A Monte Carlo-Based Analysis of Radiation Effects Mechanisms in 3D NAND Memories

Matthew L. Breeding¹, Edward P. Wilcox², Robert A. Reed¹, Ronald D. Schrimpf¹, Kevin M. Warren¹, Brian D. Sierawski¹, and Michael L. Alles¹

¹Vanderbilt University
²NASA Goddard Space Flight Center

June 16, 2021

This work is sponsored by DTRA, grant HDTRA1-18-1-0002
Outline

• 3D NAND memories
  • Charge-trap (CT) vs. floating-gate (FG)
• Development of MRED simulations for 3D NAND
  • Simulation vs. experimental results
• Comparison of dose-enhancement effect in FG & CT devices
• Conclusion
3D NAND memory

- 72-layer SK Hynix charge-trap 3D NAND
- p-BiCS structure ("U" shaped string)
- Operational modes trade reliability for density

3D NAND – two types

- Charge trap (CT)
  - Gate-last fabrication
  - Uses silicon nitride layer as CT
  - Metal (usually W) word lines

- Floating gate (FG)
  - Gate-first fabrication
  - Polysilicon FG with IPD
  - Polysilicon word lines

Compagnoni, et al. Proc. IEEE, 105(9), 2017
Simulation details for 3D NAND

• 72-layer CT 3D NAND (Hynix)
• Incident protons from 500 keV to 1.2 MeV
• Assumptions
  • Block sensitive detectors
  • Monolithic BEOL
  • No voids in stack
  • Simplified materials
  • Not p-BiCS (WL placement)
Summary of previous results

- Proton-induced SEU observed in 72-layer SK Hynix 3D NAND (CT)
- Heavy-ion irradiations for top die
Updated simulation structure – fixing assumptions

Block sensitive detectors ➔ GAA geometry
Monolithic BEOL ➔ Detailed BEOL
No voids in stack ➔ Air gap voids included
Simplified materials ➔ Full materials used
Not p-BiCS (grid) ➔ p-BiCS cell configuration
NVM stack only ➔ TSV fanout included
Comparison with MRED model – protons

• Proton-induced SEU observed in 72-layer SK Hynix 3D NAND
Comparison with MRED model – heavy ions

- Heavy-ion SEU observed in 72-layer SK Hynix 3D NAND
TID in 3D NAND – dose enhancement

Do the tungsten WLS in CT NAND lead to significant dose enhancement?

Choe, “Comparison of Current 3D NAND chip and cell architecture,” Flash Memory Summit, 2009
Parat and Dennison, “A floating gate based 3D NAND technology with CMOS under array,” IEEE IEDM, 2015
TID in 3D NAND – FG

- Floating gate $\rightarrow$ polysilicon WL
- Only expect DEF from BEOL metallization
- DEF falls off rapidly
  - $\sim$20 layers $\rightarrow$ $\sim$1 $\mu$m
- X-rays incident from backside have less effect in NAND stack

![Graph showing TID distribution for front vs backside X-ray incidence (silicon WLs).]
TID in 3D NAND – CT

- Charge trap → tungsten WL
- Expect DEF from BEOL and WLs
- DEF falls off much less rapidly
- X-rays incident from backside have similar effect
TID in 3D NAND – DEF

- Clear dose-enhancement effect
- Function of photon energy
- Poor statistics for gammas
Conclusion

• 3D NAND offers excellent storage capabilities
• Physics-based modelling with MRED is ideal for understanding radiation effects mechanisms in complex devices
• Better to account for full physical features in MRED
• The dose-enhancement effect for CT 3D NAND is significantly greater than in FG 3D NAND due to tungsten WLs
  • Depends on test environment
  • Dose-enhancement effects from BEOL in both cases