# Supplementary

| EMPAD detector specifications | | |
|---|---|---|
| **Sensor dimensions** | Active area | 19.2x19.2 mm |
| | Pixels | 128x128 |
| | Pixel size | 150 µm x150 µm |
| | Active thickness | 500 µm |
| **Performance** | DQE(0): | 0.96@60 keV, 0.95@80 keV and 0.94@300 keV |
| | Dynamic range | $10^{6}$:1 @200 keV |
| | Well capacity | 2 pA/pixel @ 200 keV |
| | SNR | 140 @200 keV |
| | Minimum integration time | 30 µs |
| | High-tension range | 30-300 keV |
| **Maximum speed** | 1100 fps (128x128 pixel) | |
| **Radiation hardness** | @300 kV > $10^{12}$ e/pixel | |
| **Storage capacity** | 4TB SATA 7200rps HDD | |
| **Control and imaging software** | • Scan control for field of view and dwell time<br>• Live synthesized STEM image via online data processing of user-defined masks for ABF, BF, DF, HAADF, iCOM and DPCx, DPCy<br>• Live single (or series) diffraction patterns<br>• Supportive live view annotations to set up and reproduce experiments quickly<br>• Advanced data management to keep track of experimental metadata<br>• Save raw data and live analysis of results<br>• Offline analysis of projects on your laptop | |
| **System requirements** | Talos/Spectra with Windows® 10 | |
| **Retrofit** | For retrofits on your tool contact sales and service organization in your region | |

<table>
<tr><th rowspan="2"></th><th>Primary Detector</th><th colspan="4">Secondary Detector Options</th></tr>
<tr><th>K3</th><th>1069.FXUP</th><th>1069.EXUP</th><th>1069.LVUP</th><th>1069.STUP</th></tr>
<tr><td>Operating range (kV)</td><td>80 – 300</td><td>40 – 300</td><td>30 – 300</td><td>30 – 60*</td><td>30 – 200*</td></tr>
<tr><td>EFTEM imaging size<br>(pixel x pixel)</td><td>6912 x 6912<br>[super resolution]</td><td colspan="3">2048 x 2048</td><td>512 x 512</td></tr>
<tr><td>EELS energy channels (pixels)</td><td>3456</td><td colspan="3">2048</td><td>1024</td></tr>
<tr><td>ω – q EELS (pixel x pixel)</td><td>3456 x 2048</td><td colspan="3">2048 x 1024</td><td>1024 x 512</td></tr>
<tr><td>Detector technology</td><td>CMOS<br>direct detection<br>counted and linear</td><td>CMOS<br>high-speed<br>XCR™ fiber /<br>scintillator</td><td colspan="2">CMOS<br>high brightness<br>XCR fiber / scintillator</td><td>Hybrid-pixel<br>direct detection<br>counted</td></tr>
<tr><td>Image frame rate (fps)</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Full-frame to memory</td><td>75</td><td colspan="3">90</td><td>2000</td></tr>
<tr><td>Sub-area (in-situ option)</td><td>3500</td><td colspan="3">180</td><td>16000</td></tr>
<tr><td>Spectroscopy</td><td>3000</td><td>8000</td><td colspan="2">2600</td><td>9000</td></tr>
</table>

* X-ray safe to 300 kV

** DualEELS and 100 ns blanker are standard for all detector options

*** *In-situ* and 4D STEM modes are optional for all detector options

## ADVANTAGES

- Extends 4k x 4k camera leadership for imaging and *in-situ* data capture
- Always have a "live" experience with 25 fps at full 4k x 4k resolution, no compromise to resolution between viewing and recording images
- Guarantee optimal image quality with real-time drift correction and outlier removal using in-line data processing
- Detect single electrons with highest signal-to-noise ratio using the most sensitive scintillator and fiber optics available
- Extend the dynamic range beyond 16-bits, no beam stop required
- Increase productivity, even for novice users, with intuitive, built-in workflows to support and optimize recording modes
- Available as the primary camera for TEMs manufactured by FEI*, Hitachi High Technologies, and JEOL

*In-situ* option

- Flexibly trade-off resolution against frame rate—from 4096 x 4096 pixels at 25 fps to 512 x 512 pixels at 300 fps, always at 100% duty cycle
- Video buffer allows you to capture only the video you want; with post-event triggering with LookBack feature
- Never miss the start of an *in-situ* reaction again
- Tailor videos to your unique applications with powerful post-processing tools

** Contact your local sales representative for the latest embedding options.*

## Specifications

| | |
|---|---|
| TEM operating voltage (kV) | Up to 400 |
| Sensor active size (mm) | 61.4 x 61.4 |
| Sensor size (pixels) | 4096 x 4096 |
| Pixel size (µm) | 15 |
| Full sensor read-out speed (fps) | 25 |
| Image display (fps) | 25 |
| Recording modes | Image<br>Video (*in-situ* option) |
| Image formats | 1:1 (4k, 2k, 1k)<br>16:9 (UHD, HD) |
| Video formats | 1:1 (4k, 2k, 1k)<br>16:9 (UHD, HD) |
| Image capture modes | Exposure time<br>Signal-to-noise<br>Specimen dose |
| 1:1 *in-situ* video capture speed (fps)<br>4096 x 4096 pixels<br>2048 x 2048 pixels<br>1024 x 1024 pixels | <br>25<br>100<br>200 |
| 16:9 *in-situ* video capture speed (fps)<br>3840 x 2160 pixels (UHD)<br>1920 x 1080 pixels (HD) | <br>40<br>135 |
| Conversion efficiency @ 200 kV (counts/primary $e^-$) | >35 |
| DQE (200 kV, 4k x 4k)<br>Quarter Nyquist (%)<br>Half Nyquist (%) | <br>>20<br>>10 |
| Dynamic range | >16-bit with frame accumulation |
| GIF compatible | Yes |

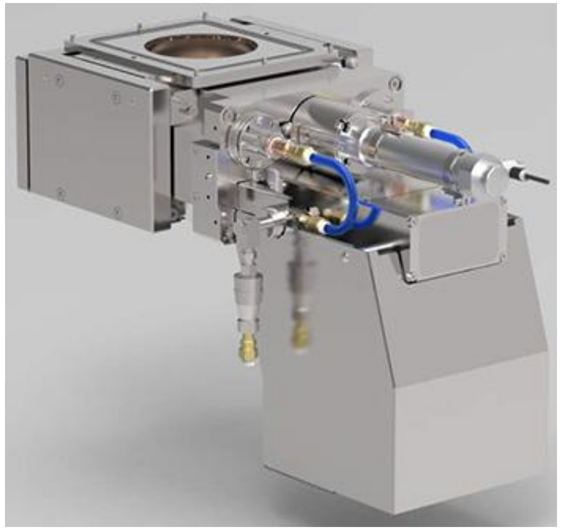
Specifications are subject to change.

## Product development background

The recent transmission electron microscope (TEM) enables a sub-Å electron probe to be formed with a spherical aberration corrector (Cs corrector). Owing to Cs correction, atomic-resolution STEM has reached a general use along with various STEM detectors for diversified observation purposes. In STEM, the extremely small probe scans over the specimen and maps on each pixel signals of transmitted and diffracted electrons.
An innovative new detector "4DCanvas" records position and intensity of all the transmitted, diffracted and scattered electrons as a 2-dimensional (2D) pattern for every pixel of STEM image. The sensor of this pixelated detector is a direct electron detection CCD with 264 × 264 pixels. In other words, the detector acts as a highly sensitive multi-channel STEM detector with channels of 264 × 264. The recorded data with this detector is 4-dimensional (4D) with axes of x & y of STEM pixel positions and u & v of detector pixel positions. "4DCanvas" is named after the dimensions of the acquired data with the detector. There have been several applications using the "4DCanvas".

1. Visualization of magnetic/electric field vectors by recording a shift of a transmitted beam or the center of mass for each diffraction pattern.
2. Since the user can create and assign an arbitrary-shaped detector on the detector plane, a STEM image is detected by the arbitrary-shaped detector. This unique capability enables high contrast imaging (e.g. differential phase contrast image).
3. By performing ptychography, a wave field of a transmitted electron beam can be reconstructed. Thus, we can observe a phase image of a sample with high efficiency. Since the detector can compensate the phase on the diffraction plane, it enables us to correct aberrations by post-processing. A series of optically sectioned Z-sliced images can be obtained (defocus is one of aberrations). The aberration corrected image is also obtained through the post processing process.

The potential applications of "4DCanvas" are expected to be increasing. This revolutionized "4DCanvas" will offer a platform to users of electron microscopes as if they freely draw a map on the canvas.



## Main Features

1. **JEOL pixelated STEM detector**
   High read-out rate of the detector enables fast acquisition of STEM images. Its signal-to-noise ratio is as high as 300:1. The quantum efficiency of this sensor is almost 100%, since the pixel size in x, y and z is large enough to detect all incoming electrons. Thus, the pixelated detector is very suitable for low-dose imaging. Furthermore, the detector functions as a high-speed and highly-sensitive direct electron detection camera for TEM imaging.
2. **Optimum mounting position of the detector**
   "4DCanvas" is placed beneath the viewing chamber, thus simultaneous acquisition of the data for the HAADF (high-angle annular dark-field) STEM detector is possible, resulting in the comparison of images by a "4DCanvas" and a HAADF detector. Since the detector is retractable, various types of cameras can be attached in the opposite face of a housing chamber. An EELS (electron energy-loss spectrometer), which is mounted at the bottom of the microscope column, is usable by the retraction.
3. **High-speed STEM data detection**
   "4DCanvas" achieves high-speed STEM image acquisition of 1,000 fps or higher, as are shown below, because the sensor is CCD, which is capable of binning.
   1,000 fps (full-frame readout, 264 × 264 pixels)
     STEM image acquisition time for 256 × 256 pixels: 64 s
   2,000 fps (1 × 2 binning, 264 × 132 pixels)
     STEM image acquisition time for 256 × 256 pixels: 32 s
   4,000 fps (1 × 4 binning, 264 × 66 pixels)
     STEM image acquisition time for 256 × 256 pixels: 16 s
4. **Detection of a wide range of accelerated electrons**
   "4DCanvas" can also detect a wide range of accelerated electrons, ranged from 30 kV to 300 kV. This feature enables us to optimize an accelerating voltage depending on the specimen. Thus, the detector is applicable to a specimen susceptible to electron-beam irradiation.
5. **Installation of the pixelated detector, "4DCanvas"**
   "4DCanvas" can be installed into the JEM-ARM300F and the JEM-ARM200F.
   Notice: In the near future, installation into the JEM-F200 will be possible.
6. **Software**
   "4DCanvas" has software that creates synthetic STEM images reconstructed from the 4D data.
   The software can map the amount and direction of beam shift for each electron probe position, resulting in a map of electric-magnetic fields vector, whose components are intensities and direction.