Performance data of a new 2048 x 2048 pixel Slow-Scan CCD camera for TEM ‡

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1. Introduction

Excellent linearity and high sensitivity have made SSCs the ideal image detector for almost every TEM application [1]. Their ability to make high quality digital images available within fraction of seconds for further evaluation and processing in a PC, have made them a non-dispensable accessory for any modern TEM. However, despite their excellent characteristics, SSCs provide a restricted number of individual image points in respect to a negative, what is considered to be the main disadvantage of this detector. To compensate for this, CCDs with 2048x2048 pixel are available since some time. SSCs using these 2kx2k CCD arrays not only provide 4 times the pixel number but also offer a lot more options people have waiting for: e. g. highly resolved low-dose or ESI images with significantly improved signal to noise ratio, or higher resolved images for diffraction analysis and holographic reconstruction.

2. Results

In addition to their product line of 1k SSCs [2], ProScan has developed a new SSC camera based on a 2048 x 2048 pixel CCD (14 x 14 µm pixel size) with full frame technology. The new camera can be installed in on-axis position on the bottom flange below the viewing screen (or below the sheet film camera) on any LEO TEM. The camera is thermoelectrically cooled and uses direct (1:1) fibre optic coupling of a YAG or phosphor scintillator to the CCD. The performance parameter listed in tab. 2 have been tested with a camera equipped with a high efficient 20 µm phosphor scintillator installed on a LEO 922 OMEGA TEM operating at 200 kV. As a criterion for the quality for the resolution of the image converter (scintillator/FO/CCD) the auto-correlation method as described by [3] has used. The obtained values (tab.1) indicate a good and homogeneous resolution over the entire scintillator area of the tested unit. The radially averaged intensity of the power spectrum, calcutated from a gain normalized flat-field image (fig. 2), indicates a contrast transfer of 13.5 % at nyquist frequency (1/28 μm^{-1}). The camera shows a perfect linearity over the full dynamic range (<1% from the calculated regression line) as shown from an exposure series (fig. 1). In addition the gain non-uniformity values calculated from uncorrected images and the very few cosmetic defects (tab. 2) demonstrate the superior quality of the scintillator, the fiber optic, and the CCD. We have been especially pleased by the very fast frame rates, this camera is able to deliver not only for images in full resolution, but especially for binned read-out modes and last not least in the 5 MHz operation mode (tab. 2). Depending on the application the camera will be used for, the conversion rate can be adapted in a wide range from ~1 to ~25 counts/e^- by selecting the appropriate scintillator and setting the internal gain. The first results we obtained from this camera (fig. 3) are very promising and clearly demonstrate that the future of SSCs in TEM will belong to 2k cameras.

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3. References

[1] O.L. Krivanek and P.E. Mooney, Applications of slow-scan CCD cameras in transmission electron microscopy, Ultramicroscopy 49 (1993), 95-108.
[2] S.A. Hiller, et al., New SSC Cameras with frame/interline CCD architecture avoid TEM shutter control, provide excellent image quality and can be easily retrofitted, Proc. MSA (1999).
[3] J. Frank, A practical resolution criterion in optics and electron microscopy, Optik 43 (1975), No. 1, 25-34.

4. Tables and Figures

Fig. 1: Linearity test results

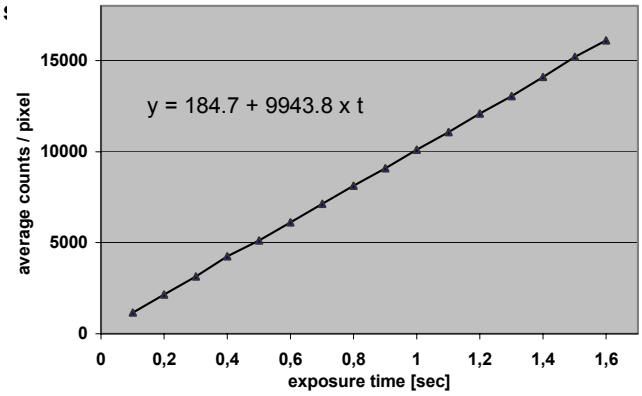
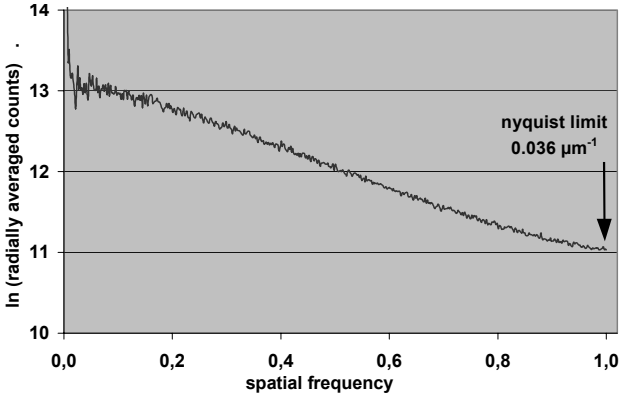
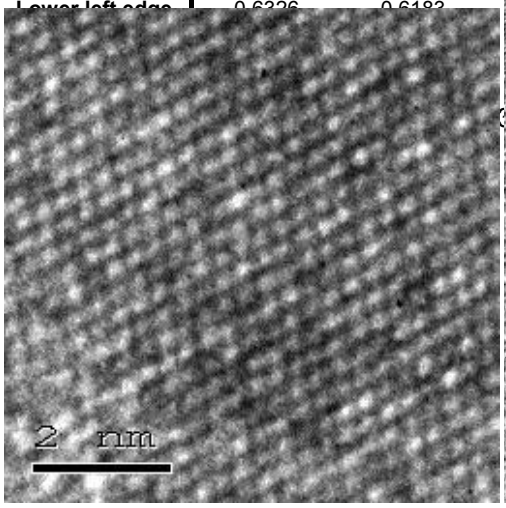


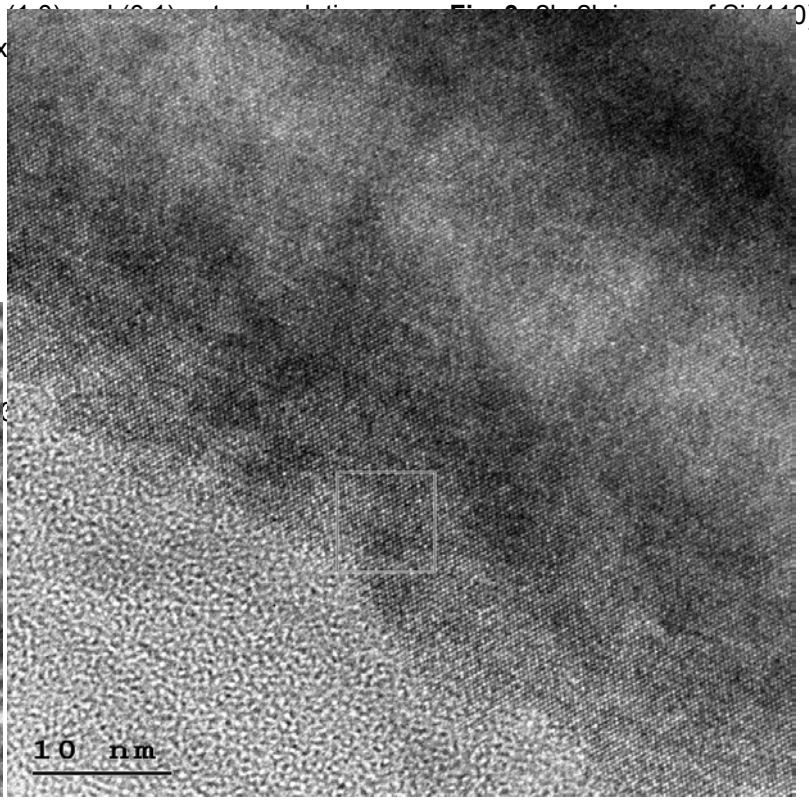
Fig. 2: Radially averaged intensity of power



Tab. 1:
LEO 922 OMEGA, 200 kV, 500kx, 1sec ex
values of 2 subtracted flat-field images

	horizontal	vertical
Upper left edge	0.6653	0.6446
Upper right edge	0.6412	0.6475
Center	0.5953	0.5782
Lower left edge	0.6326	0.6183





Tab. 2: Camera performance data

CCD technology	full frame 2048 x2048 pixel thermoelectrically cooled	**Cosmetic defects**	1 hot pixel [3] <130 dark pixel [4] (19 in 1k center of CCD) 0 bad columns
Pixel size	14 x 14 µm	**Coupling method**	direct by fiber optic (1:1)
Pixel clock rate	2 & 5 MHz	**Read-out noise**	< 3 % rms [2]
Dynamic	1:16384 (14 bit) / 2 MHz 1:256 (8 bit) / 5 MHz	**Frame rates [sec/frame]** [1] **0.5 sec exp./2 MHz gain-normalized read-out**	5.04 (full frame/2048x2048) 2.67 (2x binning/1024x1024) 2.42 (sub-area read-out of 512 center) 1.33 (4x binning/512x512)
Non-linearity	<1 % (1000 – 16000 counts) [2]	**Frame rates [sec/frame]** [1]	1.07 (2x binning/1024x1024) 0.32 (4x binning/512x512)

		0.05 sec exp./5 MHz/raw data	
Uncorrected gain non-uniformity	5.98 % rms (pixel to pixel) [2)] 5.09 % rms (4x4 pixel) [2)]	**Corrected gain non-uniformity**	1.42 % rms (pixel to pixel) [2)] 0.51 % rms (4x4 pixel) [2]
Dark current (cool)	1.47 counts/pixel/sec [2)]	**Conversion rate**	~ 20 counts/200 kVe^- (adjustable)

[1)] tested on a 500 MHz/PII PC; [2)] measured at 2 MHz; [3)] pixel with values >8000 counts in dark image; [4)] pixel with values <mean/2 in flat-field image