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GaAs:Cr as an alternative sensor material for hybrid pixel detectors in high-energy electron microscopy

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The introduction of direct electron detectors over the past fifteen years has opened up new possibilities in all branches of electron microscopy. In particular, monolithic detectors with thin Si sensors have been used to great effect for imaging in the life sciences. However, they typically have slower readout and are insufficiently robust for routine exposure to the intense central spot of a diffraction pattern. This makes them unsuitable for use in electron crystallographic experiments in materials and life sciences. The thick sensors of hybrid pixel detectors (HPDs) mean they can record full diffraction patterns, whilst their sophisticated pixel architecture means they are generally capable of fast, noiseless operation. They are therefore well suited for use in a variety of applications for which monolithic detectors are not usable.

Counting HPDs with Si sensors have been shown to offer excellent performance when using low-energy electrons. For example, the Medipix3RX detector [1] bonded to a 300 μm Si sensor is able to match the performance of an ideal imaging detector when using electrons with an initial energy $E_0 \leq 80\text{keV}$. Using a counting threshold equal to $E_0/2$, electrons are counted only in the pixel in which they enter the sensor [2]. However, the performance of HPDs deteriorates when using higher-energy electrons ($E_0 \geq 200\text{keV}$). Although it is still the case that only a single pixel records the incident electron when using a threshold equal to $E_0/2$, the pixel registering the hit is usually the pixel at the end of the electron's trajectory [3]. This is because the rate at which an electron deposits energy increases as it slows down, and a high-energy electron will scatter over many pixels in a Si sensor sufficiently thick to protect the ASIC underneath. Using high-Z materials, such as GaAs:Cr, should mean the signal produced by a high-energy electron is more localised, resulting in an improved PSF. However, such materials also have higher backscattering coefficients for primary beam electrons, which may have a negative impact on DQE.

We have compared the performance of the Medipix3RX bonded to a 500 μm Si sensor and a 500 μm GaAs:Cr sensor using energies from 60keV to 300keV. Our comparison of the two detectors has included analysis of how pixel clusters due to individual electrons change as a function of increasing energy deposition threshold. This has been done with the detectors operating in Single Pixel Mode (SPM), in which each pixel counts independently, and in Charge Summing Mode (CSM), where an arbitration circuit attempts to assign incident electrons to a single pixel. Our results indicate that the spread in signal due to high-energy electrons is significantly reduced in a GaAs:Cr sensor.

When using 200keV electrons with the detectors operating in SPM, the average area of the clusters recorded by the GaAs:Cr sensor is $\sim 2/3$ the average cluster area recorded by the Si sensor at the lowest threshold used with the GaAs:Cr sensor. The lowest threshold of the GaAs:Cr sensor ($\sim 16\text{keV}$) is higher than that of the Si sensor ($\sim 9\text{keV}$) due to the GaAs:Cr sensor's higher leakage current. Using their respective lowest threshold settings, average cluster area recorded by the Si sensor was 4.5 pixels, whilst that recorded by the GaAs:Cr sensor was 2.3 pixels. The decrease in the GaAs:Cr sensor's average cluster area with increasing threshold is also more gradual than that of the Si sensor, likely due to the electrons' energy being distributed over fewer pixels. We will present MTF and DQE measurements, currently in progress, which will confirm the extent to which the GaAs:Cr sensor offers enhanced performance relative to the Si sensor and provide further insight into how electrons interact with thick sensors.

[1] R. Ballabriga et al., Journal of Instrumentation 8, (2013), C02016

[2] J. A. Mir et al., Ultramicroscopy 182, (2016), pp.44-53

[3] G. Tinti et al., IUCrJ 5, (2018), pp.190-199

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