CNEU Webinar

Like driving a car: acquiring quality SEM/FESEM images in different situations

Dr. Bangzhi Liu

Nanofabrication Laboratory
Materials Research Institute
Penn State University

Email: bul2@psu.edu

9/16/2022

CNEU Webinar

Like driving a car: acquiring quality SEM/FESEM images in different situations

Dr. Bangzhi Liu

Nanofabrication Laboratory
Materials Research Institute
Penn State University

Email: bul2@psu.edu

9/16/2022

About me

Bangzhi Liu | Assistant Research Professor

Nanofabrication Laboratory, Materials Research Institute, Penn State University

•FESEMs, EDS, Thermal ALD, PEALD, PVD, Ellipsometry;
•Process development, training, and maintenance;
•Internal and external projects

Background

- ❑ **Ph.D. in Materials Science and Engineering | Michigan State University**
- ❑ **B.S. in Applied Physics | Dalian University of Technology, Dalian, CN**

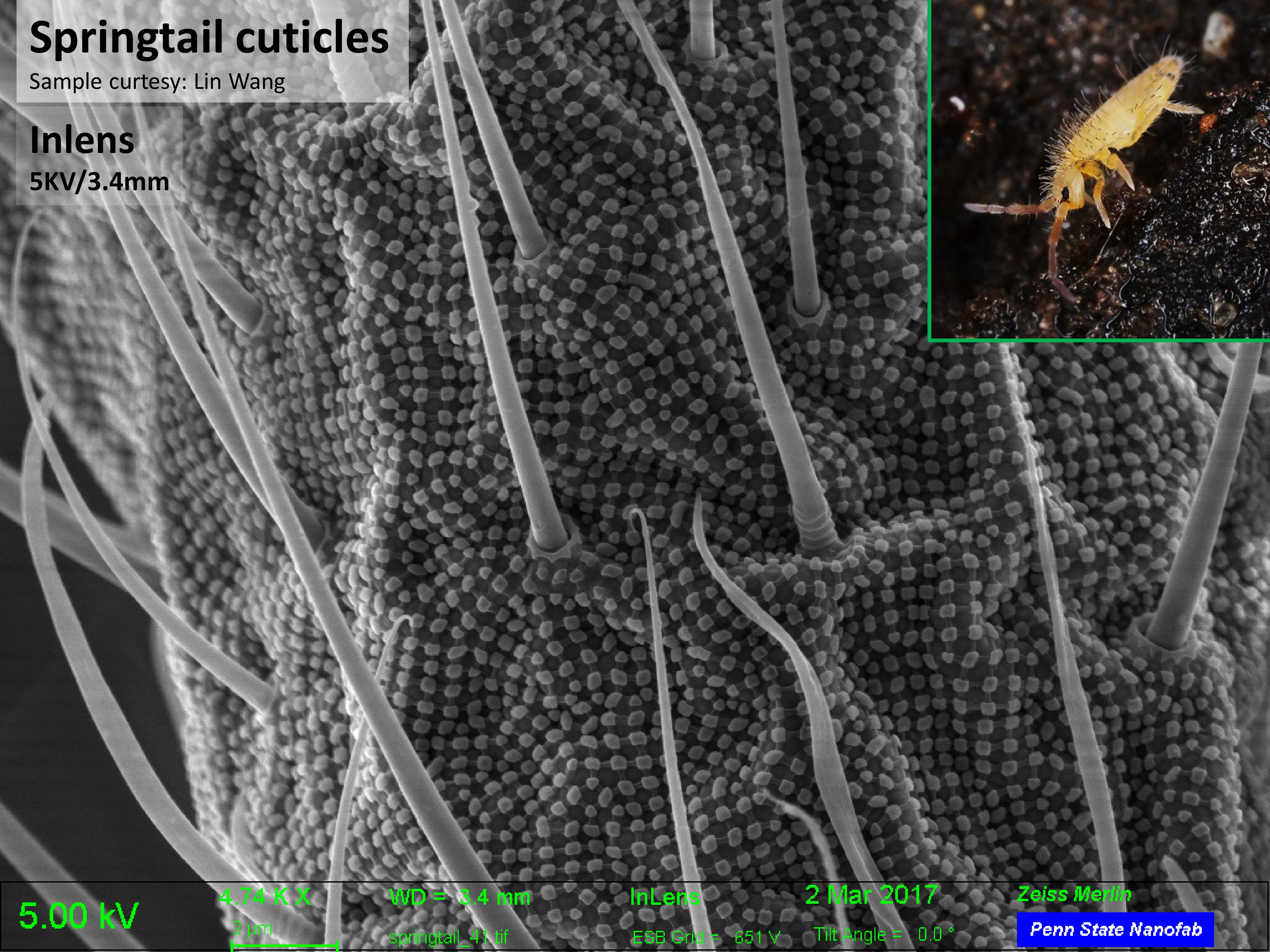
Hometown and workplace

9,500 ft^2 cleanroom (Class 1000 / 100)

2 EBL
2 FESEM
8 Dry etchers
5 ALD
1 AFM
3 Evap
4 Sputter
1 PECVD
2 Contact aligner
1 Laser Writer
1 MLA
1 Nano Imprinter
2 Wafer Bonder
3 RTA
1 Ellipsometer
1 Profilometer

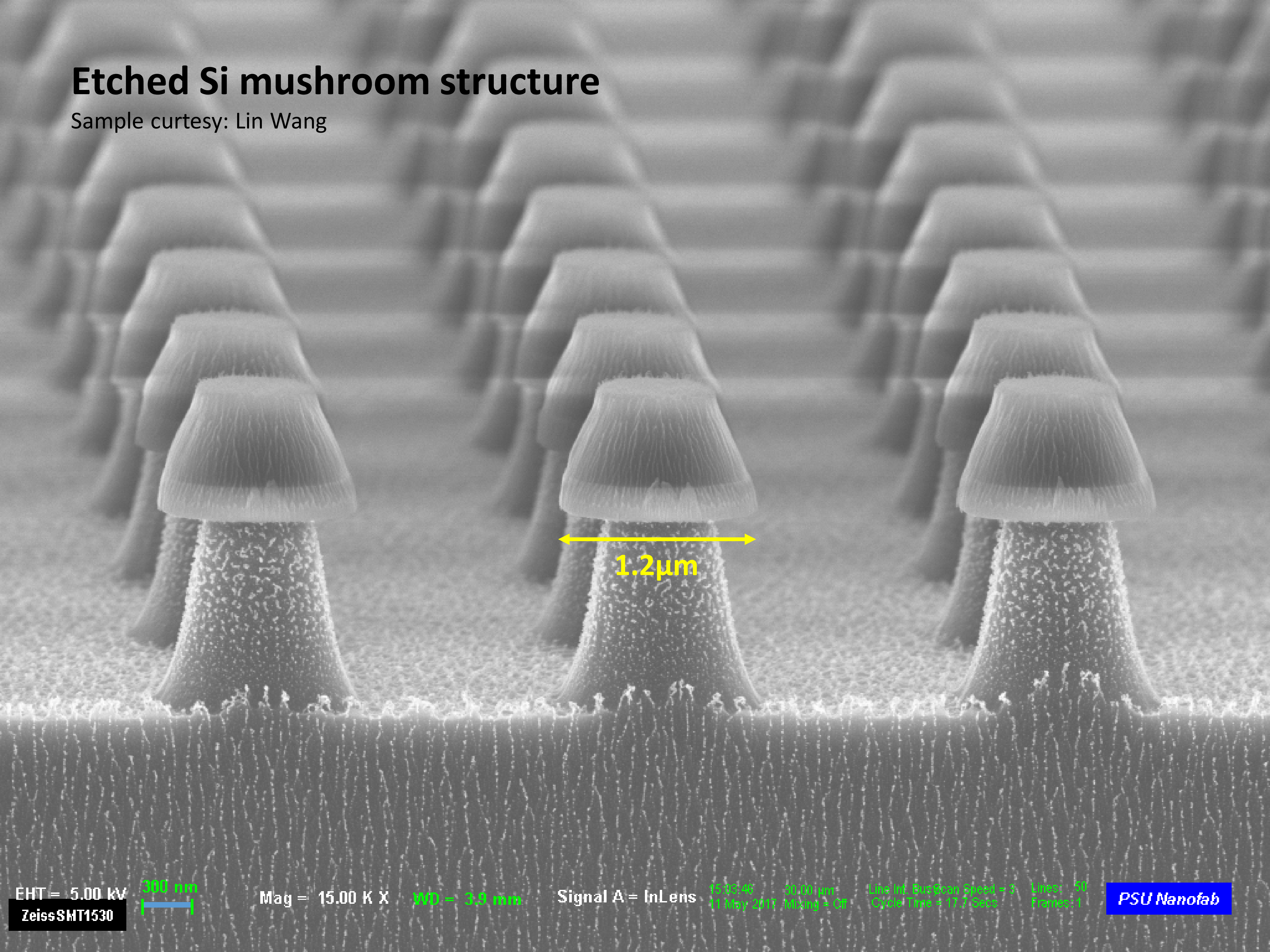
Outline

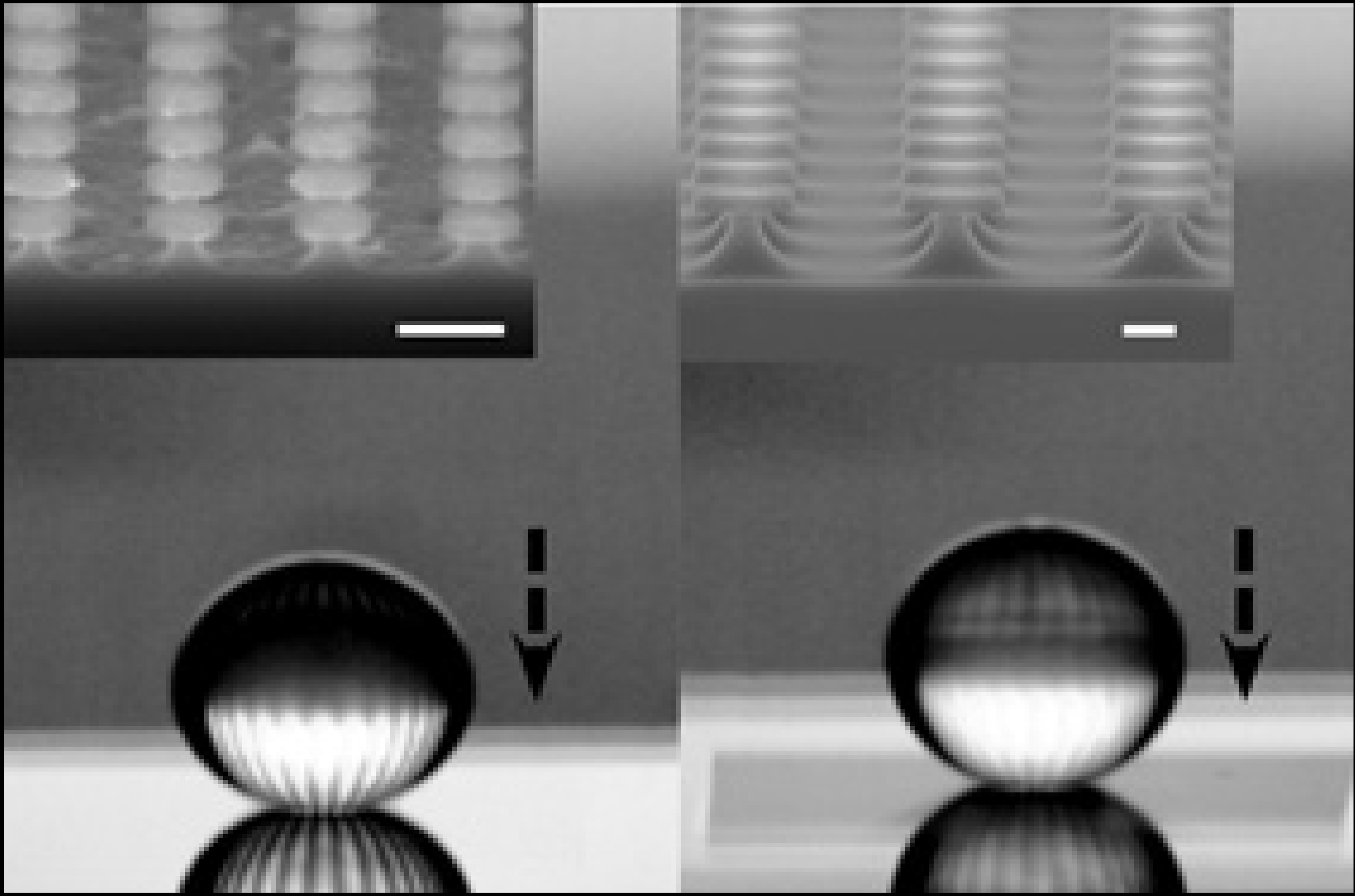
- Examples of different situations
- Key Imaging Parameters
- FESEMs we own
- How to achieve ideal beam


Springtail cuticles
Sample curtesy: Lin Wang
Inlens
5KV/3.4mm
5.00 kV
4.74 K X
2 µm
WD = 3.4 mm
springtail_41.tif
InLens
ESB Grid = 651 V
2 Mar 2017
Tilt Angle = 0.0 °
Zeiss Merlin
Penn State Nanofab

Etched Si mushroom structure

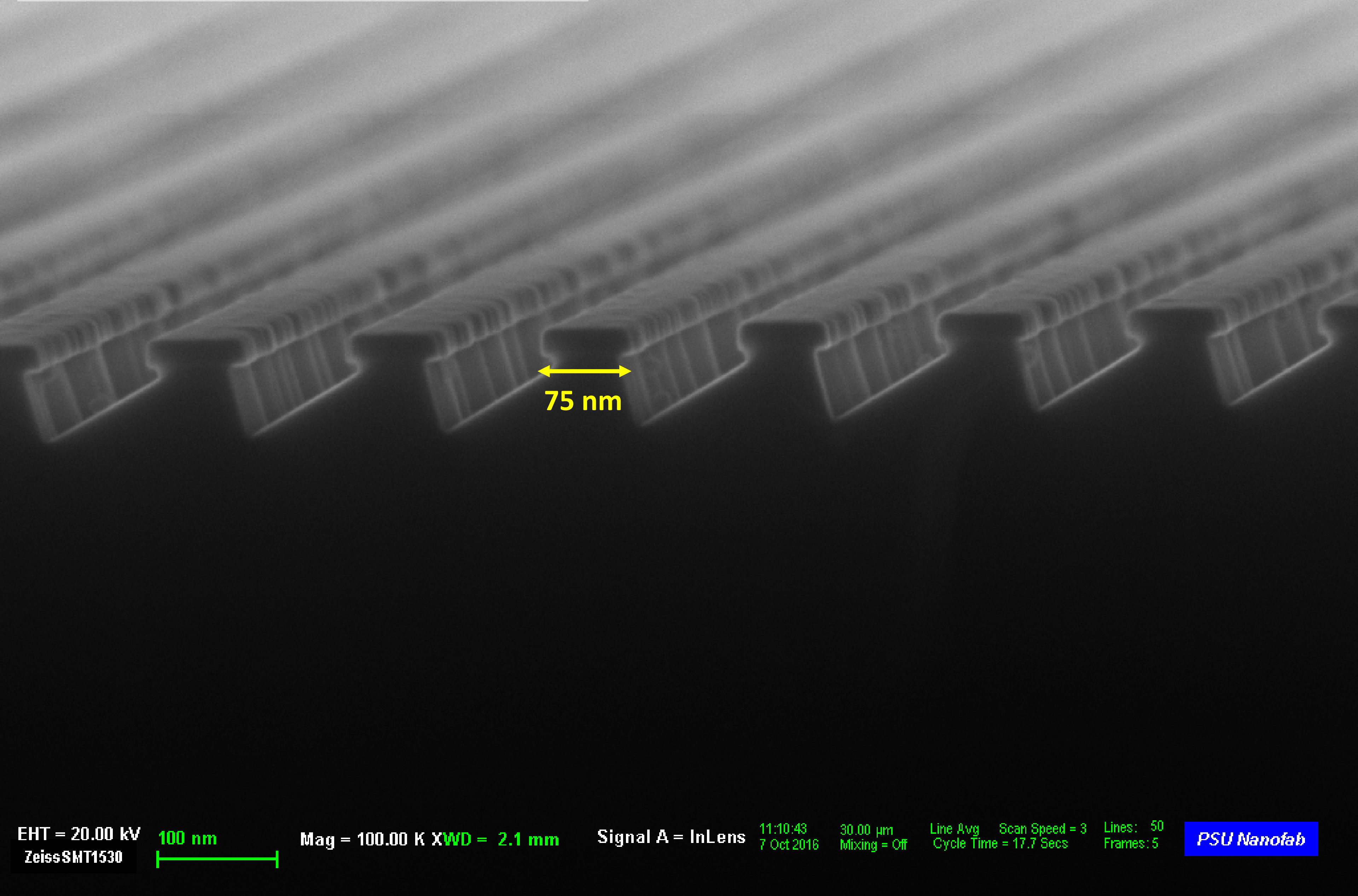
Sample curtesy: Lin Wang

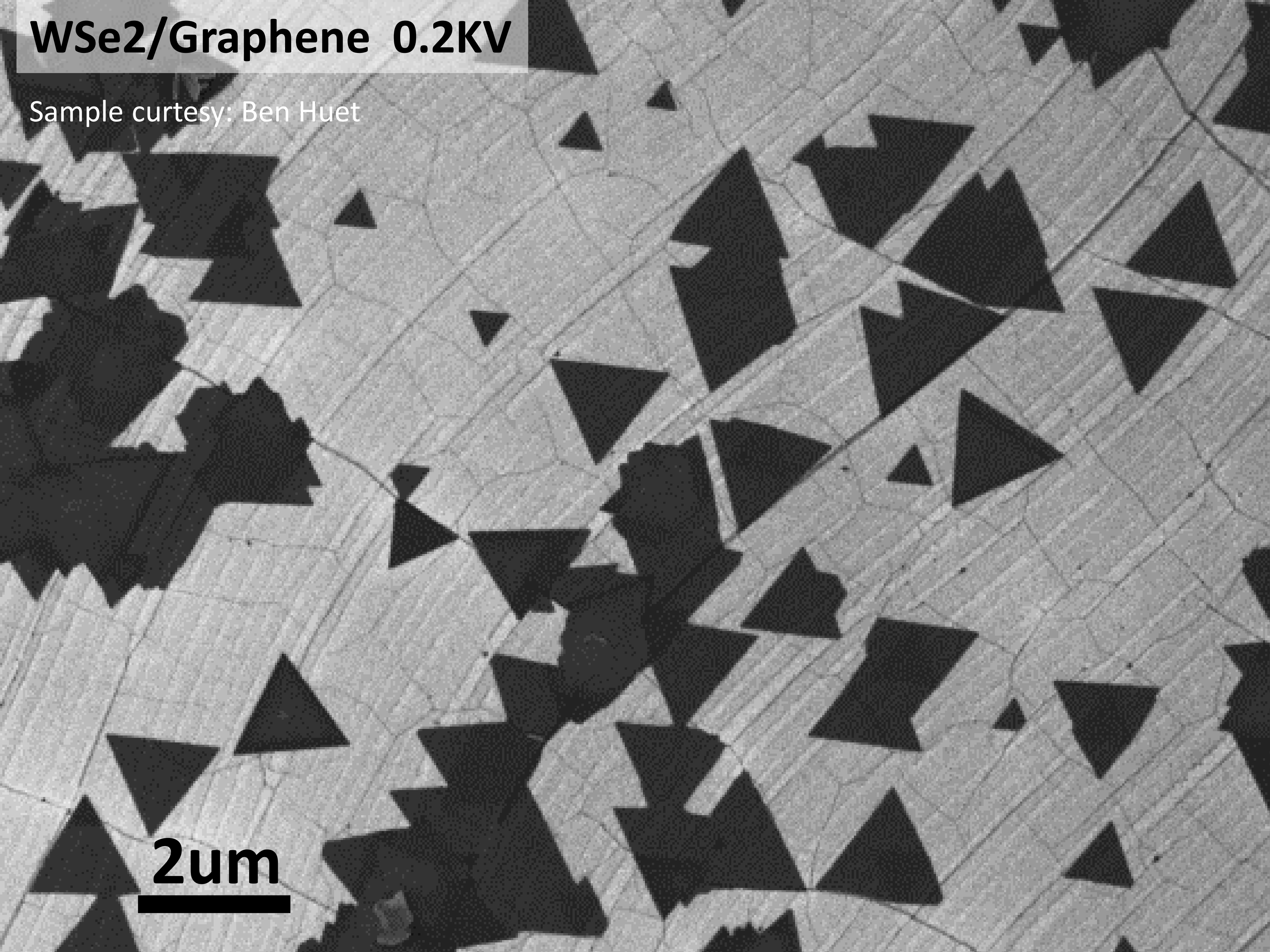




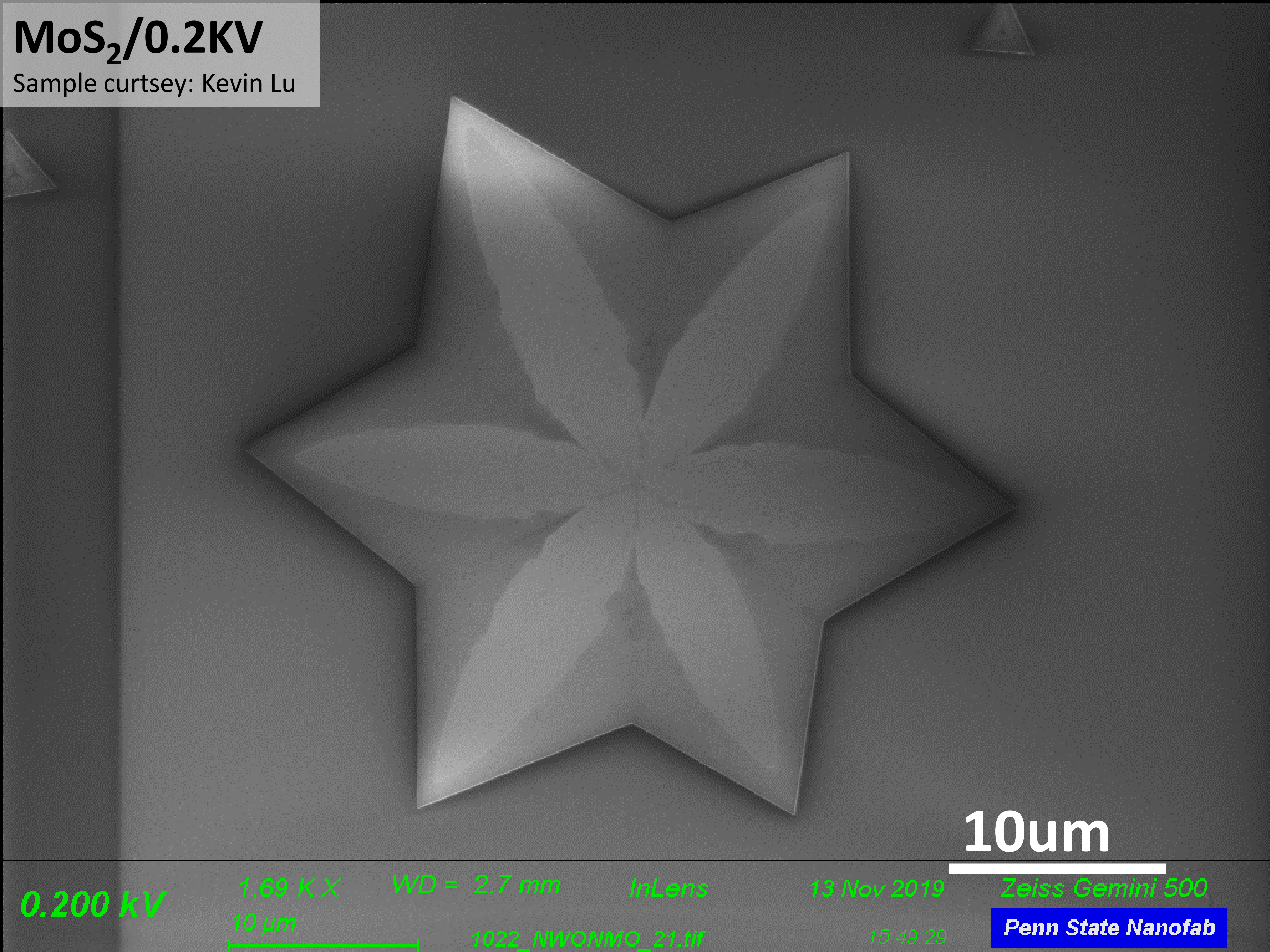
Etched Si grating

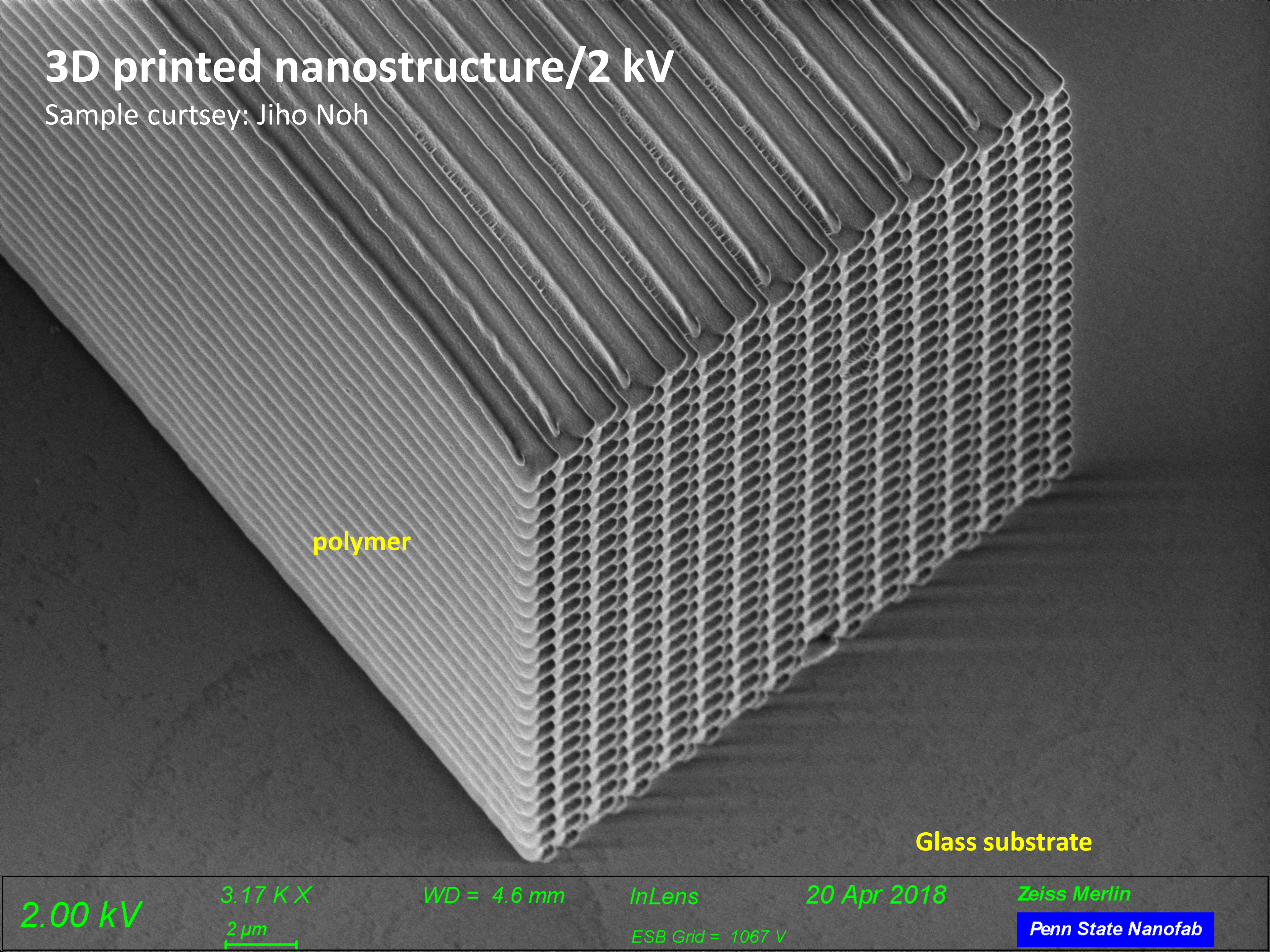
Sample curtesy: Fabin Grise



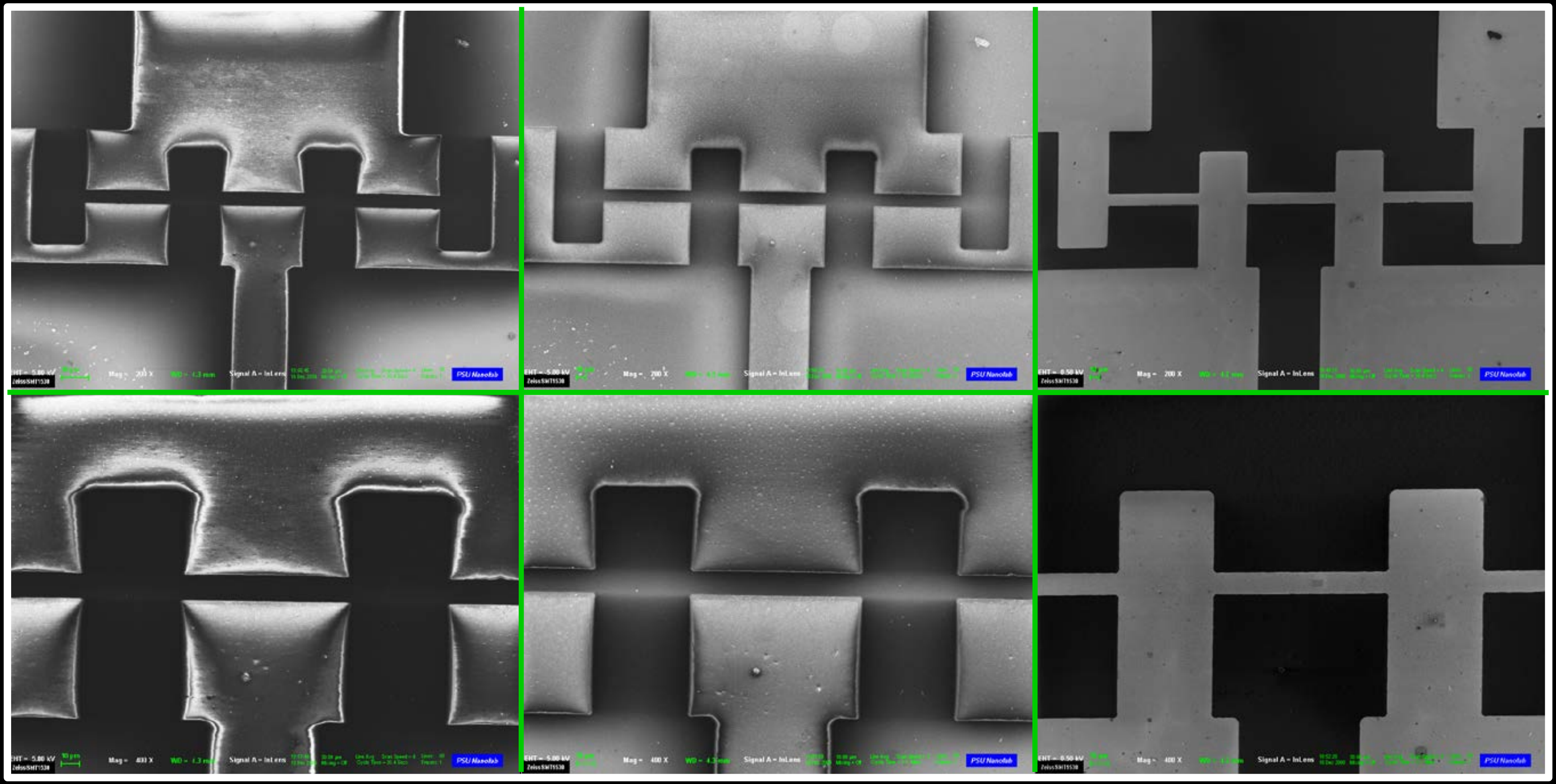


WSe2/Graphene 0.2KV
Sample curtesy: Ben Huet
2um


MoS2/0.2KV
Sample curtsey: Kevin Lu
10um
0.200 kV
1.69 K X
10 µm
WD = 2.7 mm
InLens
1022_NWONMO_21.tif
13 Nov 2019
15:49:29
Zeiss Gemini 500
Penn State Nanofab


3D printed nanostructure/2 kV
Sample curtsey: Jiho Noh
polymer
Glass substrate
2.00 kV
3.17 K X
2 µm
WD = 4.6 mm
InLens
ESB Grid = 1067 V
20 Apr 2018
Zeiss Merlin
Penn State Nanofab

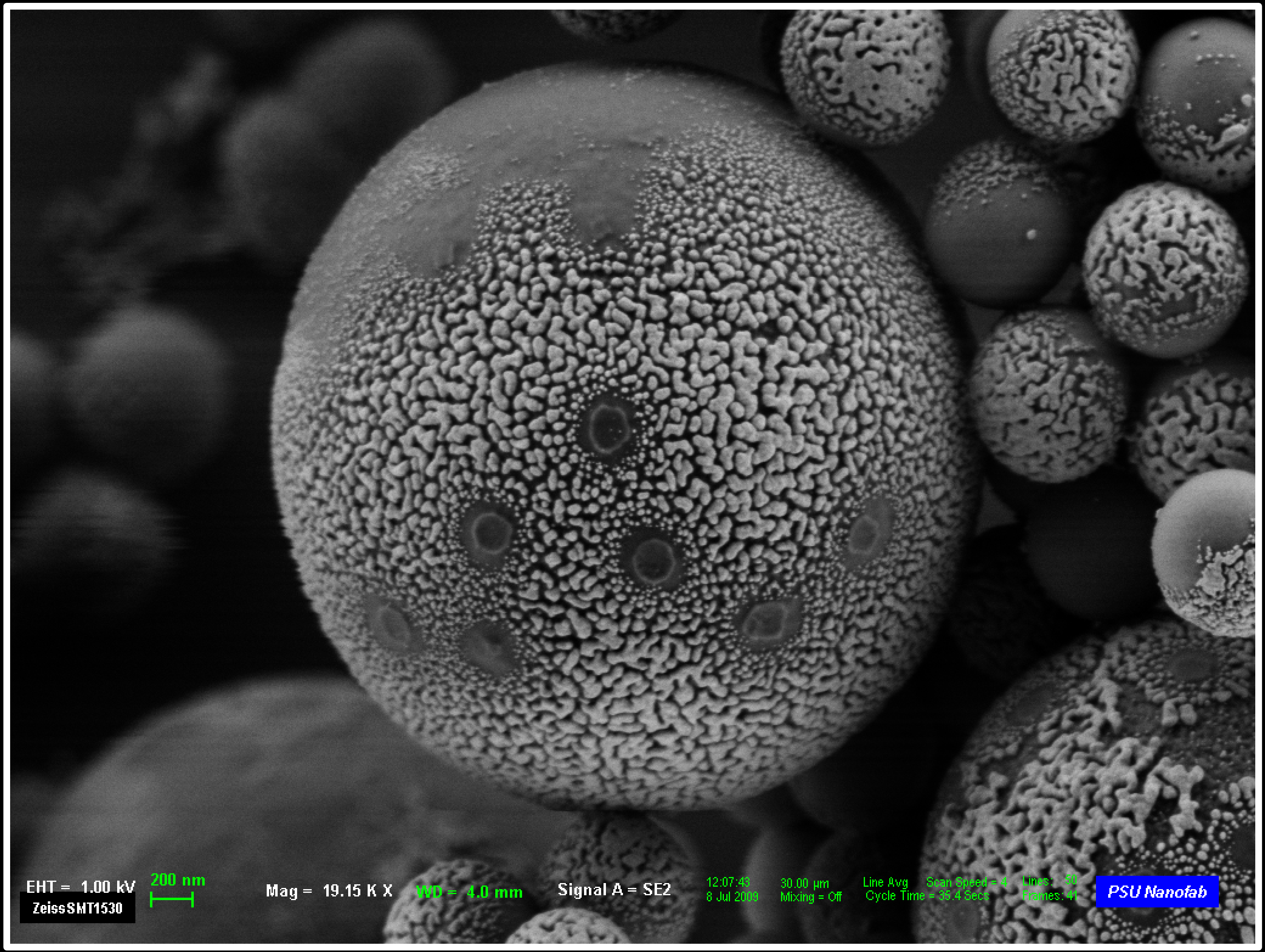
Charging effect



5 kV / 30 µm aperture   5 kV / 10 µm aperture   0.5 kV / 30 µm aperture

LEO1530

Polystyrene latex coated with Au

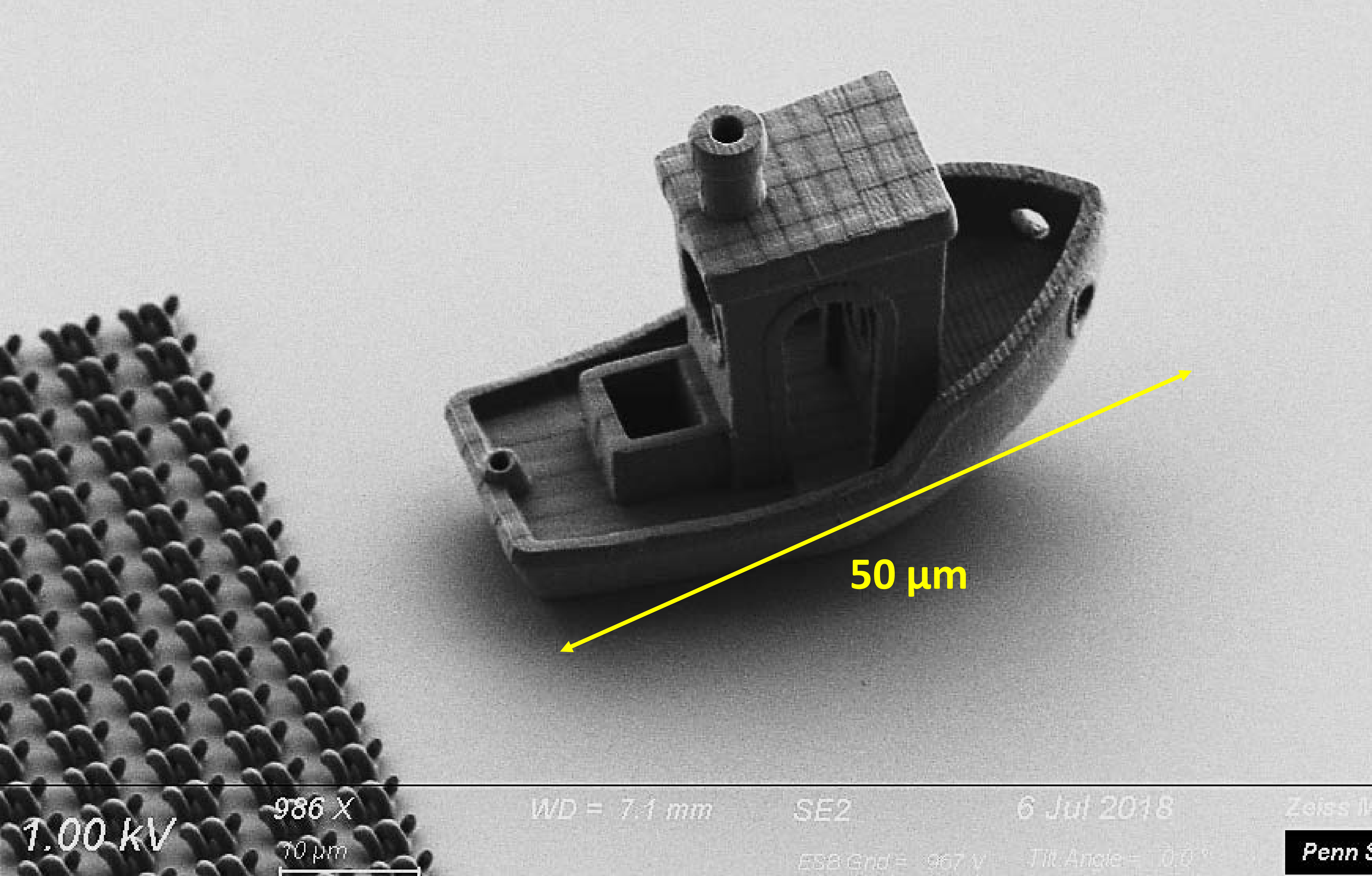



2.00 kV
100 X
200 µm
WD = 3.8 mm
SE2
ESB Grid = 333 V
1 Jun 2022
Tilt Angle = -2.9 °
Zeiss Merlin
Penn State Nanofab

50 um 3D printed boat

SE2 1KV/7.1mm

Sample curtesy: Nicole Famularo



Outline

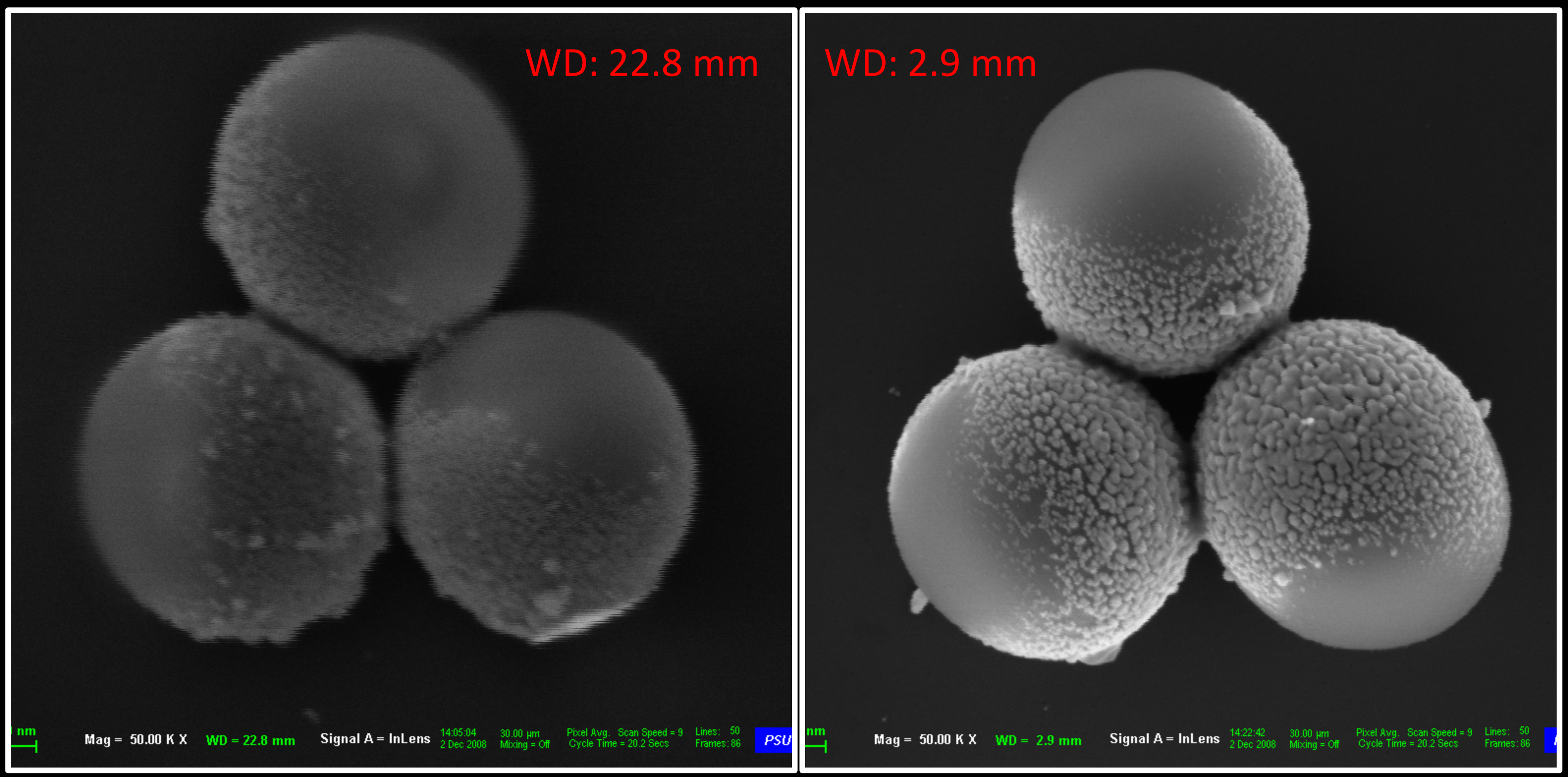
- Examples of different situations
- Key Imaging Parameters
- FESEMs we own
- How to achieve ideal beam

Key imaging parameters

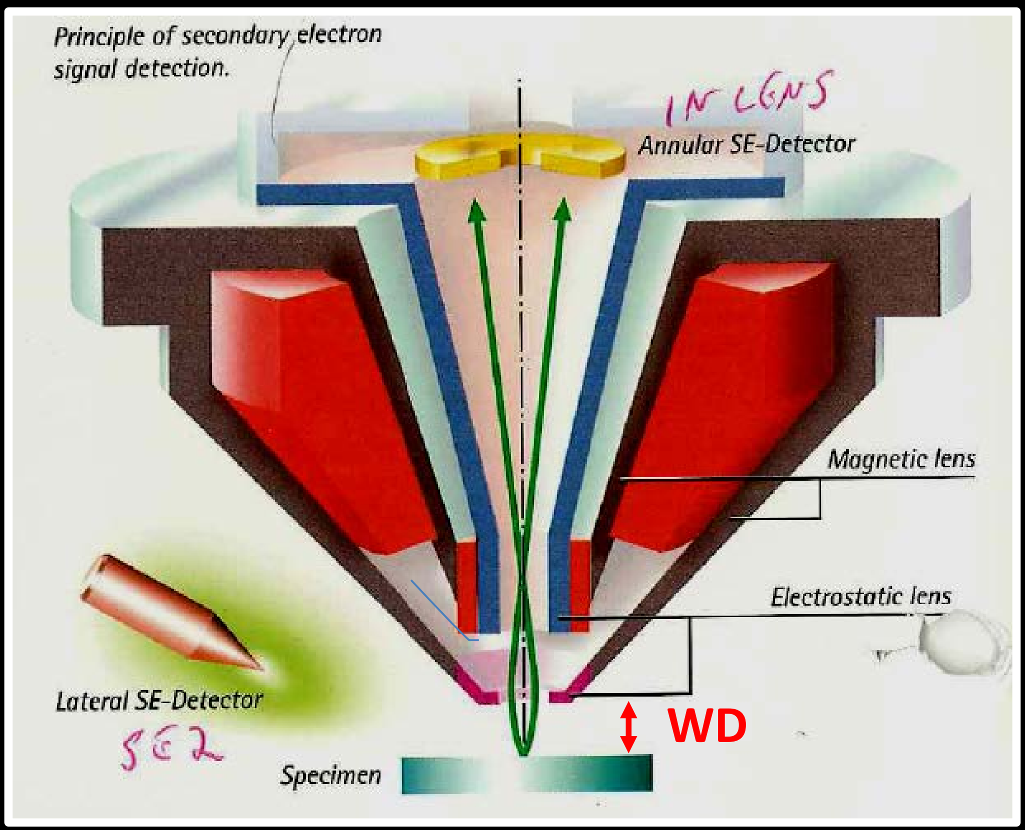
- Working distance (WD)
- Beam voltage
- Detectors

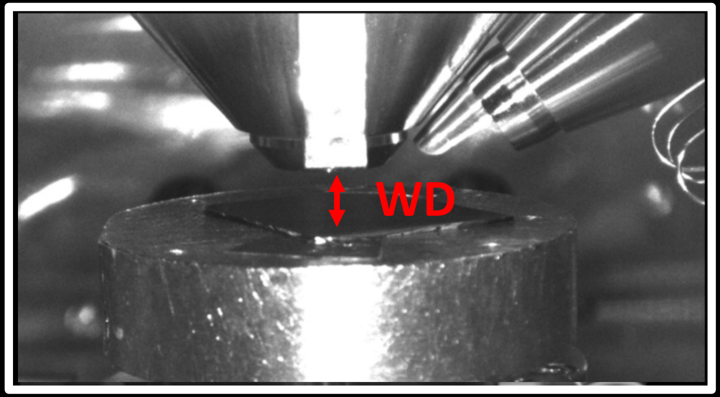
Working Distance (WD)

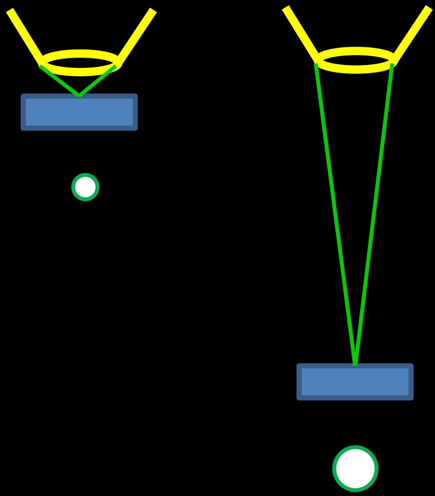
Smaller WD, better resolution



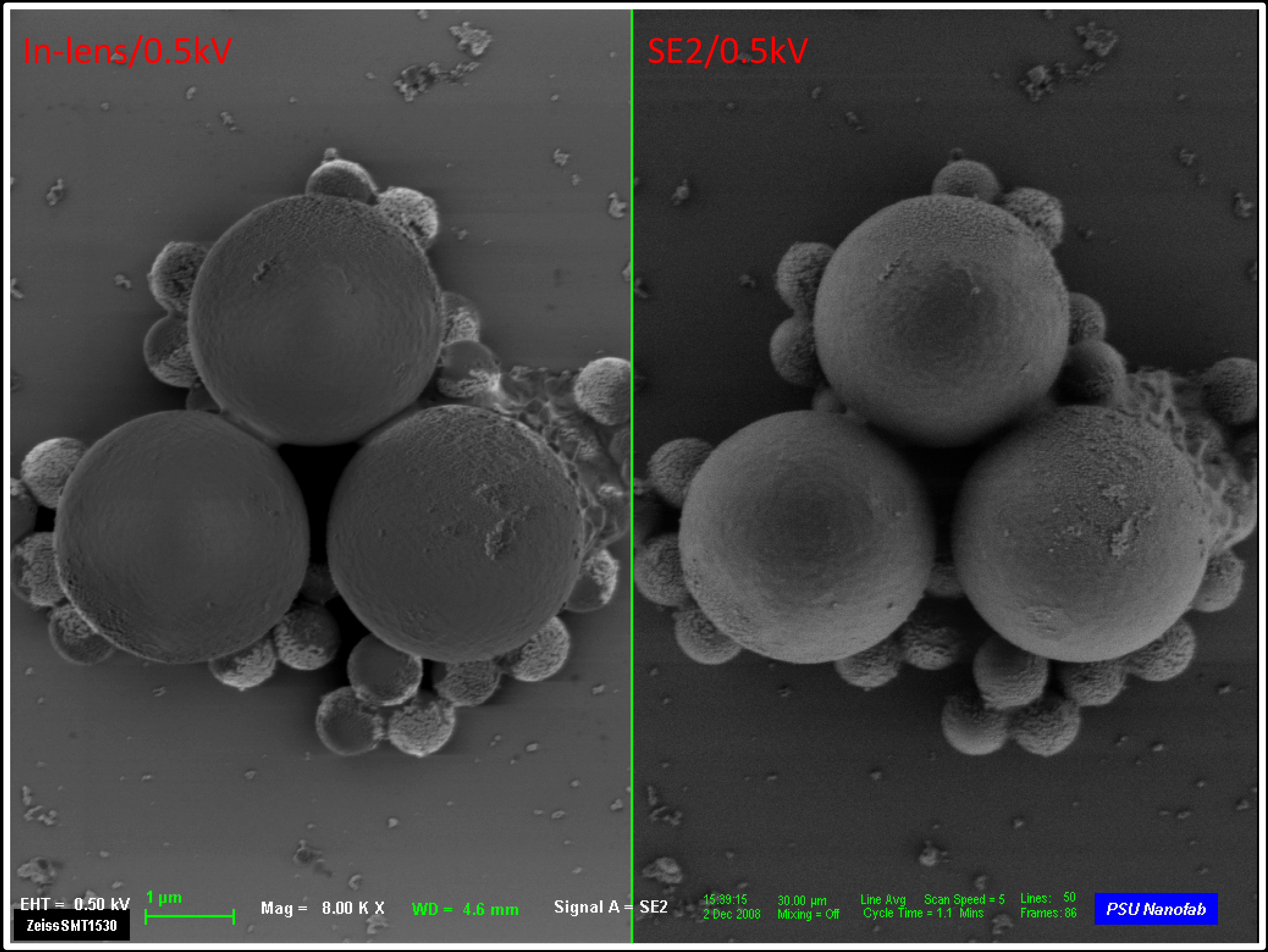
Working distance & detectors

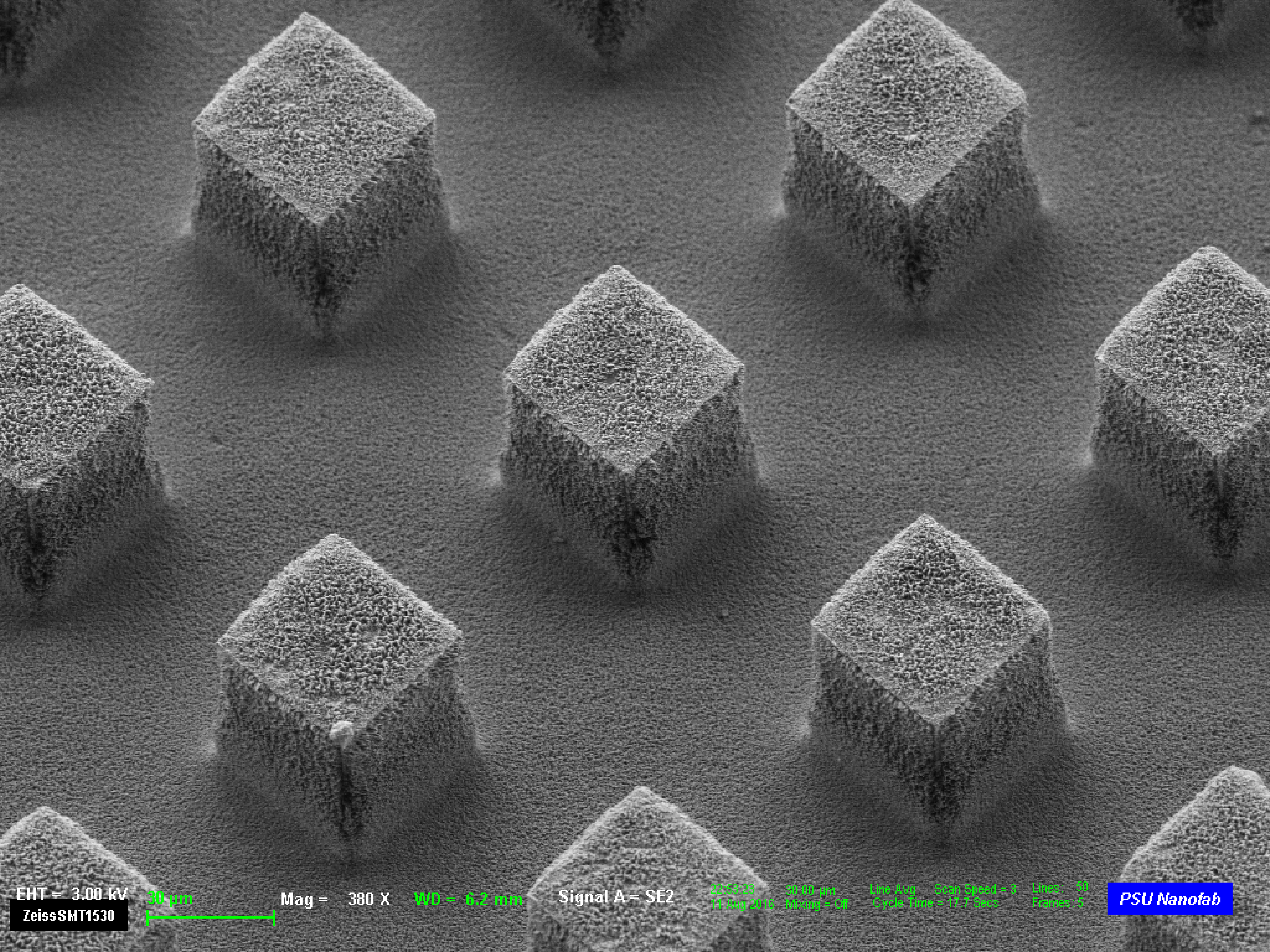




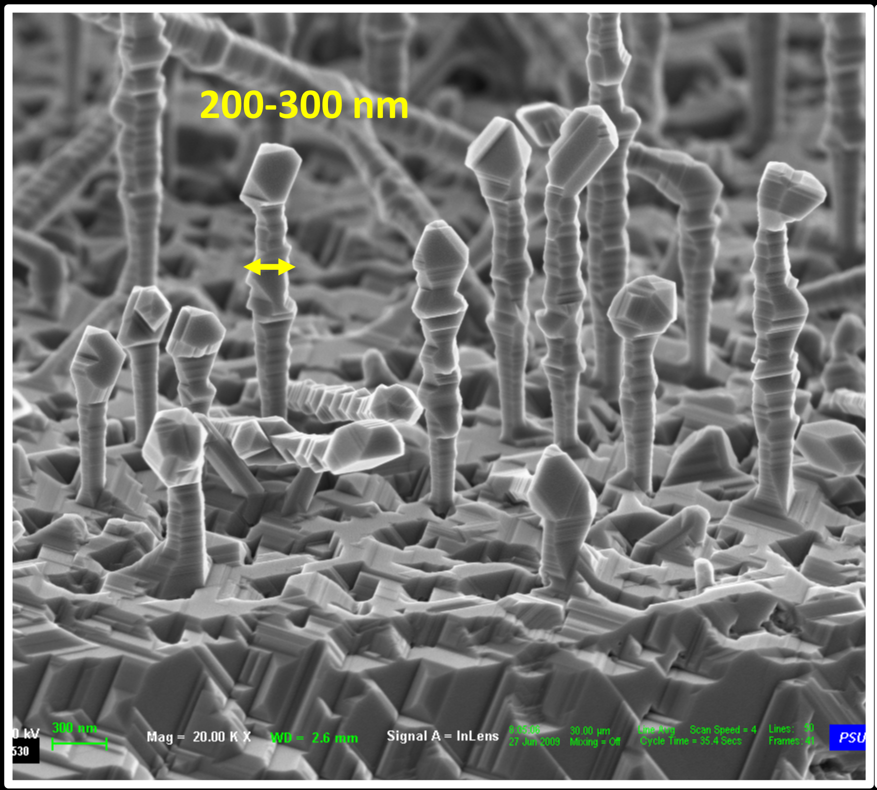


Choice of detectors

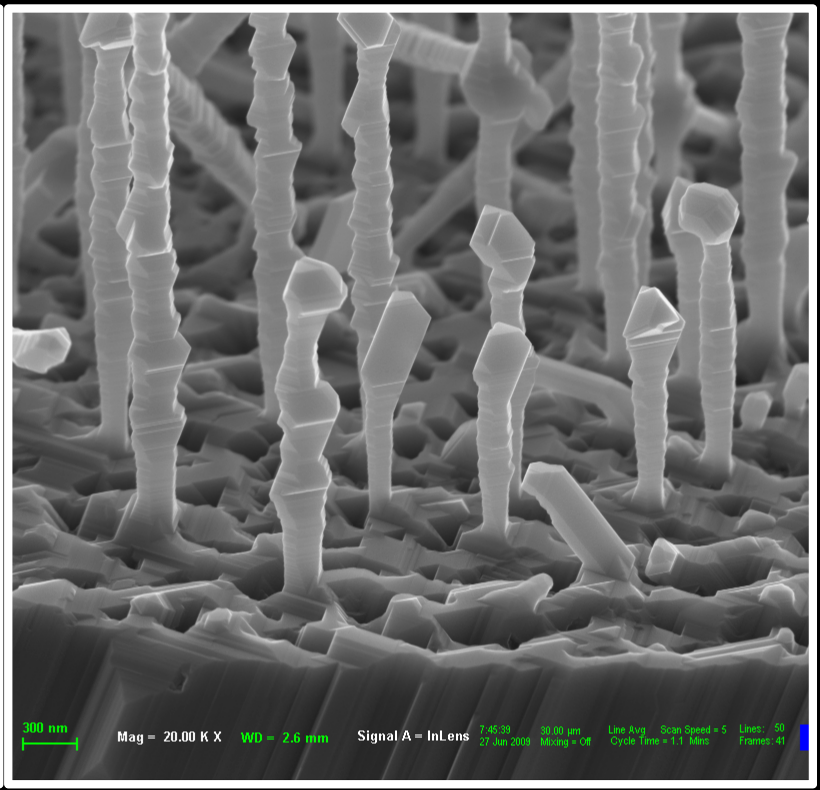



EHT = 3.00 kV
ZeissSMT1530
30 µm
Mag = 380 X
WD = 6.2 mm
Signal A = SE2
22:53:23
11 Aug 2016
30.00 µm
Mixing = Off
Line Avg
Scan Speed = 3
Cycle Time = 17.7 Secs
Lines: 50
Frames: 5
PSU Nanofab

Choice of beam voltage

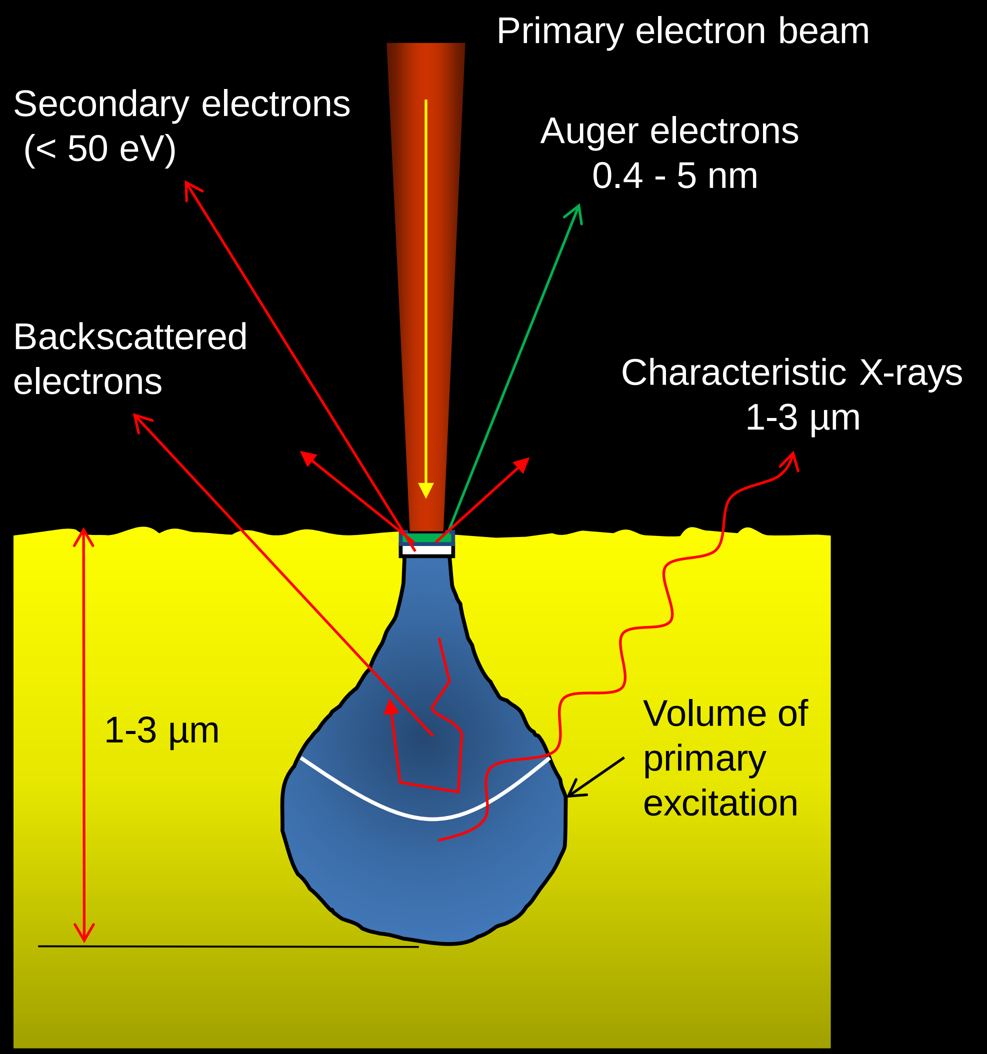


2kV/2.6mm



5kV/2.6mm

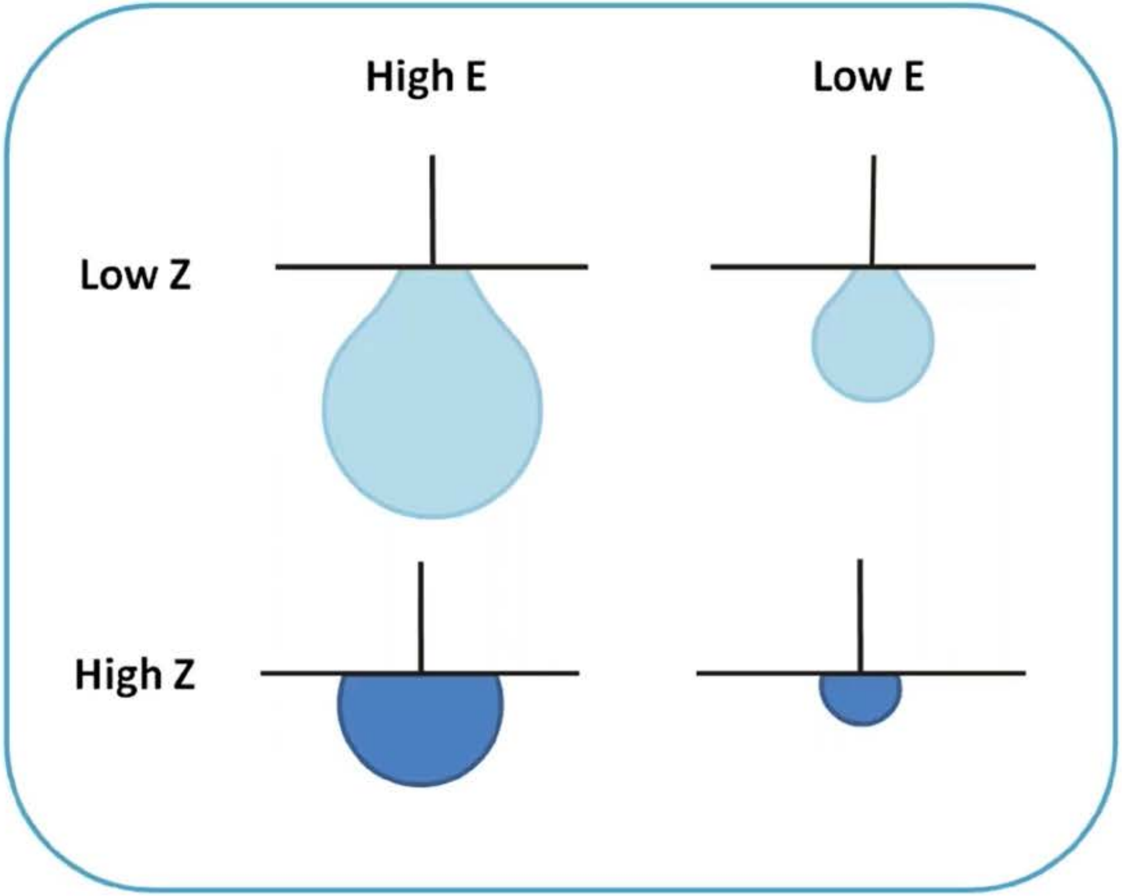
Electron and sample interaction



Electron – sample interaction volume

The size and shape of interaction volume depend on:

- Primary energy
- Atomic number (Z)
- Specimen tilt

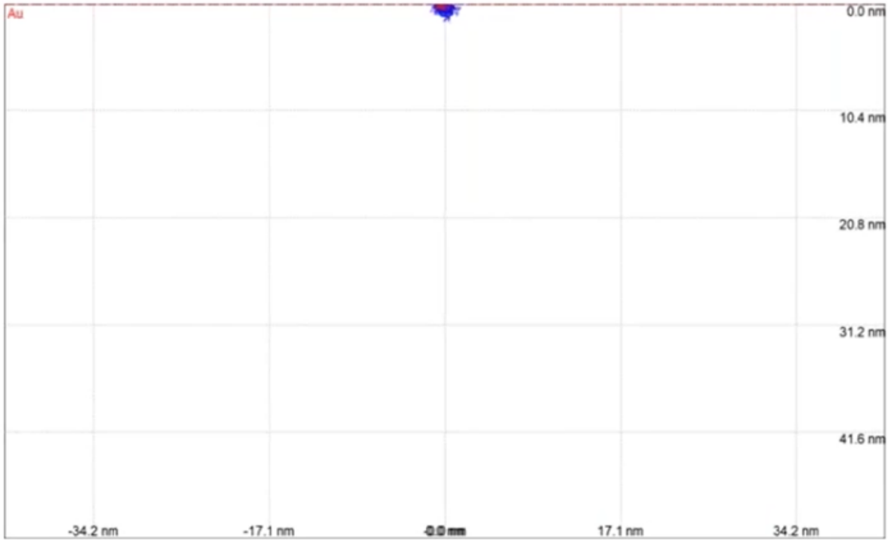


Zeiss: Low-voltage SEM-beyond sample topography (Dr. Iwona Jozwik)

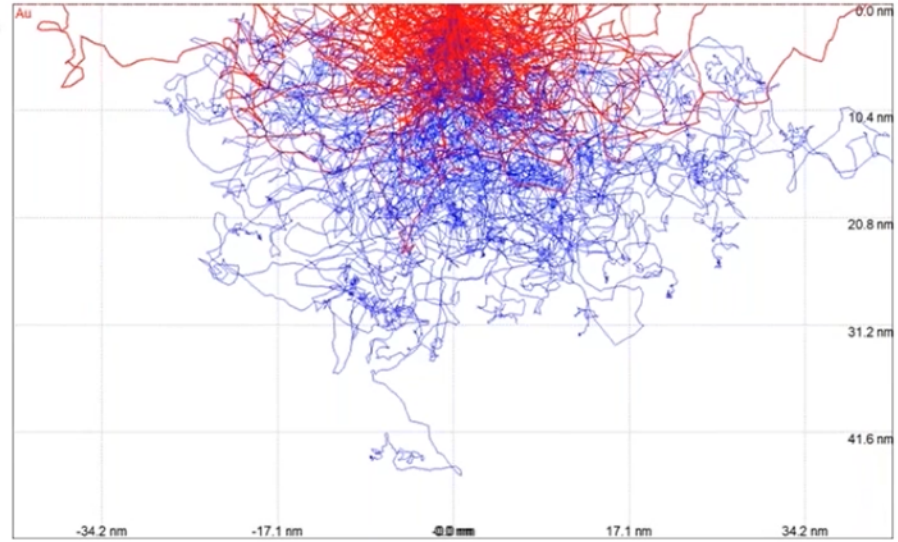
Low-voltage SEM

Example: Au

0.5 keV



5 keV

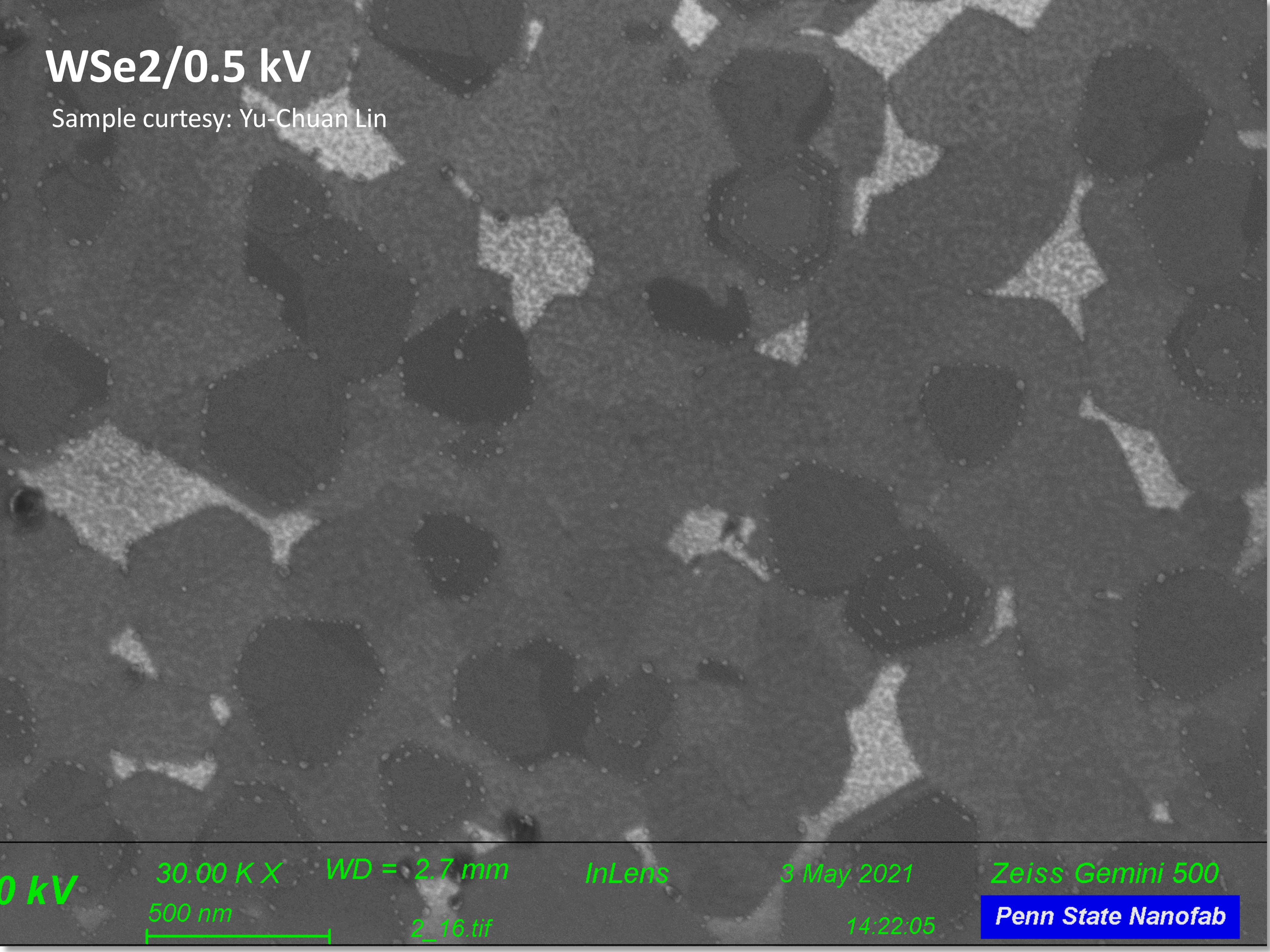


Advantages of low-voltage SEM:

- Surface sensitive information
- Imaging of non-conductive specimens
- Imaging of beam sensitive materials
- Similar interaction volume for SE and BSE
- Increased spatial resolution

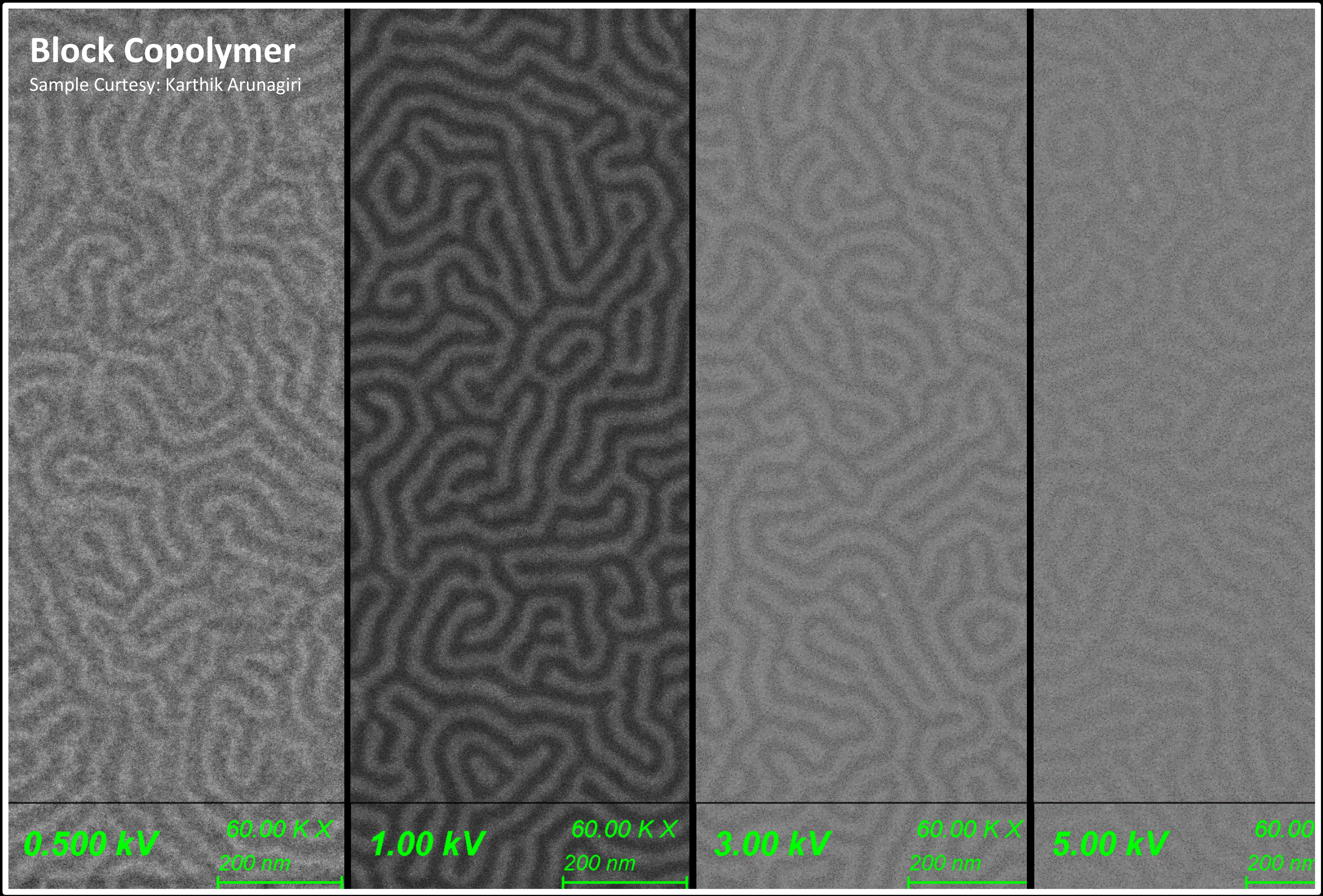
Contrast mechanisms:

- Topography
- Compositional contrast
- Channeling contrast
- Thin film contrast
- Magnetic domain contrast

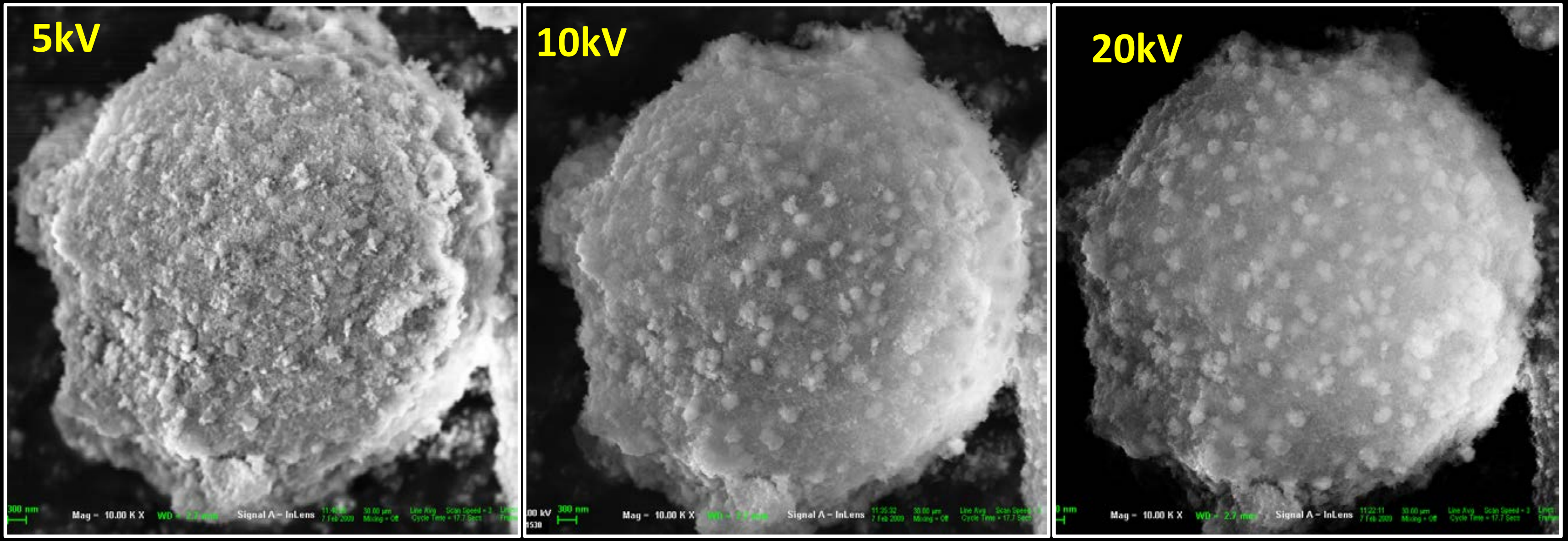

WSe2/0.5 kV
Sample curtesy: Yu-Chuan Lin
0 kV
30.00 K X
500 nm
WD = 2.7 mm
2_16.tif
InLens
3 May 2021
14:22:05
Zeiss Gemini 500
Penn State Nanofab

Block Copolymer

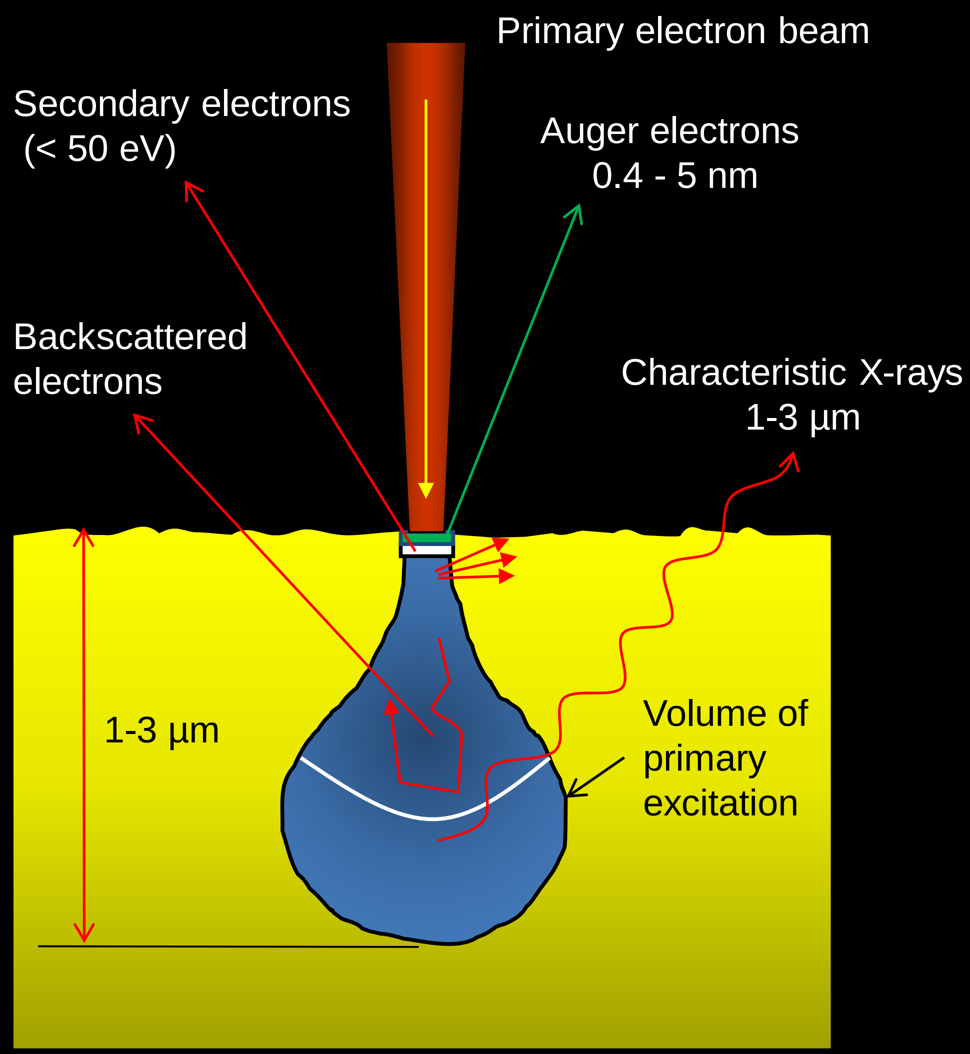
Sample Curtesy: Karthik Arunagiri



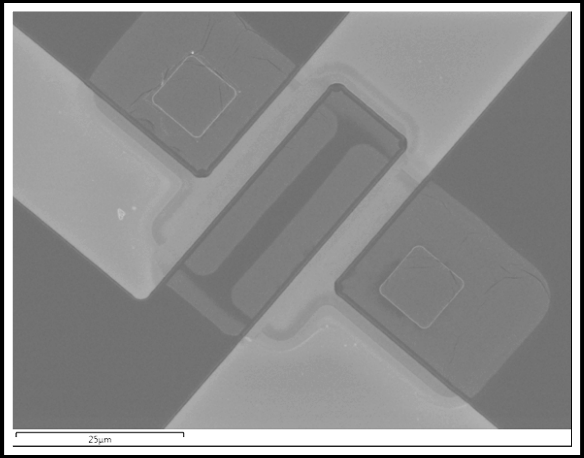
20% Ce on Al_2O_3 particle

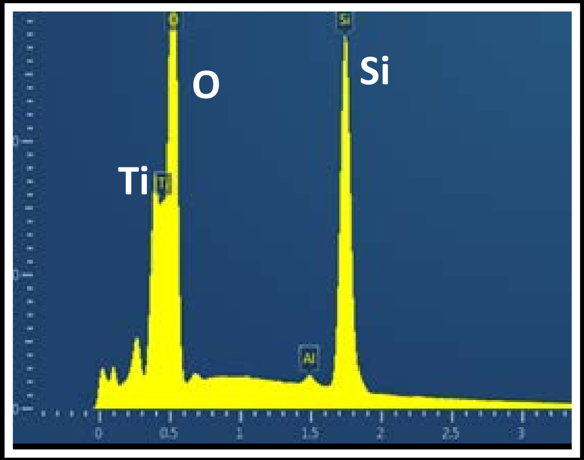


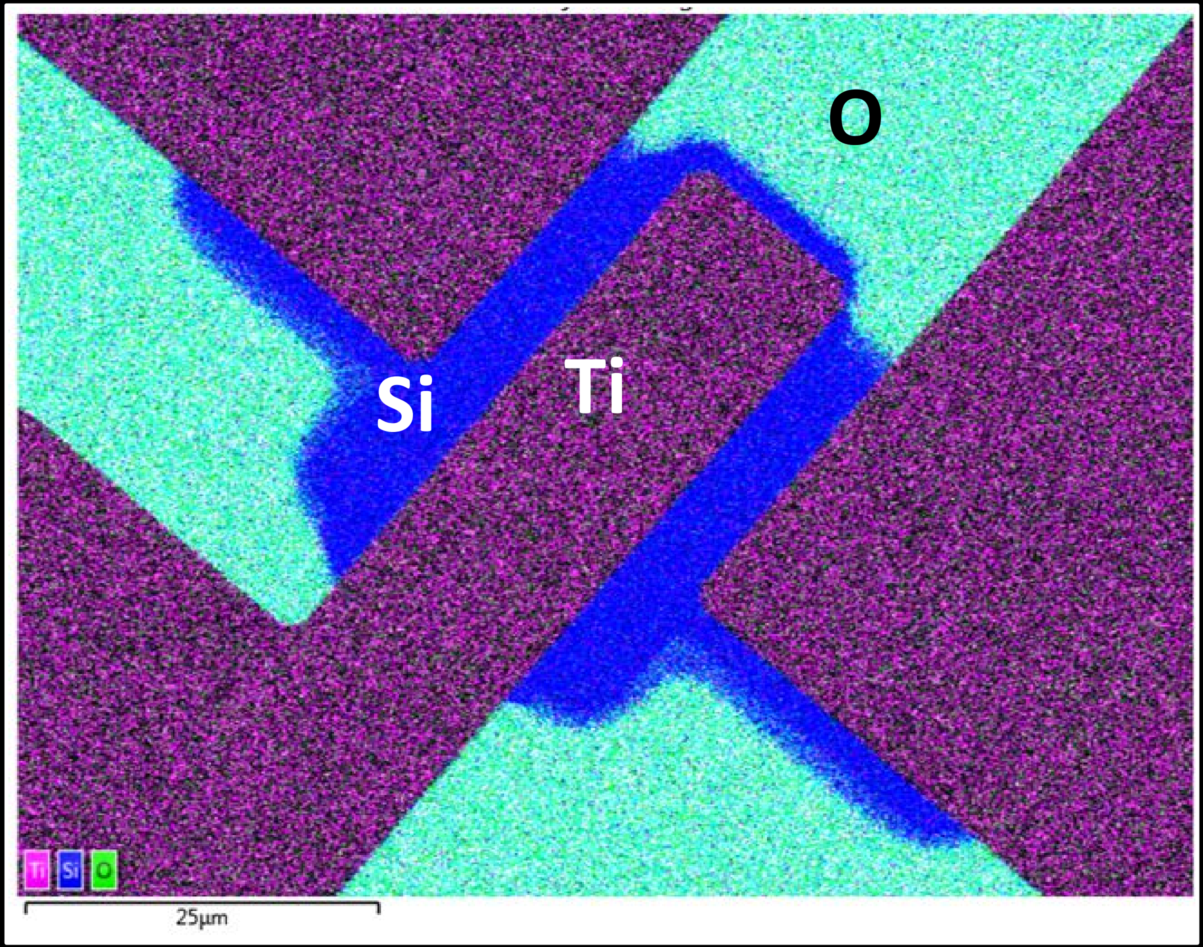
X-ray emission & EDS



Device EDS Mapping







Outline

- Examples of different situations
- Key Imaging Parameters
- FESEMs we own
- How to achieve ideal beam

MERLIN

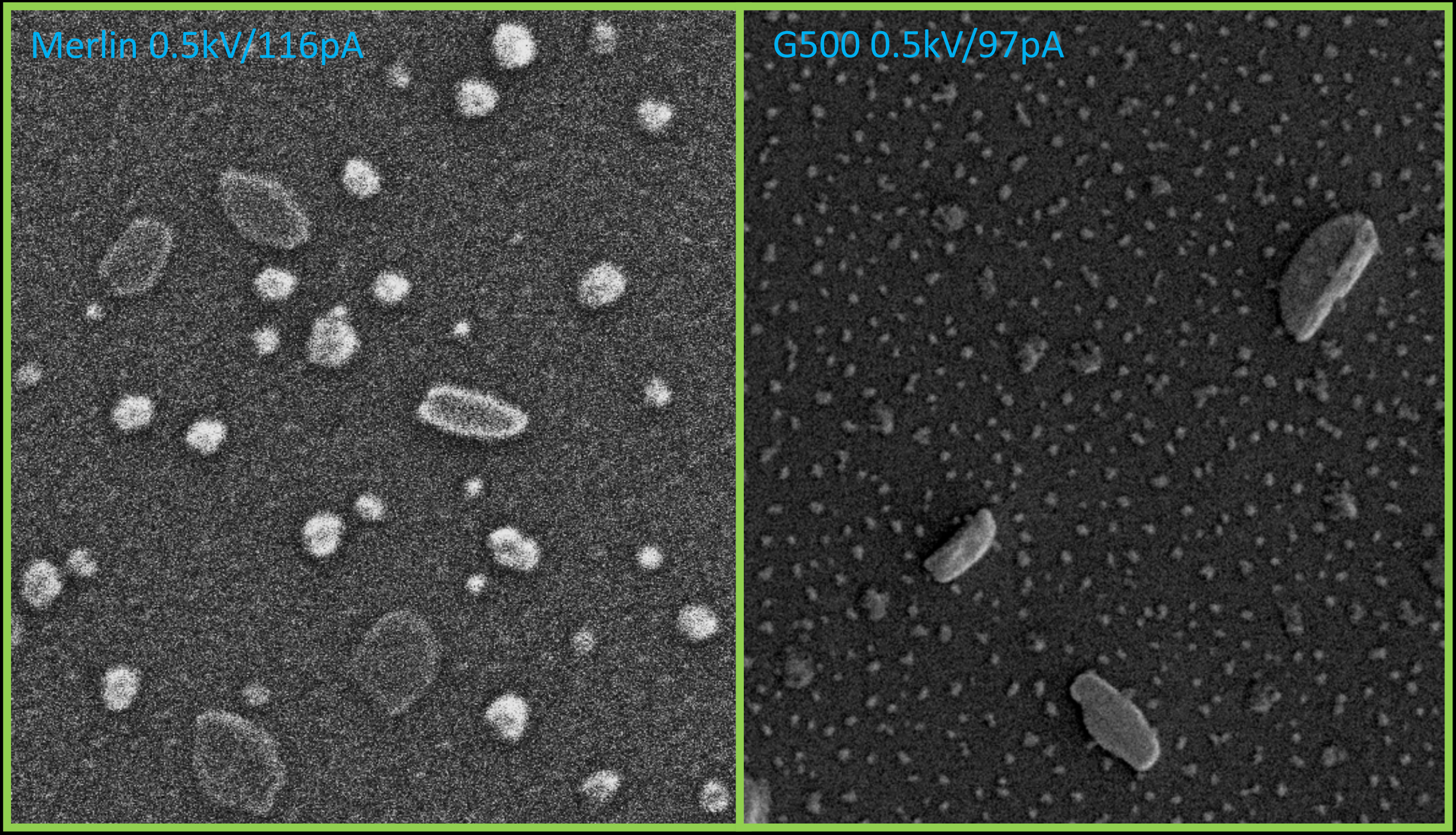
- HIGH BEAM CURRENT HIGH RESOLUTION
- EXTREME LARGE FIELD OF VIEW (6X4MM)
- HIGH SPATIAL RESOLUTION EDS
- LARGE AREA EDS MAPPING
- FAST SAMPLE TRANSFER (3" LOAD LOCK)

G500

- LOW KV HIGH RESOLUTION
- VP FOR INSULATING MATERI
- CATHODOLUMINESCENCE IM
- IN SITU PLASMA CLEANING
- FAST SAMPLE TRANSFER (3” I

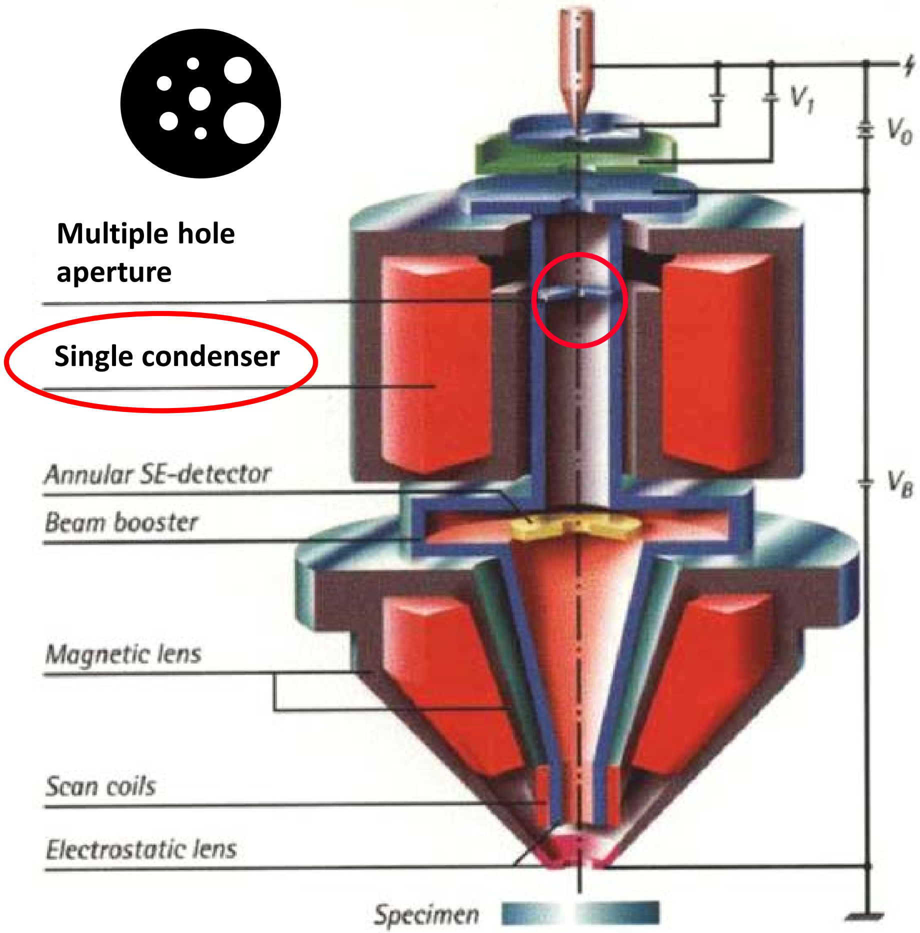
G500: Excellent resolution at low KV

2D sample 2: MoS_2 on glass

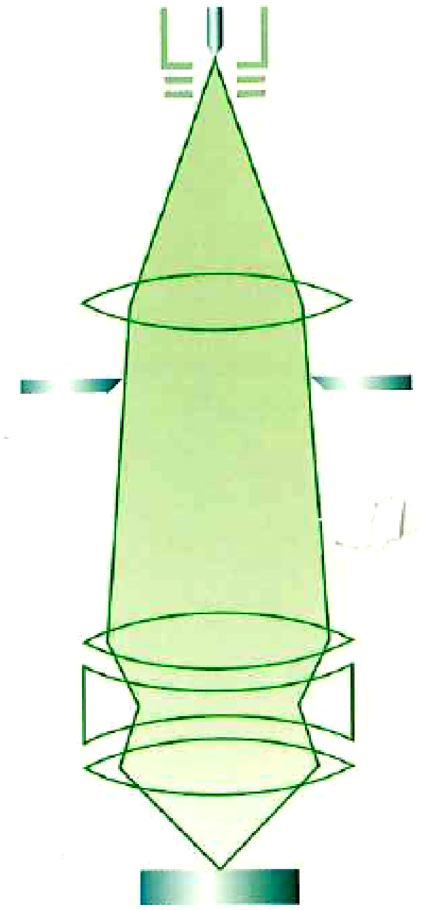


Low KV minimizes beam damage and the high resolution allows us to see the small features, in this case, nm size nucleation sites, which are barely visible on the left image taken on Merlin.

GEMINI I column (G500)

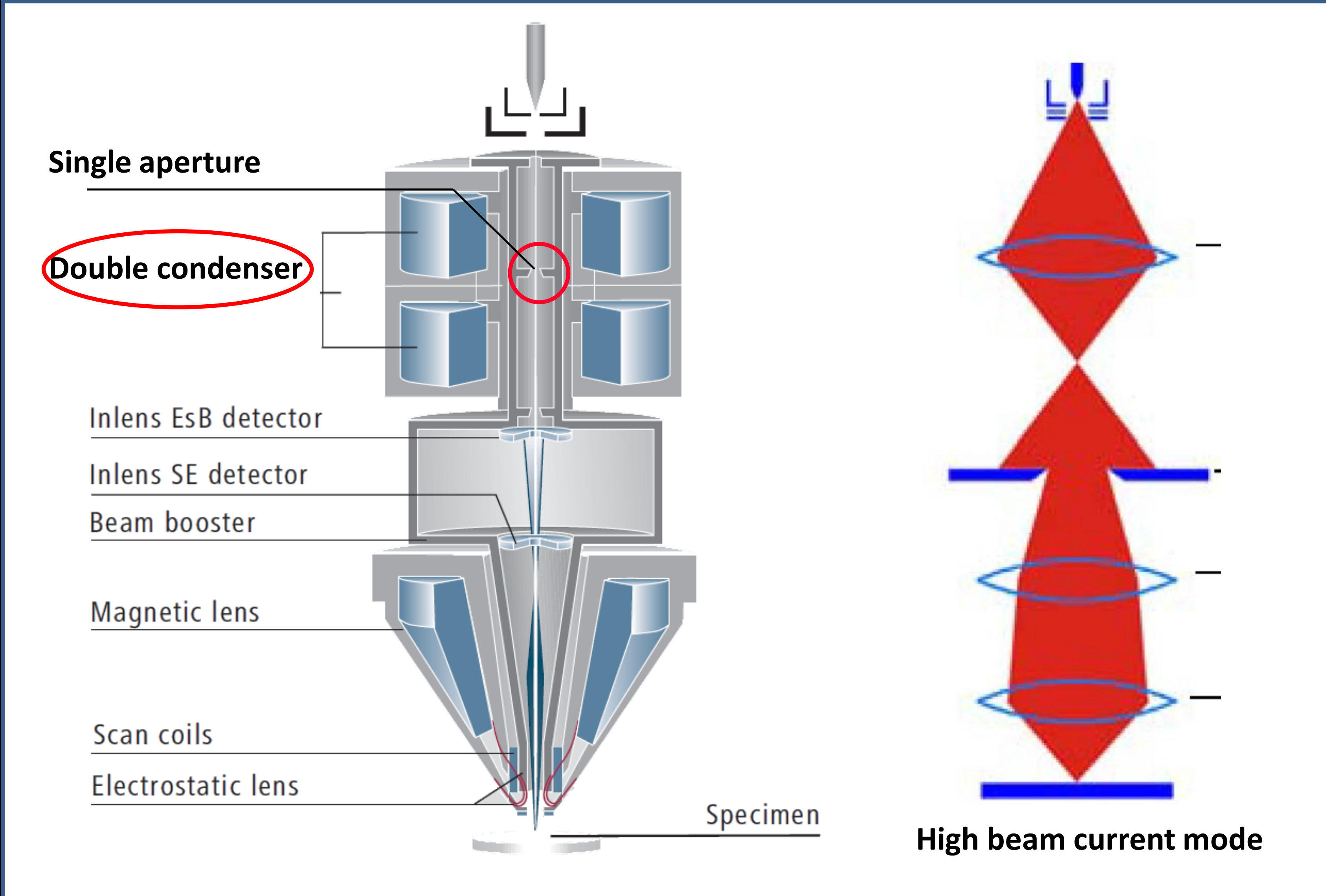


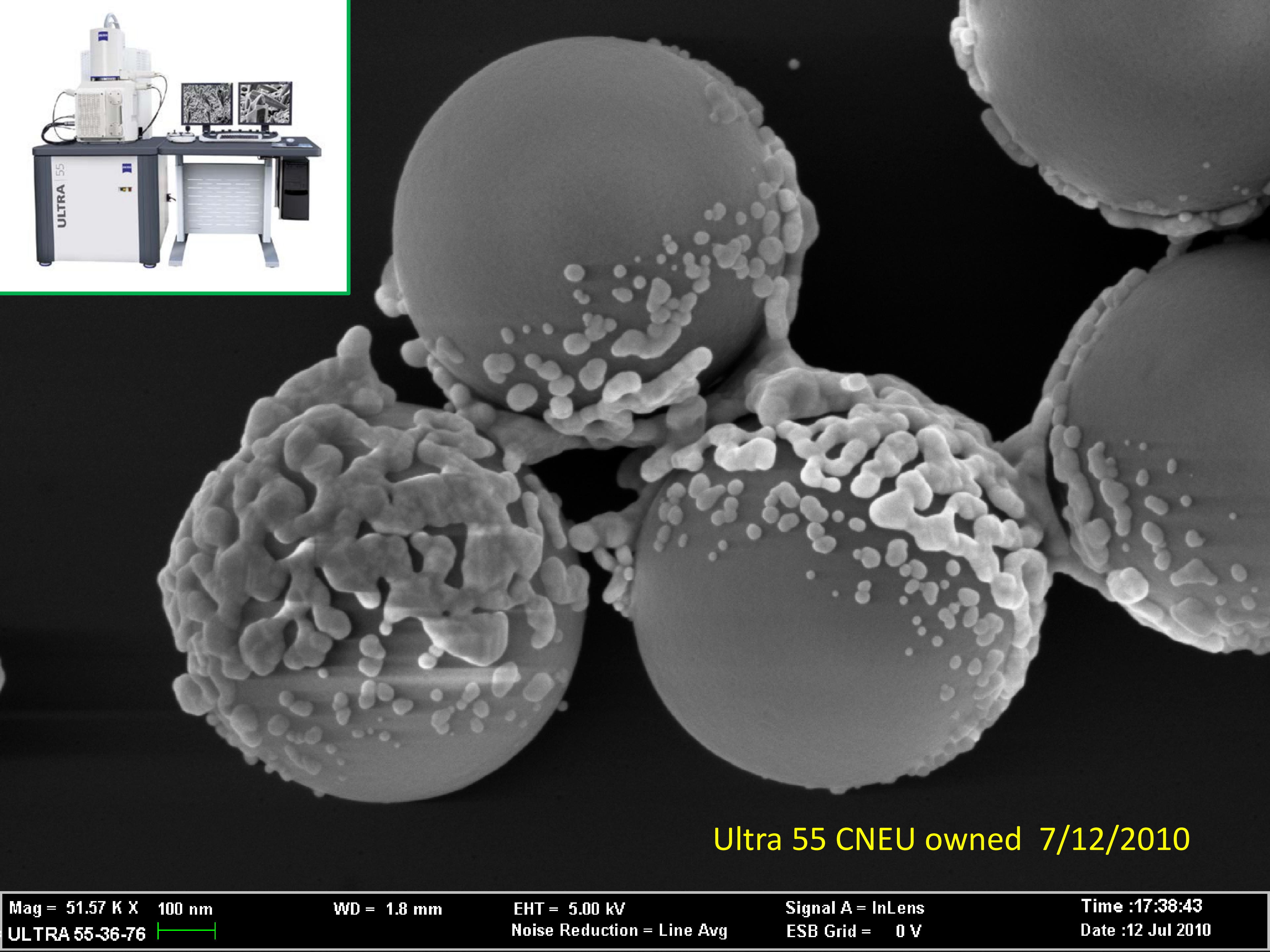
V_1 – extractor voltage at first anode
V_0 – accelerator voltage at second anode
V_B – booster voltage



Beam path with no intermediate cross-over

GEMINI II column (Merlin)

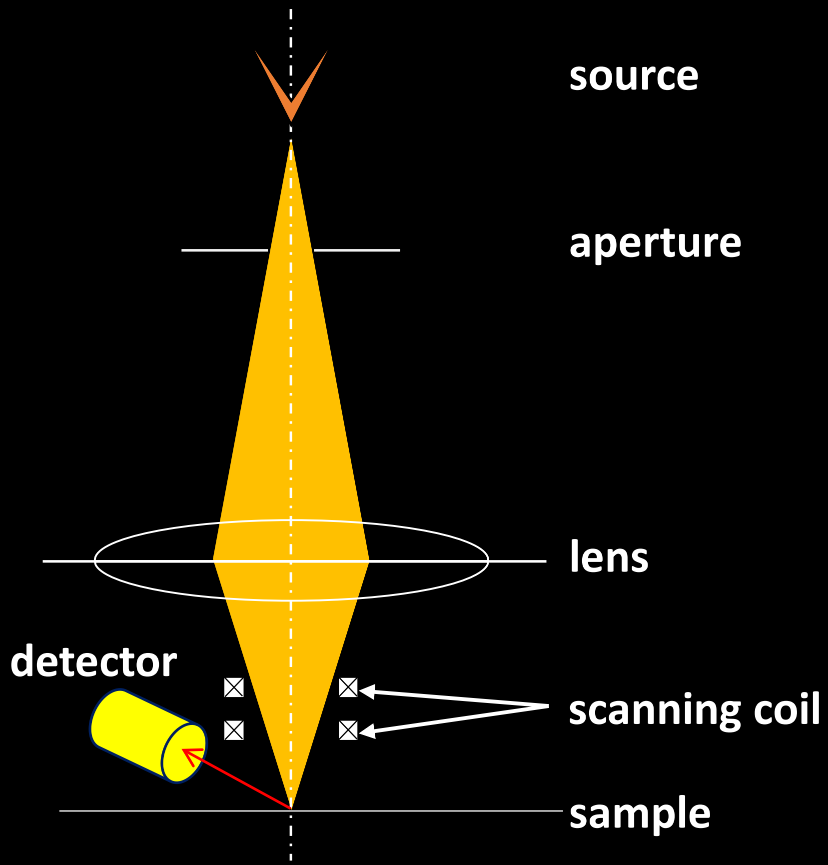



Ultra 55 CNEU owned 7/12/2010
Mag = 51.57 K X
100 nm
ULTRA 55-36-76
WD = 1.8 mm
EHT = 5.00 kV
Noise Reduction = Line Avg
Signal A = InLens
ESB Grid = 0 V
Time :17:38:43
Date :12 Jul 2010
ULTRA 55

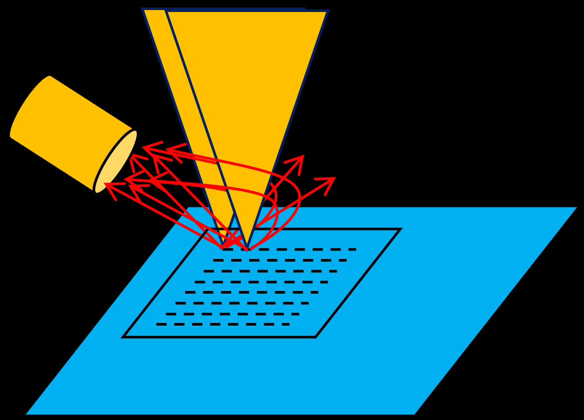
Outline

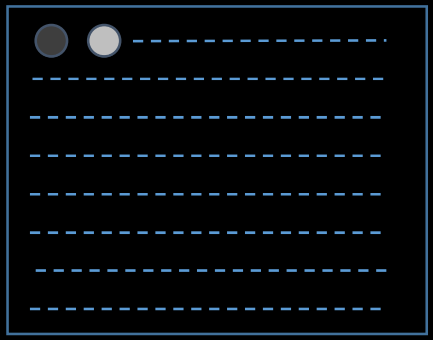
- Examples of different situations
- Key Imaging Parameters
- FESEMs we own
- How to achieve ideal beam

A simplified ray diagram of SEM

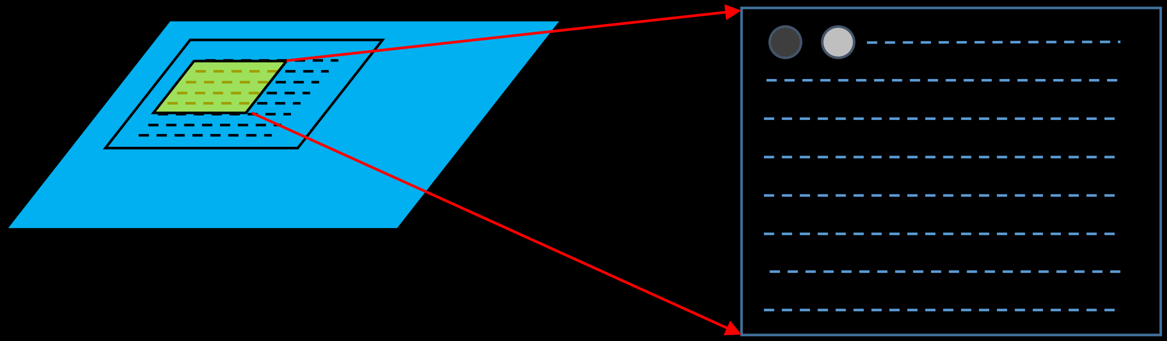


Scanning->move the beam!

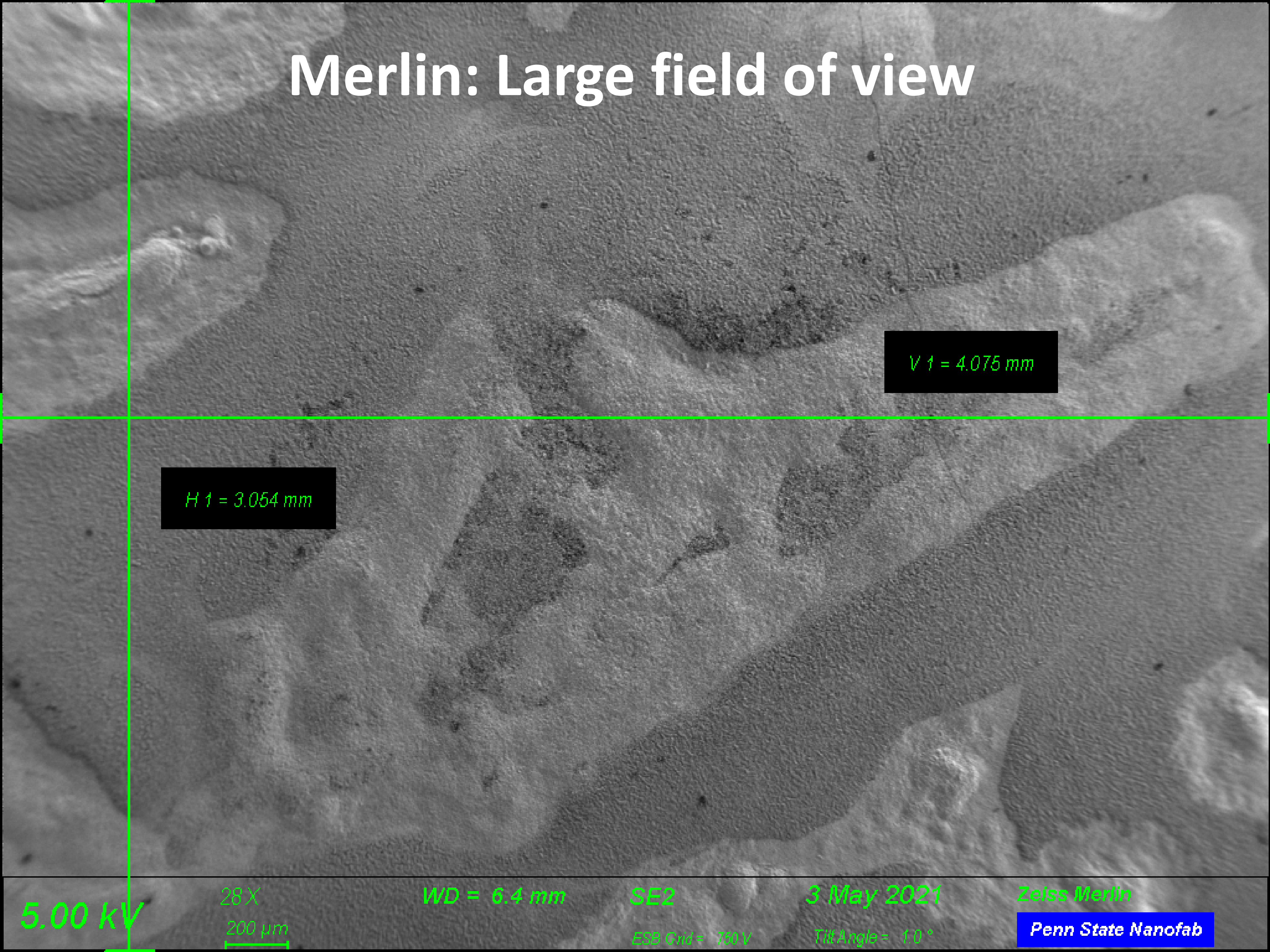




Magnification?

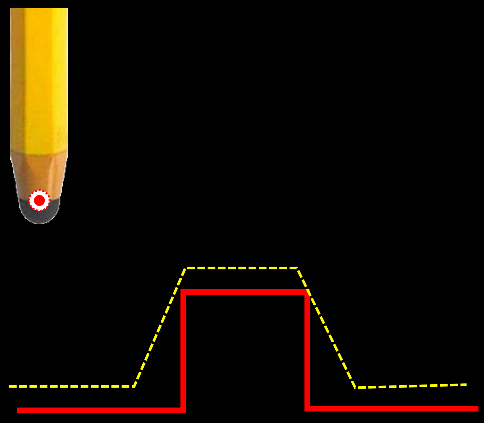


Merlin: Large field of view

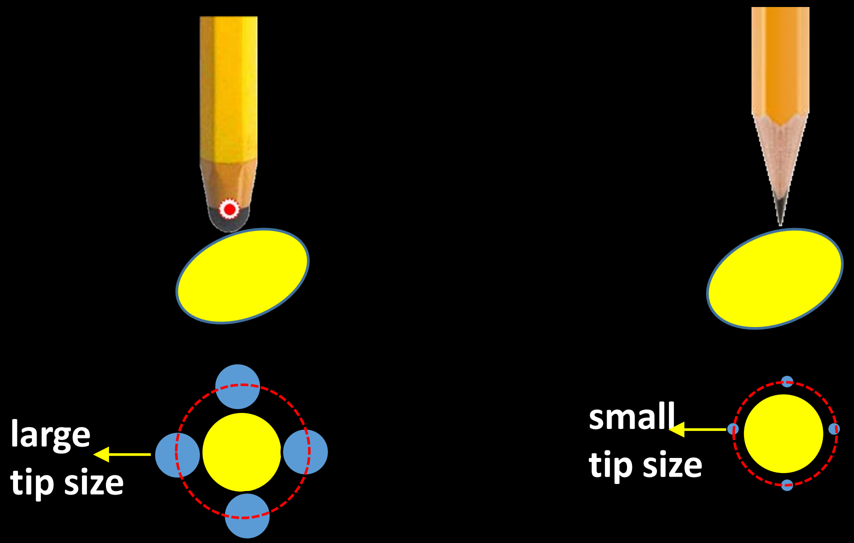


Ideal beam?

Electron beam is a probe, just like your pencil

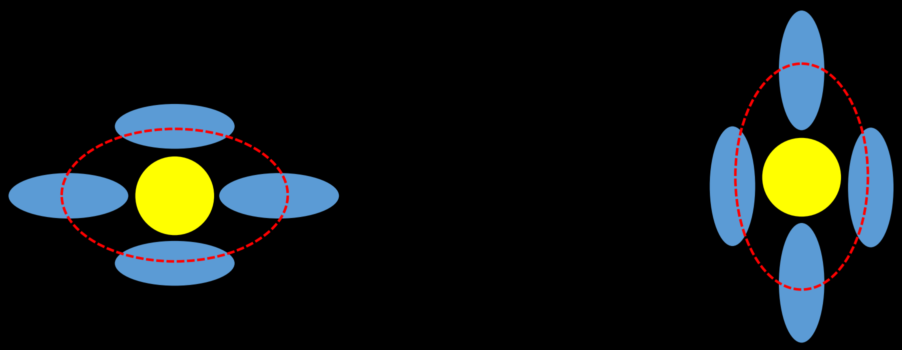


Tip size matters!

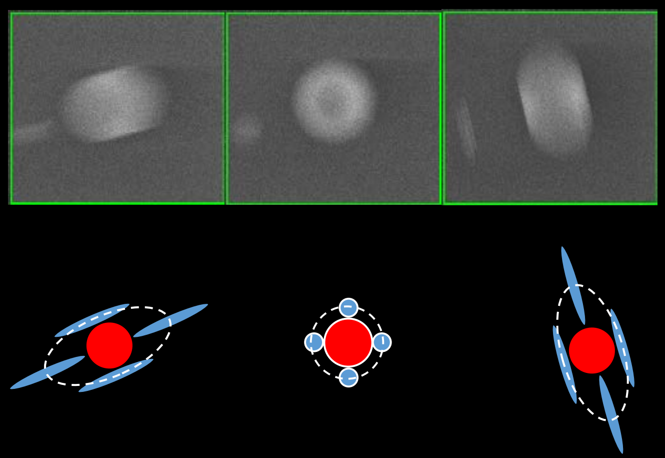


Smaller tip size -> better resolution

Tip shape matters too!



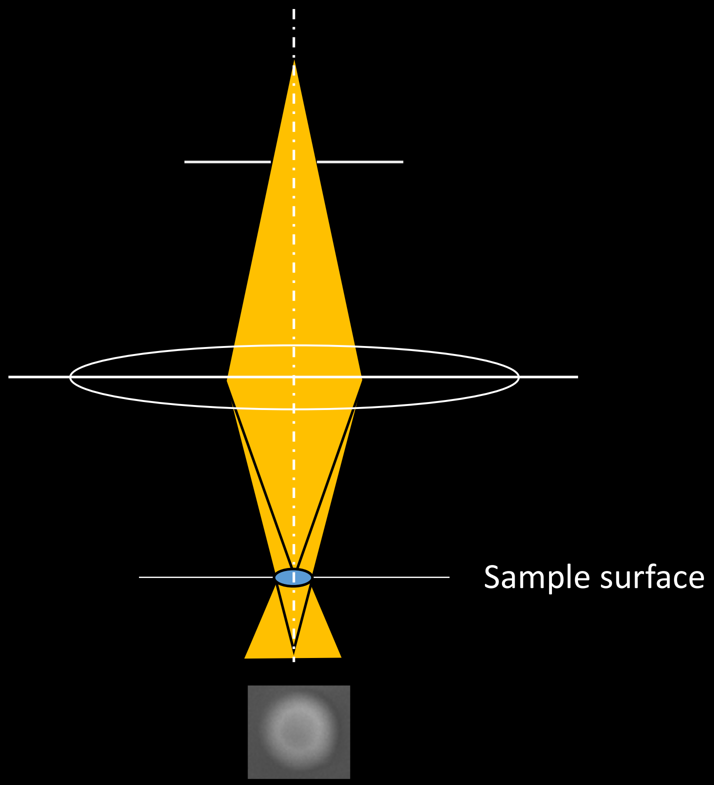
How does the beam shape affect SEM image?



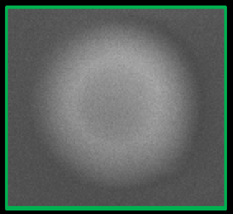
Ideal beam?

{ Small
Round
Straight

How to achieve sharp beam on FESEM?



Varying focus changes beam size !

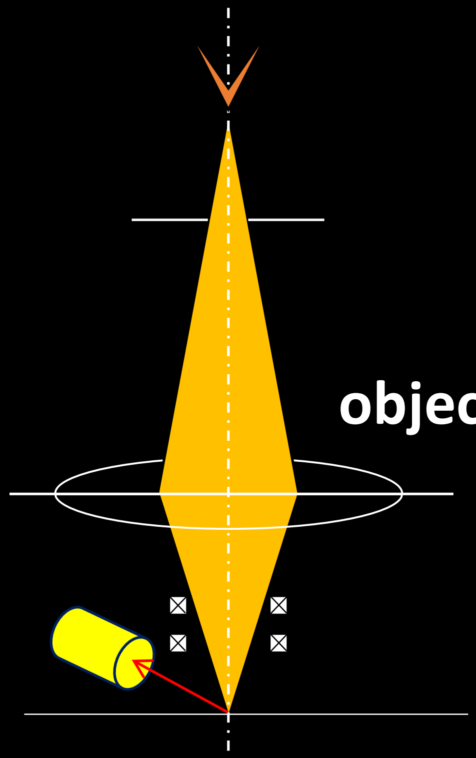


Small -> focus

Round ?

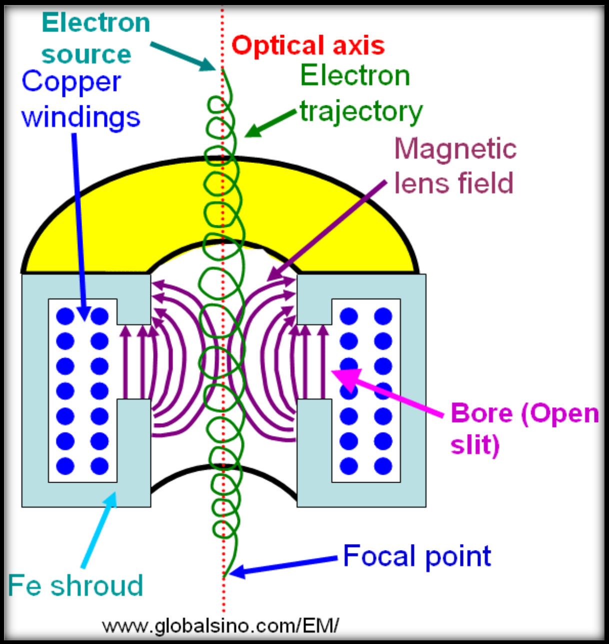
Straight

Which component control beam shape?



objective lens!

Magnetic lens or pole piece



Field is not symmetrical -> lens is not round

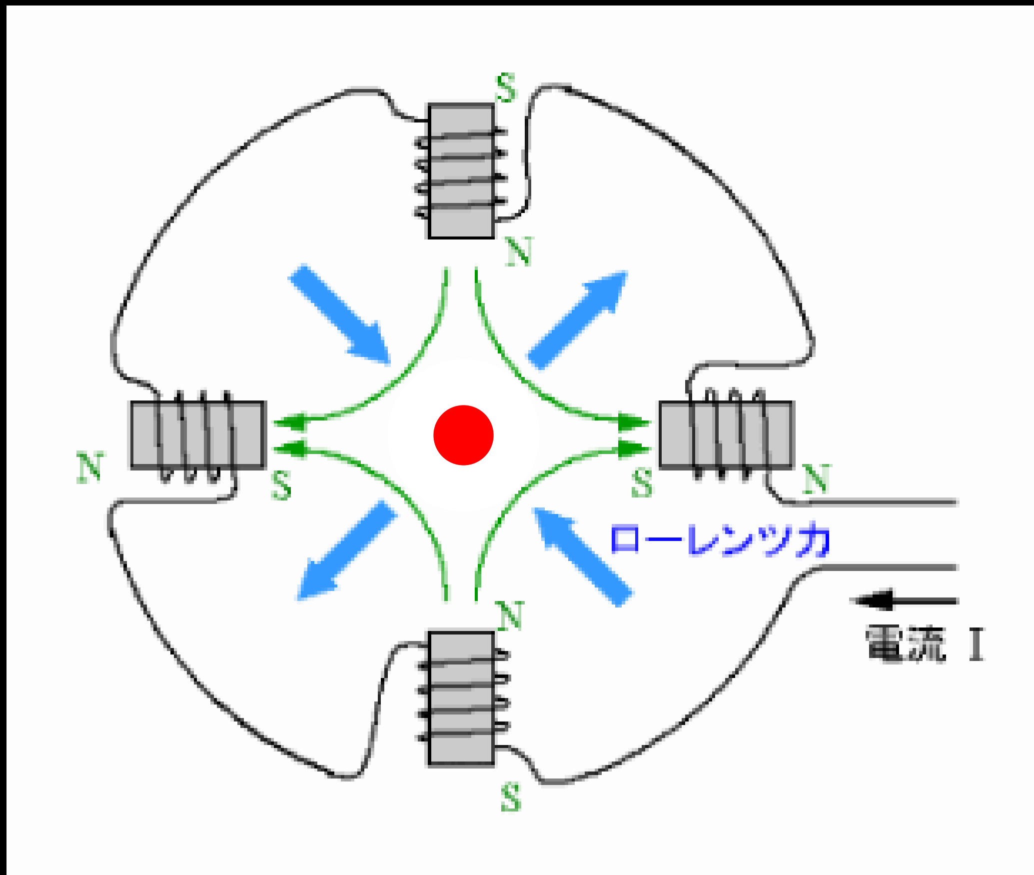
Small -> focus

Round -> Stigmation/stigmatism

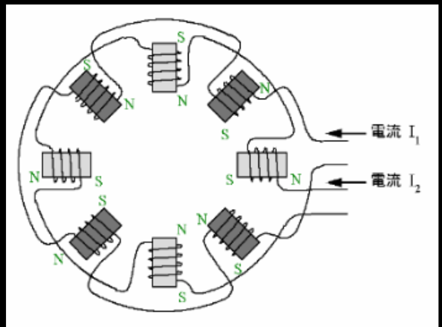
Straight

Mechanism to correct stigmation

Stigmators x/y



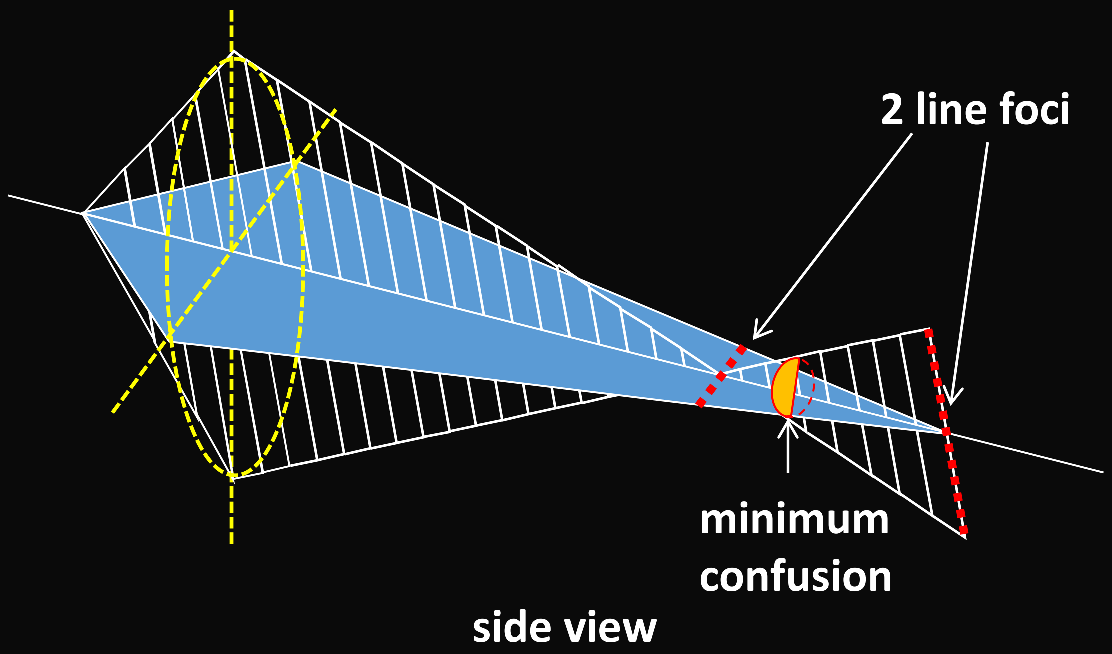
quadrupole stigmator

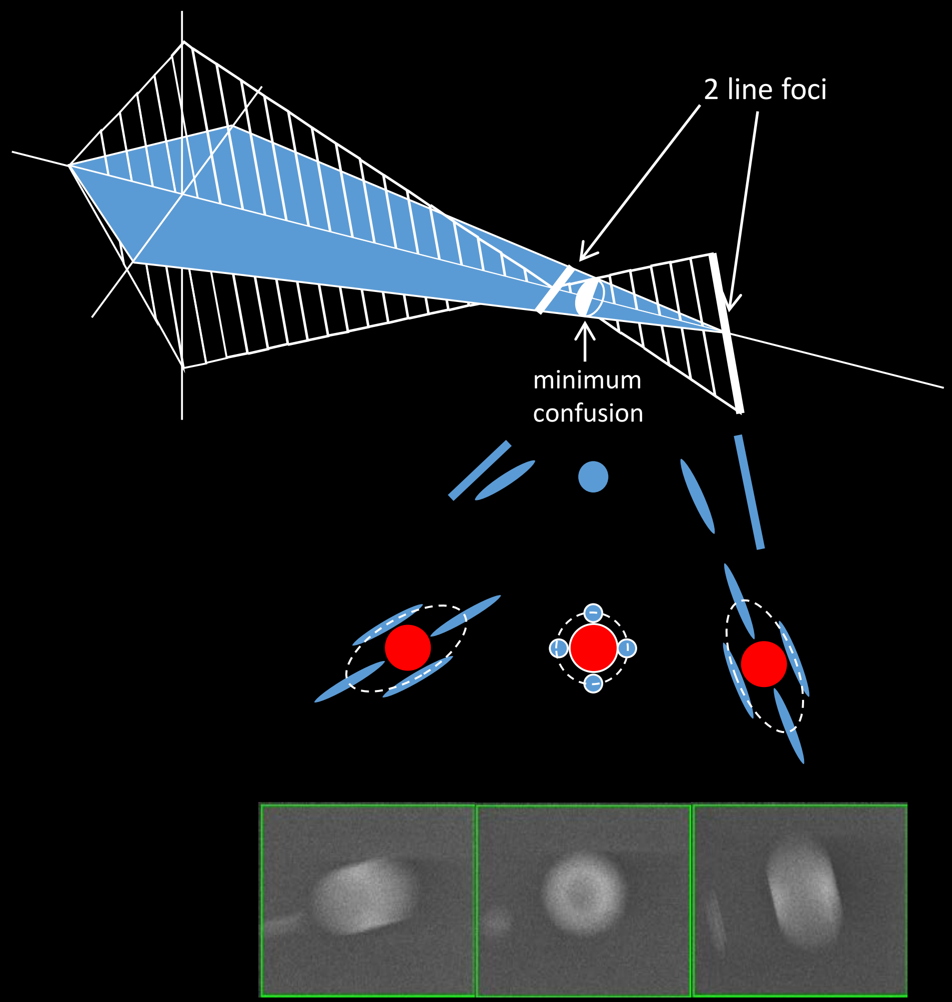


two sets of quadrupole

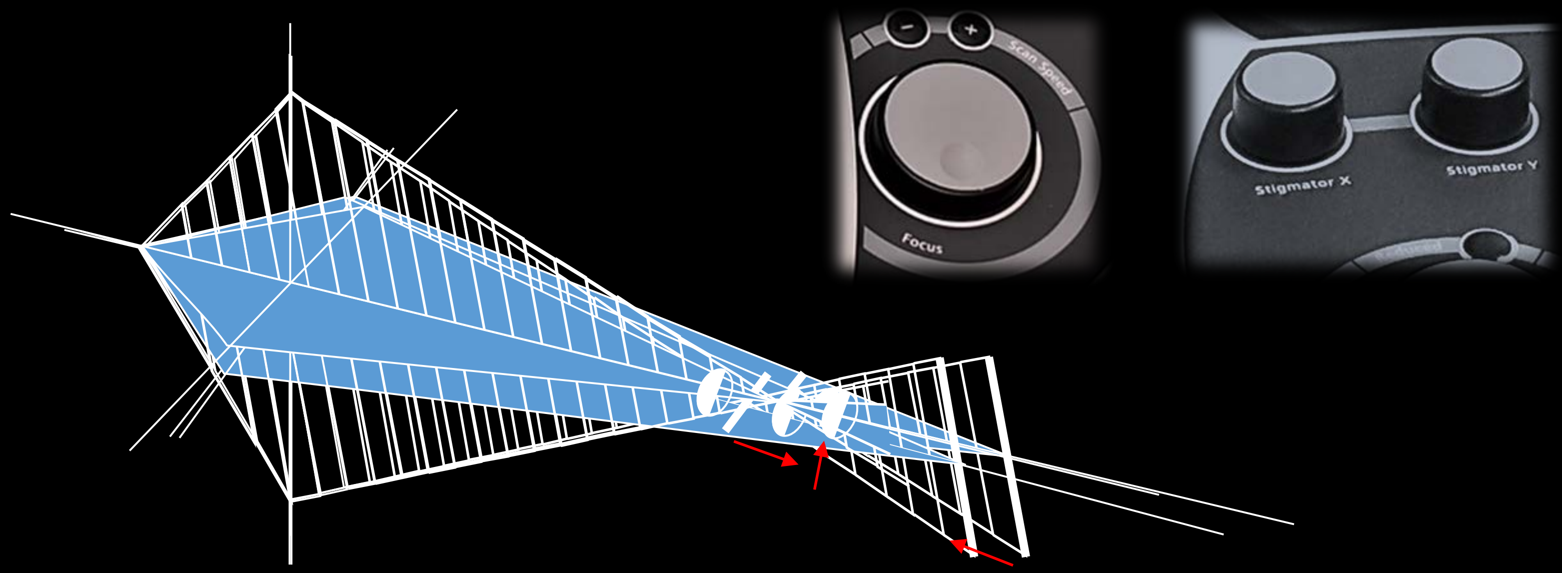
https://www.jeol.co.jp/

Ray diagram of a stigmated lens




2 line foci
minimum
confusion

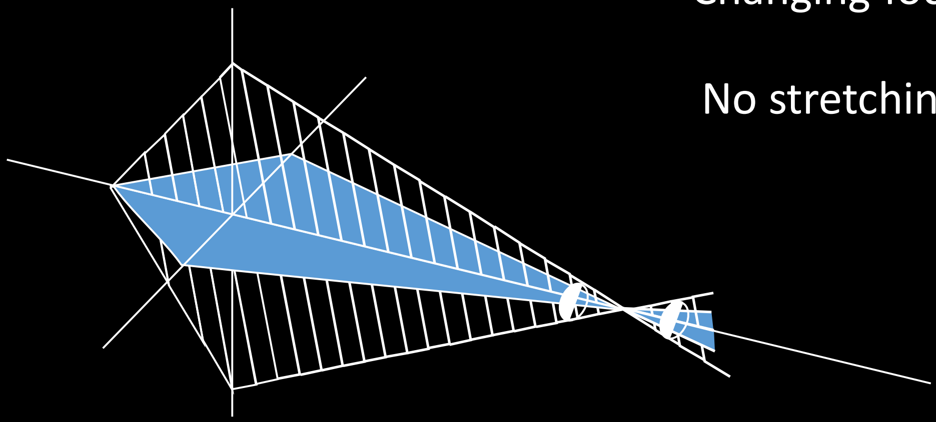
How to correct stigmation



Repeating process:

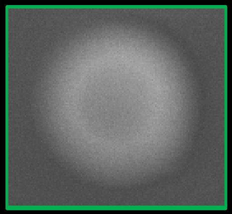
Focus first -> x/y stigmation->focus again-> x/y ->focus->……

How to test when stigmation is corrected?



Changing focus again!

No stretching should be observed



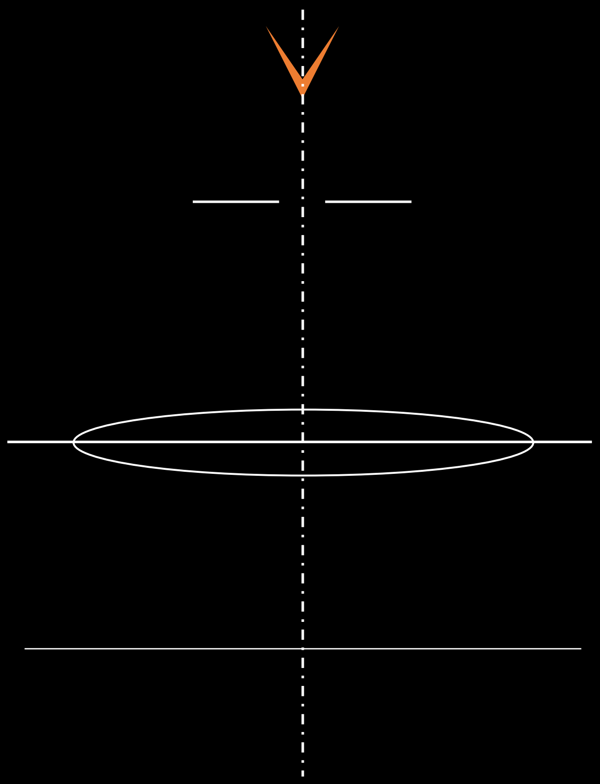
Small -> focus

Round -> stigmation

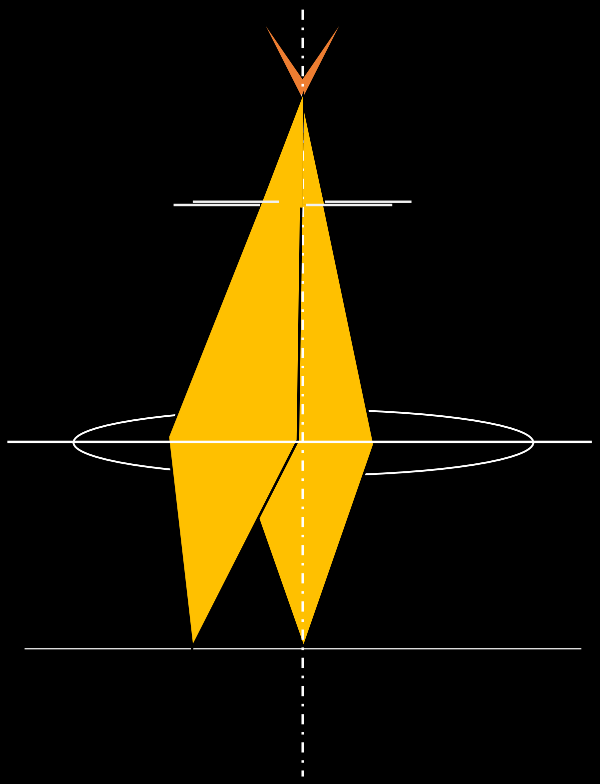
Straight ?

Why straight beam?

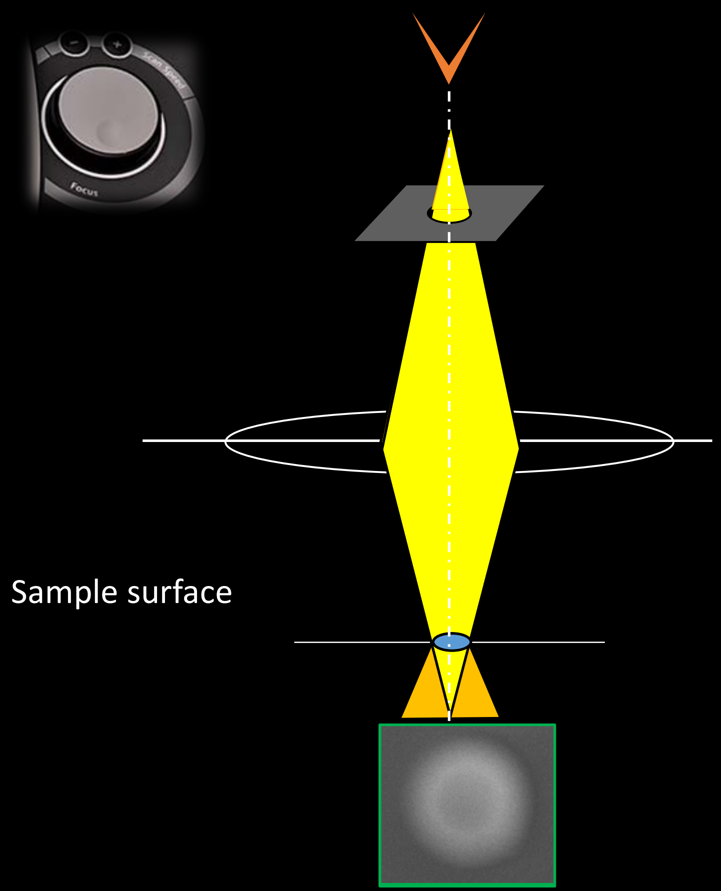
- source
- aperture
- lens

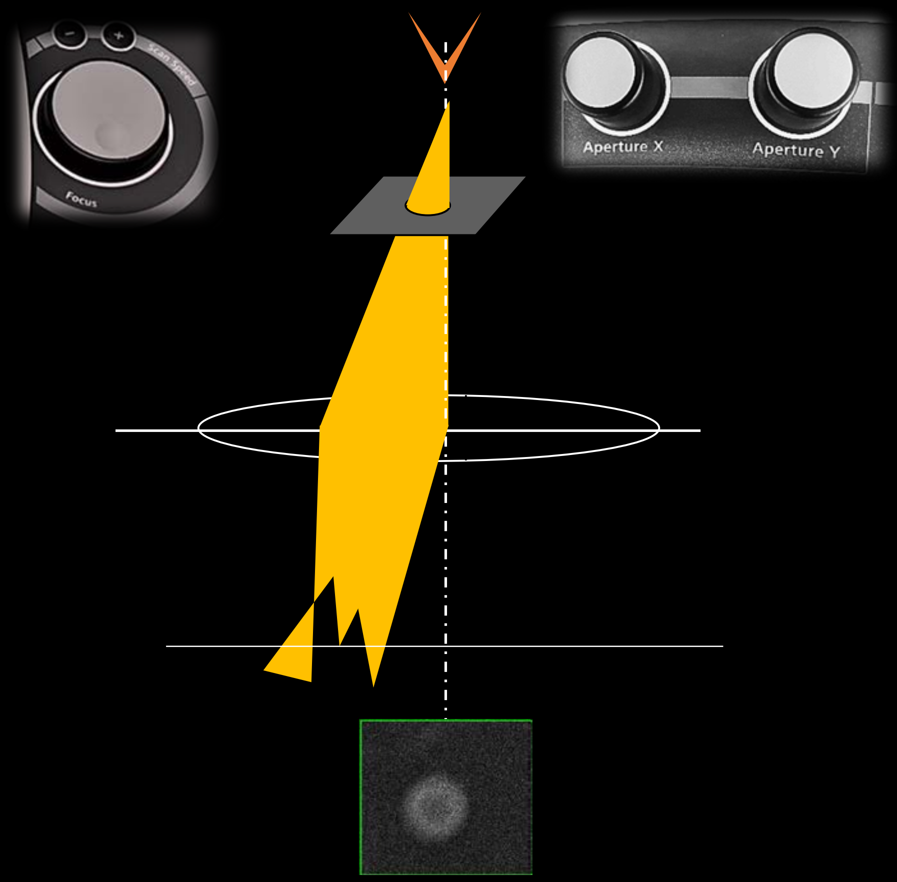


What happens when aperture is off?



How do you know when aperture is off?





Small -> focus

Round -> x/y stigmation

Straight -> x/y alignment

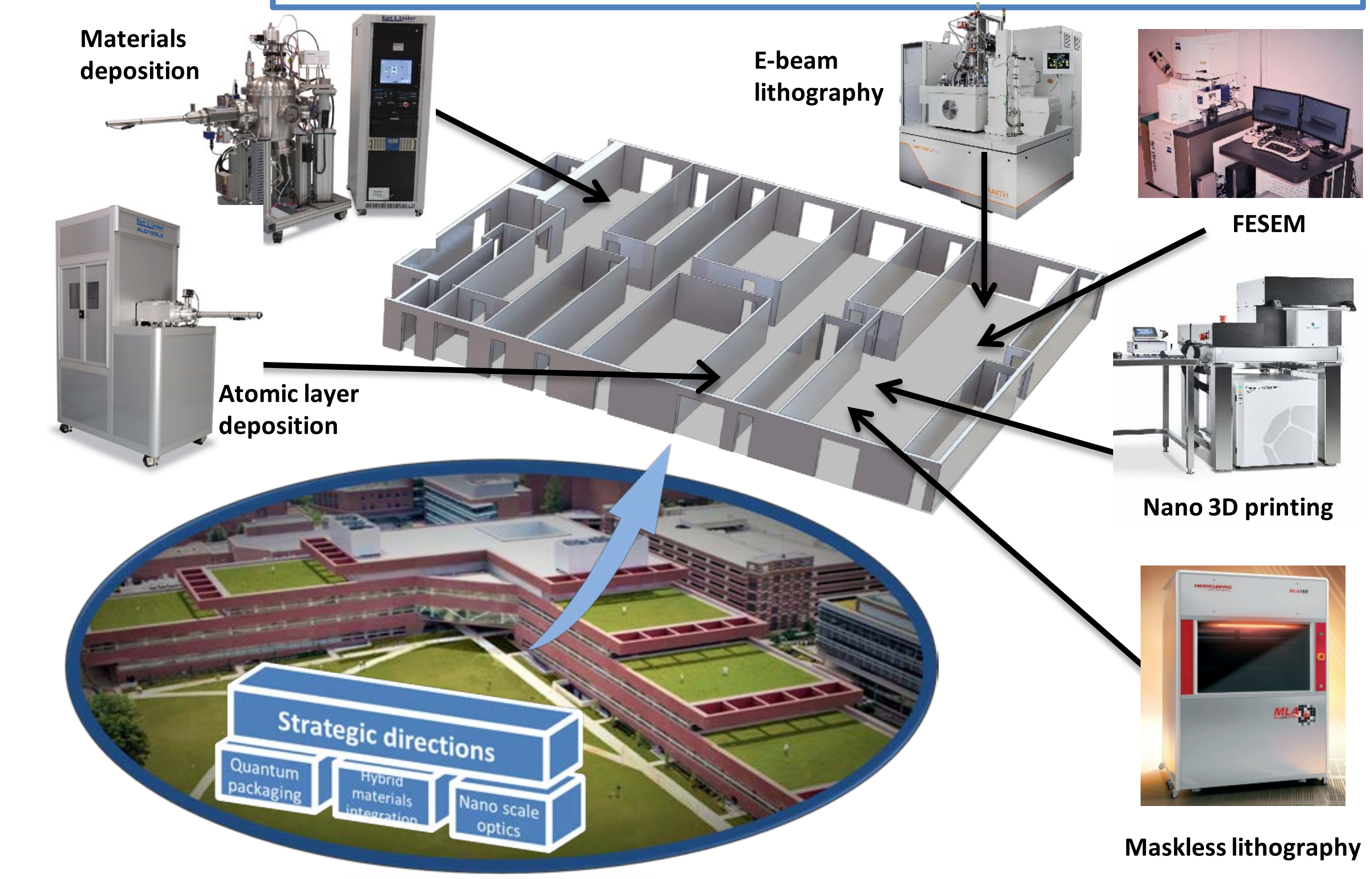
5 controls needed to correct the beam

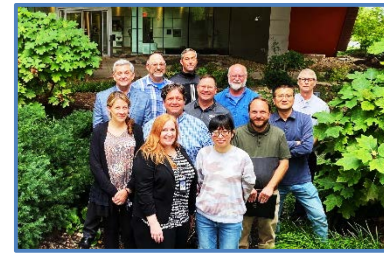
Questions?

PennState Materials Research Institute

The Nanofabrication Lab:
Enabling the future of nanoscale materials and devices at Penn State University

Chad Eichfeld, Guy Lavallee, Andrew Fitzgerald, Bangzhi Liu, Bill Mahoney,
Kathleen Gehoski, Ted Gehoski, Michael Labella, Wanlin Zhu, Shane Miller, Jaime Reish and Daniel Lopez





Materials expertise:
Metals, semiconductors, dielectrics, Van der Waals.

Lithography Suite:
Electron beam, ion beam, direct write optical, stepper, and contact lithography capabilities.

Deposition Suite:
Sputtering tools, electron beam evaporation, atomic layer and plasma-enhanced chemical vapor deposition.

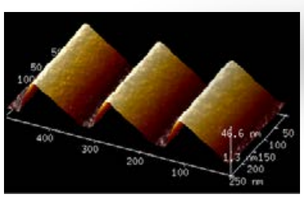
Etching Suite:
Plasma, high density plasma, and deep reactive ion etching of dielectrics and metals.

Metrology Suite:
SEM, profilometers, spectroscopic ellipsometry and atomic force microscope.

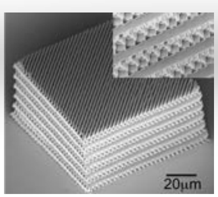
Contact:
Daniel Lopez (ovl5064@psu.edu)
Chad Eichfeld (cme133@psu.edu)
Guy Lavallee (gpl107@psu.edu)

3D FeM

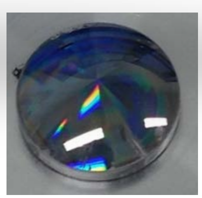
2D Crystal Consortium
NSF Materials Innovation Platform



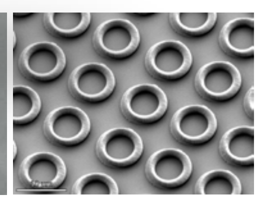
Reflection gratings for X-ray radiation



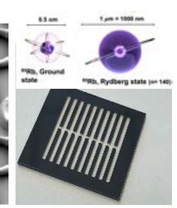
Photonic bandgap structures



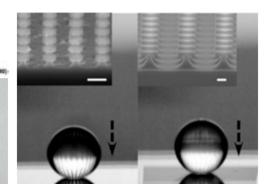
Nanostructured optics



Array of toroidal nanostructures



Atomic vapor cells



Nanostructured surfaces