Gamma, neutron, proton irradiated p-type silicon MOS capacitors with aluminium oxide

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Motivation

• SiO₂ positive oxide charge -> Electrical insulation between pixels for p-type silicon -> p-type implant between pixels - p-stop, p-spray -> additional implantation and high-temperature process steps

• An alternative is to use a different oxide with negative charge -> aluminium oxide (Al₂O₃): good dielectric properties, high negative charge

• Atomic Layer Deposition Al₂O₃ : low temperatures, high uniformity of layers, very thin layers with good accuracy

• C-V measurements in order to investigate the interface charges and surface damage of alumina films after irradiation with different particles
Samples

- Micronova Nanofabrication Centre, Espoo, Finland
- ALD Al2O3 with O3 precursor
- Oxide thickness 80nm
- 4–8 kΩcm resistivity
- Frequency 1kHz
- Hysteresis: due to ionic mobile charges in dielectric film

- The effective number of oxide charges:
  \[ N_f = \frac{\Delta V_{fb} \times C_{ox}}{charge} \]
- From acc to inv: \( V_{fb} = 2.99 \pm 0.28 \) V \( N_{f,\text{eff}} = (1.73 \pm 0.17)e12 \text{ cm}^{-2} \)
- From inv to acc: \( V_{fb} = 3.48 \pm 0.49 \) V \( N_{f,\text{eff}} = (2 \pm 0.28)e12 \text{ cm}^{-2} \)
Gamma irradiation

- from a Co-60 source at the Radiation Chemistry and Dosimetry Laboratory at the Ruder Boškovic Institute in Zagreb, Croatia
- For the acc to inv sweep: strong effect on $V_{fb}$ -> build up of positive charge
- For inv to acc: negligible effect on $V_{fb}$
- Linear increase of $\Delta V_h$ with dose ($\Delta V_h = V_{fb\_inv\_to\_acc} - V_{fb\_acc\_to\_inv}$)
- TCAD reproduction of $V_{fb}$ with variation of $N_f$

![Diagram showing capacitance vs voltage for different gamma ray doses and TCAD simulation results.](image)
Neutron irradiation

- in the Triga reactor at Ljubljana, Slovenia
- $F=0 \rightarrow 1 \times 10^{14} \text{n/cm}^2$: strong effect on $V_{fb} \rightarrow$ build of negative oxide charge
- $1 \times 10^{14} \text{n/cm}^2 \rightarrow 6 \times 10^{15} \text{n/cm}^2$: strong effect on $V_{fb} \rightarrow$ build of positive oxide charge
- $1 \times 10^{14} \text{n/cm}^2 \rightarrow 6 \times 10^{15} \text{n/cm}^2$: non-linear depletion slope, dip
- $C/C_{ox}$ ratio: Increase of bulk doping $N_{eff}$
Effect of Nit on CV-curve

Donor interface-trap:
- Strong effect on depletion slope: donating electron-> positive charge build-up-> eventually $V_{fb}$ changes the sign
- Dip

Acceptor interface-trap:
- Strong effect on $V_{fb}$ -> accepting electron-> negative charge build-up> change of $V_{fb}$ to higher voltage
- Dip at initial voltage
Effect of Donor Nit

• TCAD p-type Al2O3: $N_{\text{eff}}=5\times10^{14}$ cm$^{-3}$, $N_f=-7\times10^{12}$ cm$^{-2}$, $N_{it}=1.8\times10^{12}$ cm$^{-2}$

• Reproduction of dip and $V_{fb}$ with interface donor-trap level: strong evidence that donor $N_{it}$ dominates in alumina at high neutron fluences

<table>
<thead>
<tr>
<th>Type of trap</th>
<th>Level, eV</th>
<th>$\sigma_e$, cm$^2$</th>
<th>$\sigma_h$, cm$^2$</th>
<th>Density, cm$^{-2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Donor</td>
<td>Ev+0.6</td>
<td>1e-15</td>
<td>1e-15</td>
<td>1.8e12</td>
</tr>
</tbody>
</table>
10 MeV Proton irradiation

- 10 MeV protons at the Accelerator Laboratory at University of Helsinki
- $C_{ox}$ decreases with the increase in fluence -> displacement damage
- For the acc to inv sweep: effect on $V_{fb}$ -> build up of positive charge
- Hysteresis $\Delta V_h$ linear increase with the dose -> mobile traps
- Simulation is in progress
Summary

MOS capacitors with Al$_2$O$_3$:

- Gamma measurement & simulation results suggest significant accumulation of positive oxide charge and mobile charges.
- Neutron measurement & simulation gives a strong evidence that donor $N_{it}$ dominates over $N_f$ in alumina at high neutron fluences.
- Proton measurement results suggest build up of positive oxide charge and an increase in the number of mobile charges.
Thank you!