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

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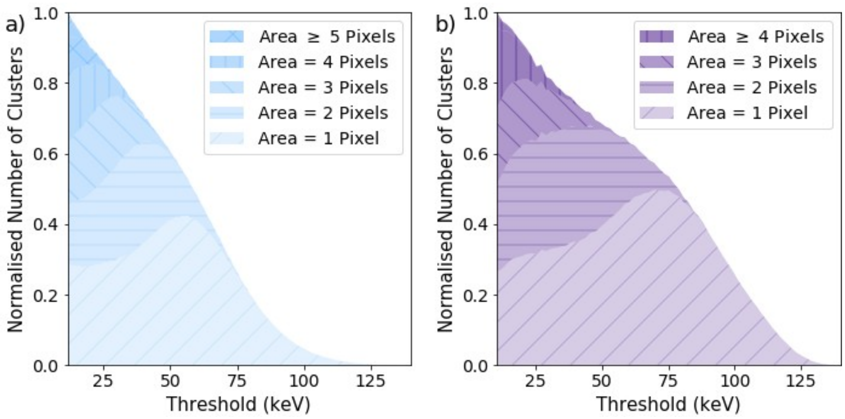
Hybrid pixel detectors (HPDs) are a class of direct electron detector (DED) that have been used to achieve novel insights in both biology [1] and materials science [2]. They consist of an application specific integrated circuit (ASIC) bonded to a thick (≥300μm) sensor that protects the ASIC from incident 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 [1, 2] and high- speed filming of dynamical processes [3].

Although HPDs can perform as ideal detectors when using low-energy (≤120keV) 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 [4]. 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 [5].

We have compared the performance of two Medipix3 HPDs [6], one with a Si sensor and one with a GaAs:Cr sensor, using electrons in the energy range of 60keV-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.



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