**

XRD diagram



Ferroelectric properties

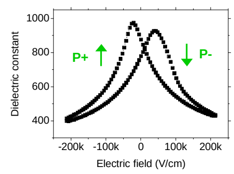


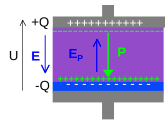
PZT thickness = 200nm
Top electrode : 220*250µm²

Capacitance – voltage measurements
From -4V to 4V and from 4V to -4V

$$C = \frac{\varepsilon_0 . \varepsilon_r . A}{d_r}$$

Dielectric constant – Electric field



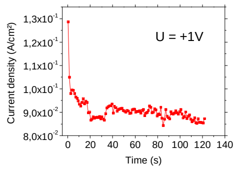


Butterfly loop → ferroelectric layer
ε_r at 0V = 820

Series capacitor model :
interface capacitance (Schottky) + bulk capacitance

Transient currents

Typical i-t curve

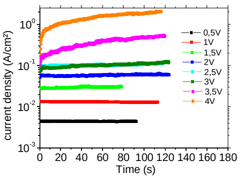


❖ decrease at onset
- polarization reversal (ns)
- emptying/filling of traps (ms to s)

❖ steady state :
- current flow between electrodes through sample
= **True leakage current**

i-t curves at different voltage

Steady state depends on temperature and applied voltage



❖ Increase of current above a **threshold voltage**
Here : 2.5V

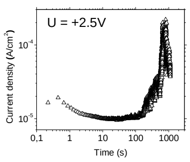
→**Resistance degradation**

❖ Possible cause :
Migration of oxygen vacancies

Protocol for I-V measurements

❖ Avoid resistance degradation
→ Max voltage below threshold

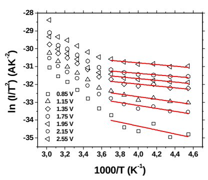
❖ Avoid polarization reversal current and charging/discharging current from traps
→ Prepolarization before I-V acquisition



➡ ❖ **Prepolarization** at 2.5V for 30s, from 2.5V to 0V
❖ **Prepolarization** at -2.5V for 30s, from -2.5V to 0V
❖ Under vaccum

Conduction mechanisms

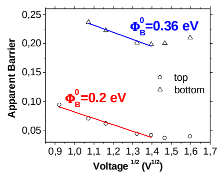
200K<T<270K



Schottky mechanism
Interface controlled conductivity

$$J_{sch} = A^{**}T^2 \exp\left(-\frac{q}{kT}\left(\phi_B^\circ - \sqrt{\frac{qE}{4\pi\varepsilon_0\varepsilon_r}}\right)\right)$$

Slope of Arrhenius plot = Apparent barrier height : voltage dependent



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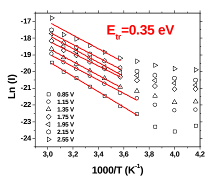
interface states and interface defects

270K<T<330K



Hopping mechanism
bulk controlled conductivity

$$J_{hop} \propto E \exp\left(-\frac{E_{tr}}{kT}\right)$$

slope of Arrhenius plot = activation energy for hopping E_{tr} voltage independent

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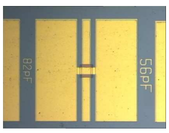
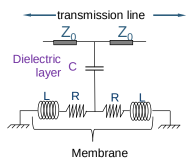
Grain boundaries = high defect concentration
→ Easy way for charges to flow trough the film

RF characterization



RF MIM capacitor
Model of capacitive RF MEMS with membrane in down position

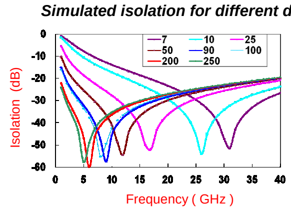
Model



RLC circuit with a frequency resonance : $f_0 = \frac{1}{2\pi\sqrt{LC}}$

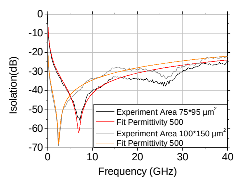
Capacitance : $C = \varepsilon_0 \varepsilon_r \frac{A}{d}$

Simulated isolation for different dielectric constants



Thickness : 200nm
Area : 100µm * 120µm

Isolation of RF MIM capacitor with PZT dielectric layer



❖ Isolation >30 dB at 10GHz

❖ Max isolation at 2.5GHz : 70dB

❖ **ε_r(GHz) = 500**

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