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A New Energy-filtering EBSD/TKD Direct Detector

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Electron backscatter diffraction (EBSD) is a powerful and widely used technique in scanning electron microscopy (SEM) for characterizing crystalline or polycrystalline materials. EBSD facilitates measurement of crystallographic orientation, texture, defects, strain, grain size and boundary types, and phase identification with spatial resolution of tens of nanometers [1]. Characterizing this microstructure is critical for understanding the properties and performance of materials, including engineered materials, microelectronics, materials for renewable energy, and geological materials.

Modern EBSD detectors use a scintillator to convert incoming electrons to light, which is then transmitted through lenses to a CCD- or CMOS-based image sensor. Indirect detection through a scintillator and lenses attenuates the sensitivity of these detectors [2], and their lenses also may introduce distortions that limit the accuracy and resolution of the technique [3].

Further compounding the limited sensitivity of current EBSD detectors is the fact that they cannot be tuned to detect only electrons within a certain energy range. Kikuchi bands in EBSD patterns are generated by electrons that lose no more than ~20% of their energy in the specimen. Conventional EBSD—where all electrons are collected regardless of energy—has significantly lower contrast than if energy filtering is applied so that only low-loss electrons are collected [4].

We have developed and characterized a new large-format direct detection sensor, with single-electron sensitivity to energies commonly used for EBSD, from 30 kV down to 3 kV. The detector has 2048 × 2048 pixels and operates with either rolling- or global-shutter continuous high-speed readout. Monte Carlo simulations show that the detection efficiency exceeds 80% for all SEM energies above 5 kV and approaches 100% at 8 kV and above (Fig. 1a).

Additionally, when the SEM beam current is sufficiently low compared to the frame rate of the sensor (Fig. 1b), the sensor records not only the location but also the energy of each detected electron (Fig. 2a). Energy measurement is realized by calculating the total integrated intensity of all pixels in each detection event—that is, a distinct "blob" of one or more pixels. The linearity of energy discrimination of the detector exceeds 85% for electrons at 4 kV energy and higher, and exceeds 99.5% for electrons at 10 kV energy and higher (Fig. 2b). This reproducible energy discrimination enables energy filtering of EBSD patterns *ex post facto*, including complex schemes for applying different energy thresholds to different regions of the diffraction pattern [5,6].

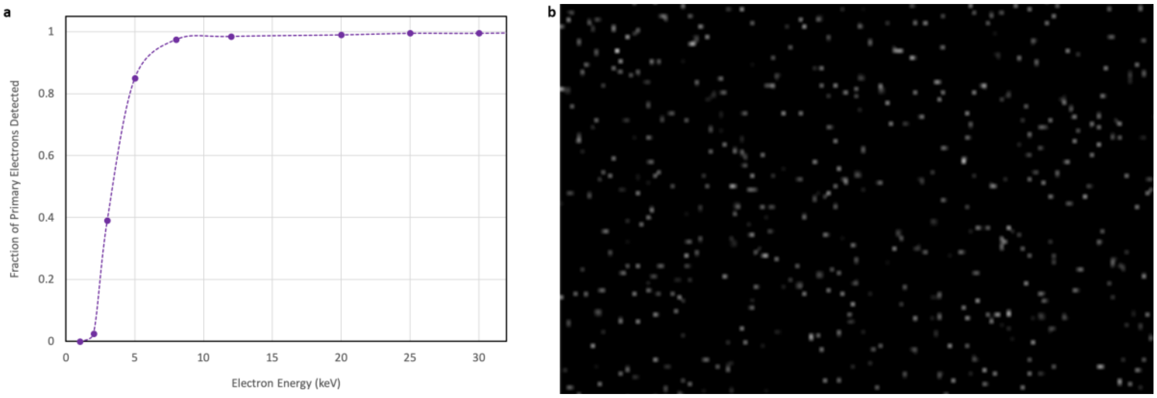

Figure 1. (a) The simulated fraction of incident electrons that are detected at various energies. Simulations were completed using PENELOPE [5]. (b) A cropped region of a single frame showing a sparse distribution of single electrons detected by our new sensor. The frame was part of an EBSD acquisition of a single-crystal silicon sample with an accelerating voltage of 12 kV and a beam current of 50 pA. The location and energy of each detected events can be measured by calculating the centroid and total integrated intensity of each "blob," respectively.

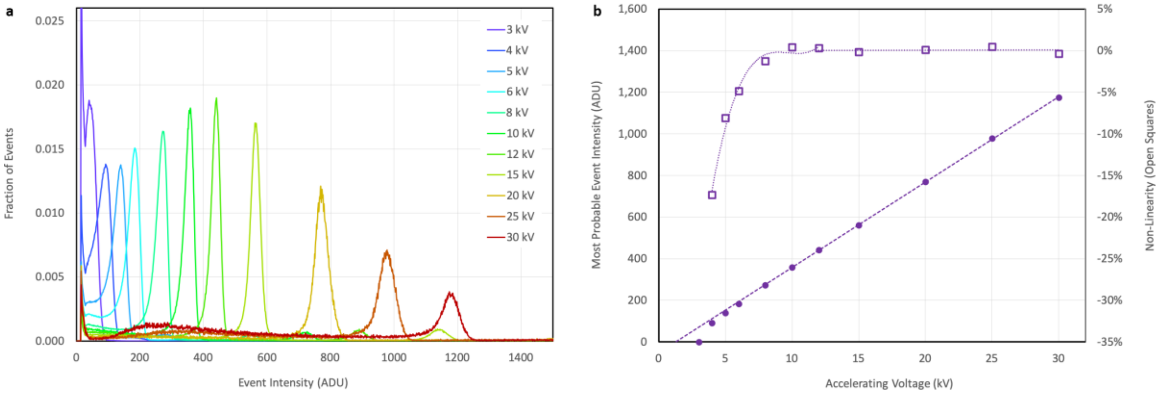

Figure 2. (a) The histogram of measured intensities of individual electrons detected by the sensor. Note that for some energies, there is a second small peak is precisely 2× the intensity of the first large peak, indicating that the "blobs" measured for this higher-intensity peak represent locations on the detector where two electrons were detected simultaneously. (b) The measured linearity of our new detector. The closed circles show the measured most-probable event intensity for single electrons (Y-axis) for each accelerating voltage (X-axis). The open squares show the deviation from linearity as determined by a linear fit to the most-probable intensity values from 10 to 30 kV.

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[5] We thank Earl Weltmer at ScanService (Tustin, CA), who provided access to an SEM for sensor characterization.

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