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Direct Electron Detection for Electron Microscopy with an Optimized DDD® Sensor

L. Jin,* and R. Bilhorn,*

* Direct Electron, LP, 13240 Evening Creek Drive S., Suite 311, San Diego, CA 92128

Direct electron detectors, capable of detecting electrons without use of scintillators, have been proven to dramatically improve the image quality for low dose EM images [1-3]. As the first commercially available direct electron detector, the 12 megapixel 6µm DDD® camera (DE-12) has shown high Modulation Transfer Function (MTF) and Detective Quantum Efficiency (DQE) performance [4] and holds great promise to replace scintillator-based CCD systems as well as film. In this report, we demonstrate the experimental results from the latest optimized DDD® sensors, which bring the imaging quality even higher, achieving 2-3 times improvement over the best CCD camera systems and matching/surpassing film performance.

It is known that electron backscattering in the silicon sensor degrades the sharpness of image quality (as measured by MTF). In 2009, McMullan et al. showed that thinning the substrate improved the MTF performance in a 25µm pixel detector [5]. With a much smaller pixel size, the DDD® sensor has shown a similar improvement after thinning (**FIG. 1**). At low spatial frequencies (less than ½ Nyquist), the normal sensor suffers a drop corresponding to the backscattering electrons, which is not existent in the thinned sensor result. Additionally, by reducing the pixel-pixel crosstalk caused by backscattering electrons, the high frequency region (above ½ Nyquist) is also consistently higher.

Based on the success of the DE-12 DDD® rev1 sensor, the pixel design has been recently improved specifically in terms of 120-200keV response. At 200keV, the new pixel design in experimental testing boosted both MTF and DQE performance (**FIG. 2**), achieving a DQE of 0.3 at ½ Nyquist frequency. As expected, the rev2 sensor showed only slightly better results than rev1 at 300keV, due to the fact that the rev1 sensor is already performing with 30% DQE at half Nyquist. The MTF/DQE results are measured using the standard edge method [6-7].

Lastly, further progress in software integration has allowed full integration of DE-12 camera with Leginon automation package [8] for single particle Cryo-EM and with SerialEM [9] for Cryo-Electron Tomography. Full size DDD images are instantly available after each exposure without the long readout delay in CCD cameras, enabling high throughput microscopy.

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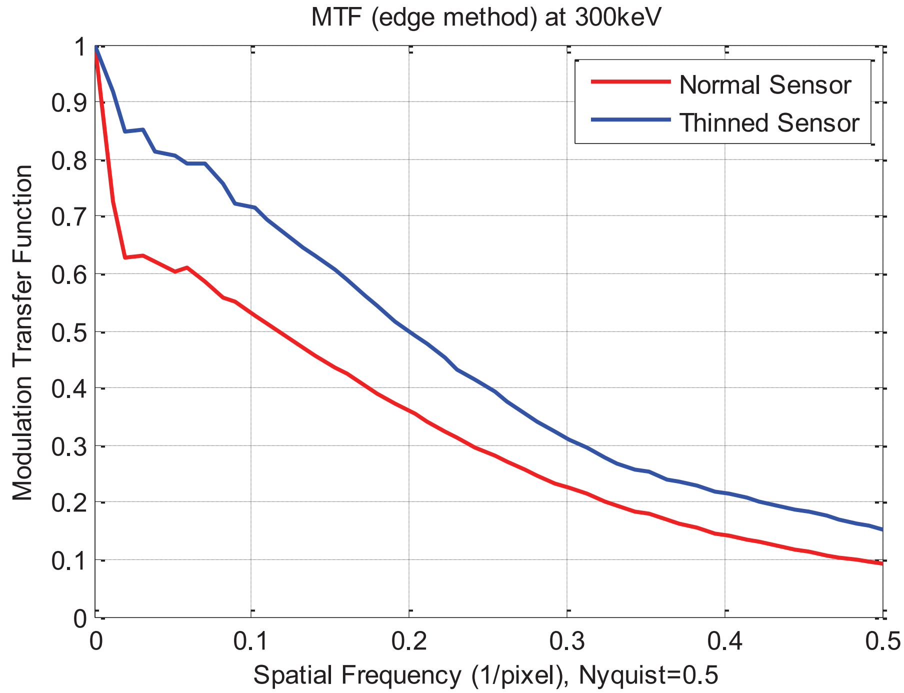

FIG. 1. MTF curves from a normal thickness DE-12 DDD® sensor and a thinned sensor measured at electron acceleration energies of 300kV. JEOL JEM-3200EF, NCMIR at UCSD.

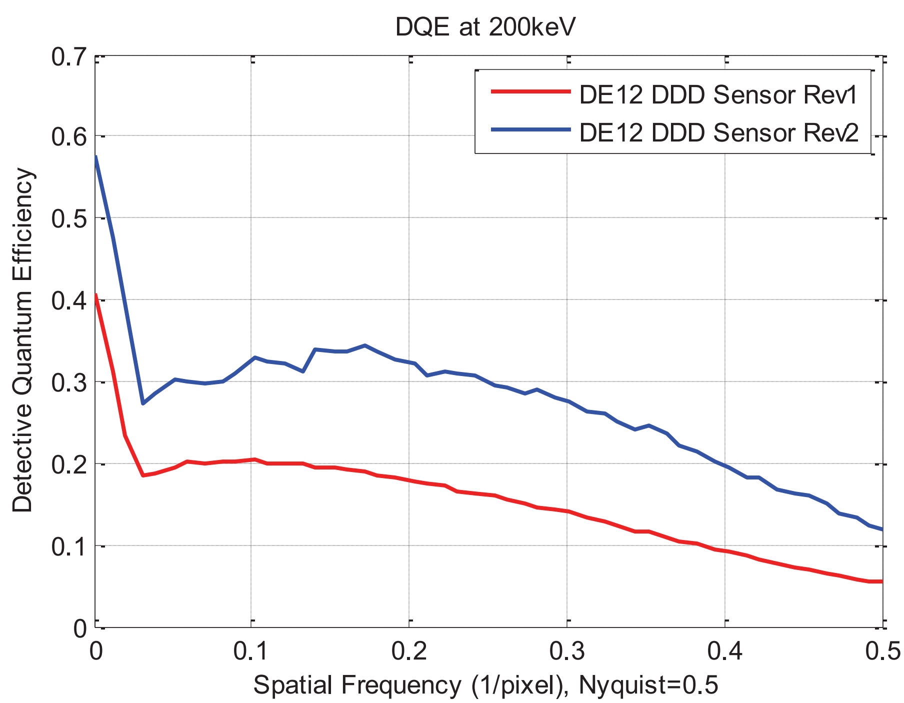

FIG. 2. DQE curves from the revision 1 and 2 of the DE-12 DDD® sensors measured at electron acceleration energies of 200kV. JEOL JEM-3200EF, NCMIR at UCSD.

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