Synchrotron characterization of polarization effects in compound semiconductor X-ray detectors

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Polarisation, that is, the build-up of localised charge within a crystal, can be a major source of operational degradation in the performance of X-ray detectors fabricated from semiconducting materials, such as, TlBr, CZT and HgI_2 [1-3]. The characteristics of such a detector, which may initially be excellent, can deteriorate drastically during extended exposure to radiation, and even result in a total collapse of detector response. Recently, Bale and Szeles [4] have developed a detailed dynamical model of polarisation of a semiconductor by intense X-radiation. They proposed that polarisation occurs because of carrier trapping by deep levels, resulting in a dense space charge region, which changes the internal field profile. However, many details of the effect are still not understood, particularly those relating to the polarisation process itself - the extent of the polarised region, the energy dependence of the process and information on the trapping processes responsible.

In the present work, carried out at the HASYLAB synchrotron research facility, our objective has been to study the polarisation process in greater experimental detail using focussed X-ray beams to obtain high spatial resolution (50 micron), in contrast to the uniform illumination used in previous investigations. The sample detectors were 5×5×2 mm^3 cut from a single TlBr crystal with gold contacts covering most of the square faces. Fig. 1 shows a typical set of data illustrating the degradation of detector response to a beam of a 60 keV X-rays at a rate of 1 kHz. Over a period of 1 hour the peak channel position (and hence charge collection efficiency) declined by 10%, whilst the FWHM resolution deteriorated from 2.0 to 4.5 keV, and overall the response curve became badly asymmetric. Using an original model extending the theoretical work of Bale and Szeles, we were able to reproduce the form of the curves using a credible set of parameters [5].

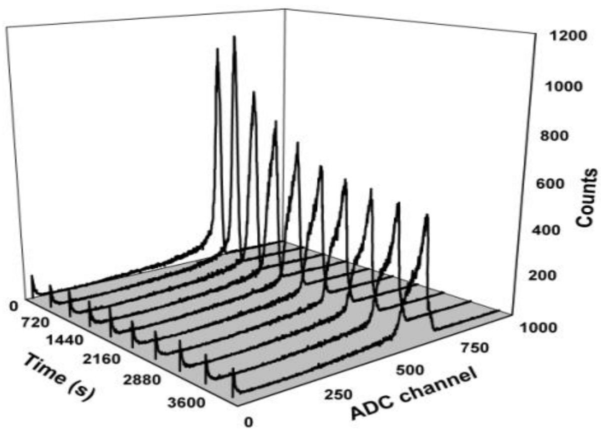

Fig. 1: Evolution of the 60 keV photopeak lineshape as a function of exposure time.

In order to study the spatial extent and state of the polarised region as a function of time and energy we used a pump-and-probe technique. First, a spot region immediately below the anode surface was irradiated at a high flux of fixed photon energy for several minutes. Then the response of the detector was observed using a much lower flux of photons of the same energy scanned through the spot, along a direction normal to the beam. Hence, we were able to observe the lateral, spatial extent of the polarised region in which the detector performance was degraded (see Fig. 2). It is clear that the polarised region in which the detector performance is degraded significantly exceeds the size of the exposed spot. By changing the photon energy of the probe, we were able to study the polarised region in depth and hence obtain a 3D image of the phenomenon.

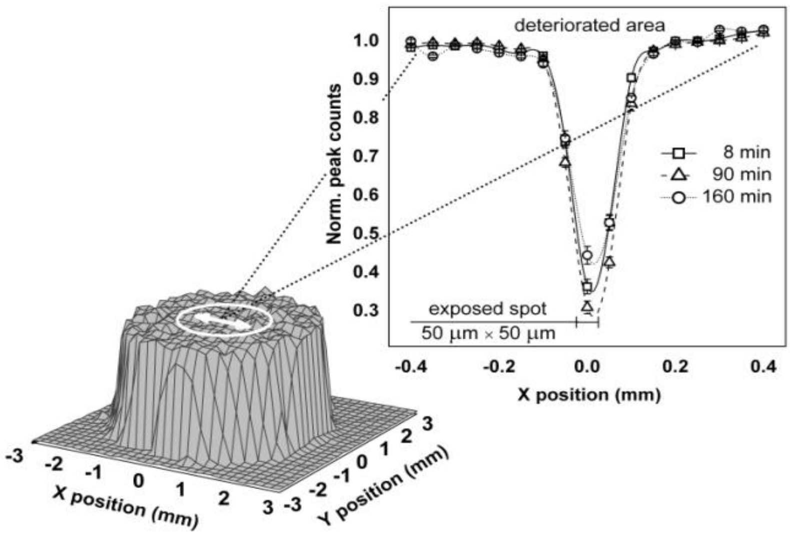

Fig.2: Normalised peak counts as a function of the position of the centre of the probe relative to the centre of the polarised area.

With this set-up we were also able to study the effects of varying temperature and detector bias voltage. We illustrate the latter in Fig.3. First a polarised spot was created by an intense pulse of 60 keV photons (~5 Gray) at a bias of 840V. Then the first probe scan of Fig. 3 was taken at the same bias immediately after the pump, confirming strong polarisation. The second scan taken with the bias reduced to 740V showed a similar effect. However, the third scan with the bias restored to 840V seemed to indicate that polarisation was no longer present. Investigation has shown that this is not directly due to the modulation of the bias supply, but rather to a relaxation of the space charge by the release of trapped electrons precipitated by the reduction in bias.

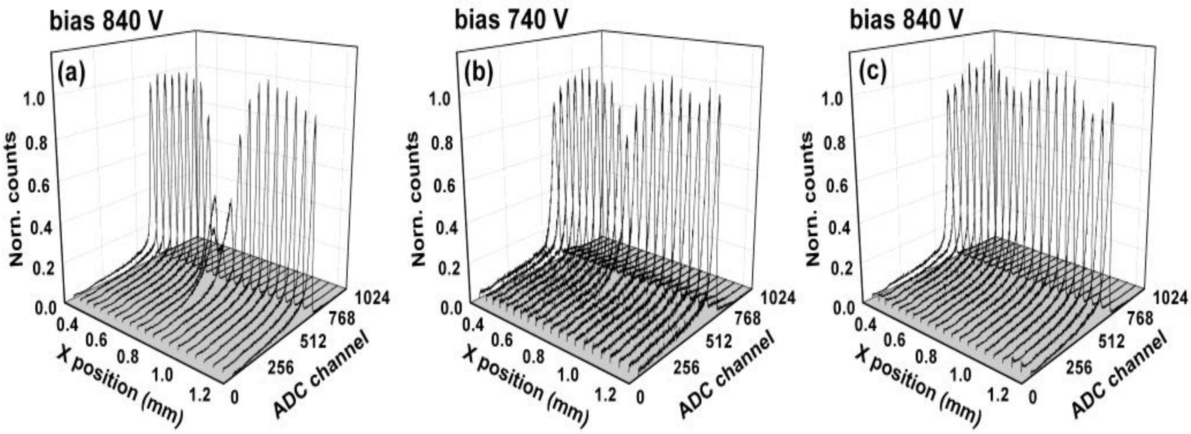

Fig.3: Results of sequential 60 keV scans across the damaged region through a sequence of bias settings (a) bias 840V, (b) bias 740V, (c) bias 840V, all at a temperature of -25^{o}C.

In summary, our results illustrate the power and future potential of the high resolution scanning technique for elucidating details of polarisation effects in semiconductor X-ray detectors.

References

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