Contribution ID: **58** Type: **Oral Paper**

Studying defects in the silicon lattice using CCDs

Friday, September 12, 2014 9:50 AM (20 minutes)

Silicon has long been the material of choice for the production of detectors for many applications, from space astronomy to synchrotron research. When operating in space, or within a synchrotron or other accelerator, the detector can be subjected to a harsh radiation environment. The presence of these high energy electrons, protons and gamma-rays can lead to radiation-induced damage within the silicon lattice of the detector, creating further defects or "traps" in addition to any defects intrinsic to the lattice.

Charge-Coupled Devices (CCDs) have been used for many years to populate the focal planes of space telescopes, with recent examples ranging from the Hubble Space Telescope to the more recently launched ESA Gaia mission. The radiation environment in such missions is often dominated by high-energy protons, and leads to traps which act to capture electrons from signal charge packets as they are transferred through the device Any captured electrons are then released later in time, with this time determined by the emission time constant of the trap species in question. The repeated capture and release of signal as it is transferred through the CCD produces a "smearing" effect, resulting in a change in shape of the objects imaged. This change in shape is not only undesirable, but has particular importance to future applications such as the ESA Euclid mission, in which the subtle shape changes due to weak gravitational lensing are to be measured.

In order to correct against any radiation damage present in a CCD, one must be able to produce a model that accurately represents the transfer of charge through a device containing such traps. While current models are often based on fitting to observed data, it is now highly desirable to be able to actively predict the effects of any radiation on the device through a deeper understanding of the defects present in the lattice, at a sub-pixel, single-trap level. However, currently our understanding of defects within silicon has been based largely on techniques which analyse the average properties of many traps, often over several trap species.

Here we present a selection of methods, both experimental and simulated, that can be used to begin to study populations of lattice defects down to individual defects themselves. These studies have enabled the investigation of not only the defect densities and the device-averaged trap parameters, but also the properties of individual lattice defects in the device, en route to actively predicting the impact of the radiation environment before launch.

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Session Classification: Session 15: Detectors for High Radiation and Extreme Environments

Track Classification: Detectors for High Radiation and Extreme Environments