Enhancing the Performance of Hybrid Pixel Detectors for High-Energy Transmission Electron Microscopy by Using High-Z Sensors


Hybrid pixel detectors (HPDs) are a class of direct electron detector (DED) that have been used to achieve novel insights in both biology and materials science. They consist of an application specific integrated circuit (ASIC) bonded to a thick sensor that protects the ASIC from incident electrons, making them highly robust. Their sophisticated on-pixel signal processing circuitry makes them capable of noiseless operation and high frame rates. These properties are highly advantageous for many applications in transmission electron microscopy, including diffraction-based experimental modalities and high-speed filming of dynamical processes.

Although HPDs can perform as ideal detectors when using low-energy electrons, their performance deteriorates as the energy, and therefore range, of incident electrons increases. However, the range of an incident electron decreases as the atomic number, Z, of the sensor increases. HPD sensors are usually made from Si (Z=14), but, unlike the sensors of other DEDs, can be made from high-Z materials such as GaAs:Cr (average Z=32). Using high-Z sensors should therefore improve the performance of HPDs, but there has been speculation that any improvement in performance may be mitigated by a reduction in detector efficiency due to the increased backscatter of incident electrons.

We have compared the performance of two Medipix3 HPDs, one with a Si sensor and one with a GaAs:Cr sensor, using electrons in the energy range of 60-300keV. The Medipix3 counts electrons on-pixel, with a pixel registering an incident electron as a hit if the signal induced on the pixel exceeds a user-set threshold. Measurements of the devices’ modulation transfer function and detective quantum efficiency as a function of counting threshold confirm that the GaAs:Cr device out-performs the Si device when using high-energy electrons and can match and surpass the performance of an ideal detector in some respects. Analysis of the detectors’ response to individual electrons such as that seen in figure 1 provides further insight into detector response. Our results confirm that high-Z sensors can enhance the performance of HPDs used in transmission electron microscopy, increasing the range of experiments for which they are suitable, and have important implications both for how high-Z sensors can be best utilised in electron microscopy and for the development of future DEDs.

Figure 1: Number of pixel clusters due to individual 200keV electrons as a function of counting threshold, normalised to the maximum number of clusters recorded, for a) the Si device and b) the GaAs:Cr device. The shading indicates how the number of pixel clusters of a given area changes with counting threshold. The typical cluster size is much smaller for the GaAs:Cr device than it is for the Si device at low threshold, indicating that the GaAs:Cr device has a superior point spread function. The number of clusters falls to zero at a counting threshold equal to the maximum amount of energy deposited on a single pixel.

References