Proton-Induced Transients and Charge Collection
Mechanisms in a LWIR HgCdTe Focal Plane Array

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Outline

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  – 256 x 256 LWIR HgCdTe array
• Data Analysis & Results
• Charge Collection Modeling
• Summary
Introduction

- The Problem: Low noise performance of IR detectors is required, even in the presence of charged particles.
  - galactic cosmic rays,
  - trapped protons & solar energetic particles
  - Particle induced transients identified as an important source of noise on ESA’s ISO satellite
    - Also observed on NICMOS Instrument on NASA’s Hubble Space Telescope
• Tools to analyse particle-induced transients have been developed by Pickel et al.¹
  – To date, comparisons of model have been made to flight data for a HgCdTe array exposed to trapped protons, and to a Si array exposed to laboratory protons.
• We report ground based proton transient measurements in a modern LWIR HgCdTe array operating under cryogenic conditions.
  – Demonstration of charge collection mechanisms
  – Provide benchmarks for modeling tools

LWIR HgCdTe Array Description

- 256 x 256 pixel array
  - Epitaxially grown multi-layer planarized heterojunction structure
  - Cutoff wavelength ~14 \( \mu \)m
  - Pixel pitch is 60 \( \mu \)m
  - Unit cell utilizes a central implanted diode for drift induce charge collection
    - Optical measurements indicate lateral collection with effective diffusion length of 16 \( \mu \)m
  - QE is 54% with no coatings
  - Pre-rad pixel dark current <0.05 pA
Detector array is bump bonded to CMOS readout integrated circuit (ROIC)

- ROIC provides snapshot readout with 100 Hz frame rate
- ROIC includes
  - analog and digital test modes
  - analog and digital monitor points
    - Threshold shifts of representative FETs
    - Node voltages
    - Clock lines
- Measured conversion gain is 0.82 µV/electron
Experimental Approach

- 30 and 63 MeV protons incident at 45°
  - Dewar modified to permit both proton irradiation with minimal energy loss and full radiometric capabilities.
- The transient response of the bare ROIC also measured.

To be presented at Nuclear and Space Radiation Effects Conference, Monterey, CA 7/23/03
Experimental Approach, cont.

- Data acquired at 40K using full frames readouts under low illumination (pixel dark currents <0.05 pA)
- Two readout timing conditions compared:
  - 100% starring efficiency with integration occurring during readout.
  - 50% starring efficiency with an interleave-then-integrate scheme with slightly elevated read noise
- Integration time is 39.54 ms for both readout methods.
- Each run consisted of a series of clear frames followed by sequences of multiple frames (either 87 or 40).
  - Clear frames allow baseline subtractions
- Measurements for >2 orders of magnitude in beam flux acquired
  - All fluxes low enough to provide sparse proton strikes
Data Analysis

- Considerable effort required to validate proton-struck pixels versus erratic pixels and normal pixels against a background of random noise.
  - The large number of data and clear frames were essential.
  - See paper for details.
Histograms of Integrated Charge

- Total charge is integrated over struck pixel and nearest neighbors (if their charge exceeds the noise floor).

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Histograms of Number of Pixels Affected

- No single pixels hits!
- Charge diffusion in field free regions of the detector array result in charge collection over several pixels (crosstalk).

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Stacked Line Traces

- >1000 30 MeV proton hits are correlated to the central pixel and averages taken to reveal the relative number of pixels affected.
- High degree of symmetry, with pixels sharing a boundary being most affected. (Beam trajectory effects are absent.)

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• Charge collection model incorporates both analytical and Monte Carlo techniques to track ion deposited charge collected by both drift and diffusion.
  – We extend the previous model by incorporation of the field free region surrounding the central diode in each pixel.
    • Charge generated in field free regions are tracked until recombination, collection or collision with an inactive portion of the device.
    • Fidelity of model is strongly dependent on correct treatment of the diffusion characteristics of this device, hence these data provide benchmarking for model.
• Initial line source of minority carrier distribution based on particle LET and trajectory
• See paper for details and comparison to measured results.
Summary

- 30 and 63 MeV proton transient signatures were characterized for a LWIR HgCdTe array at 40K.
- Crosstalk is a significant issue with no single pixel hits observed.
- Diffusion in field free regions is the primary mechanism for charge spreading.
  - Directional effects due to beam trajectory not seen.
- Combine 30 and 63 MeV data will provide stringent test of diffusion modeling.