Image Sensor Dark Current Non Uniformity modeling using GEANT 4

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Deffects in semiconductor

CCDs, CMOS and IR imagers
(increased dark current & hot pixels, Random Telegraph Signals (RTS))

Solar array
(power loss)

Optocoupler
(charge transfer ratio (CTR) degradation)

Bipolar and III-V transistors (gain degradation & increased leakage currents)

LED & Laser diodes
(light output degradation)

Photodiode
(photocurrent loss & dark current increases)
Deffects in semiconductors: Carrier transport degradation

- Recombination
- Generation
- Scattering
- Trapping

Conduction band

Trap level

Valence band

holes

Mobility reduction

Conductivity reduction
Image sensors degradation

Nuclear reactions

↓

Damage cascade

↓

Dark current

Different number of nuclear reactions initiated in each pixel (Poisson's Law)

Different recoil nuclei

Initiating different damage cascade

Hot pixels critical

For star trackers

Dark signal Distribution

Non uniform increase in dark current

Geant4 : 185 MeV

JADE measurements : 185 MeV

5.31 $\times 10^{+11}$ protons/cm$^2$
Existing modelling approach

- Gaussian or Gamma shape are assumed recoil damage distribution
- Parameterised using average Damage energy (NIEL) and variance

- Nuclear inelastic reactions roughly simulated
  - Many recoil nuclei with different mass (different range) can be produced
  - Border Crossing effect is neglected
    - The damage is supposed to be confined in the pixel

- Supposed to work for pixels greater than ~10 µm side
- What about pixels of a few µm?

Analytical approach

DSNU Modelling

Pixel design → Geant4 modelling → Damage pixel databank → DSNU modelling

**FASTRAD GDML**

- Depleted zone = sensitive detector
- Dead zones + substrate + upper layers

**G4Binary**
- nuclear reaction model

**G4screenedNuclearRecoil**
- Coulombic damage of cascade

**G4XWrapperProcess**
- Cross section Biasing

Central pixel irradiation
- Storage: number of displacements in the impacted pixel + its neighbours

Number of nuclear reactions randomly selected in a Poison distribution

For each reaction the damage in the irradiated pixel + its neighbours is randomly selected in the Precalculated dataset

Typically 10,000 nuclear reactions

Atomic displacements

Pattern produced by GEANT4 simulation
DSNU : Comparison with E2V JADE measurements

- Good predictions
- High accuracy that evidences "abnormal" events that standard approaches are not able

- Discrepancy due partly to coulombian scattering
- Discrepancy partly due to nuclear elastic events
- Ionizing dose

Publicaiton IN RADECS 2012
• Evidences of "abnormal" events
• Enhancement phenomena
Border Crossing effect analysis

The distribution of damage through the neighbours pixels changes the shape of the DSNU. This phenomenon appears for pixels of a few µm side.
Conclusions and perspectives

• Original 3D Monte Carlo approach for DSNU prediction
• Very good predictions knowing only the size of the pixels
• Border crossing evidence for small pixels (few µm side)
• Improvement of the model in progress
  • Nuclear elastic scattering
  • Coulombic scattering

Potential SPENVIS application for image sensor degradation prediction ?!