Electron-induced Single-Event Upsets in integrated memory device

Pablo Caron – 2nd année – DPHY

Christophe Inguimbert, ONERA, DPHY Laurent Artola, ONERA, DPHY Guillaume Hubert, ONERA, DPHY Robert Ecoffet, CNES



THE FRENCH AEROSPACE LAB



State of the art

Heavy particles : first to trigger upsets

2013 : first measurements of electroninduced SEU [1]



[1] M. P. King et al., "Electron-Induced Single-Event Upsets in Static Random Access Memory," IEEE Trans. Nucl. Sci., vol. 60, no. 6, pp. 4122–4129, Dec. 2013.



State of the art

Heavy particles : first to trigger upsets

2013 : first measurements of electroninduced SEU [1]

New missions which involve intensive environments (JUICE)





[1] M. P. King et al., "Electron-Induced Single-Event Upsets in Static Random Access Memory," IEEE Trans. Nucl. Sci., vol. 60, no. 6, pp. 4122–4129, Dec. 2013.



State of the art



[1] M. P. King et al., "Electron-Induced Single-Event Upsets in Static Random Access Memory," IEEE Trans. Nucl. Sci., vol. 60, no. 6, pp. 4122–4129, Dec. 2013.



Physical mechanisms induced by electron irradiation



Below ~ 10 MeV:

→ Coulomb interactions (elastic and inelastic)

Above ~ 10 MeV:

- \rightarrow Nuclear interactions
- → Bremsstrahlung process become more and more important
- → Recoil nuclei by Coulomb elastic scattering are more and more energetic

How to investigate these physical mechanisms ?



How to investigate these new physical mechanisms ?



Geant4: GEometry ANd Tracking

C++ toolkit to simulate transport of particles through matter

International collaboration



How to investigate these new physical mechanisms ?



Geant4: GEometry ANd Tracking

C++ toolkit to simulate transport of particles through matter

International collaboration

Sensitive region as parallelepiped

Two degrees of freedom: sensitive volume and critical charge

Simulation of deposited energy:
If Q_{dep} > Q_{crit} then upset





Experimental measurements



[2] A. Samaras *et al.*, "Experimental Characterization and Simulation of Electron-Induced SEU in 45-nm CMOS Technology," *IEEE Trans. Nucl. Sci.*, vol. 61, no. 6, pp. 3055–3060, Dec. 2014
 [3] M. J. Gadlage, et al., "Electron-Induced Single-Event Upsets in 45-nm and 28-nm Bulk CMOS SRAM-Based FPGAs Operating at Nominal Voltage," *IEEE Trans. Nucl. Sci.*, vol. 62, no. 6, pp. 2717–2724, Dec. 2015

ONERA

THE FRENCH APPOSPACE IA

NATIONAL D'ÉTUDES SPATIALES



What interactions are involved?

[2] A. Samaras *et al.*, "Experimental Characterization and Simulation of Electron-Induced SEU in 45-nm CMOS Technology," *IEEE Trans. Nucl. Sci.*, vol. 61, no. 6, pp. 3055–3060, Dec. 2014 [3] M. J. Gadlage, et al., "Electron-Induced Single-Event Upsets in 45-nm and 28-nm Bulk CMOS SRAM-Based FPGAs Operating at Nominal Voltage," *IEEE Trans. Nucl. Sci.*, vol. 62, no. 6, pp. 2717–2724, Dec. 2015





ONERA

THE FRENCH APPOSPACE IA

E NATIONAL D'ÉTUDES SPATIALES

[2] A. Samaras *et al.*, "Experimental Characterization and Simulation of Electron-Induced SEU in 45-nm CMOS Technology," *IEEE Trans. Nucl. Sci.*, vol. 61, no. 6, pp. 3055–3060, Dec. 2014 [3] M. J. Gadlage, et al., "Electron-Induced Single-Event Upsets in 45-nm and 28-nm Bulk CMOS SRAM-Based FPGAs Operating at Nominal Voltage," *IEEE Trans. Nucl. Sci.*, vol. 62, no. 6, pp. 2717–2724, Dec. 2015



[2] A. Samaras *et al.*, "Experimental Characterization and Simulation of Electron-Induced SEU in 45-nm CMOS Technology," *IEEE Trans. Nucl. Sci.*, vol. 61, no. 6, pp. 3055–3060, Dec. 2014
 [3] M. J. Gadlage, et al., "Electron-Induced Single-Event Upsets in 45-nm and 28-nm Bulk CMOS SRAM-Based FPGAs Operating at Nominal Voltage," *IEEE Trans. Nucl. Sci.*, vol. 62, no. 6, pp. 2717–2724, Dec. 2015

ONERA

THE FRENCH APPOSPACE IA

IATIONAL D'ÉTUDES SPATIALES

[2] A. Samaras *et al.*, "Experimental Characterization and Simulation of Electron-Induced SEU in 45-nm CMOS Technology," *IEEE Trans. Nucl. Sci.*, vol. 61, no. 6, pp. 3055–3060, Dec. 2014
 [3] M. J. Gadlage, et al., "Electron-Induced Single-Event Upsets in 45-nm and 28-nm Bulk CMOS SRAM-Based FPGAs Operating at Nominal Voltage," *IEEE Trans. Nucl. Sci.*, vol. 62, no. 6, pp. 2717–2724, Dec. 2015

ONERA

THE FRENCH APPOSPACE IA

Coulomb elastic-induced SEU: explains high SEU region

 ^[2] A. Samaras *et al.*, "Experimental Characterization and Simulation of Electron-Induced SEU in 45-nm CMOS Technology," *IEEE Trans. Nucl. Sci.*, vol. 61, no. 6, pp. 3055–3060, Dec. 2014
 [3] M. J. Gadlage, et al., "Electron-Induced Single-Event Upsets in 45-nm and 28-nm Bulk CMOS SRAM-Based FPGAs Operating at Nominal Voltage," *IEEE Trans. Nucl. Sci.*, vol. 62, no. 6, pp. 2717–2724, Dec. 2015

Bremsstrahlung-induced SEU: ✓ Negligible

Does not take into account a complete material environment

electronuclear-induced SEU: does not explain experimental errors

ionization-induced SEU: explains low SEU region

Coulomb elastic-induced SEU: explains high SEU region

Conclusion and discussion

- Physical exlpanations has been established about electron-induced SEU in integrated devices
 - Two SEU regions mainly driven by two mechanisms:

Up to ~ 10 MeV From ~ 10 MeV

Coulomb inelastic Coulomb elastic

- ✓ GEANT4 modules has been coded to simulate the sensitivity of devices under electron irradiations
- New heavy ion transport models has been developed to simulate a more accurate track of secondaries (Coulomb elastic and electronuclear processes)

Communications

- Publications (available)
 - P. Caron, C. Inguimbert, L. Artola, N. Chatry, N. Sukhaseum, R. Ecoffet, F. Bezerra, *Physical mechanisms inducing electron Single Event Upset, 2018, IEEE TNS*
- Publications (in progress)
 - P. Caron, C. Inguimbert, L. Artola, R. Ecoffet, F. Bezerra, *Comparison of different proton-induced and heavy ions-induced ionization models, JAP*
 - P. Caron, C. Inguimbert, L. Artola, R. Ecoffet, F. Bezerra, *Implementation* of new models to describe Coulomb inelastic scattering down to very low energy in GEANT4, JAP
 - P. Caron, C. Inguimbert, L. Artola, R. Ecoffet, F. Bezerra, *Contribution of Coulomb elastic interaction in proton-induced SEU, IEEE TNS*
- International conference
 - RADECS 2017, Geneva, oral presentation

ONERA

THE FRENCH APPOSPACE IA

Thank you

