Charge Collected by Active Pixel Sensors

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When an energetic charged particle interacts in the epitaxial layer of an APS (Active Pixel Sensor), it produces electron-hole pairs throughout the chip. The *conventional* explanation for energy collection assumes that the electrons that are produced in the epitaxial layer diffuse until they reach an n-diode where they are collected. [1]

Deptuch [2] has shown by using ISE-TCAD simulations that this "substrate contribution" is significant and beneficial for APS. He has calculated that there is at least a 3 μm substrate contribution for MIMOSA-5. However, this effect had not been confirmed by experimental results.

To measure the charge collected by an APS sensor, we put a simple APS sensor in the 1.5 GeV/c external BTS beam line at LBNL's Advanced Light Source. This sensor, APS-1 [3] was built with the 0.25 μm TSMC process and has a pixel pitch of 20 μm.

Selecting a seed pixel above a specific threshold and then summing the charge around its 8 closest neighbors identifies a cluster. A spectrum of the total charge in these clusters is shown in Fig. 1.

Because charged particles have few interactions in thin materials, the algorithm to calculate the energy deposition must take into account atomic structure. Bichsel and Saxon [4] showed that individual collisions dominate interactions in 1 μm Si and that the straggling function is very different from the original Landau function. Essentially, it reflects the difference between Poisson and Gaussian statistics.

Figure 1a shows the Bichsel algorithm plotted for 8 μm (the actual thickness of the epitaxial layer). The Bichsel algorithm [5] calculates straggling functions of energy loss. It does not include Bremsstrahlung, as its contribution is negligible for thin detectors. Fig. 1a clearly demonstrates that there is a larger contribution to the collected charge than calculated for the epitaxial layer. By comparing the most probable value of each curve, we find that there is approximately 1.5× more charge in the experimental data. To obtain this additional charge, there must be an extra 4 μm of Si contributing to the energy deposition sum. This extra charge could come from liberated electrons in both the upper p-well and p^{++} substrate. Only a small fraction of the p^{++} substrate contributes, because its impurity is much higher than the epitaxial layer and recombination is more common there.

We then compared the data to the Bichsel formulism with an effective epitaxial layer of 12 μm. The two curves in Fig. 1b are remarkably similar, so that this explanation of a substrate contribution is reasonable.

Knowledge of the thicknesses of the different layers is important when deciding to thin a sensor. There is about 12 μm of material above the epitaxial layer in the TSMC process. Adding the 8 μm epitaxial layer and the extra contribution of the 4 μm of the bulk leads to the conclusion that it is necessary to have a detector with a thickness of at least 24 μm to achieve maximum collection of charge.

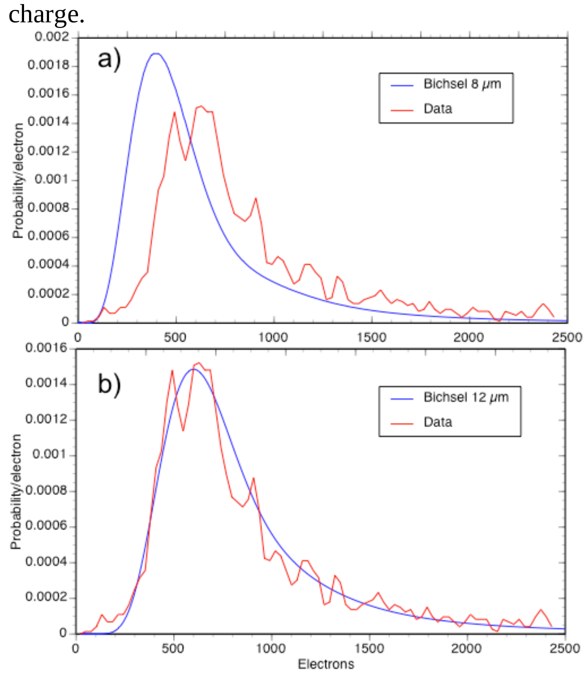

Fig. 1. Energy spectrum deposited by 1.5 GeV/c electrons in the APS detector. The jagged curve (blue) is the same data in both *a* and *b*. The smooth curve (red) in *a* and *b* are from Bichsel's calculation of the energy loss for 8 μm and 12 μm epitaxial thicknesses.

REFERENCES

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