Modelling Gaia CCD pixels with Silvaco 3D engineering software

George Seabroke[1,2], Thibaut Prod'homme[3], Gordon Hopkinson[4], David Burt[5], Mark Robbins[5], Andrew Holland[1]

[1] e2v centre for electronic imaging, The Open University, Walton Hall, Milton Keynes, MK6 7AA, UK, [2] Mullard Space Science Laboratory, University College London, Holmbury St. Mary, Dorking, Surrey, RH5 6NT, UK, [3] Leiden Observatory, Leiden University, The Netherlands, [4] Surrey Satellite Technology Ltd., Sevenoaks, UK, [5] e2v technologies plc, 106 Waterhouse Lane, Chelmsford, Essex, CM1 2QU, UK

Abstract

Gaia will only achieve its unprecedented measurement accuracy requirements with detailed calibration and correction for radiation damage. We present our Silvaco 3D engineering software model of the Gaia CCD pixel and its three applications for Gaia: (1) physically interpreting supplementary buried channel (SBC) capacity measurements (pocket-pumping and first pixel response) in terms of e2v manufacturing doping alignment tolerances; (2) deriving electron densities within a charge packet as a function of the number of constituent electrons and 3D position within the charge packet as input to microscopic models being developed to simulate radiation damage; (3) deriving effective charge packet volumes as a function of the number of constituent electrons as input to macroscopic Charge Distortion Models being developed to correct for radiation damage in Gaia data processing chains.

CCD pixel model

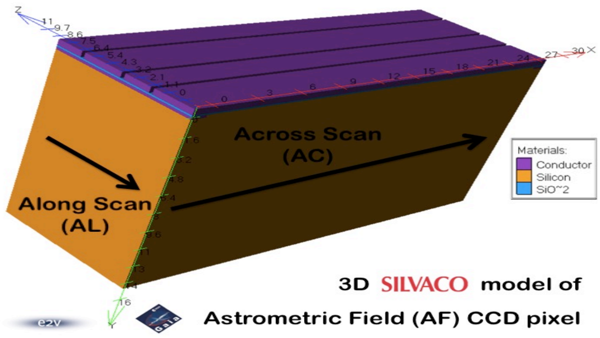

Figure 1: 3D Silvaco model of a single AF CCD pixel. In the AL direction, the model has 4 electrodes that make up 1 pixel. In the AC direction, the model runs from half way through one Anti-Blooming Drain (ABD, seen above as a conductor region beneath the oxide) to half way through the next ABD, delineating 1 CCD column.

Silvaco is a commercially available suite of engineering software. We have been using ATLAS, Silvaco's device simulation framework: ``ATLAS is a physically based two and three dimensional device simulator. It predicts the electrical behaviour of specified semiconductor structures and provides insight into the internal physical mechanisms associated with device operation". ATLAS has been successfully benchmarked against e2v measurements and other simulation software (Seabroke et al. 2009a). The 3D Silvaco model of the AF CCD pixel consists of four different doping regions: buried channel (BC, Seabroke et al. 2009b), supplementary buried channel (SBC), ABD shielding and the ABD itself; using doping derived to agree with proprietary e2v manufacturing processes.

Electron densities

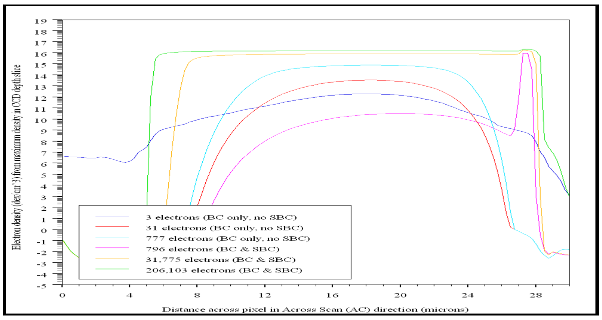

Figure 3: Silvaco pixel model-simulated AC electron density profiles through different sized charge packets. The AC cut is the same as in Fig. 1 i.e. there is half a ABD at 0-1 μm and another half a ABD at 29-30 μm. The SBC (at around 27-28 μm) causes the bimodal distribution at low signal size (when it is present in the simulation) and the BC runs from 4.5 to 28.

The original motivation for developing the Silvaco pixel model for Gaia was to provide electron densities of charge packets as a function of position within the pixel and as a function of the number of constituent electrons. This will be used by CEMGA microscopic simulations to calculate how many radiation-induced traps any charge packet will meet and whether the trap will capture one of the charge packet's electrons, the probability of which depends on electron density in the vicinity of the trap (see Seabroke et al. 2008 for more details). The full dynamic range of Gaia signal size (0-190,000 electrons) still needs to be simulated but Fig. 3 shows a representative sample of electron density profiles. CEMGA currently uses an analytical electron density distribution (Gaussians). Fig. 3 shows that this assumption is not physical but can be made more realistic by including a flattening factor in the analytical distribution.

Interpreting measurements

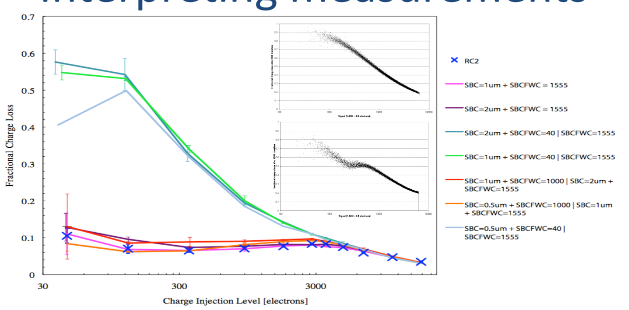

Figure 2: CTI Effects Models for GAia (CEMGA) simulations of First Pixel Response (FPR) measurements of a Gaia AF CCD: with working SBCs in both AL halves of the CCD (scenario 1) and; no SBCs in the upper AL half and working SBCs in the lower AL half (scenario 2). In addition to the Astrium Radiation Campaign 2 (RC2) measurements agreeing with the model with working SBCs in both AL halves, the insets show FPR measurements of different stitch blocks in an engineering model (EM) Gaia AF CCD exhibiting both scenarios.

Kohley et al. (2009) first discovered the 2 possible SBC scenarios (see Fig. 2 for details) and consequent SBC capacities using the pocket-pumping technique on a single close-reject AF flight model (FM). This discovery is supported by the Fig. 2 insets. The Silvaco pixel model has explained these scenarios in terms of doping alignment on a stitch block basis. In the absence of pocket-pumping measurements, a comparison of FPR measurements to CEMGA simulations can distinguish between the 2 possible SBC scenarios and derive SBC capacities. In the absence of systematic SBC capacity testing of FMs prior to launch, Seabroke et al. 2010 will apply this method to 7 EM CCDs in order to increase the sample size and derive SBC capacities, which can be interpreted by the Silvaco pixel model to constrain the most likely SBC scenario.

Charge packet volume

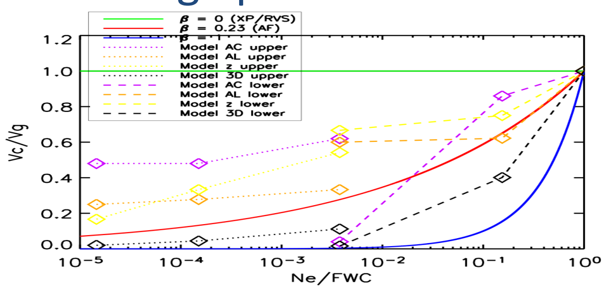

Figure 4: Charge packet volume (Vc) normalised by maximum geometrical charge packet volume (Vg) plotted against the number of constituent electrons (Ne) normalised by the Full Well Capacity (FWC). β is the exponent that relates these 2 quantities in the Charge Distortion Model (CDM02). The key gives 3 values of β, 2 of which have been derived from RC2 AF data. The Silvaco pixel model simulates a CCD with scenario 2 and follows the charge packet growing in size as it moves along 1 CCD in the AL direction. In the upper AL half, the charge packet grows in the BC only. In the lower half, the charge packet is small enough to go into the SBC before filling it and spilling out into the BC and reaching FWC.

The same Silvaco pixel model simulations that will derive the charge packet electron densities can also be used to derive how the charge packet volume increases with signal size, which is one of the parameters of CDM02, which is the current macroscopic model for correcting for radiation damage in the DPAC processing chains. Fig. 4 shows that the current model 3D volume estimates are larger than the fits obtained from test data. This is because plots like Fig. 3 were used to derive a representative length of each charge packet in each dimension. The volume was then crudely estimated assuming each packet is a cuboid thus multiplying each dimension's length together, giving an overestimation of the volume. Future simulations will trace the complex packet volumes by splitting them up into volume elements and summing the appropriate elements to derive an effective volume.

1. Seabroke, G., Holland, A., Cropper, M., 2008, In: Dorn, D.A., Holland, A.D. (eds.) High Energy, Optical, and Infrared Detectors for Astronomy III, vol. 7021 of Proc. SPIE (Bellingham, WA, USA)
2. Seabroke, G.M., Burt, D., Robbins, M.S., Holland, A.D., 2009a, In: Warren, P., Marshall, C. (eds.) Astronomical and Space Optical Systems, vol. 7439A of Proc. SPIE (Bellingham, WA, USA)
3. Seabroke, G.M., Burt, D., Robbins, M.S., Holland, A.D., 2009b, Modelling Gaia pixels: Silvaco planar simulations of buried channels, internal Gaia Livelink document (GAIA-C5-TN-OU-GMS-001)
4. Kohley, R., Raison, F., Martin-Fleitas, J. M., 2009, In: Warren, P., Marshall, C. (eds.) Astronomical and Space Optical Systems, vol. 7439A of Proc. SPIE (Bellingham, WA, USA)
5. Seabroke, G.M., Prod'homme, T., Hopkinson, G., Burt, D., Robbins, M. S., Holland, A. D., 2010 (in prep.)