Flatband Voltage Shift of La-based Gate Oxides with Alkali-earth-elements Incorporation

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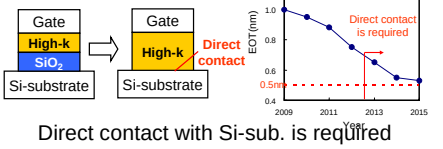
Introduction

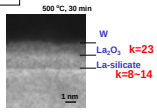
To realize continuous scaling



Direct contact with Si-sub. is required

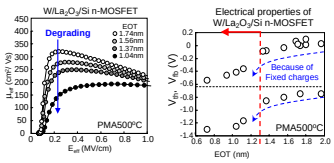
Advantage of La_2O_3 as a gate oxide

- High k-value (ε_r:23.4)
- Wide band-gap (E_g=5.6eV)
- Fairly nice electrical properties by forming **La-silicate** at the interface

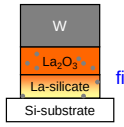


La_2O_3 is expected to be one of the promising high-k gate dielectrics.

Problem with EOT scaling



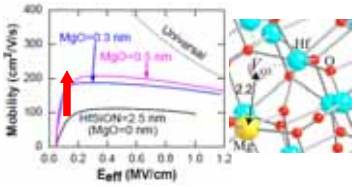
The cause is …



Metal gate induced fixed charge generation.

Mechanism for preventing increase of the fixed charge is required.

Mobility improvement with Mg incorporation



N. Mise, et al.: IEDM Tech Dig. (2007) 527

N. Umezawa, : Appl.Phys .Lett.93, (2008) 223104.

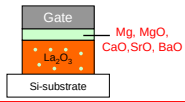
Mobility in Hf-based MOSFET can be improved with **Mg incorporation**.

→ We focused on alkali-earth-elements

H							
Li	Be						
Na	Mg						
K	Ca	Sc					
Rb	Sr	Y					
Cs	Ba						

Purpose of this study

1. Modeling of the V_{fb} dependence on EOT using fixed charge
2. Impact of alkali-earth-elements incorporation on La_2O_3 gated MOS device

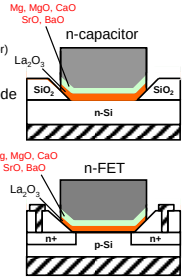


Experimental procedure

300nm-thick-SiO_2 isolated n-Si(100)wafer for capacitors
S/D pre-formed locos isolated p-Si(100) wafer for n-FETs

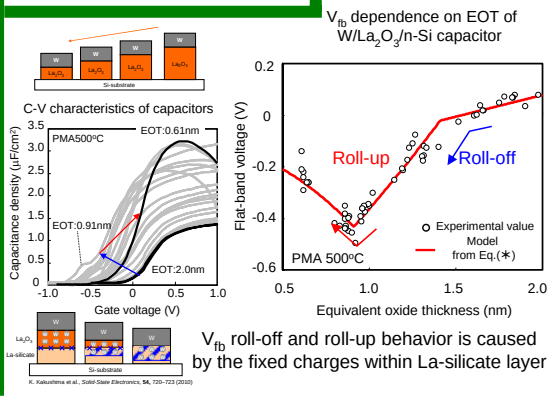
- SPM cleaning and HF treatment
- E-beam deposition [La_2O_3, Mg, MgO, CaO, SrO, BaO] / W (as metal gate) deposition by RF sputtering — *in situ* ~10^{-6}(Tor)
- Patterning by RIE to form gate electrode
- Annealing in F.G. for 30 min.(500°C)
- capacitor / n-FETs
  - Contact hole forming
  - Al wiring
- Al deposition as backside contact by thermal evaporation

Electrical characterization

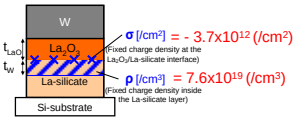


Result & Discussion

V_{fb} roll-off and roll-up behavior



V_{fb} roll-off and roll-up behavior is caused by the fixed charges within La-silicate layer

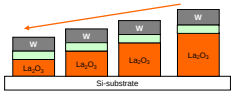


$$V_{fb} = -q\left(\frac{\sigma t_{LaO}}{\varepsilon_{La2O3}} + \frac{\rho\, t_W t_{LaO}}{\varepsilon_{La2O3}} + \frac{\rho\, t_W^2}{2\varepsilon_{LaSi}}\right) + \phi_{ms}$$

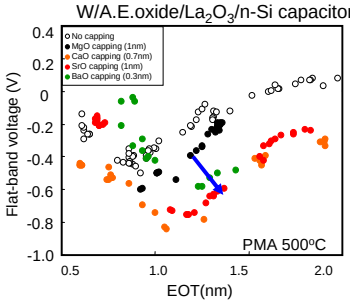
With using this model

We can quantitatively analyze the relation of V_{fb} and fixed charges and succeeded in making a reasonable explanation of the V_{fb} shift on EOT

Enhancement of La-silicate growth



W/A.E.oxide/La_2O_3/n-Si capacitor

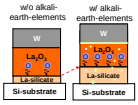


More negative shift was observed.

Oxygen ionic conductivity of La-silicate

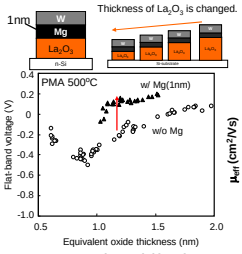
Compound	Ionic conductivity (mS/cm)@700°C
$La_{9.33}Si_6O_{26}$	0.3
$La_{9.6}Si_6O_{26.4}$	1.8
$La_9Ca_1Si_6O_{26.5}$	6.3
$La_9Sr_1Si_6O_{26.5}$	8.7
$La_9Ba_1Si_6O_{26.5}$	11.4

A.Vincent et al., j. eur. ceram.soc., **27**, 1187 (2007)
H.Yoshioka et al., j. eur. ceram. soc., **176**, 2395(2005)

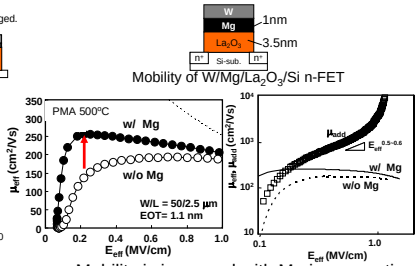


With alkali-earth oxide incorporation
More O atoms can easily move in dielectrics.
↓
La-silicate generation is enhanced.
↓
Total amount of W atoms in the La-silicate increases.
↓
Induced fixed charges increase to enhance the negative shift of V_{fb}.

Suppression of fixed charge generation with Mg incorporation

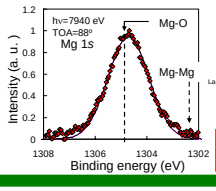


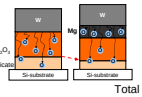
Negative shift of V_{fb} can be suppressed.



Mobility is improved with Mg incorporation.
→Decrease of RCS

→ Indicating the decrease of fixed charge with Mg incorporation.





Excess supply of O atoms is suppressed with combination of Mg and O.
↓
La-silicate generation can be also suppressed.
↓
Total amount of W atoms in La-silicate layer decreased.
↓
Induced fixed charges in the La-silicate are suppressed.

Conclusion

- We have proposed a model of the V_{fb} dependence on EOT
- V_{fb} shift on EOT changed with alkali-earth-elements incorporation due to enhancement of La-silicate formation accompanied by increase in the fixed charge
- Fixed charge generation can be suppressed with metal Mg incorporation