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Applications of high-throughput multibeam SEM in materials science

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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A new way to look at images! (HD View from Microsoft as an example)

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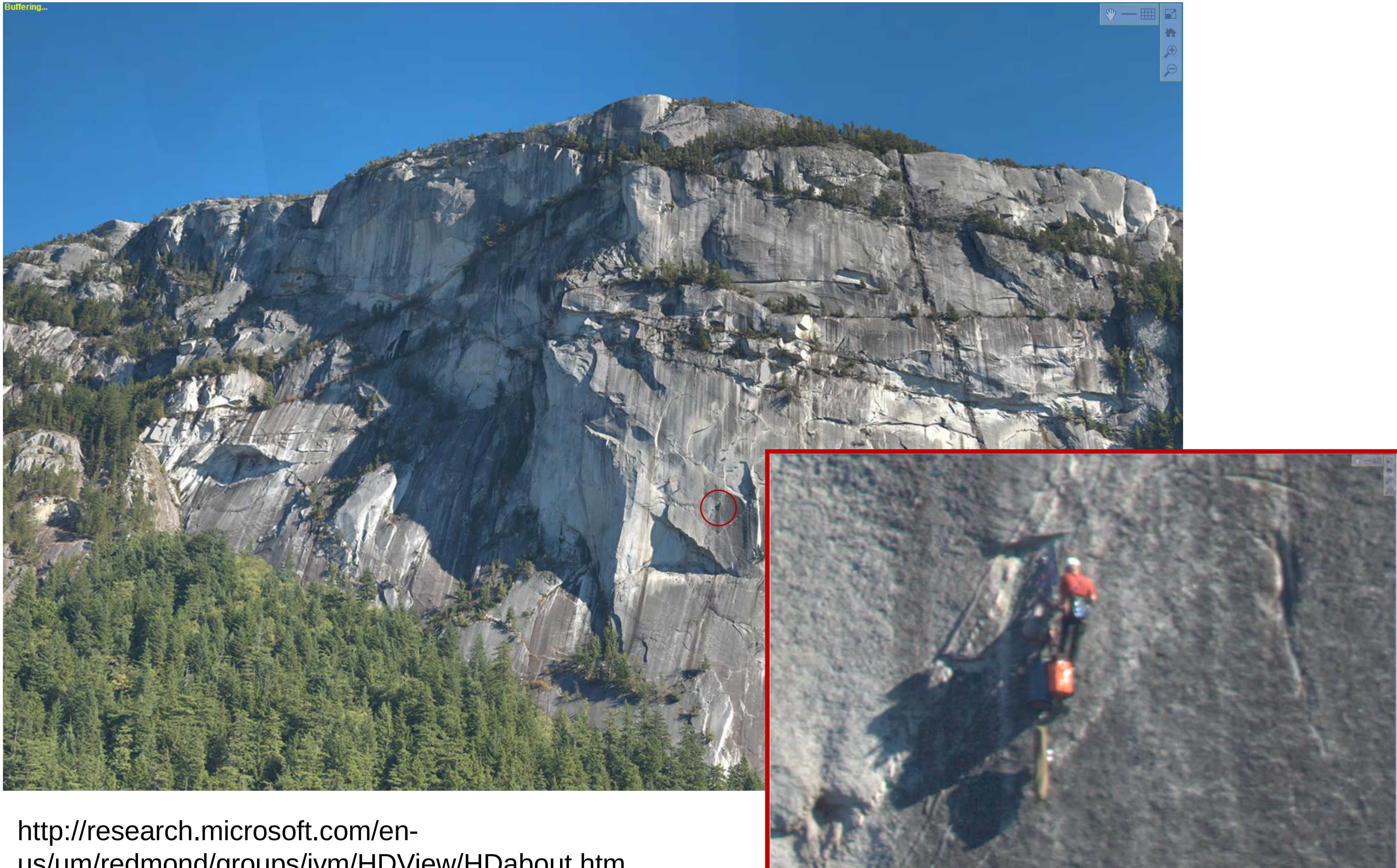


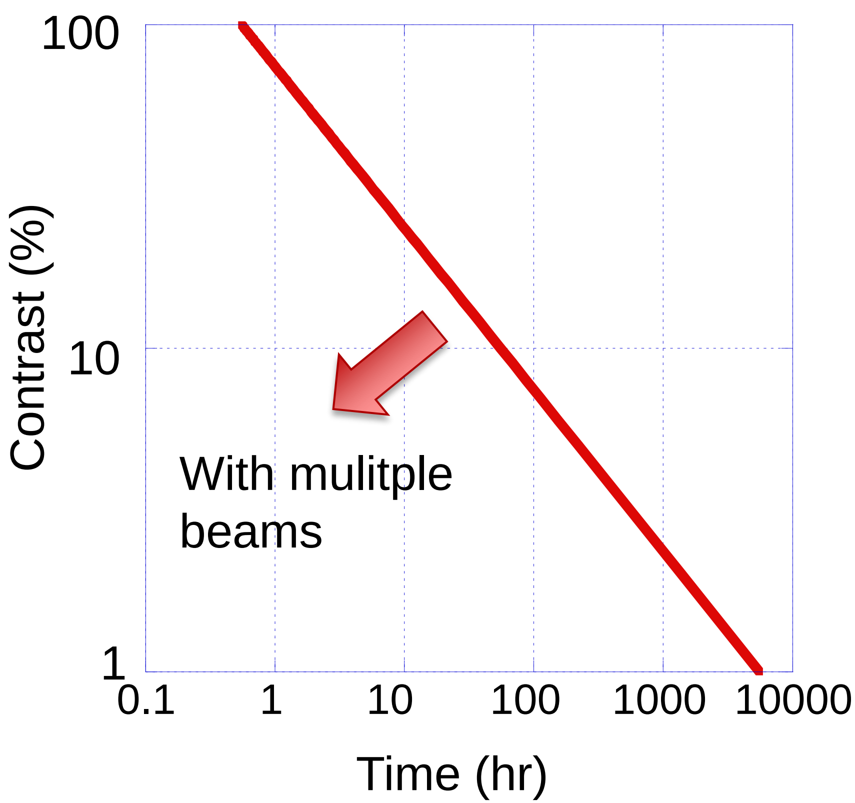
http://research.microsoft.com/en-us/um/redmond/groups/ivm/HDView/HDabout.htm

How can large area high-resolution imaging be accomplished in the SEM?

Need huge numbers of pixels with small spacing between them for high resolution to cover the large area image.

$$T_f > \frac{\left(4X10^{-18}\right) n_{pixels}}{\delta (DQE) C^2 I_B}$$

This is slow!

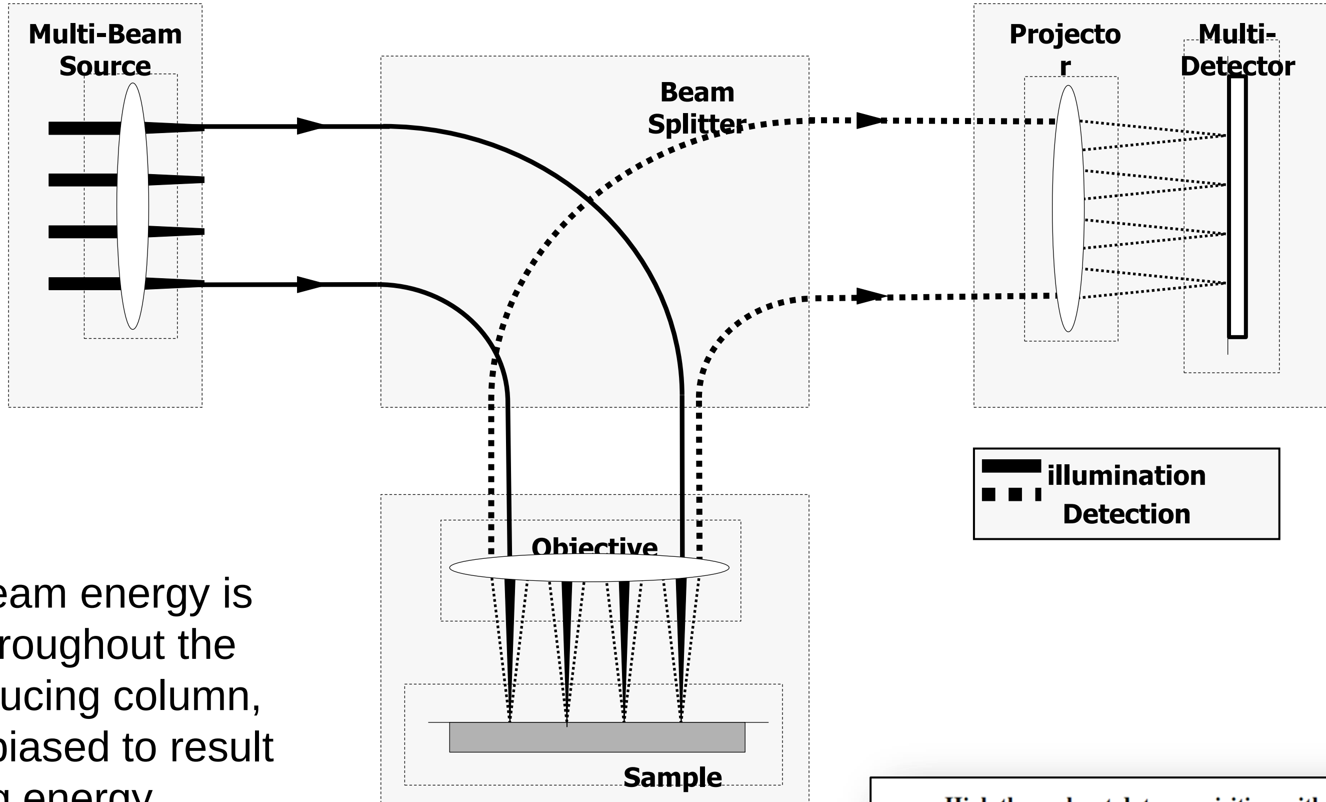


Time required to image 1 mm^2 with 0.5 nA beam current with 4 nm pixels.

Not including stage moves or other overhead.

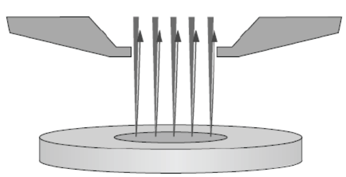
Properly engineered mulitibeam SEM can improve these times.

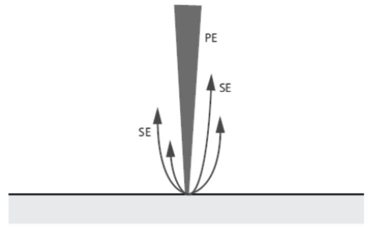
Multi-beam SEM electron optics

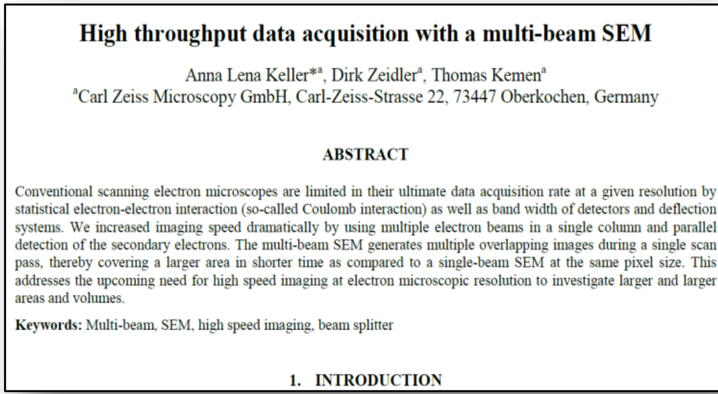


Electron beam energy is at 30 kV throughout the probe producing column, sample is biased to result in a landing energy between 100 ev and 6 kV

Proc. SPIE, doi: 10.1117/12.2069119







High throughput data acquisition with a multi-beam SEM

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ABSTRACT

Conventional scanning electron microscopes are limited in their ultimate data acquisition rate at a given resolution by statistical electron-electron interaction (so-called Coulomb interaction) as well as band width of detectors and deflection systems. We increased imaging speed dramatically by using multiple electron beams in a single column and parallel detection of the secondary electrons. The multi-beam SEM generates multiple overlapping images during a single scan pass, thereby covering a larger area in shorter time as compared to a single-beam SEM at the same pixel size. This addresses the upcoming need for high speed imaging at electron microscopic resolution to investigate larger and larger areas and volumes.

Keywords: Multi-beam, SEM, high speed imaging, beam splitter

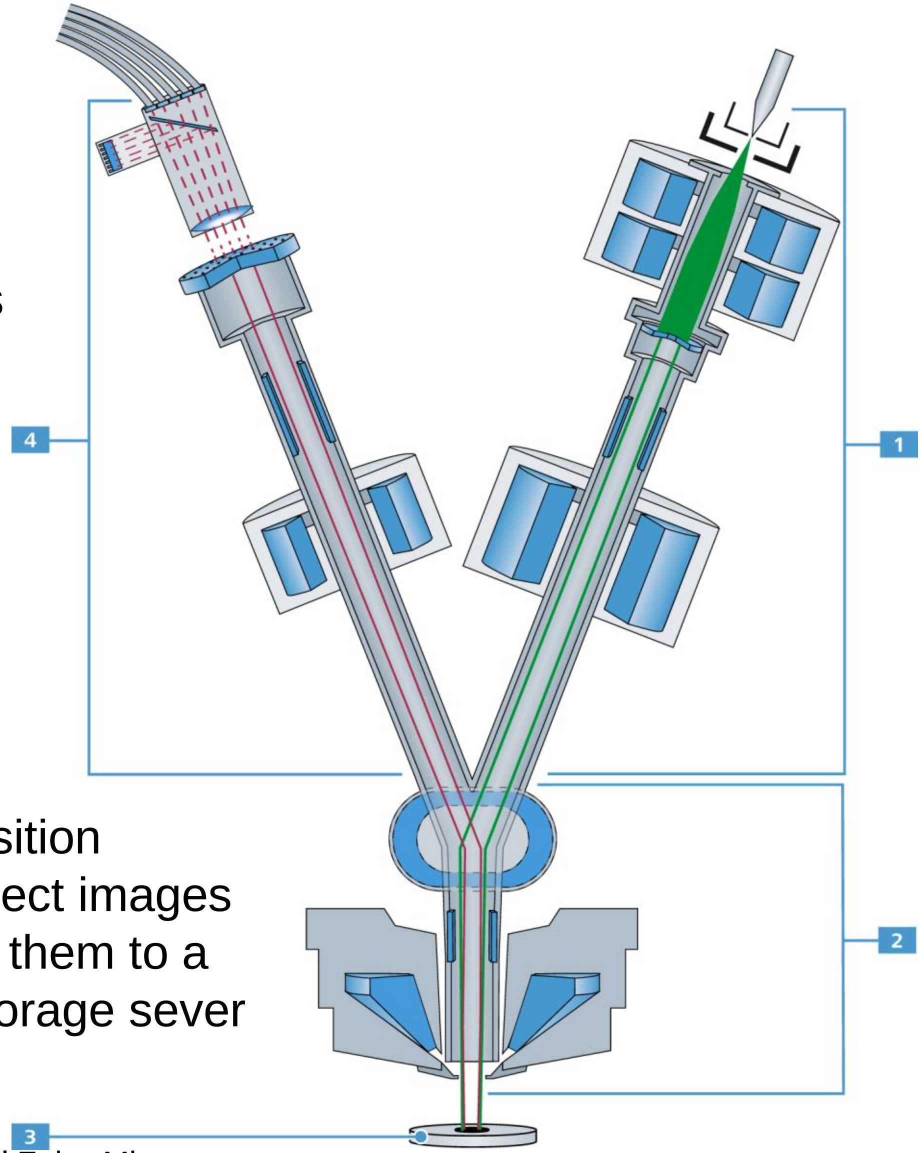
1. INTRODUCTION

Electron Source and projective column

Projective column collects 61 separate secondary electron signals

Schottky electron source

Multi-optic forms 61 beams



Magnetic prism

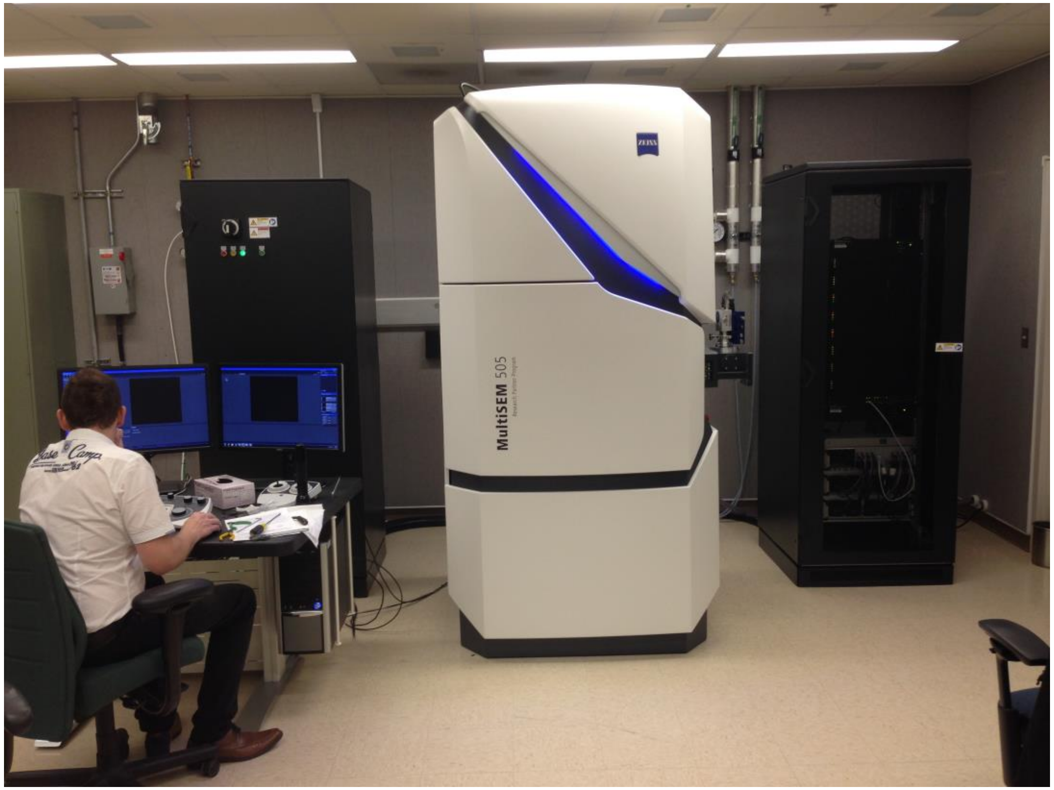
8 image acquisition computers collect images and then send them to a large image storage sever

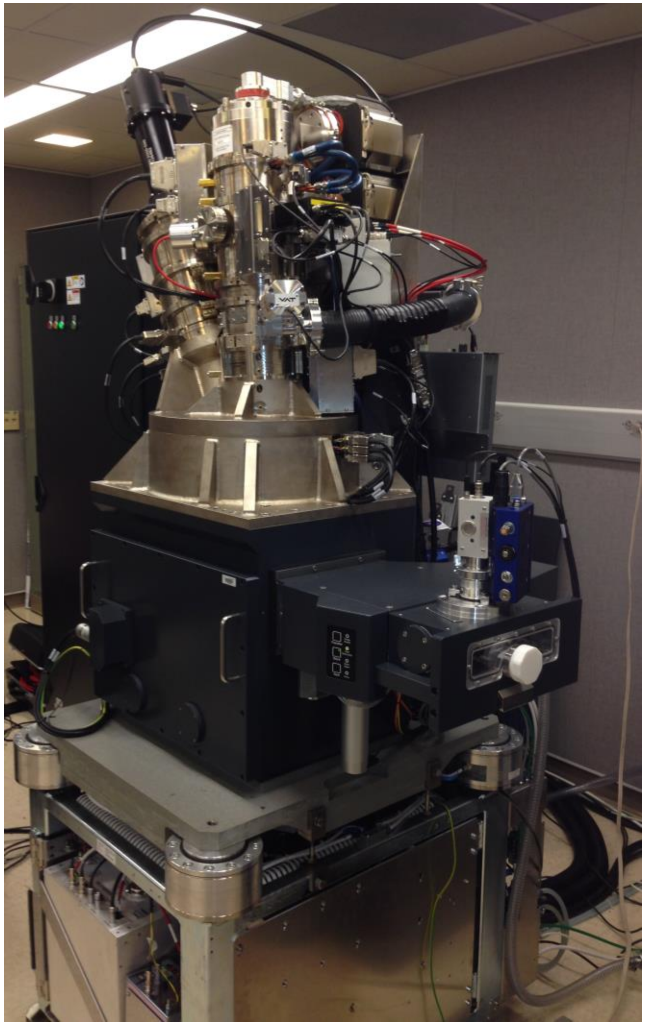
Imaging lens

Sample

Diagram courtesy Carl Zeiss Microscopy

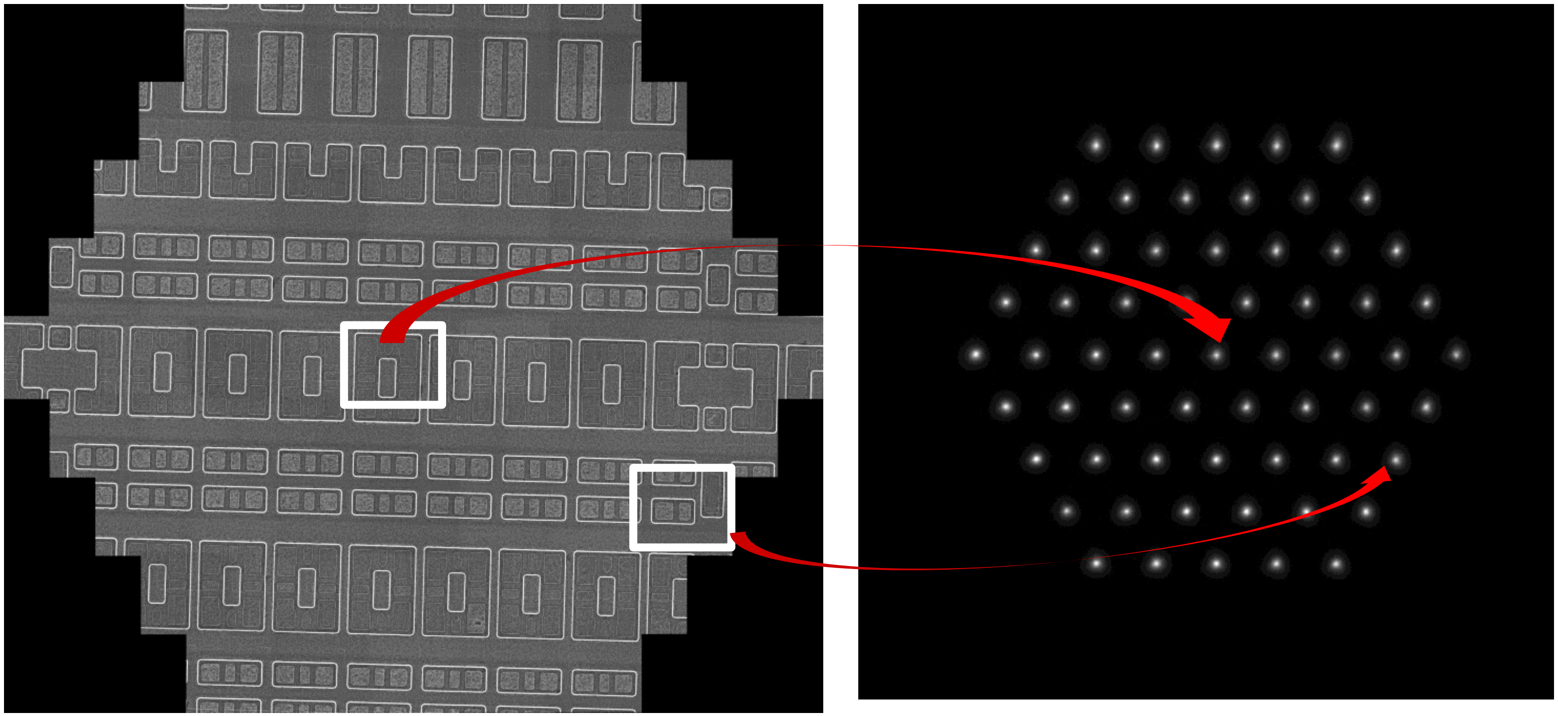
Zeiss MultiSEM





Zeiss MultiSEM installation completed in June, 2015

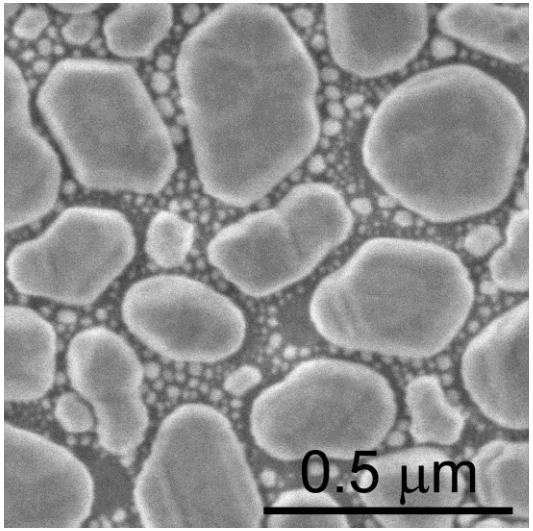
Relationship between scanned beams and secondary electron signals



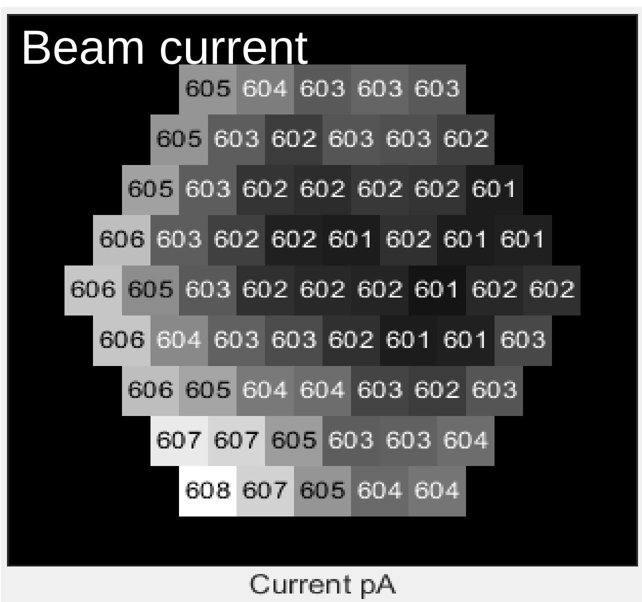
Each of the 61 primary beams of electrons creates a beam of secondary electrons that are collected in parallel. Maximum throughput is 1.2billion pixels/sec.

For large area mapping the stage is moved the process repeated to cover the desired area

MultiSEM Performance



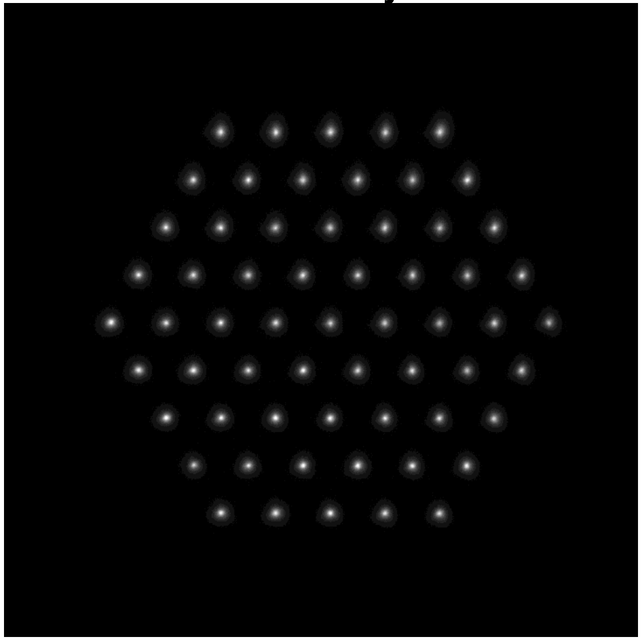
Spot size

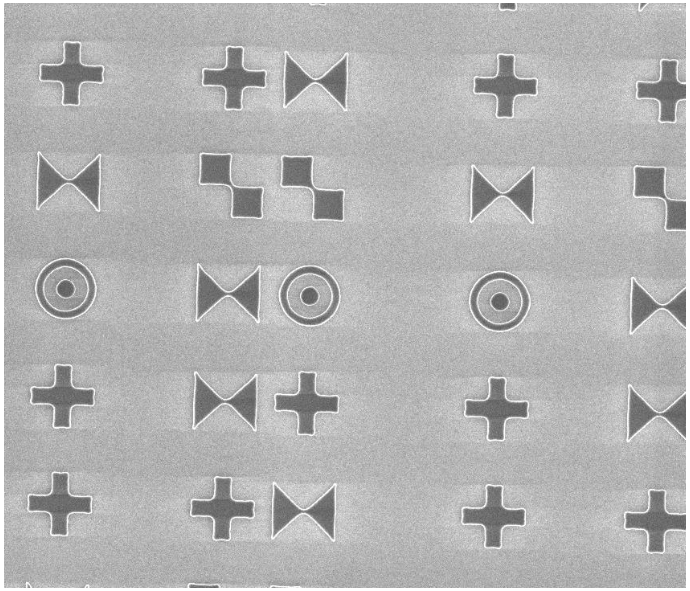


Calibrations and acceptance criteria are done for each beam in the 61 beam array!

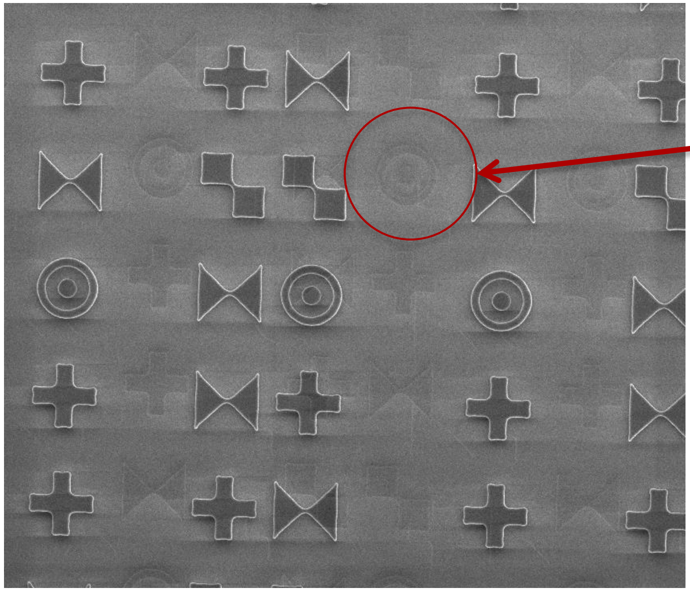
These are just a few of the many performance metrics developed to deal with mulitple beams in one SEM.

Crosstalk – Occurs when secondary electron signal from one beam extends into an adjacent beam





Metroboost calibration chip at 6 kV



Ghost image

Proper alignment of the secondary electron beams with the optical fibers reduces crosstalk to acceptably low levels

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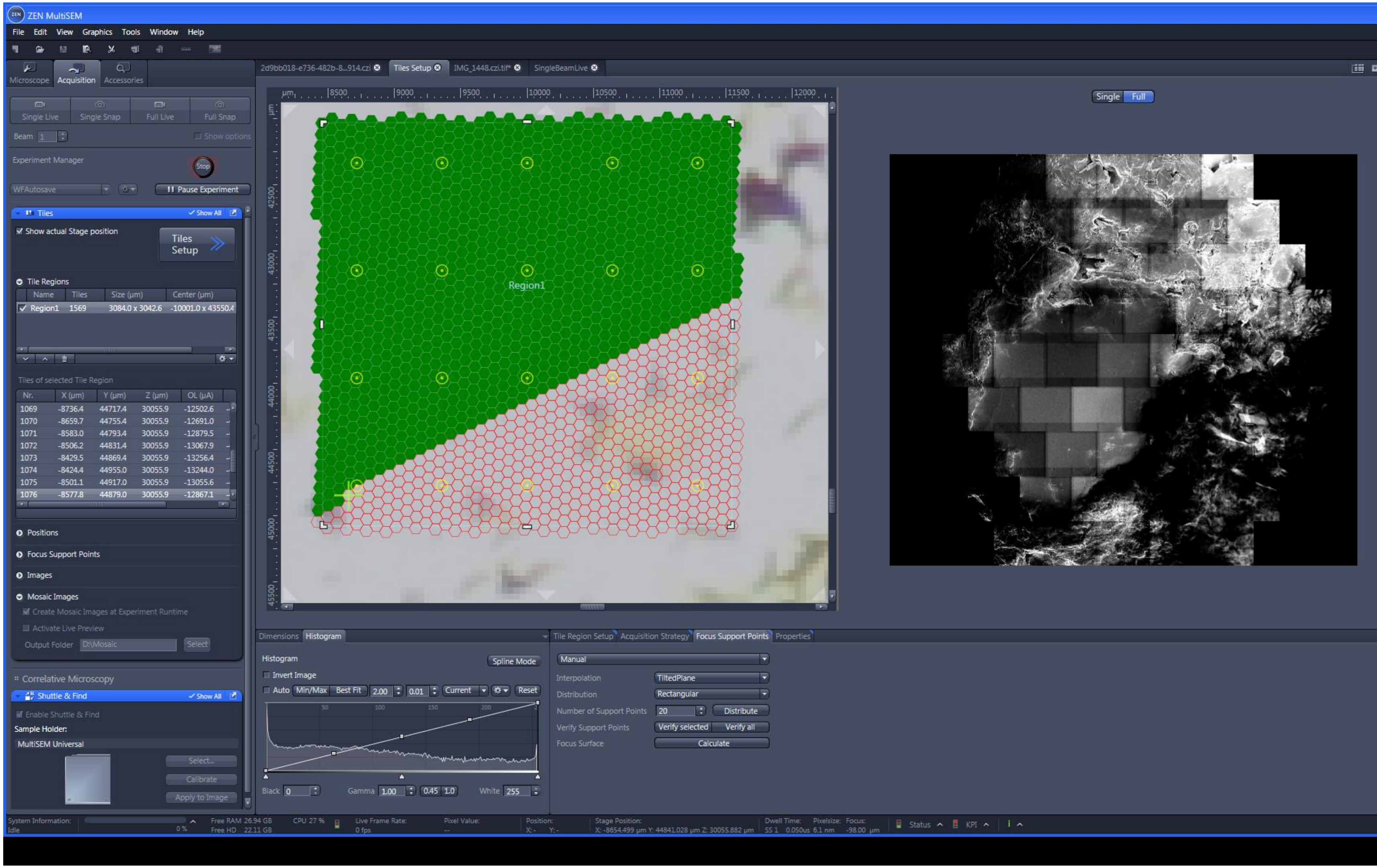
Large area imaging in the multiSEM



Sample requirements:

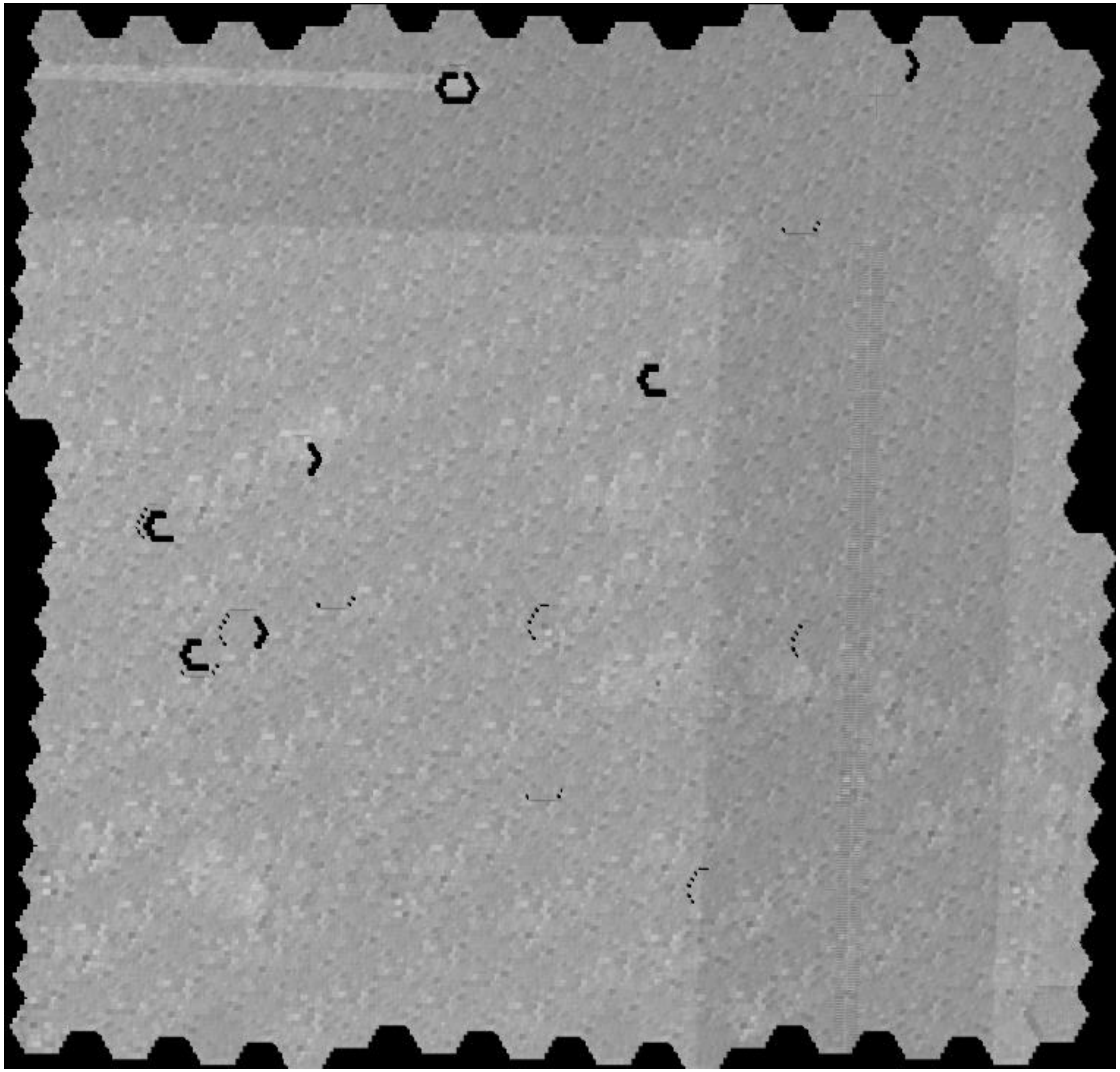
<u>Sample must be relatively flat</u> – Rough or samples that are not flat can cause difficulties with the collection of the secondary electrons. Working distance of 1.4 mm.

Auto focus at each stage position or interpolation improves imaging of rough samples

<u>Samples must be conductive</u> – Required to get the expected landing energy, conductive coatings are helpful

Some samples that have areas that are conductive surrounded by regions of non-conductive material can be imaged without coating.

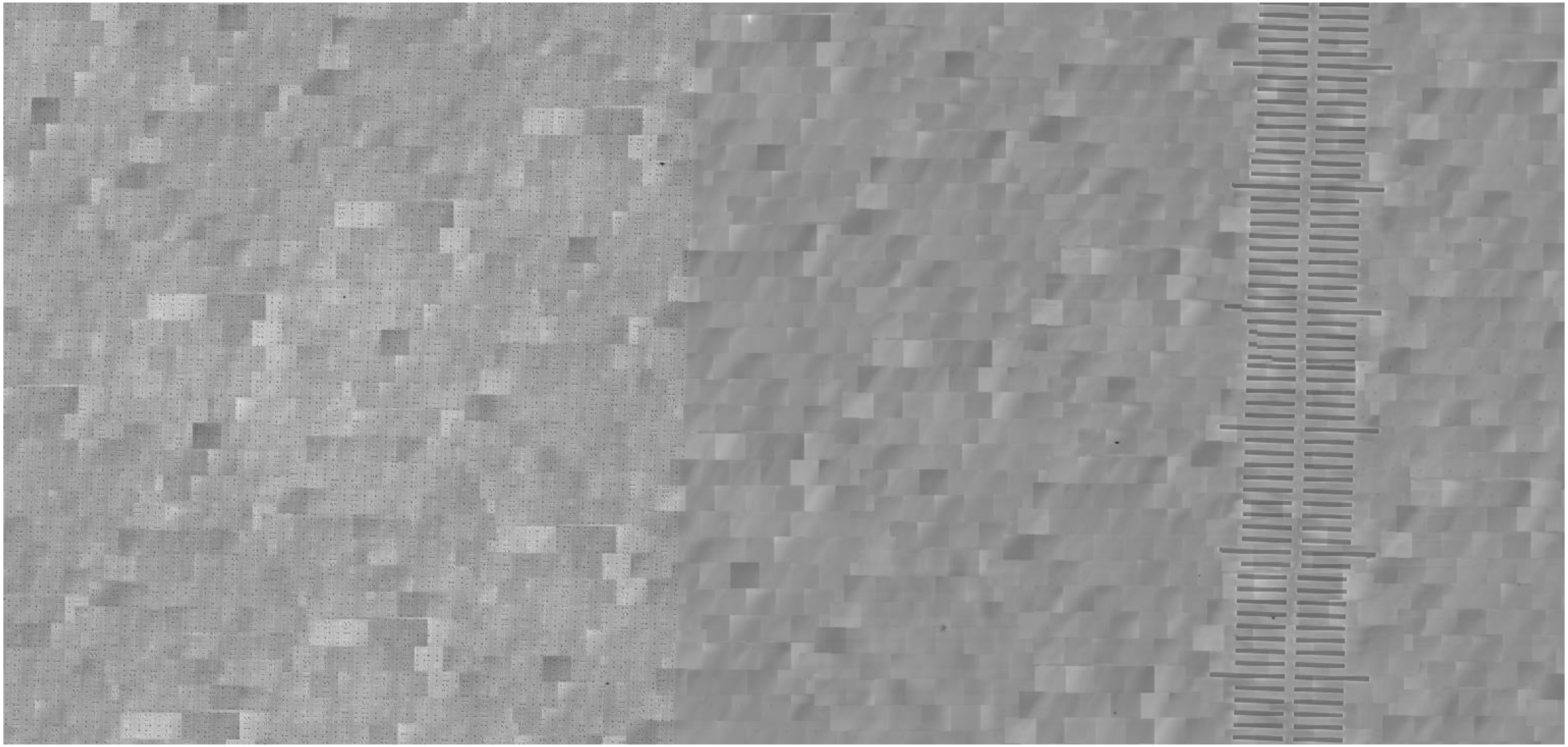
Metroboost image test chip (1.5 keV landing energy)



2.3 x 2.1 mm area acquired at 3.8 nm/pixel.

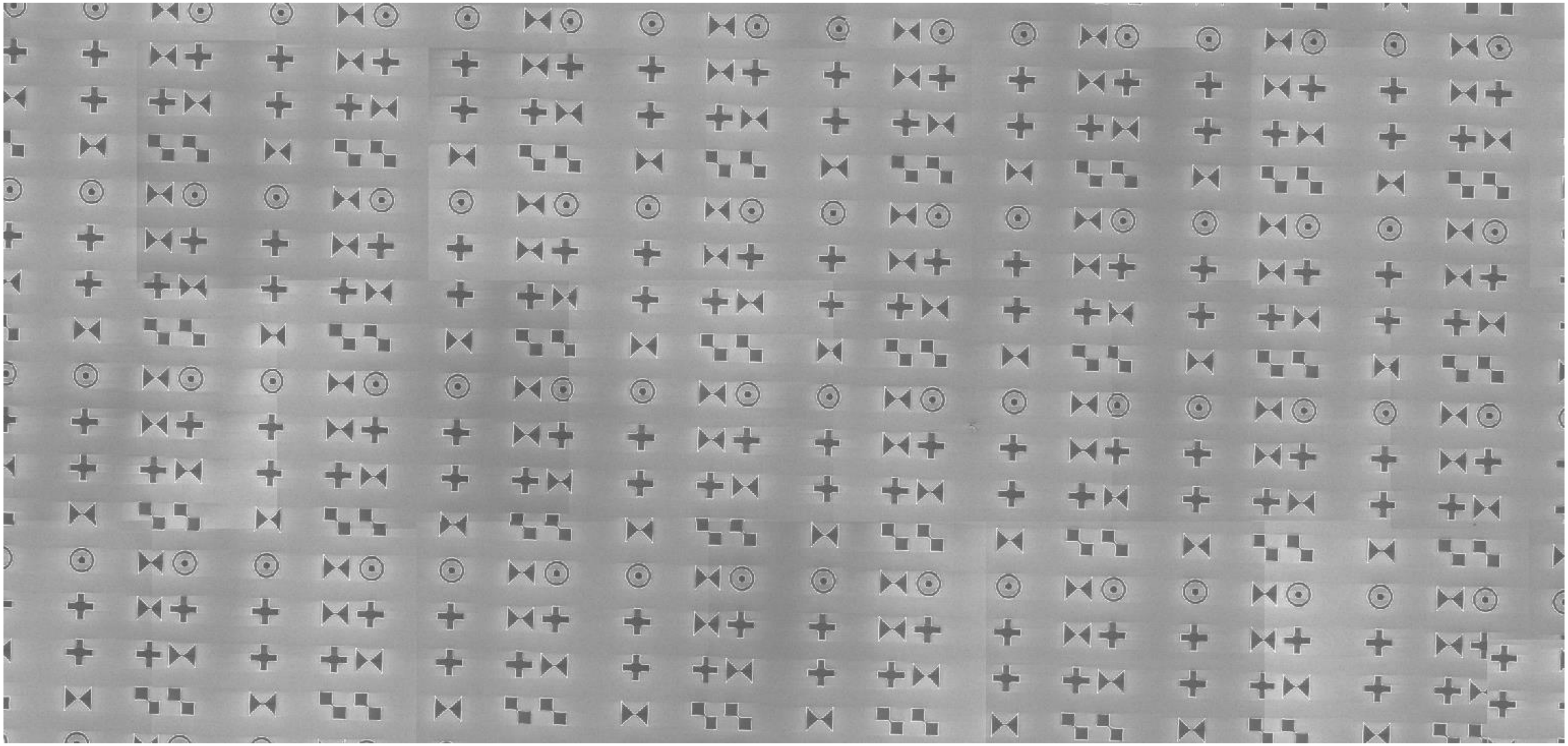
480 mFOVs collected in 25 minutes.

Calibration sample (1.5 keV landing energy)



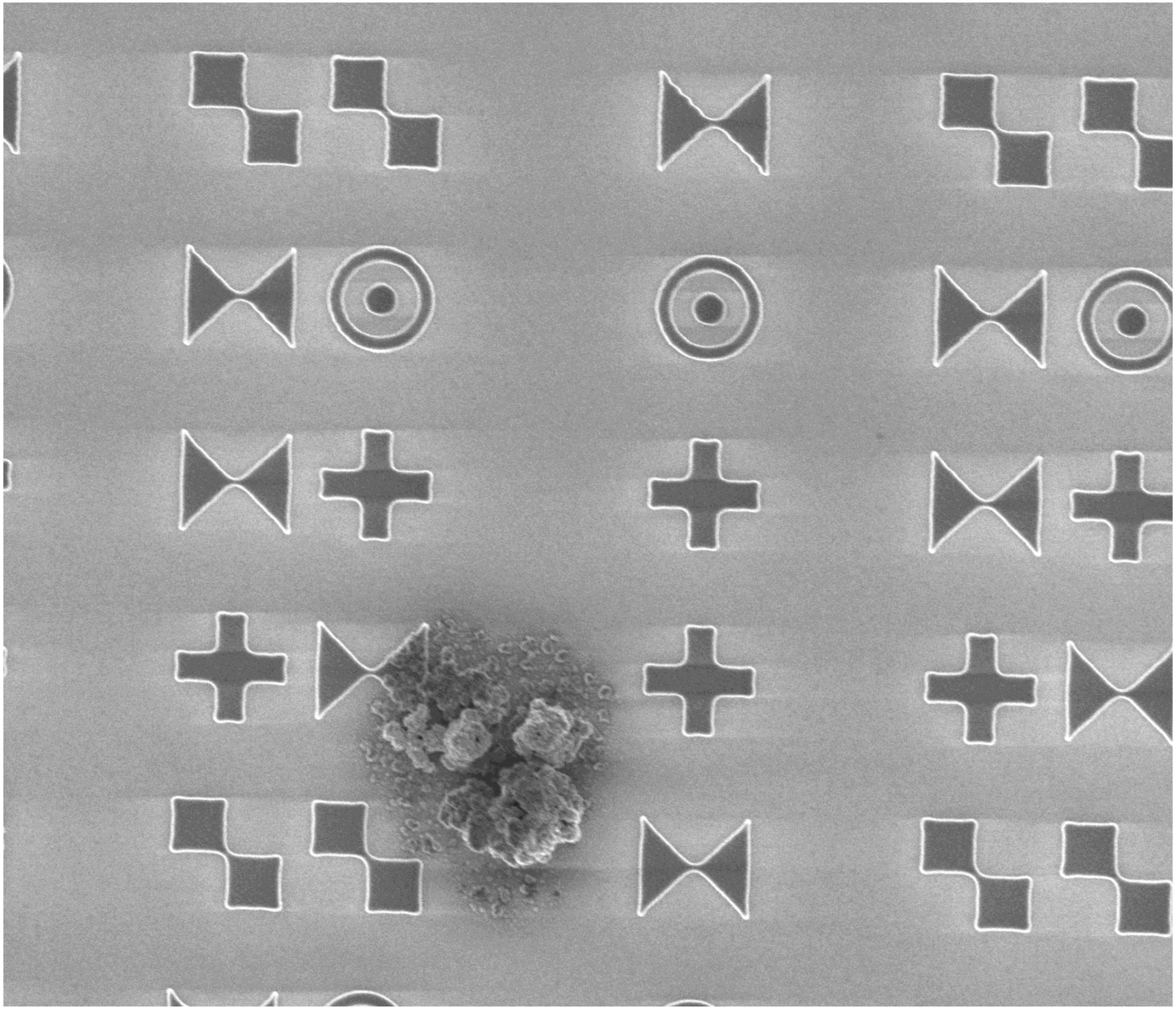
Metroboost calibration sample

Calibration sample (1.5 keV landing energy)



Metroboost calibration sample

Calibration sample (1.5 keV landing energy)

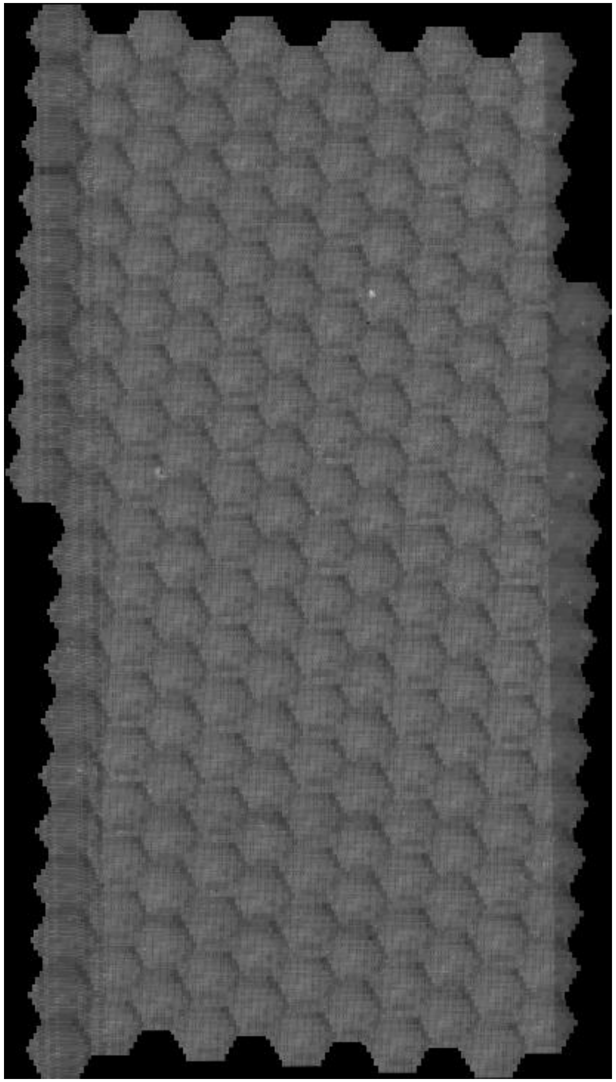


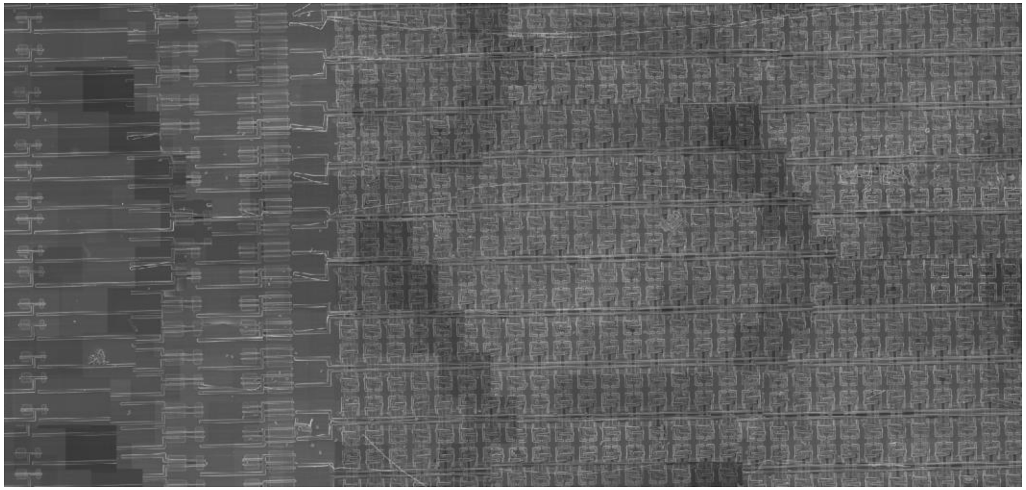
Single image tile

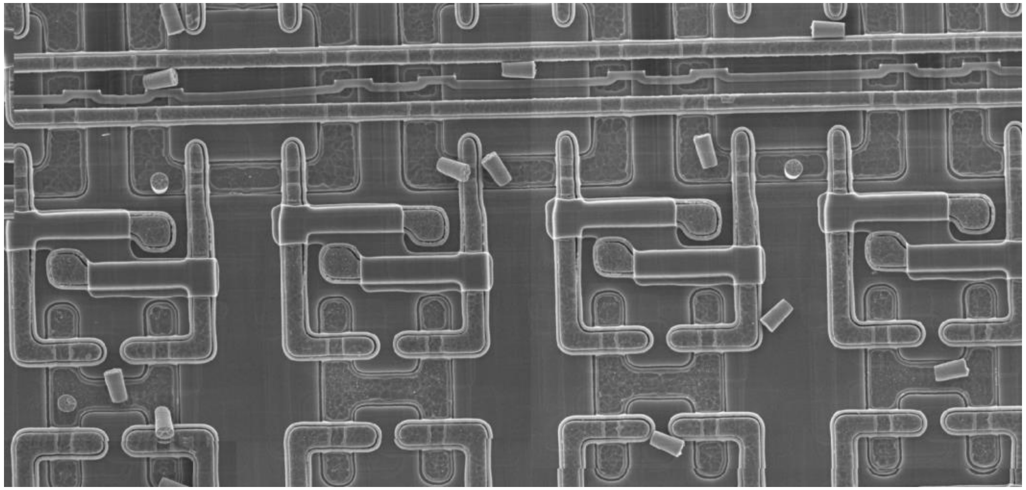
3340x2868 pixels

3.8 nm/ pixwl

SRAM test Structure (3.0 kV landing energy)

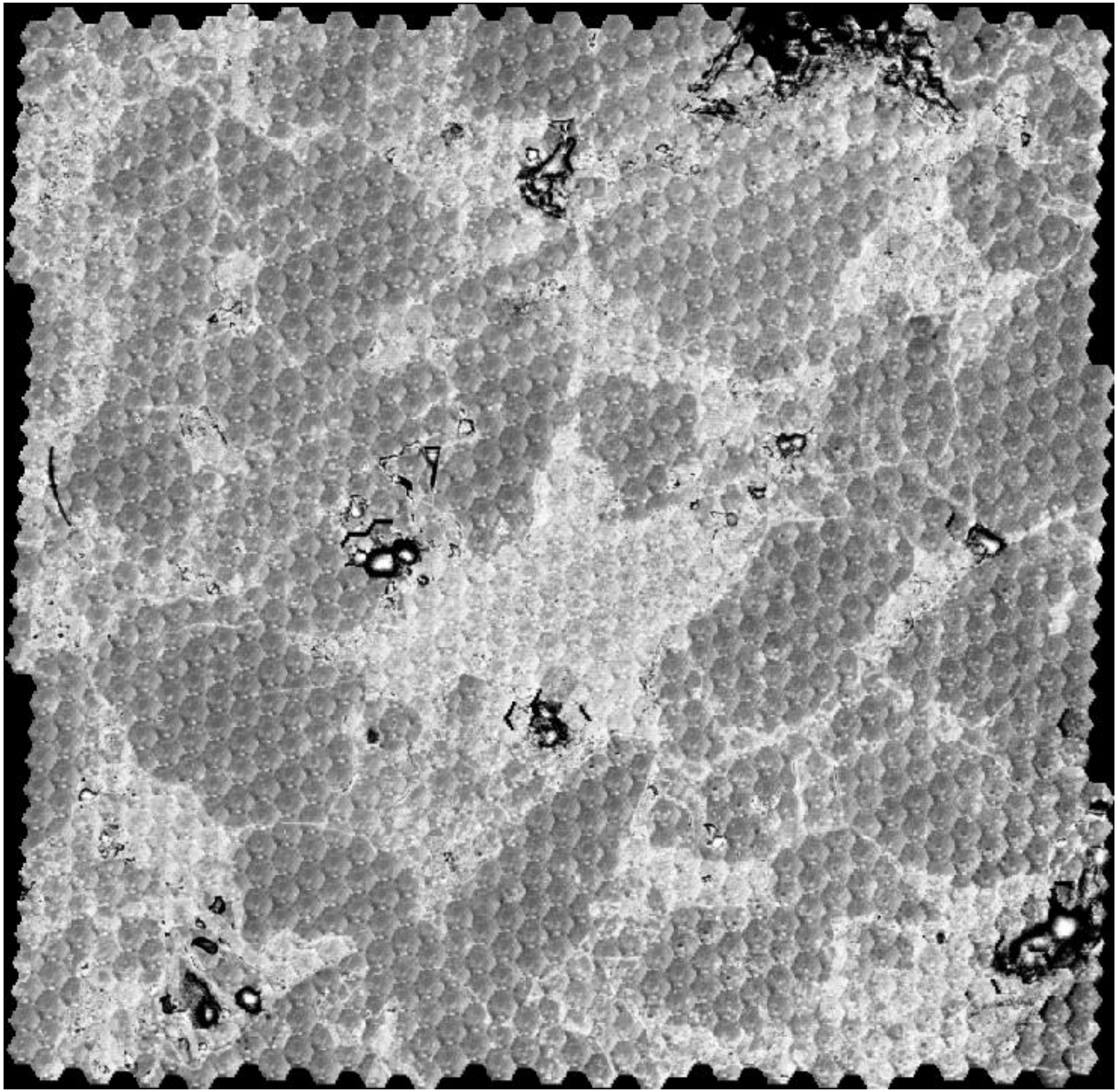






2 X 1 mm area (210 mFOVs) scanned at 3.8 nm/pixel in 32 minutes

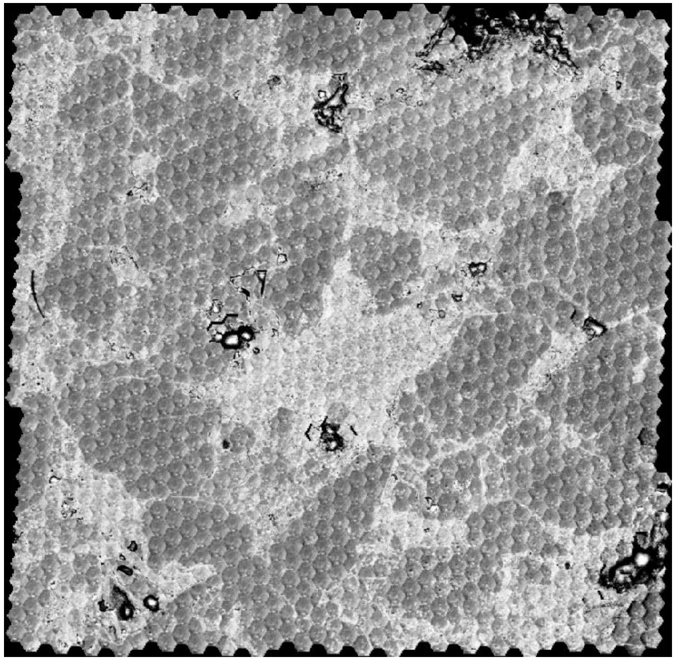
Polished sandstone sample - coated with AuPd (1.5keV)

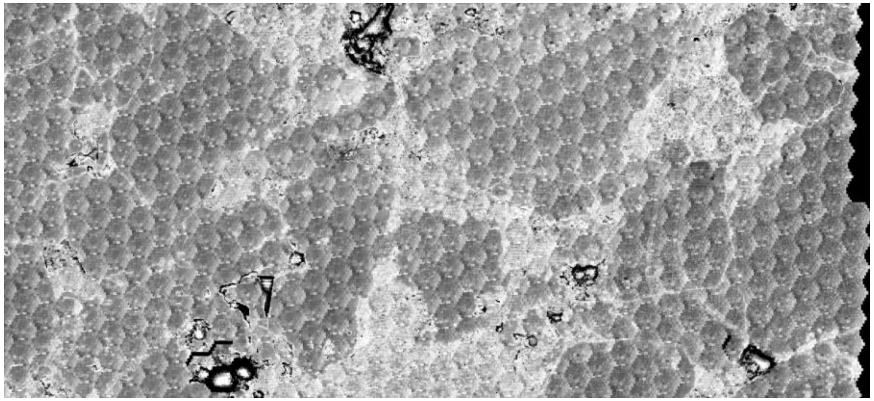


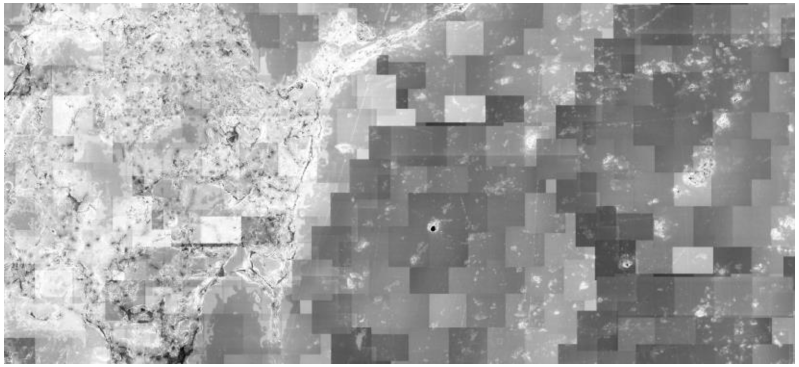
3 mm X 3 mm area at 6 nm/pixel

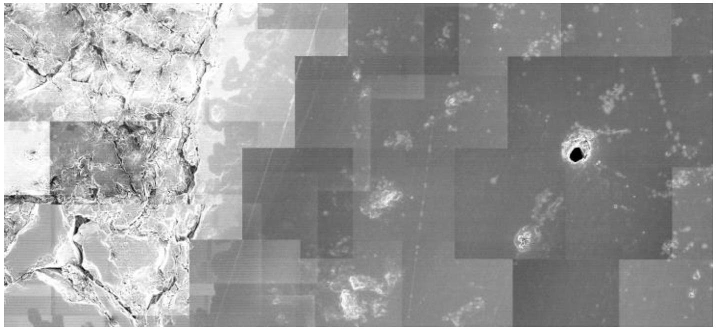
1569 mFOVs scanned in 19 minutes

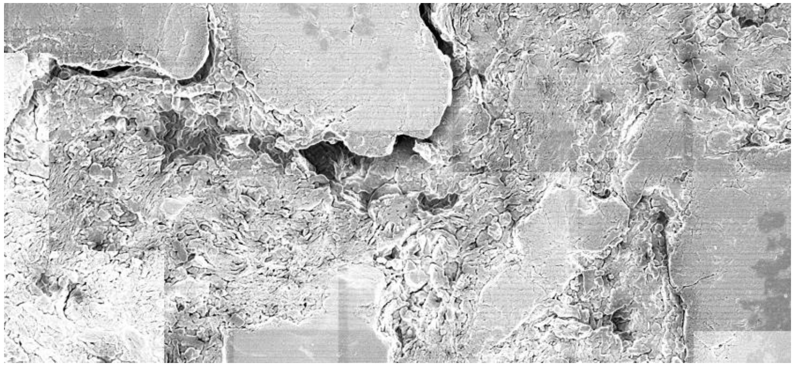
Polished sandstone sample - coated with AuPd (1.5keV)







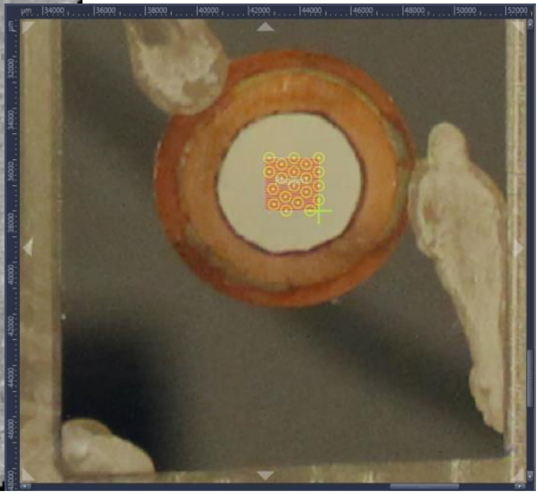




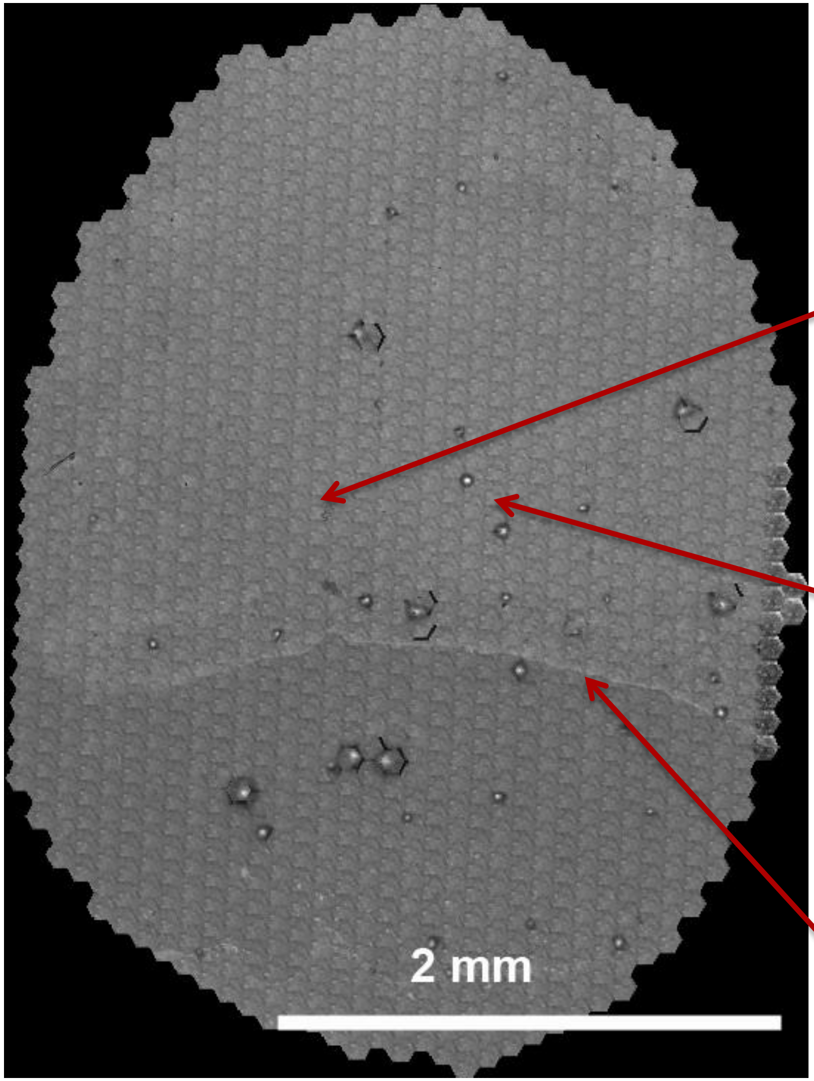
Tin-plated copper – tin whisker mitigation study (1.5 kV Landing energy)

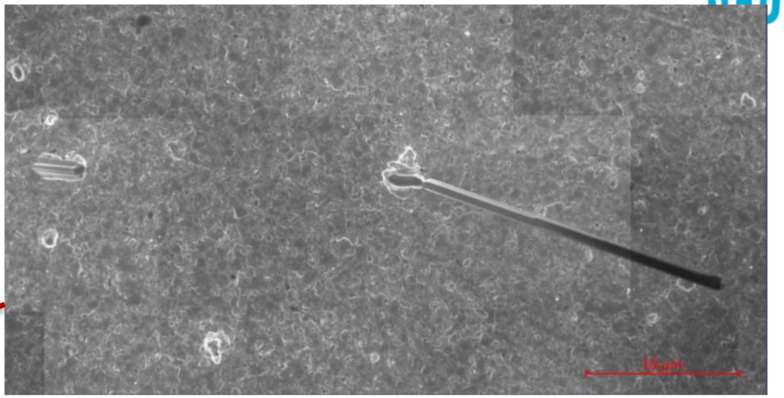
3 X 2.5 mm area at 3.8 nm/pixel

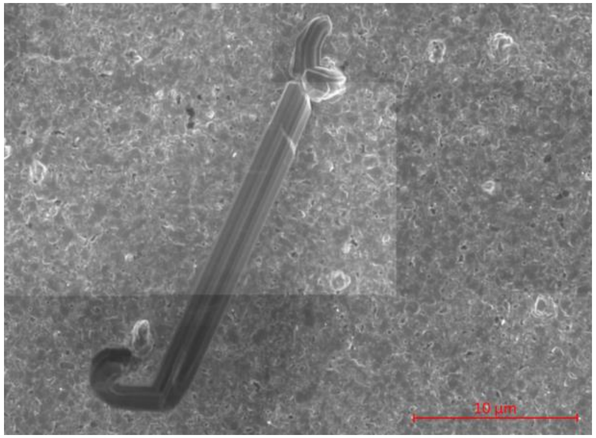
815 mFOVs acquired in 51 minutes

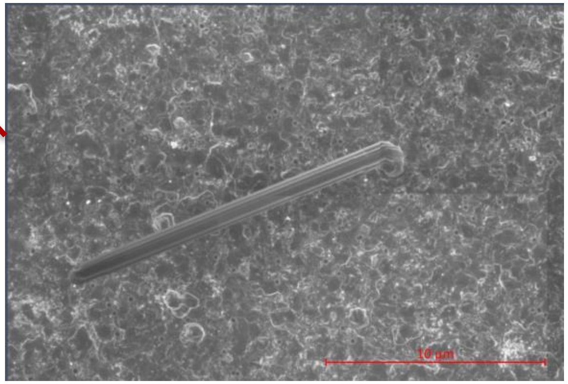


Tin-plated copper – tin whisker mitigation study







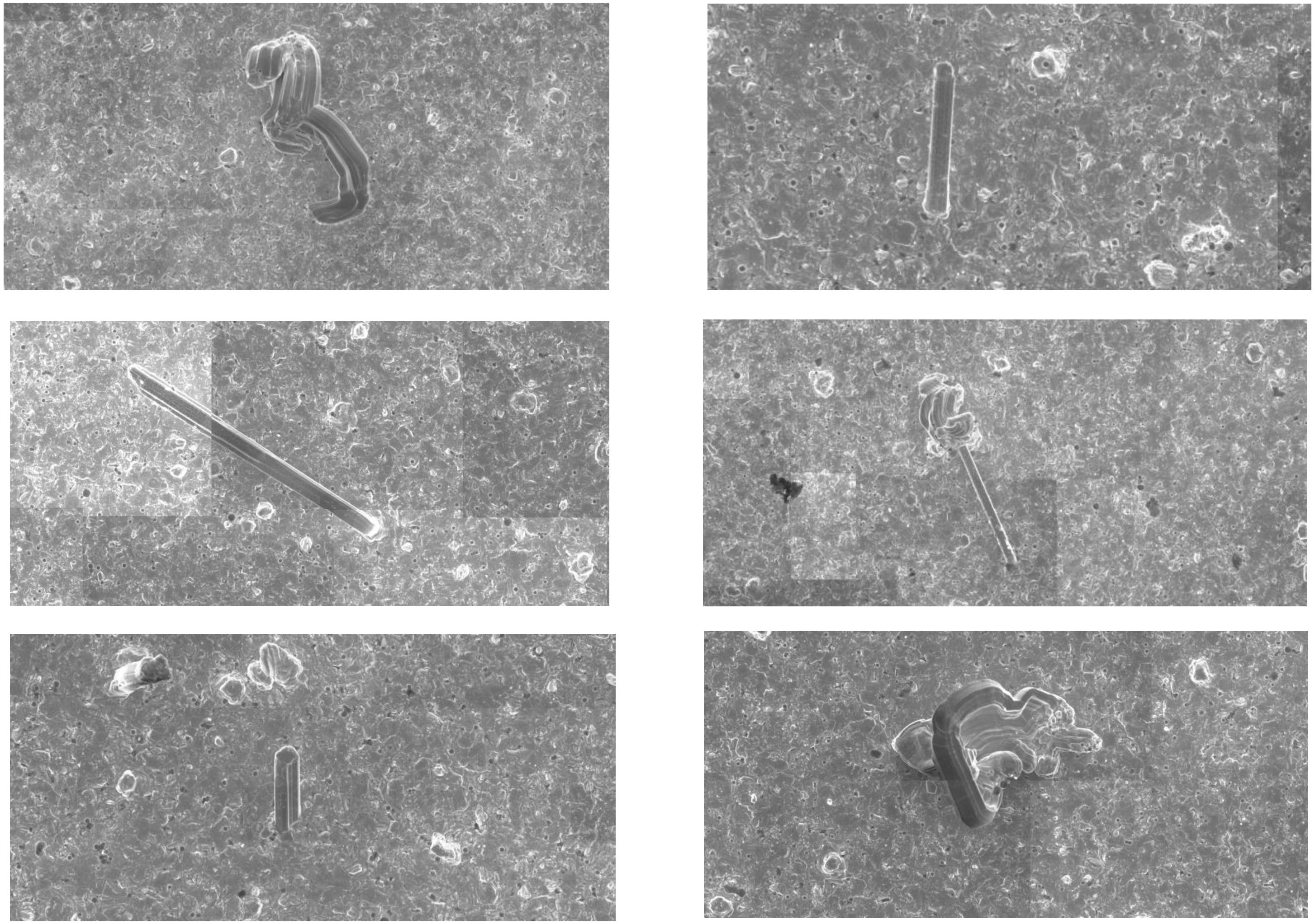


1.5 keV
landing energy

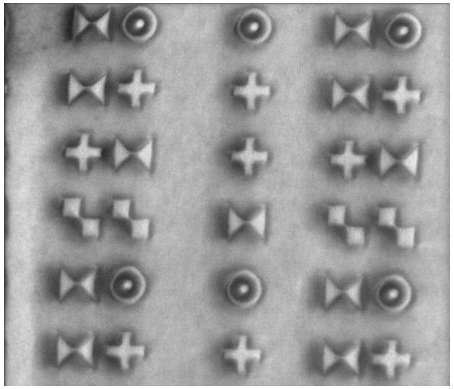
1207 mFOVs collected in 84 minutes

Tin-plated copper – tin whisker mitigation study

Various whisker images extracted from large area



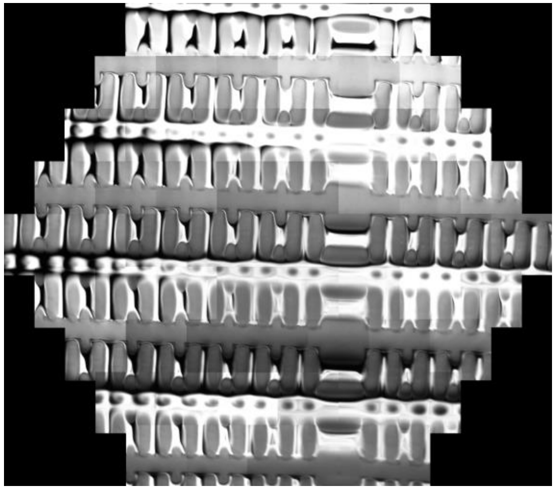
Low landing energy capabilities



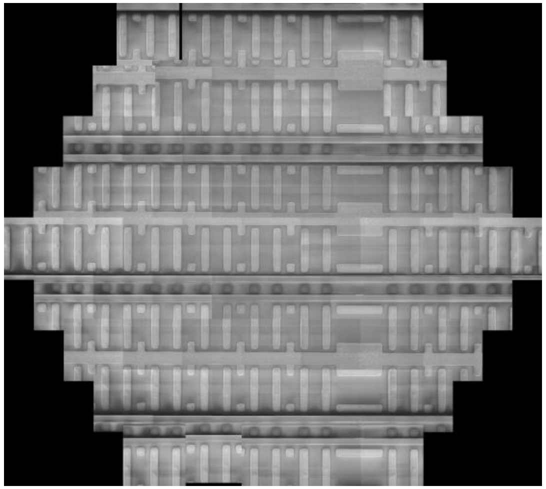
6 eV landing energy

Low landing energy capabilities produce interesting imaging modes and possibilities

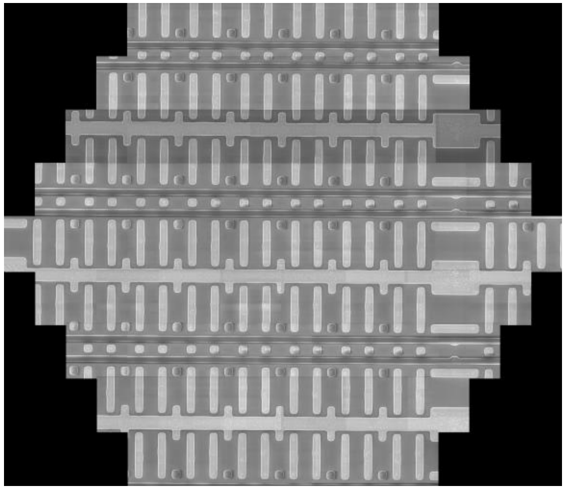
SRAM test structure



7 eV landing energy



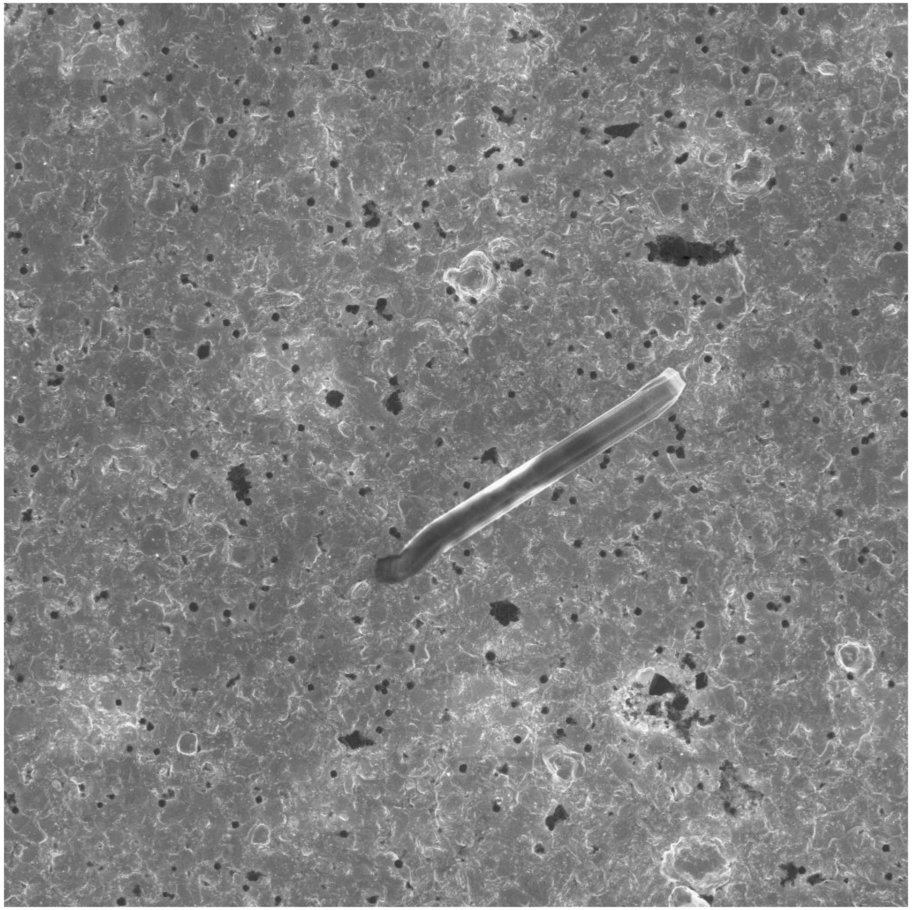
100 eV landing energy



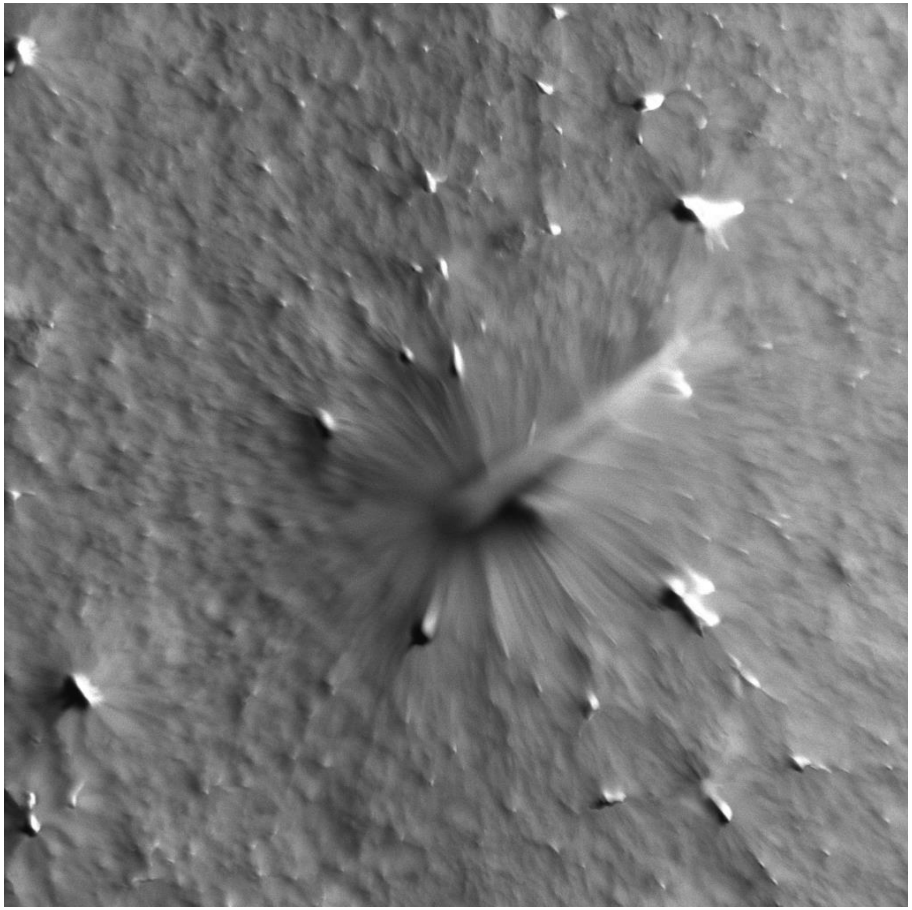
500 eV landing energy

Low voltage imaging with MultiSEM

Tin whisker



1.5 kV landing energy



2 eV landing energy

Conclusions

The need for speed:

- ✓ 61 beam mulitSEM – 1.22 Gpixels/sec maximum throughput
- ✓ 4 nm pixel size
- ✓ Large areas can be imaged quickly with good contrast
- ✓ Secondary electron imaging only – no BSE, x-ray etc.
- ✓ Landing energy can be varied over a useful range (few eV to 6 kV)
- ✓ Samples must be conductive and reasonably flat
- ✓ Operation similar to SEM with additional complications due to mulitbeams
- ✓ Interesting applications in microelectronics, geology and materials science