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Optimized Ultra-Fast Low Dose Electron Detection

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Electron Microscopy (EM) is and has been a standard technique in material investigation for a long time. With all its benefits such as superior spatial resolution, depths of focus and different contrast/information, there are still challenges, like beam sensitive and/or non-conductive specimen. Low dose electron imaging is a way to overcome these limitations. One main field of these low dose applications is bio science and life science, including the investigation of cells and tissues in single sample imaging or serial microtome applications. Especially, Back Scattered Electron (BSE) detectors are used in this field since they offer the best contrast for biological samples. Here, we will address the requirements to a low dose EM setup and show the effect of the optimized BSE detection capability.

For low dose detection, there are three major demands: To collect as much signal as possible, to work as fast as possible in order to further minimize the overall dose on the sample and to ensure that these points stay consistent under operation. In terms of BSE detection, collecting as much signal as possible means ensuring that a high portion of the BSE hits the detector and that as many as possible are detected. Knowing the spatial distribution of the BSE, the available build space and the operation conditions, like working distance (WD) etc., it is possible to choose the optimum size of the BSD diode in order to maximize the Geometric Collection Efficiency (GCE). The GCE is the ratio of BSE impinging on the active area of the diode in relation to the overall count of BSE which originate from the sample. After maximizing the GCE, the next step is to ensure that most electrons hitting the diode get detected. In low dose conditions with electron energies around and below 1 keV, it is critical to ensure a high detector collection efficiency (DCE) with DCE being the ratio of detected electrons and electrons impinging on the detector. This is done by way of special treatments of the surface of the diode to reduce the so called dead layer to a minimum thickness. Thus, collecting as much BSE signal as possible means maximizing the overall collection efficiency CE as the product of GCE and DCE (GCE x DCE) as a function of electron energy and geometric factors, such as the working distance. The next step is to increase the measurement speed. Here, the main point is to find a compromise between signal to noise ratio SNR and acquisition time. However, a low SNR level in general helps to reduce the acquisition time further and further. Here, the electrical properties of the BSE detector come into account which are mostly dominated by the dark current (I_{dark}) levels and the capacitance of the BSE diode (C_{diode}). Low values of I_{dark} ensure that there is no contribution to the SNR of the image. Low C_{diode} values ensure higher speeds, i.e. higher bandwidth at greater first stage amplifications, resulting in lower overall noise. To achieve low C_{diode}, the BSE diode is biased in order to enlarge the depletion zone - and thus lower the capacitance. To further support the low detector capacitance, the first amplification stage should be placed near the diode, ideally next to it in the SEM chamber. Furthermore, it is possible to utilize different first stage amplification factors to cover a wider field of bandwidth and amplification settings. After focusing on the CE and the acquisition speeds, one needs to consider the robustness of the setup. Here, the radiation hardness is a major point. While tailoring the CE and the speed to its maximum, it needs to be considered that these detectors are often used in highly frequented setups up to 24/7 usage and a degradation of detector performance over time is not acceptable. Next to the DCE which may not decay over time, it is crucial to ensure that the low dark current level of the diodes is not affected by electron radiation during the lifetime of the detector, especially when using a diode bias with its benefits as mentioned above.

In summary, for reliable low dose BSE detection, a maximum collection efficiency, high gain with sufficient bandwidth, minimal noise contribution and sufficient radiation hardness are needed. This can be reached by optimizing the detectors CE (including GCE and DCE), optimizing the electrical properties, such as I_{dark} and C_{diode} supported by matched electronics and doing this without confessions in radiation hardness. We will show in detail, how these points can be realized in state-of-the-art SEM setups and detector configurations for low dose applications.

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