2011 中技社科技研究獎學金

CTCI Science and Technology Research Scholarship

高度微縮等效氮化矽厚度之電荷捕獲記憶體、金屬-絕緣層-金屬電容結構和氮化鎵電晶體之研究

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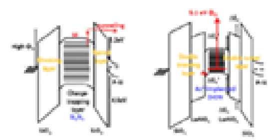
研究重點

1. **Charge-Trapping Flash:** Using both higher κ ZrON and As^{+} implantation to improve the device performance and downscale the ENT of 3.6 nm
2. **MIM Capacitor:** Using the laser annealing technique to attain higher κ dielectric for future generation MIM capacitors
3. **GaN MOSFETs:** Using a high-κ $LaAlO_3/SiO_2$ gate dielectric with a small 3 nm CET to achieve high performance device

研究成果

1 Charge-Trapping Flash

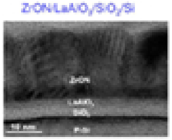
Schematic Energy Band Diagrams



To improve retention, double tunnel and blocking layers were used.

The As^{+} implantation to ZrON provides both higher trap density and deep 5.1 eV work-function of As at small 3.6 nm ENT.

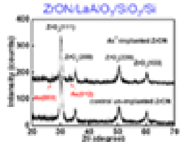
XTEM of As^{+}-implanted Structure



Smooth $SiO_2/LaAlO_3$ and ZrON were found in X-TEM.

After 950°C RTA, the ZrON poly-grains are found in X-TEM and lead to the higher k value and smaller ENT.

XRD of As^{+}-implanted Structure



After 950°C RTA, strong diffraction peaks indicates the good crystallinity to provide higher κ~35 with a smaller ENT of 3.6 nm. Extra weak As peaks were also found in As^{+}-implanted ZrON, suggesting the possibility to form small As clusters within ZrON.

Retention Characteristics of CT Flash

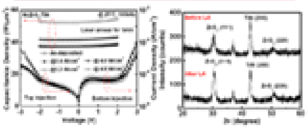
A large 10-year extrapolated window of 3.1 V is measured at 125°C in As^{+}-implanted CT flash at 100 μs and ±16 V P/E and significantly better than the 1.9 V 10-year window in control devices.

The large retention window allows MLC storage even at 125°C.

The good retention is due to better confinement in $LaAlO_3/ZrON/LaAlO_3$ and physically thicker double high-κ/SiO_2.

2 MIM Capacitor

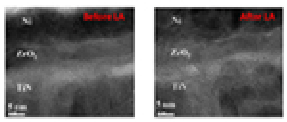
C-V, J-V & XRD of ZrO_2 w/ and w/o LA



Although the leakage current increases slightly with LA energy, low leakage current of 2.5×10^{-7} A/cm² at -1 V is still reached with a very high capacitance density of 52 fF/μm², a higher κ of 45 and a CET of 0.66 nm.

The LA improves the ZrO_2 crystallinity of tetragonal-phase, indicating that the improved capacitance density is related to laser energy.

Cross-section Inspection by TEM



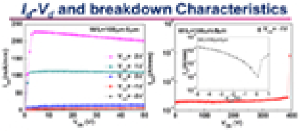
The figures show cross-sectional TEM of $Ni/ZrO_2/TiN$ capacitors before and after laser annealing. Clear better crystallization of ZrO_2 is observed after laser annealing, which is consistent with the stronger XRD signal of ZrO_2.

ΔC/C Variation

Good 10-year reliability with a small ΔC/C of 1.7% at 2 V is obtained for $Ni/ZrO_2/TiN$ capacitor operation with a very high 52 fF/μm² capacitance density.

3 GaN MOSFETs

I_d-V_d and breakdown Characteristics



The enhancement mode operation and high transistor drive current were measured. A small R_{on} of 13.5 Ω-mm was obtained from I_d-V_d characteristics at a V_d of 2 V.

Such low R_{on} is an advantage of gate-recessed GaN MOSFETs due to high 2DEG electron density and high mobility.

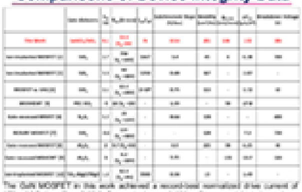
This high-κ gate dielectric GaN MOSFET has a breakdown voltage of 385 V that is useful for high power and high temperature electronics.

C-V and mobility Characteristics

High gate capacitance of 11.4 fF/μm² was measured, revealing a small CET of only 3.0 nm. The positive accumulation voltage in the C-V curve is opposite to that of the Si n-MOS capacitor.

A high peak mobility of 201 cm²/Vs was obtained, resulting in one of the most favorable data for GaN MOSFETs. This mobility is substantially lower than the 2DEG mobility of 1458 cm²/Vs due to the dielectric/GaN interface scattering.

Comparisons of Device Integrity Data



The GaN MOSFET in this work achieved a record-best normalized drive current of 172 μA/V², low R_{on} of 13.5 Ω-mm, high g_m of 136 mS/mm, and high breakdown voltage of 385 V simultaneously.

研究生活及心得

我在博士班研究生活中經過了許多的酸甜苦辣，在教授長期指導下，學到了許多科學方法及研究精神，也因在失敗中不斷地求進步使我遇到問題不會畏懼反而學會去思考並尋求解決之道，經過這一番磨練使我生涯受益良多。我們在做研究並非只靠著自己的力量，同時也需要許多貴人的支持與幫忙才能使我們做事能事半功倍。如果有人問我如何突破自己邁向成功的頂端，我會告訴他:「信心與堅持的態度是持續讓你通往成功之路的好夥伴。」

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