

## Design and Characterization of 16 MegaPixel Fiber Optic Coupled CMOS Detector for Transmission Electron Microscopy

Stumpf M., Bobolas K., Daberkow I., Fanderl U., Heike T., Huber T., Kofler C., Maniette Y., and H.R. Tietz

TVIPS GmbH, Eremitenweg 1, 82131 Gauting, Germany

Within the last decade, CCD cameras turned out to be an important tool for image recording in TEM. A CMOS based technology has been used by TVIPS to produce a 16 MPixel image sensor with fiber optic coupling to the scintillator for applications in Transmission Electron Microscopy. The pixel array contains  $4096 \times 4096$  squared pixels with a pixel size of  $15.6 \mu\text{m}$ . For fiber optic coupled cameras, a large pixel size is mandatory. The readout is done on 4 channels synchronously, each at 10 MHz in stripes of  $1024 \times 4096$  pixels. The sensor area is divided into  $1024 \times 1024$  pixel areas which can be addressed individually.

Two different image acquisition modes are available. For very low noise and high sensitivity single image acquisition the so called CDS (correlated double sampling) mode is used. For fast readout the sensor can be operated in the rolling shutter mode where line by line is first readout and then reset. Frame rates up to 10 frames/sec at  $1024 \times 1024$  pixels can be reached. For reading the camera at full resolution in the CDS mode, we achieve 1 frame/sec, which represents an improvement of around  $5 \times$  in comparison to up-to-date 4k multi-port CCD cameras.

The camera is integrated into TVIPS EM-MENU 4.0 image processing package for transmission electron microscopy. The camera is also a new device in the CAMC4 COM module. This allows all TVIPS cameras to be controlled by external software. The TemCam-F416 camera is mounted in the on-axis position below the plate camera and therefore perfectly suitable for high-resolution work.

Procedures have been developed to determine the main camera characteristics. These are mainly

- (1) The sensitivity, respectively the signal-to-noise ratio (mean signal for single primary electrons in respect to the readout noise).
- (2) The lateral resolution (Noise Transfer Function NTF respectively Modulation Transfer Function MTF).
- (3) The dynamic range (ratio of maximum useable grey value in respect to readout noise).

Although the fill factor of a F416 pixel is only 72%, which is smaller than that of a full frame or frame transfer CCD (which have 100%), the camera shows very good sensitivity. In a High Sensitivity (HS) configuration, F416 ( $4k \times 4k$ ,  $15.6 \mu\text{m}$  pixel) has a mean response of about 100 counts per single 120 kV primary electron. Taking into account a readout noise level of 5 counts, this leads to a clear detection of single electron events with an average signal-to-noise ratio of 20:1 (refer FIG. 1).

At first, the lateral resolution of TemCam-F416 is determined by the NTF. For the measurements, we used the same HS configuration, as for the sensitivity measurement before. This actually results in an increased sensitivity, but decreased resolution. With this HS type, we achieve for NTF at 120 kV around 35% at 1/2 Nyquist and around 10% at Nyquist (refer FIG. 2).

Besides that, the resolution can be determined by averaging single electron events, which lead, in first approximation, to the Point Spread Function PSF. The Fourier transform of the PSF gives the MTF, by taking into account aliasing effects.

Mainly due to the large pixel size (large full well capacity) and the CDS mode, this camera offers a large dynamic range (>10000:1), making it very useful for recording diffraction patterns. In addition, the CMOS sensor shows no blooming effects as CCD due to the discharge of a pixel, rather to charging upon illumination. The digitization of TemCam-F416 is done with 16bit. By using the automated series and integration option in EM-MENU, the dynamic range of an acquired image can be increased up to its digitization limit.

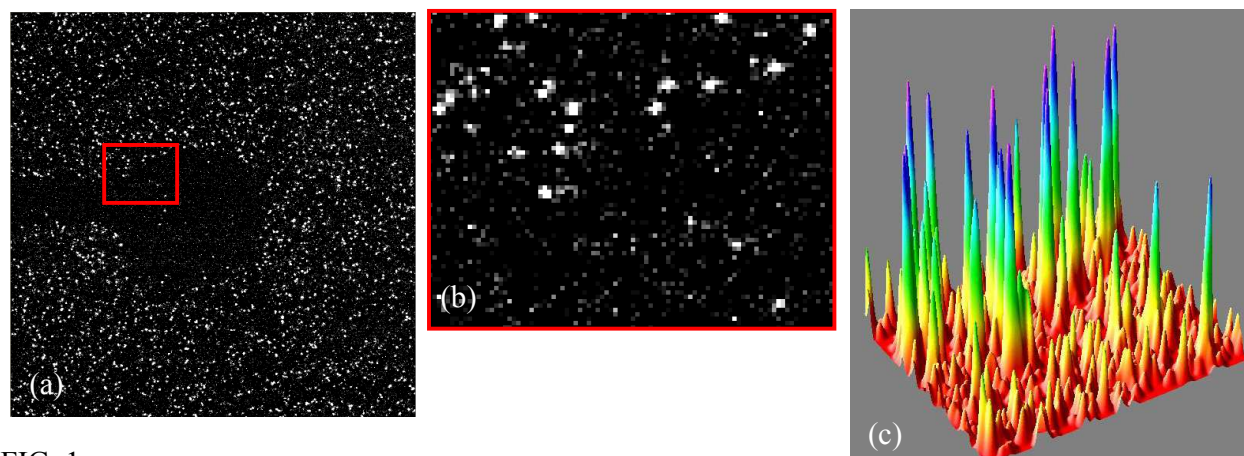


FIG. 1:

(a) Flatfield corrected 512×512 pixel sub area of a 4k×4k image acquired with F416 at very low dose (~ 0.05 electron / pixel) with the beamstop in the center position; (b) shows a 92×73 pixel sub area; (c) shows a rendered surface plot of (b). **Single electron events are clearly visible.** Please note the different heights of the peaks; these arise from the polycrystalline structure of the used P43 scintillator material as well as from the position of impact in respect to the pixel position.

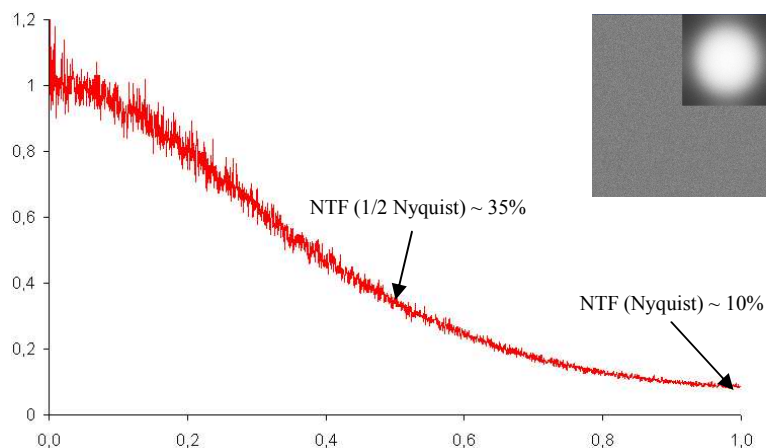


FIG. 2:

NTF of TemCam-F416. The image was acquired at about half dynamic @ 120kV using a comparable thick (HS) scintillator.