X-Ray Radiation Damage in CCDs

Introduction

There is a growing use of CCD detectors for direct detection applications in synchrotrons and the new X-ray Free Electron Lasers (XFELs). XCAM has developed camera systems in collaboration with several SR and XFEL experiments. However, it was apparent that for applications where the often intense X-ray flux might impact the dielectric layers of the sensor, that ionising damage would occur which could ultimately limit the operational lifetime of the sensor in the system. This might particularly occur close to the beam axis in diffraction experiments where the intensity is many orders of magnitude higher than further away from the beam

Over the years, XCAM has therefore investigated a range of photon-induced damage in CCDs from wavelengths ranging from EUV to hard X-rays

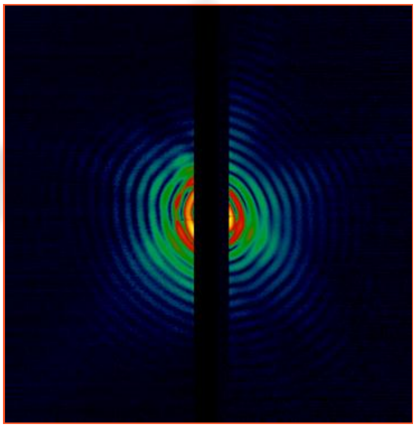

Figure 1 X-ray diffraction image from an XFEL plotted in log colour scale showing the intense region close to the beam centre

Experiments

Several experiments have been performed using a range of detectors (CCD30, CCD47, CCD230) in both standard technology and using e2v's proprietary "rad hard" thin oxide technology. Since the CCD is an imaging device, several irradiation experiments can be conducted on a single detector. The pattern in Figure 2 gives an indication of one such experiment with the exposure patterns shown in red.

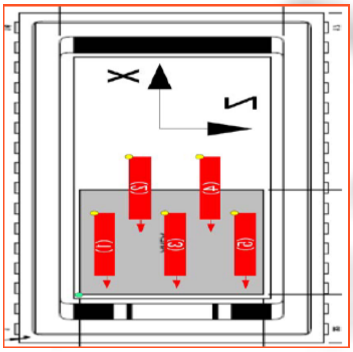

Figure 2 X-ray irradiation patterns over the test CCD

Results

The results of the X-ray irradiations indicated a number of damage mechanisms reading to :

- Increases in dark current
- Increases in flatband voltage

The first, dark current, affects the system operating temperature used for the operations, whilst the second, changes to Vfb, can impact on the CCDs ability to function correctly, particularly when transferring charge.

Ultimately, these effects combine to affect the lifetime of the CCDs in any particular application, and impact on the working lifetime of the detector. As part of system management, this information can then be used by the facility to advise on the spares policy to be used; treating the CCDs themselves as a consumable item !

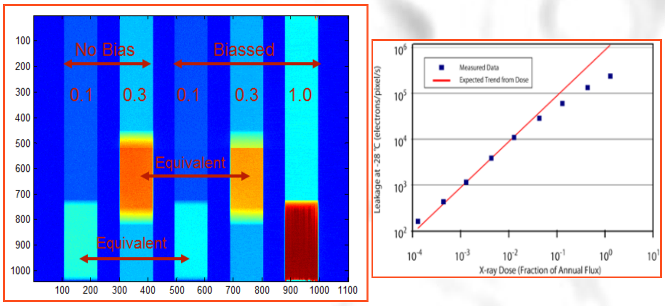

Figure 3 Dark current generated in the image from X-ray exposures and a plot showing the increase in dark current with increasing photon dose

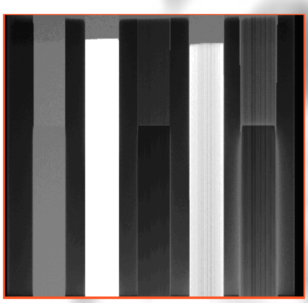

Figure 4 Image showing flatband voltage changes in addition to the dark current increase

Conclusions

We perform up-front studies of X-ray photon radiation damage in CCD sensors in advance of recommending their use in specific applications where operation could be affected by either new energy regimes or intensities. The new range of XFELs work at the extremes of Physics, with intense pulses of X-rays being delivered in femto-seconds. Our work has explored the use of BI and FI CCDs with standard and thin gate technologies and has characterised increases in dark current and flatband foltage arising from X-ray exposure. This work has guided the use of CCDs, with recommendations for system operating temperatures and lifetime predictions which impacts on spares policy.

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