

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

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DUE 2000725



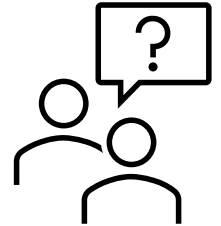
CENTER FOR NANOTECHNOLOGY
EDUCATION AND UTILIZATION

This webinar is being recorded and links will be available at:

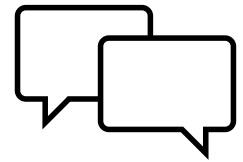
<https://www.cneu.psu.edu/webinars/>
NACK Center YouTube channel



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Host



Zac Gray

Managing Director
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Co-host



Vishal Saravade

*Assistant Teaching
Professor*
CNEU

Presenter



Bangzhi Liu

*Assistant Research
Professor*
Materials Research
Institute

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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 ft² 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

Dalian



Millennium Science Complex



Outline

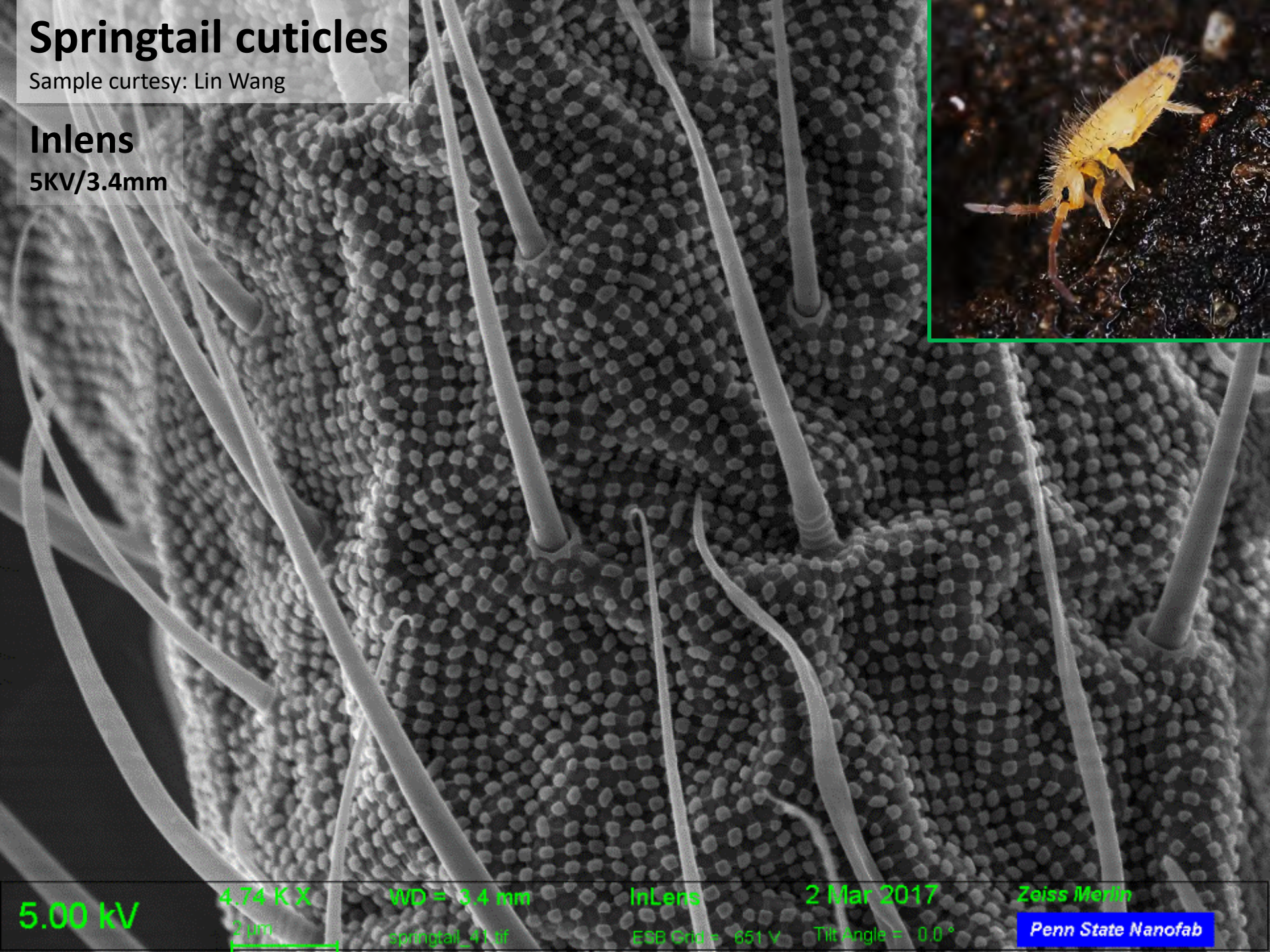
- **Examples of different situations**
- Key Imaging Parameters
- FESEMs we own
- How to achieve ideal beam

Springtail cuticles

Sample curtesy: Lin Wang

Inlens

5KV/3.4mm



5.00 kV

4.74 KX

2µm

WD = 3.4 mm

springtail_41.tif

InLens

ESB Cond = 851 V

2 Mar 2017

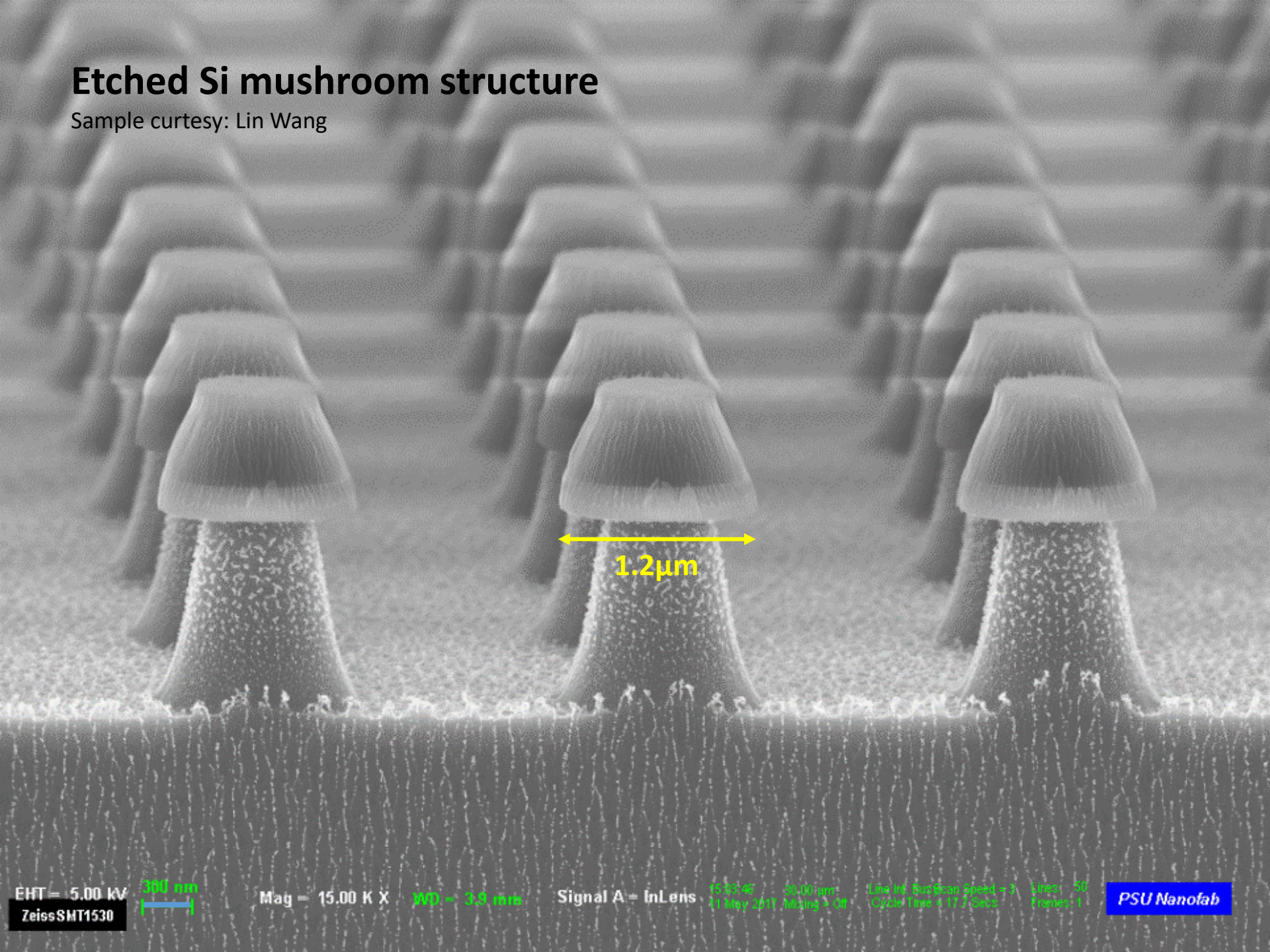
Tilt Angle = 0.0°

Zeiss Merlin

Penn State Nanofab

Etched Si mushroom structure

Sample curtesy: Lin Wang



1.2 μm

EHT = 5.00 kV
Zeiss SMT1530

300 nm

Mag = 15.00 K X

WD = 3.5 mm

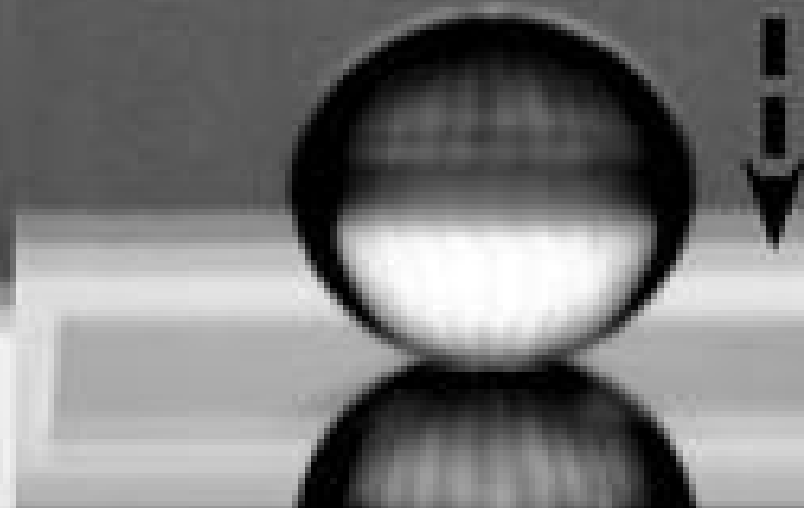
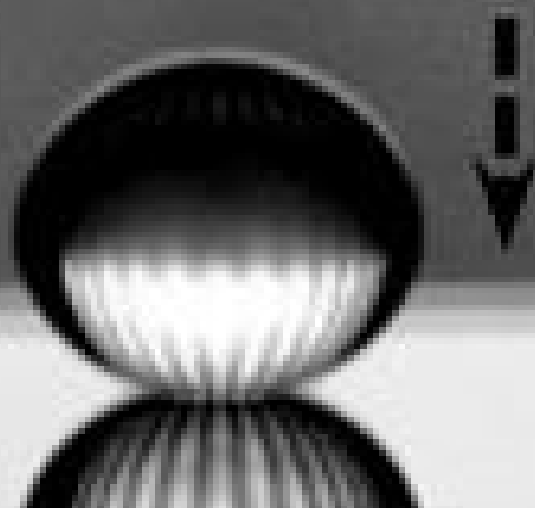
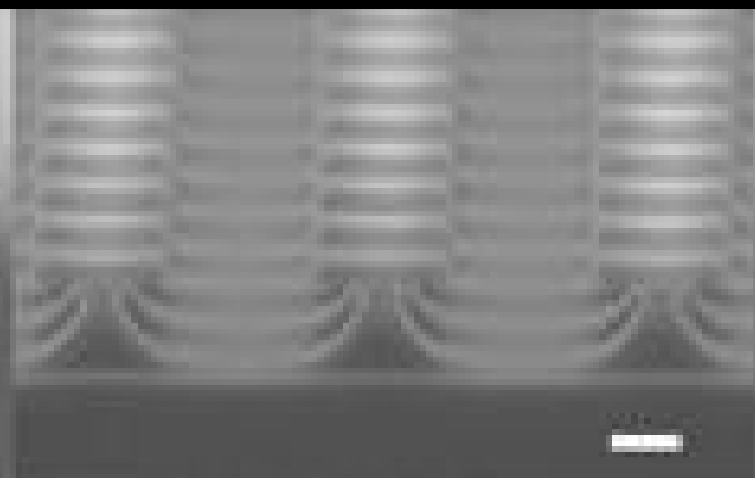
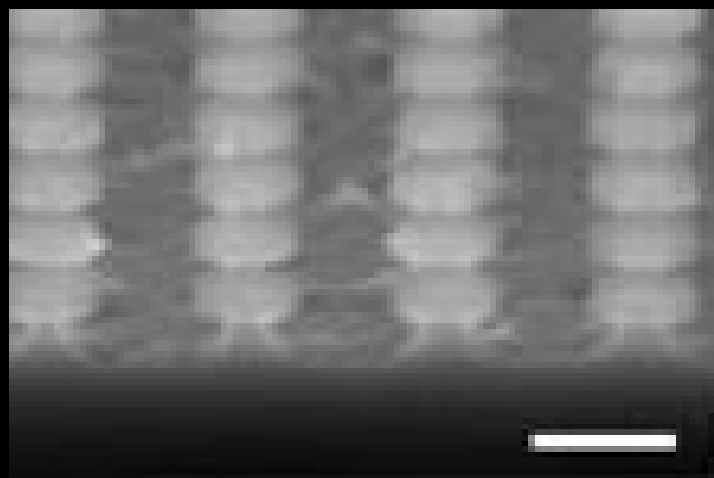
Signal A = InLens

15.00 kV
21 May 2011 10:00:00 AM

Line 16 Scanline Speed = 3
10240 Lines x 11.7 Lines

1000 = 10
Frames = 1

PSU Nanofab



Etched Si grating

Sample courtesy: Fabian Grise



75 nm

EHT = 20.00 kV
Zeiss SMT1530

100 nm

Mag = 100.00 K XWD = 2.1 mm

Signal A = InLens

11:10:43
7 Oct 2016

30.00 μ m
Mixing = Off

Line Avg Scan Speed = 3
Cycle Time = 17.7 Secs

Lines: 50
Frames: 5

PSU Nanofab

WSe₂/Graphene 0.2KV

Sample curtesy: Ben Huet

2um



This scanning electron micrograph (SEM) displays a WSe₂/Graphene heterostructure. The image shows a complex, interconnected network of dark, irregularly shaped regions, which are the WSe₂ domains, dispersed on a lighter, textured background representing the graphene substrate. The WSe₂ domains vary in size and shape, with some appearing as small, sharp triangles and others as larger, more elongated, and jagged structures. The overall morphology suggests a high degree of interfacial contact between the two materials. A scale bar at the bottom left indicates a length of 2 micrometers.

MoS₂/0.2KV

Sample courtesy: Kevin Lu



10um

0.200 kV

1.69 K X
10 μm

WD = 2.7 mm

InLens

13 Nov 2019

Zeiss Gemini 500

1022_MWCHMPO_21.HF

15:49:39

Penn State Nanofab

3D printed nanostructure/2 kV

Sample courtesy: Jiho Noh

polymer

Glass substrate

2.00 kV

3.17 K X

WD = 4.6 mm

InLens

20 Apr 2018

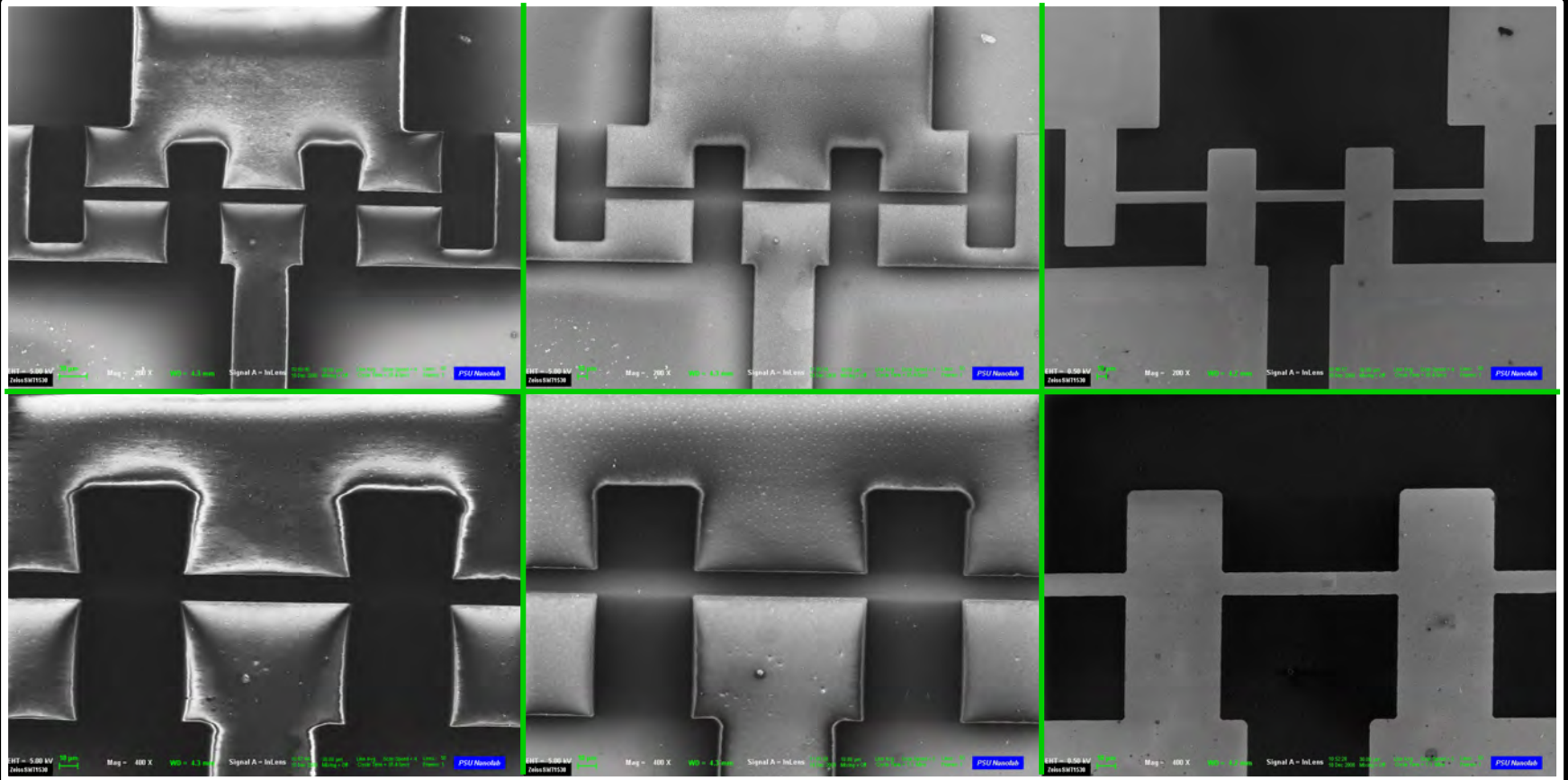
Zeiss Merlin

2 μ m

ESB Gnd = 1067 V

Penn State Nanofab

Charging effect



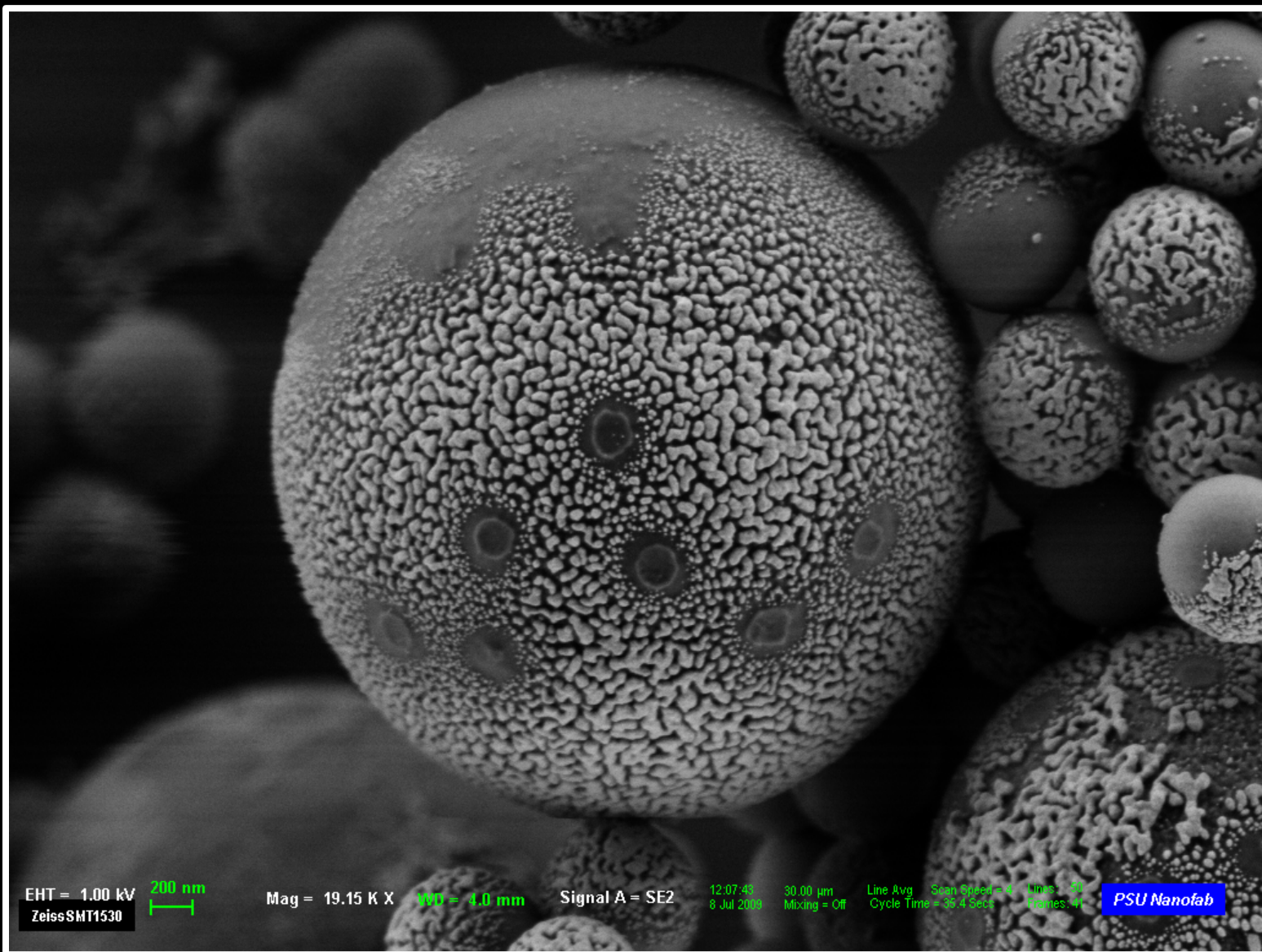
5 kV / 30 μm aperture

5 kV / 10 μm aperture

0.5 kV / 30 μm aperture

LEO1530

Polystyrene latex coated with Au



EHT = 1.00 kV
Zeiss SMT1530

200 nm

Mag = 19.15 K X

WD = 4.0 mm

Signal A = SE2

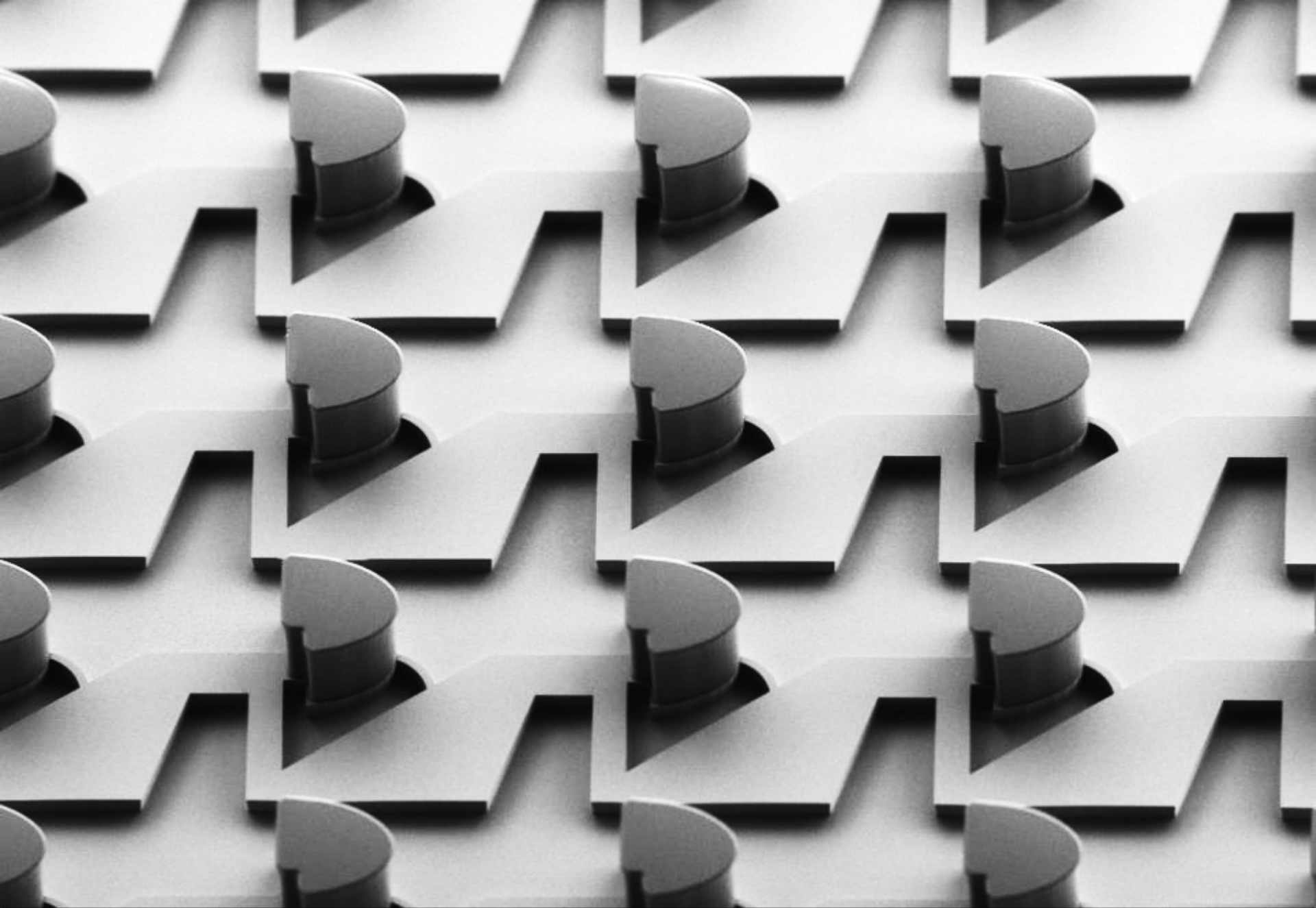
12:07:43
8 Jul 2009

30.00 μ m
Mixing = Off

Line Avg
Cycle Time = 35.4 Sec

Scan Speed = 4
Lines = 50
Frames = 47

PSU Nanofab



2.00 kV

100X
200 μm

WD = 3.8 mm

SE2

1 Jun 2022

Zeiss Merlin

ESB Grid = 333 V

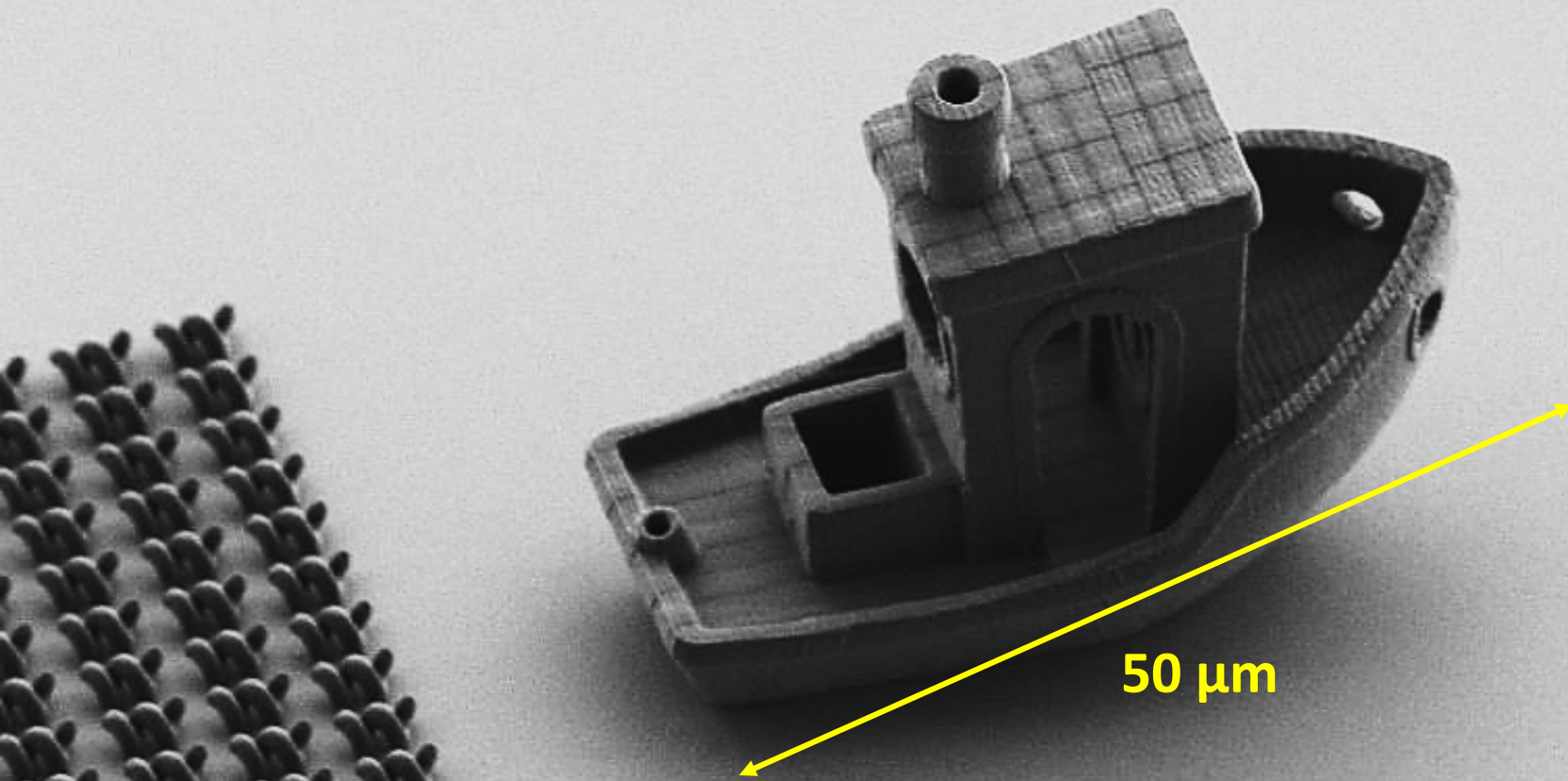
Tilt Angle = -2.9°

Penn State Nanofab

50 μm 3D printed boat

Sample curtesy: Nicole Famularo

SE2 1KV/7.1mm



50 μm

1.00 kV

986 X

70 μm

WD = 7.1 mm

SE2

6 Jul 2018

Zeiss M

ESB Grid = 967 V

Tilt Angle = 0.0°

Penn S

Outline

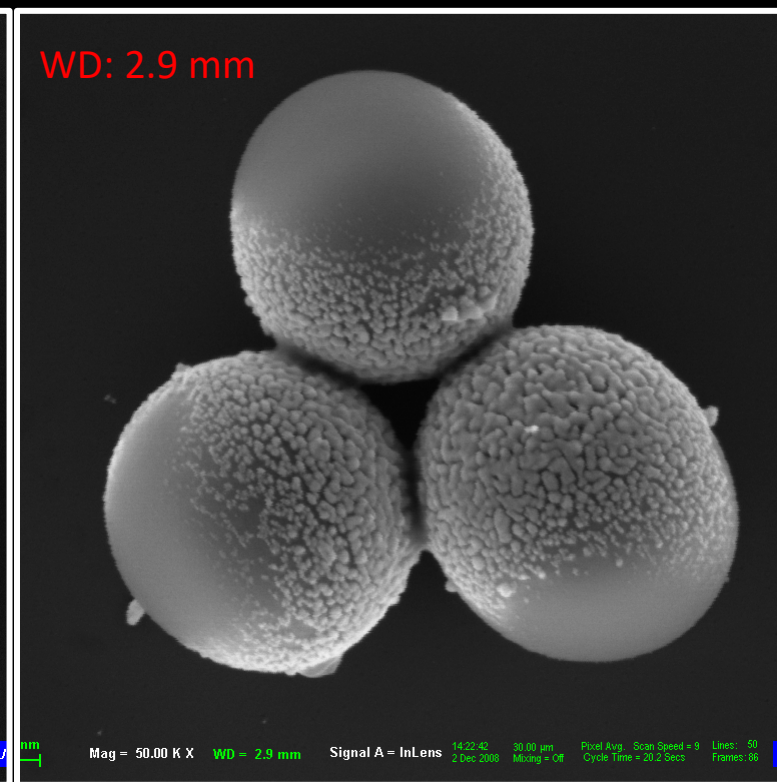
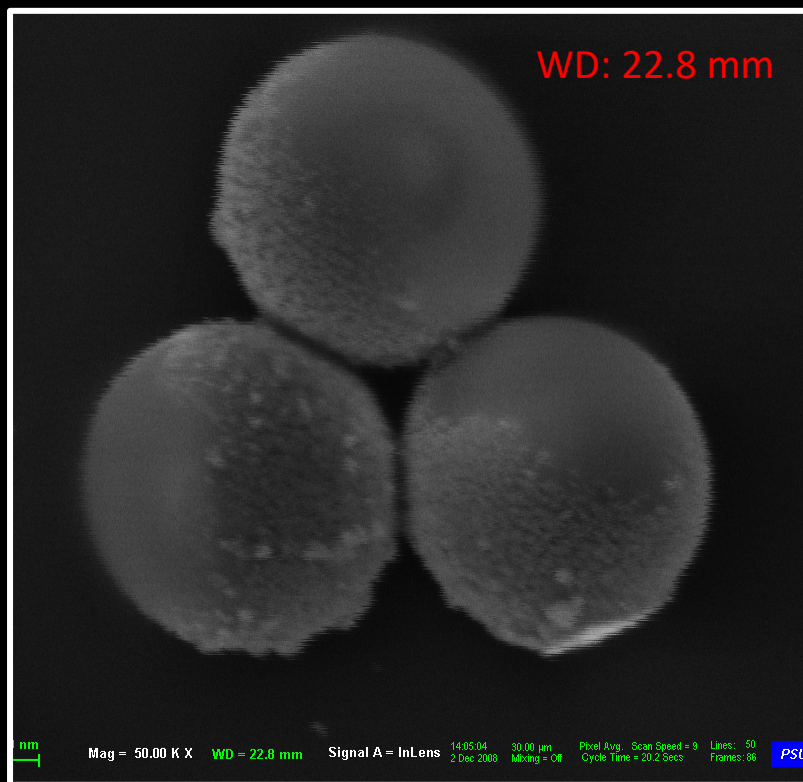
- Examples of different situations
- **Key Imaging Parameters**
- FESEMs we own
- How to achieve ideal beam

Key imaging parameters

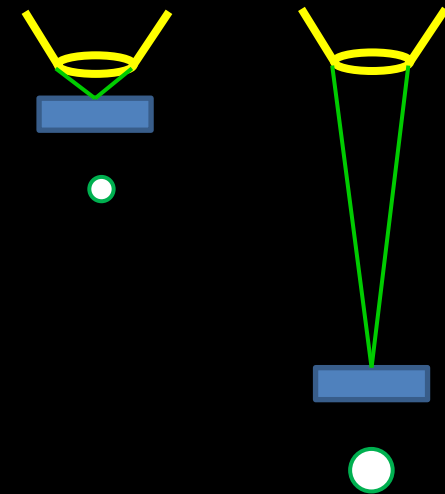
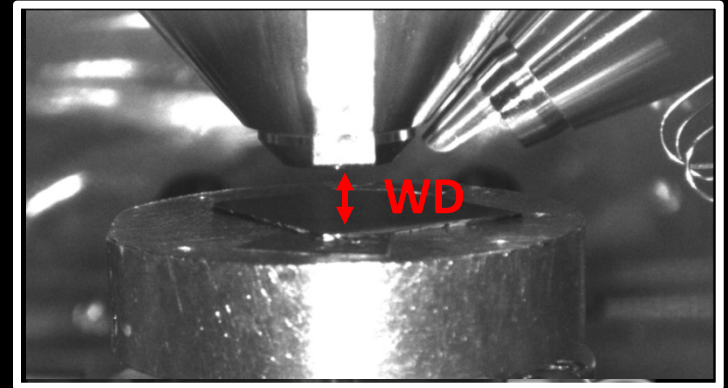
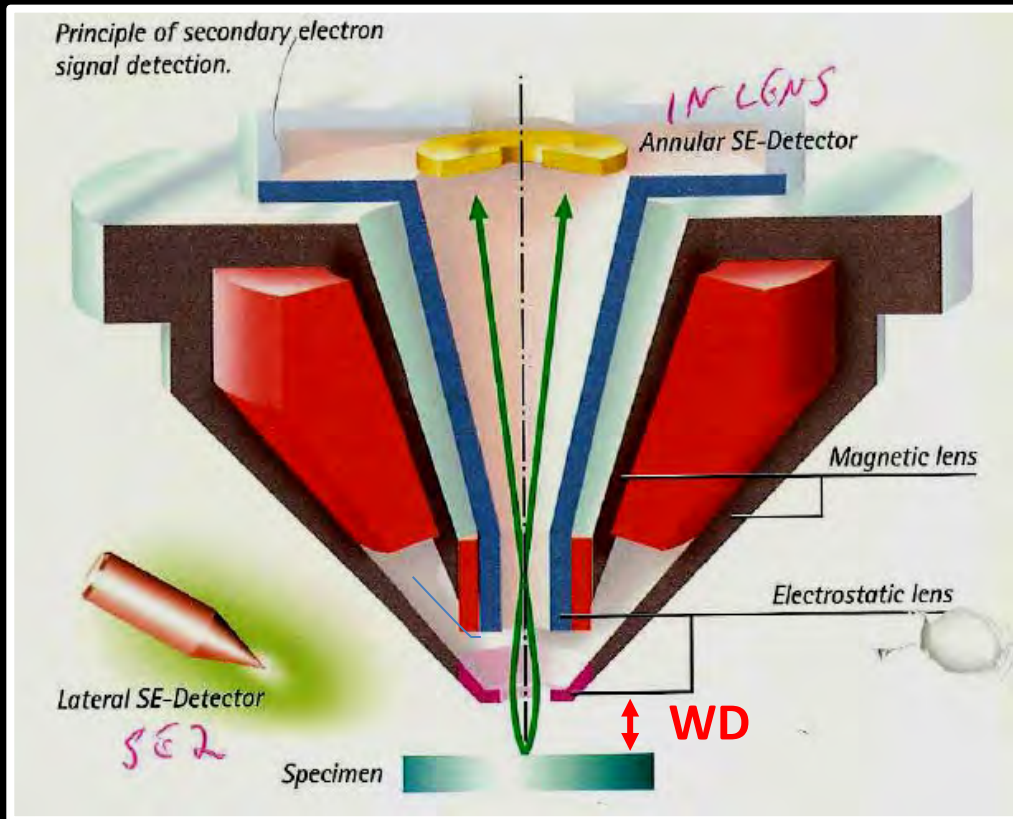
- **Working distance (WD)**
- **Beam voltage**
- **Detectors**

Working Distance (WD)

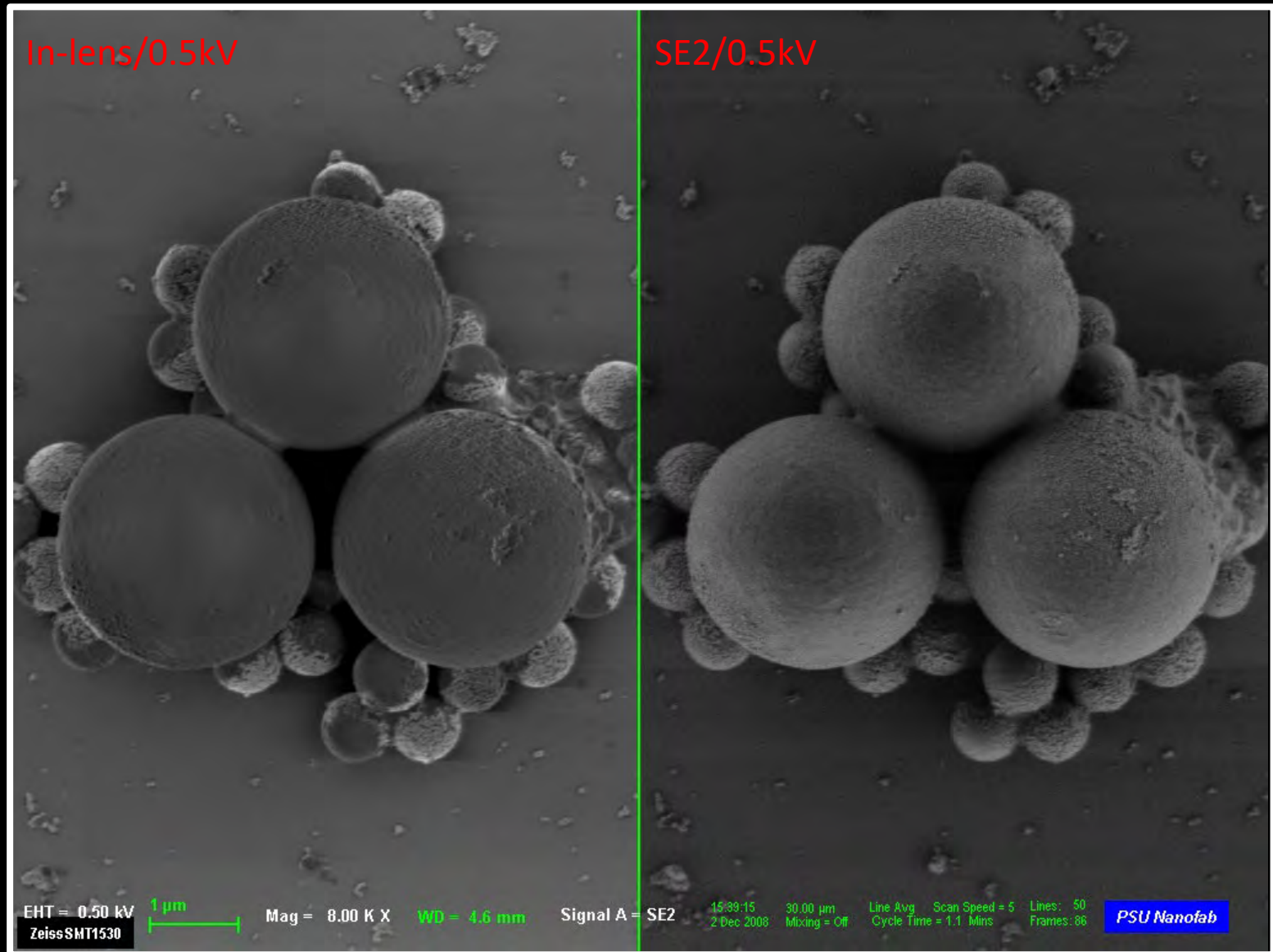
Smaller WD, better resolution

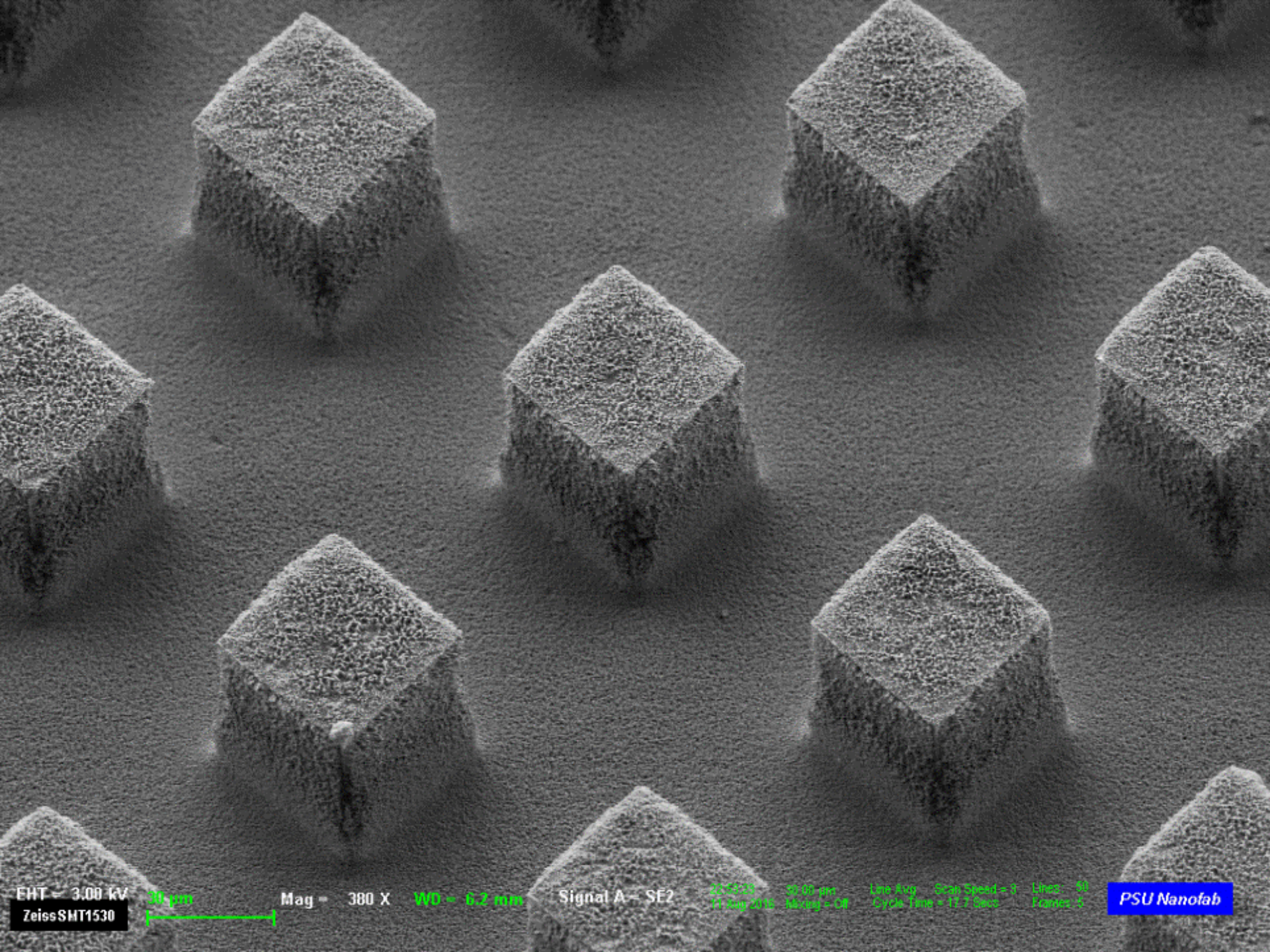


Working distance & detectors



Choice of detectors





EHT = 3.00 kV
Zeiss SMT1530

30 µm
└──────────┘

Mag = 380 X

WD = 6.2 mm

Signal A = SE2

20.5833
11 Sep 2015

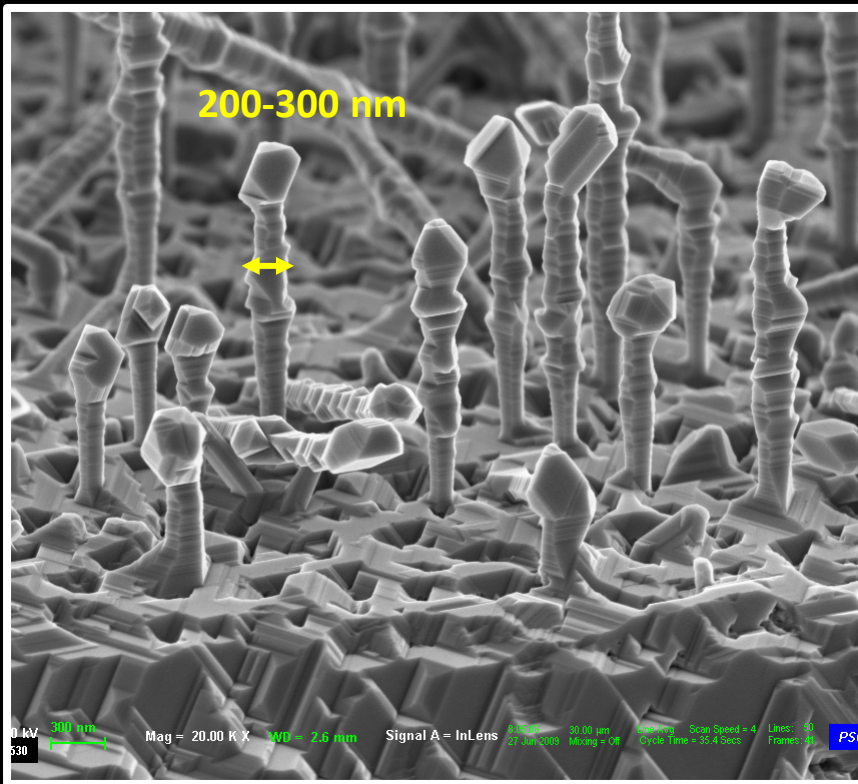
50.00 µm
Mag = 380

Low Vac Scan Speed = 1
Cycle Time = 11.7 Secs

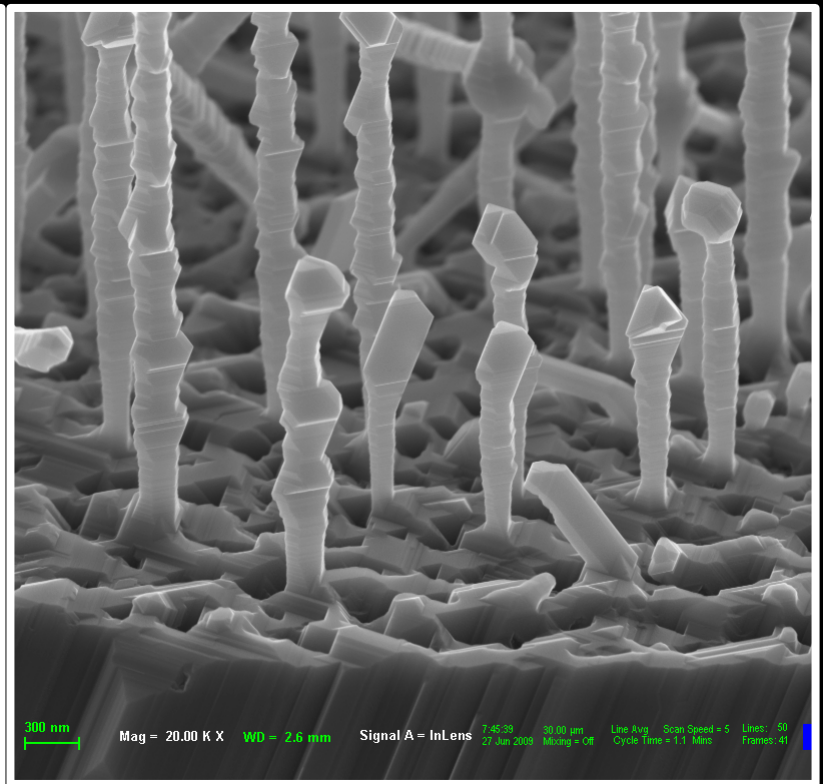
Lines = 50
Frames = 1

PSU Nanofab

Choice of beam voltage

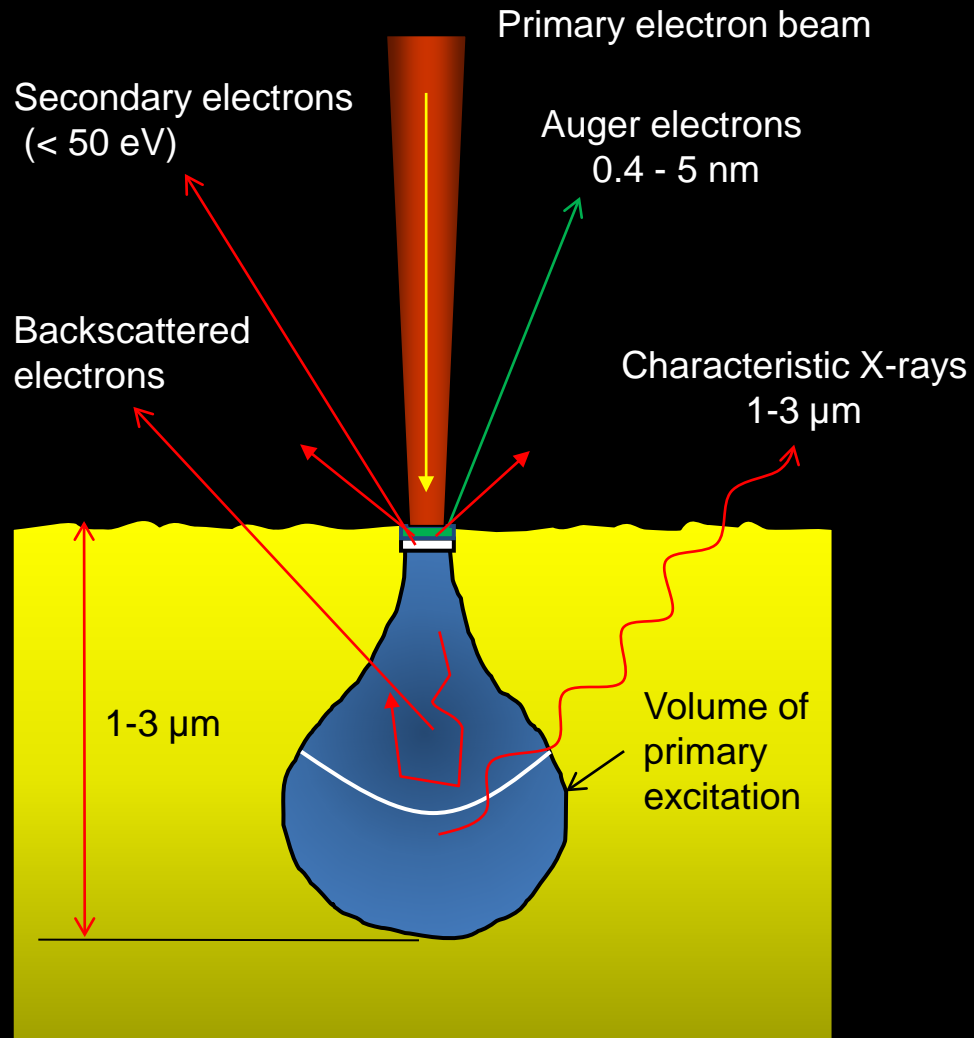


2kV/2.6mm



5kV/2.6mm

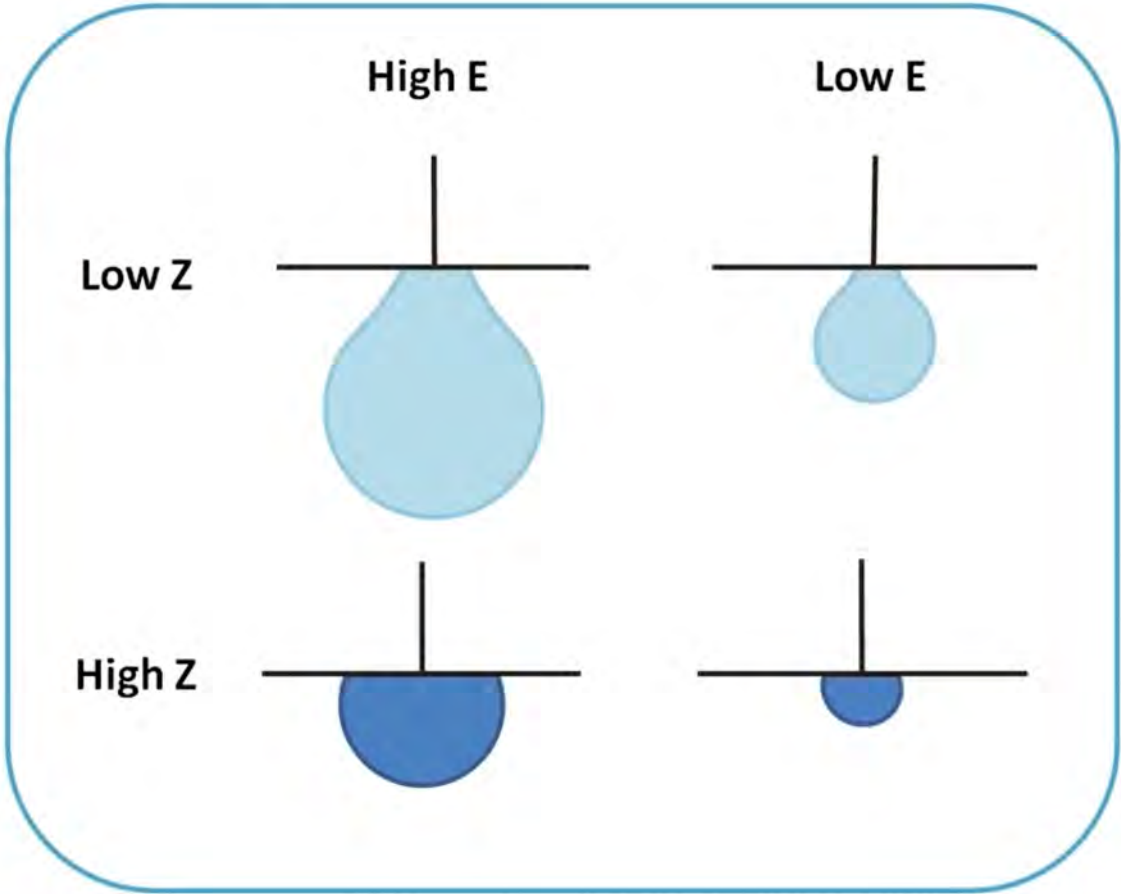
Electron and sample interaction



Electron – sample interaction volume

The size and shape of interaction volume depend on:

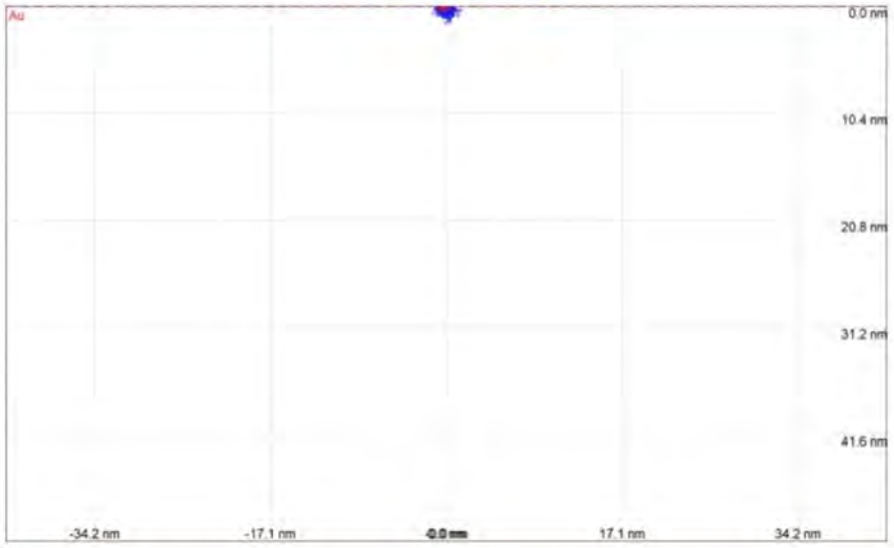
- Primary energy
- Atomic number (Z)
- Specimen tilt



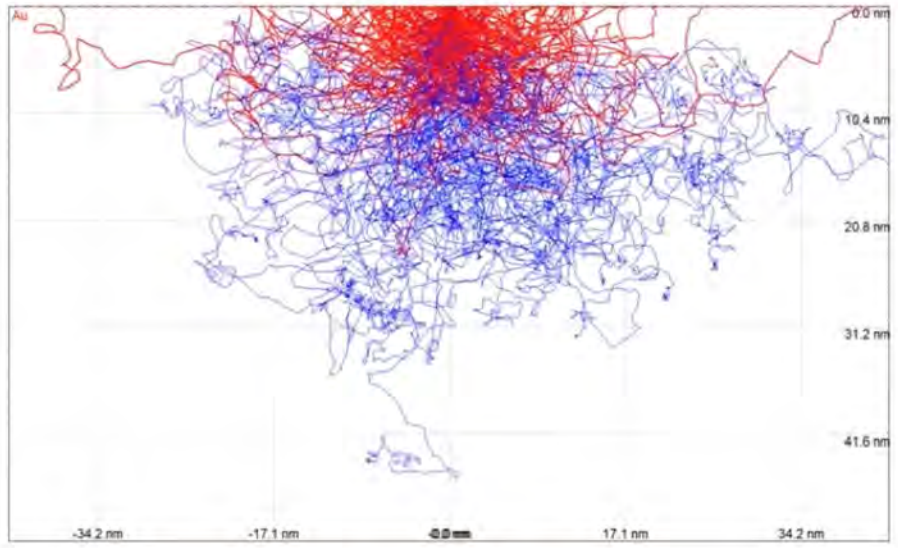
Low-voltage SEM

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

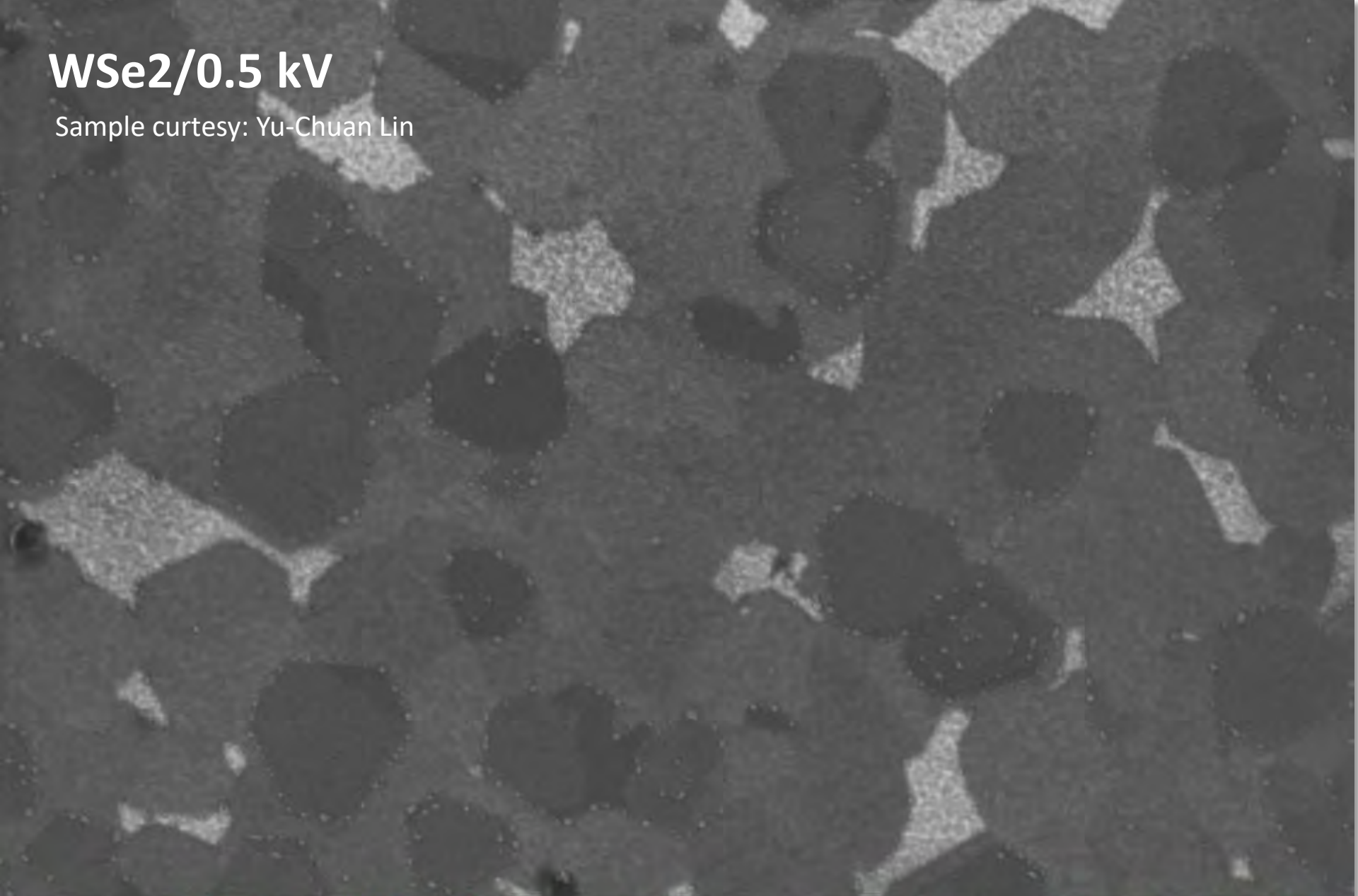
Contrast mechanisms:

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

Ł-ITME & NCBJ
na Józwik

WSe₂/0.5 kV

Sample curtesy: Yu-Chuan Lin



0 kV

30.00 K X

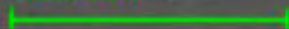
WD = 2.7 mm

InLens

3 May 2021

Zeiss Gemini 500

500 nm



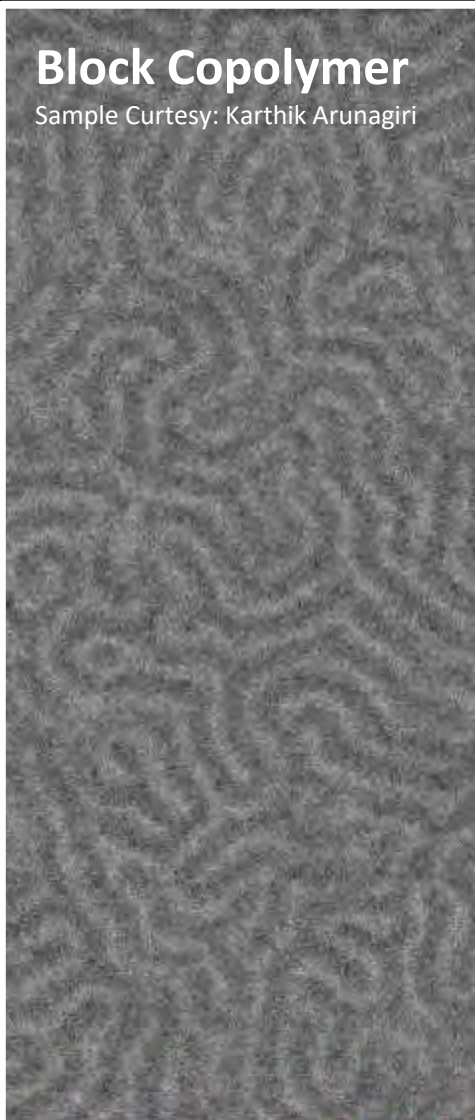
Z 15.0 μm

14:23:05

Penn State Nanofab

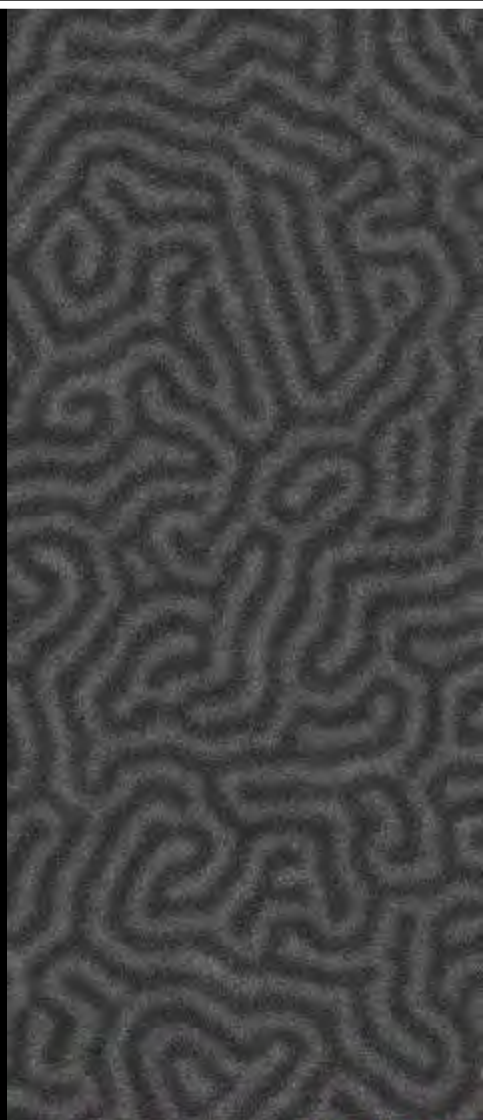
Block Copolymer

Sample Courtesy: Karthik Arunagiri



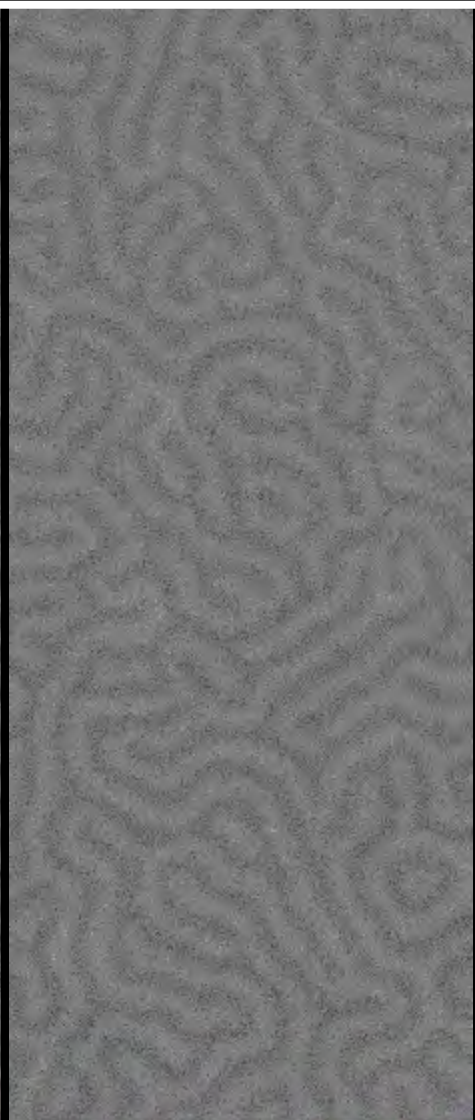
0.500 kV

60.00 K X
200 nm



1.00 kV

60.00 K X
200 nm



3.00 kV

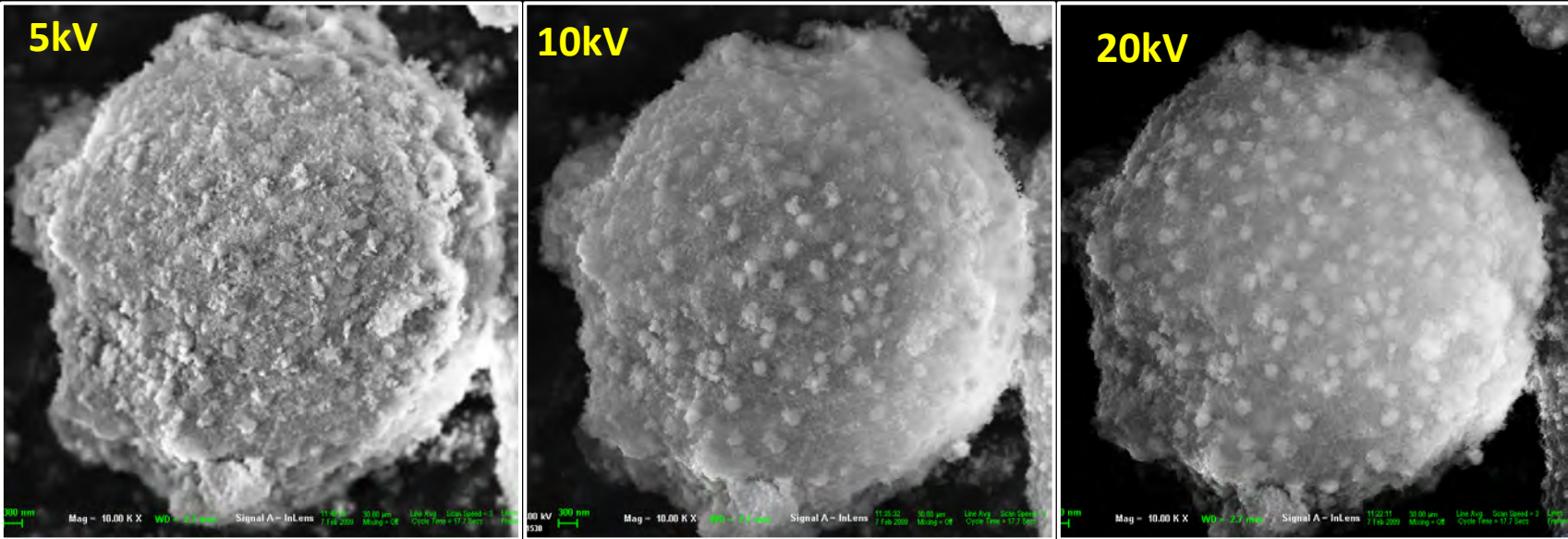
60.00 K X
200 nm



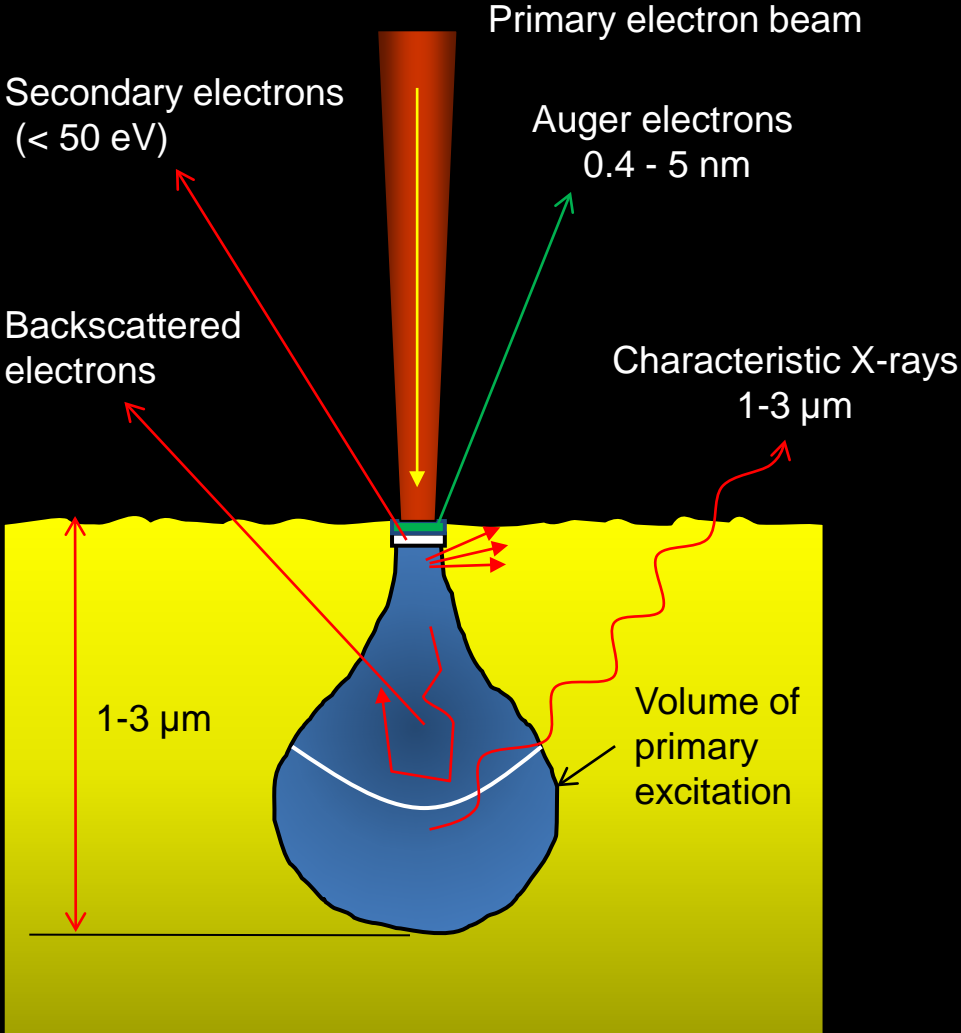
5.00 kV

60.00 K X
200 nm

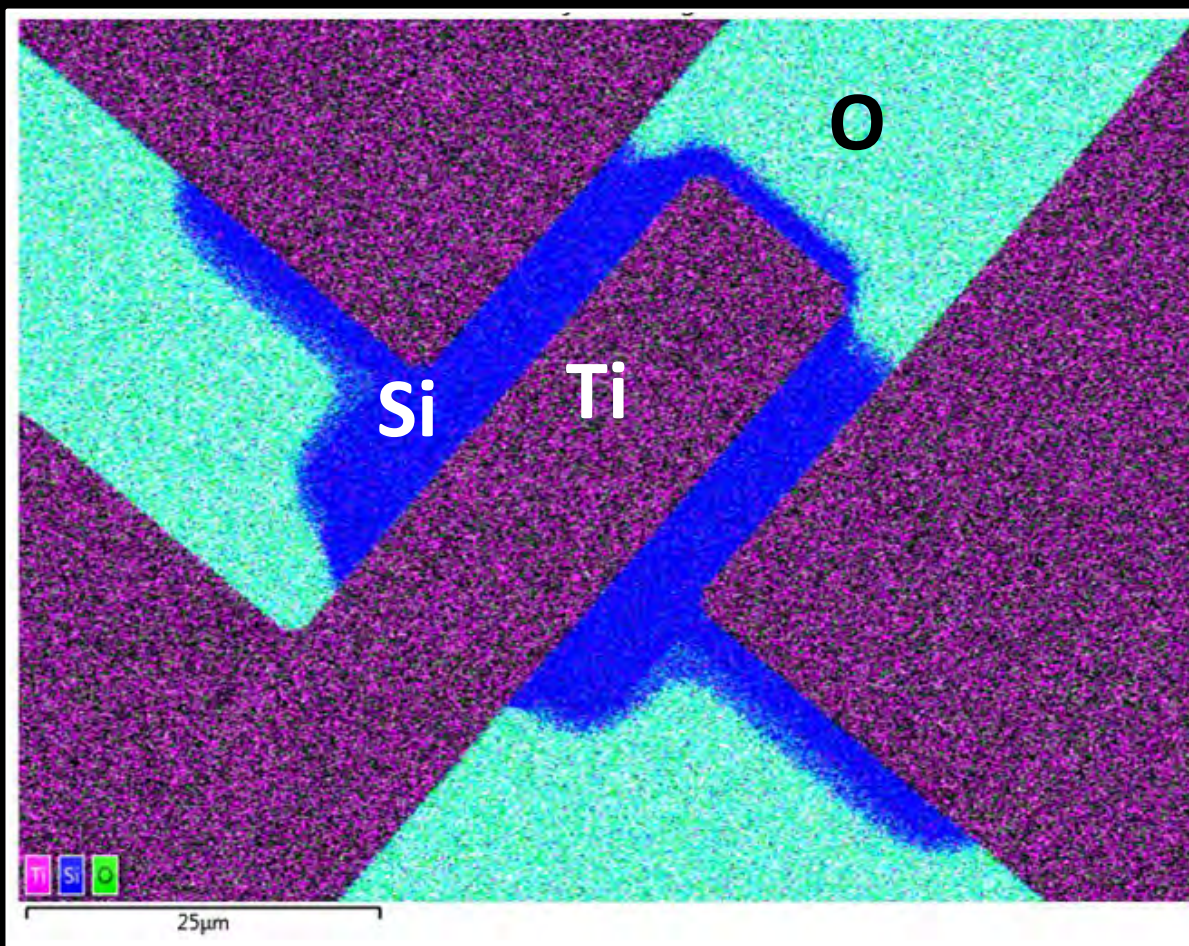
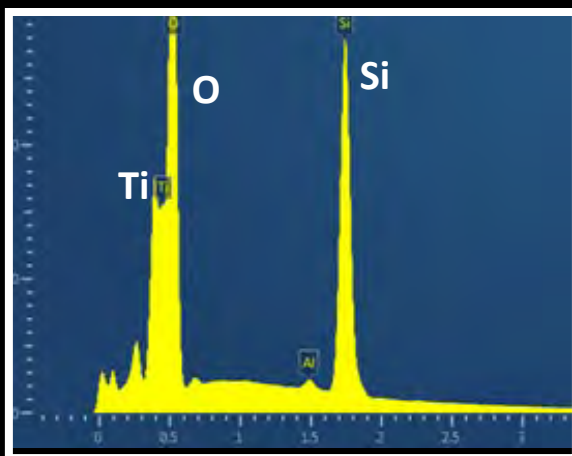
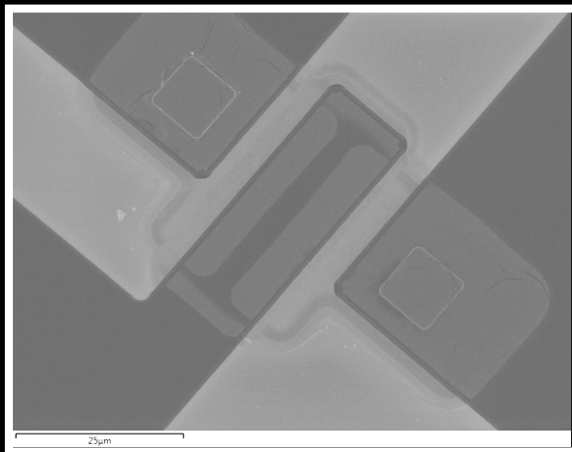
20% Ce on Al₂O₃ particle



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)



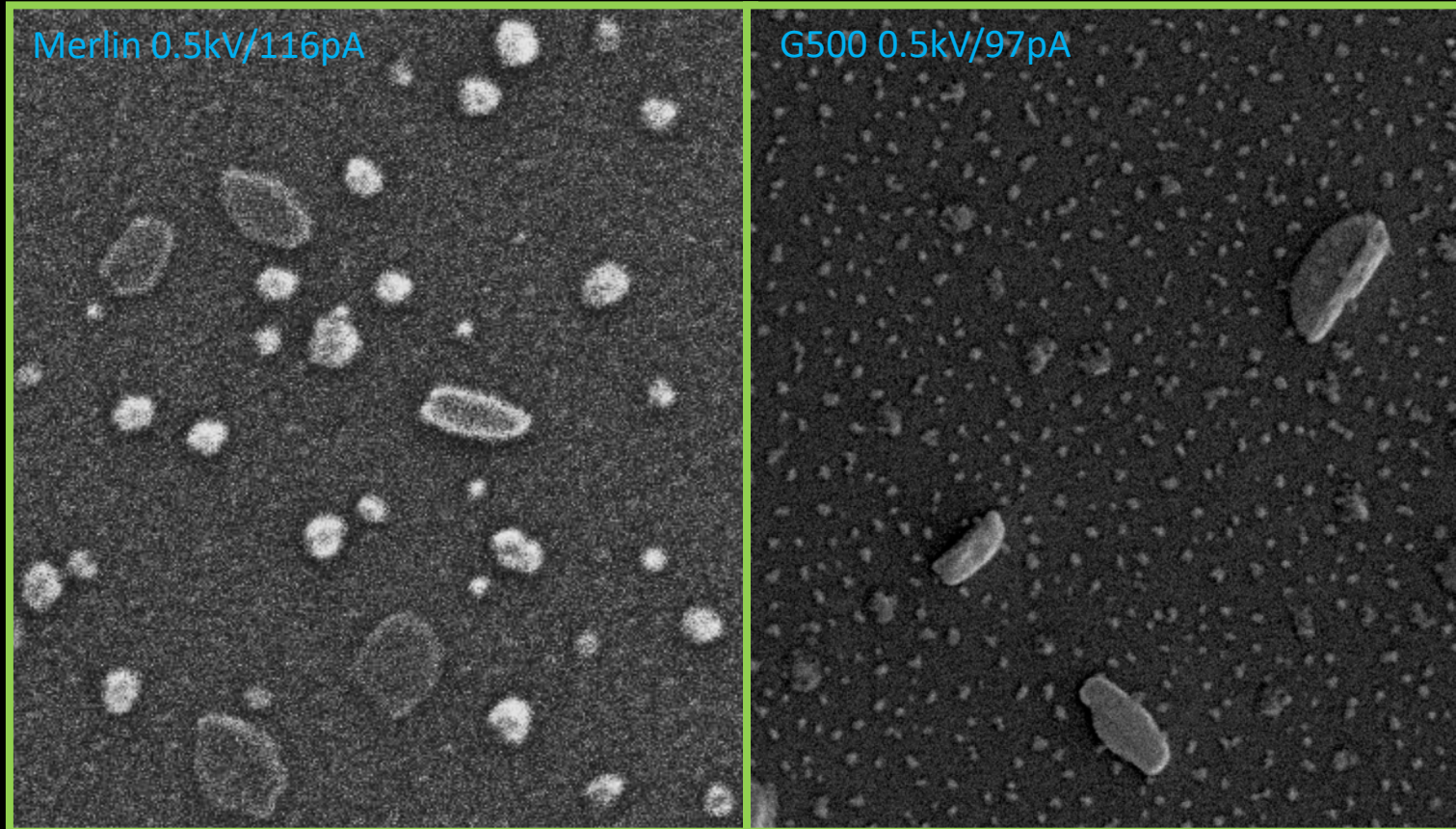
G500

- Low KV high resolution
- VP for insulating materials
- Cathodoluminescence imaging
- In situ plasma cleaning
- Fast sample transfer (3" load lock)



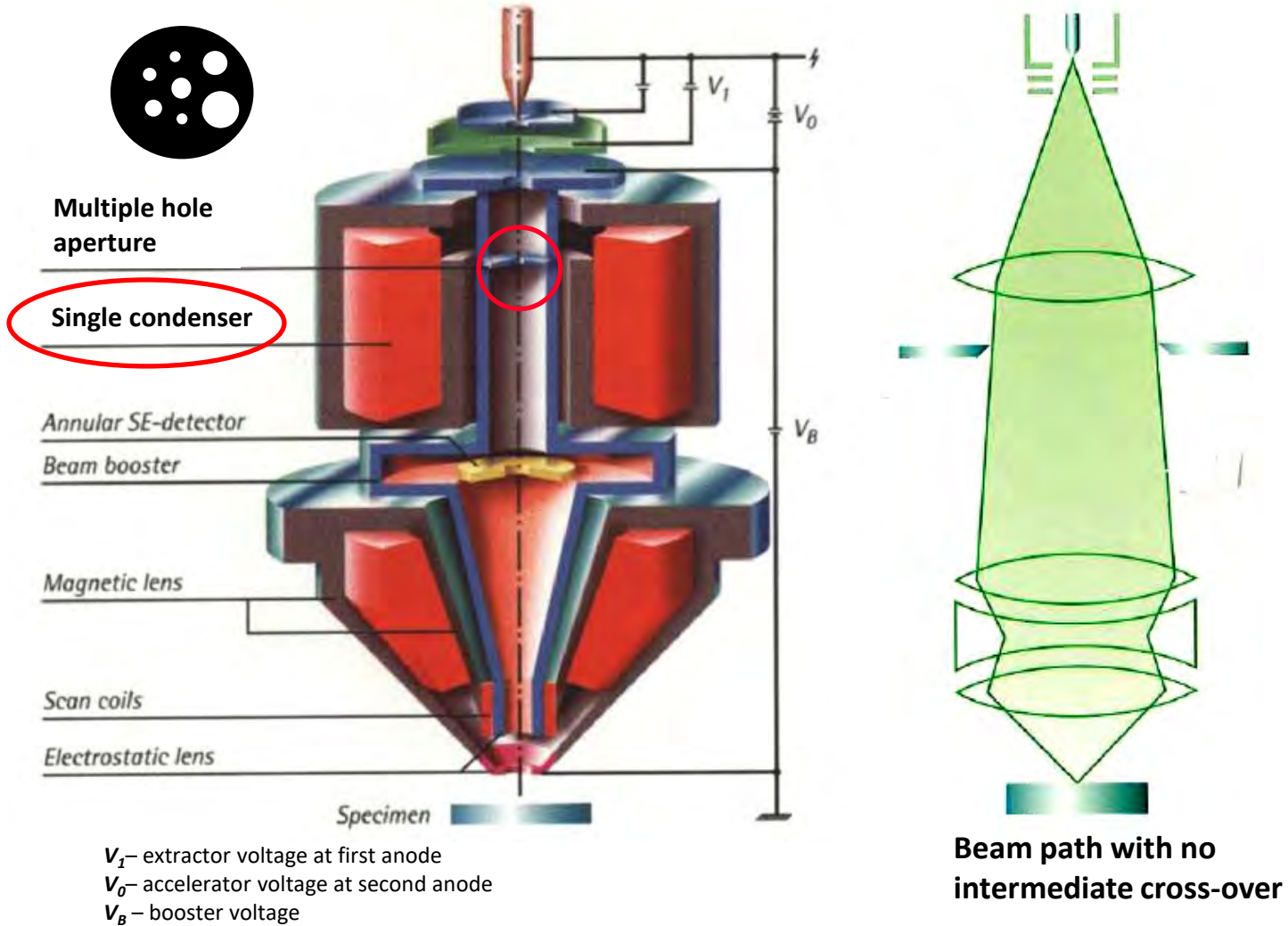
G500: Excellent resolution at low KV

2D sample 2: MoS₂ on glass

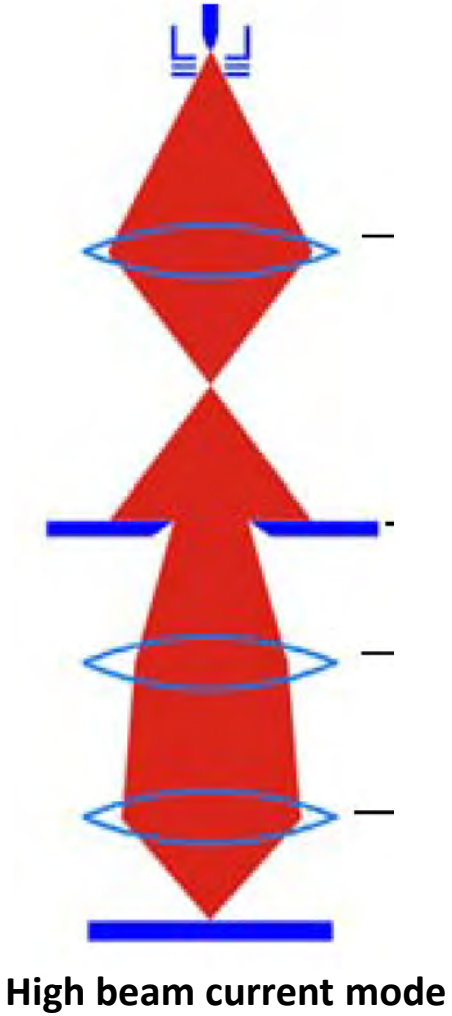
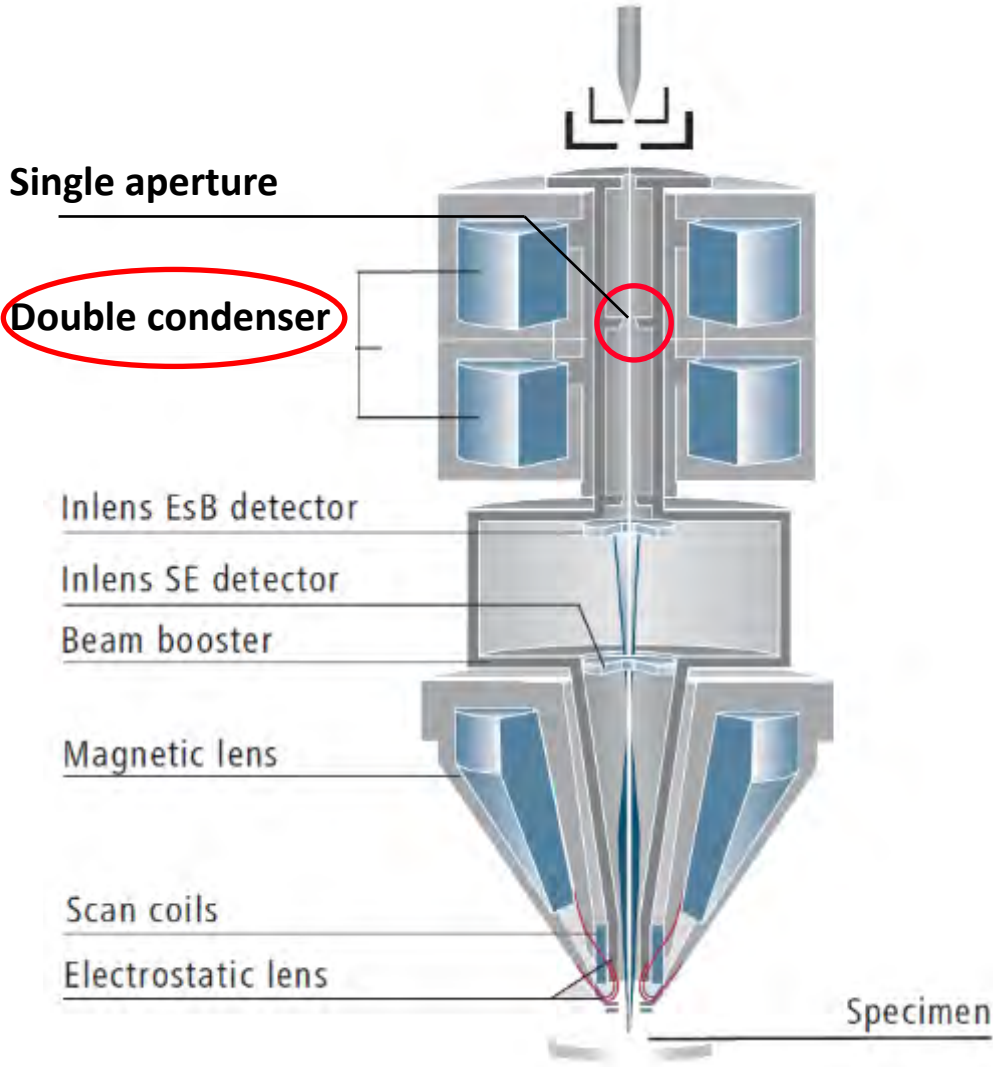


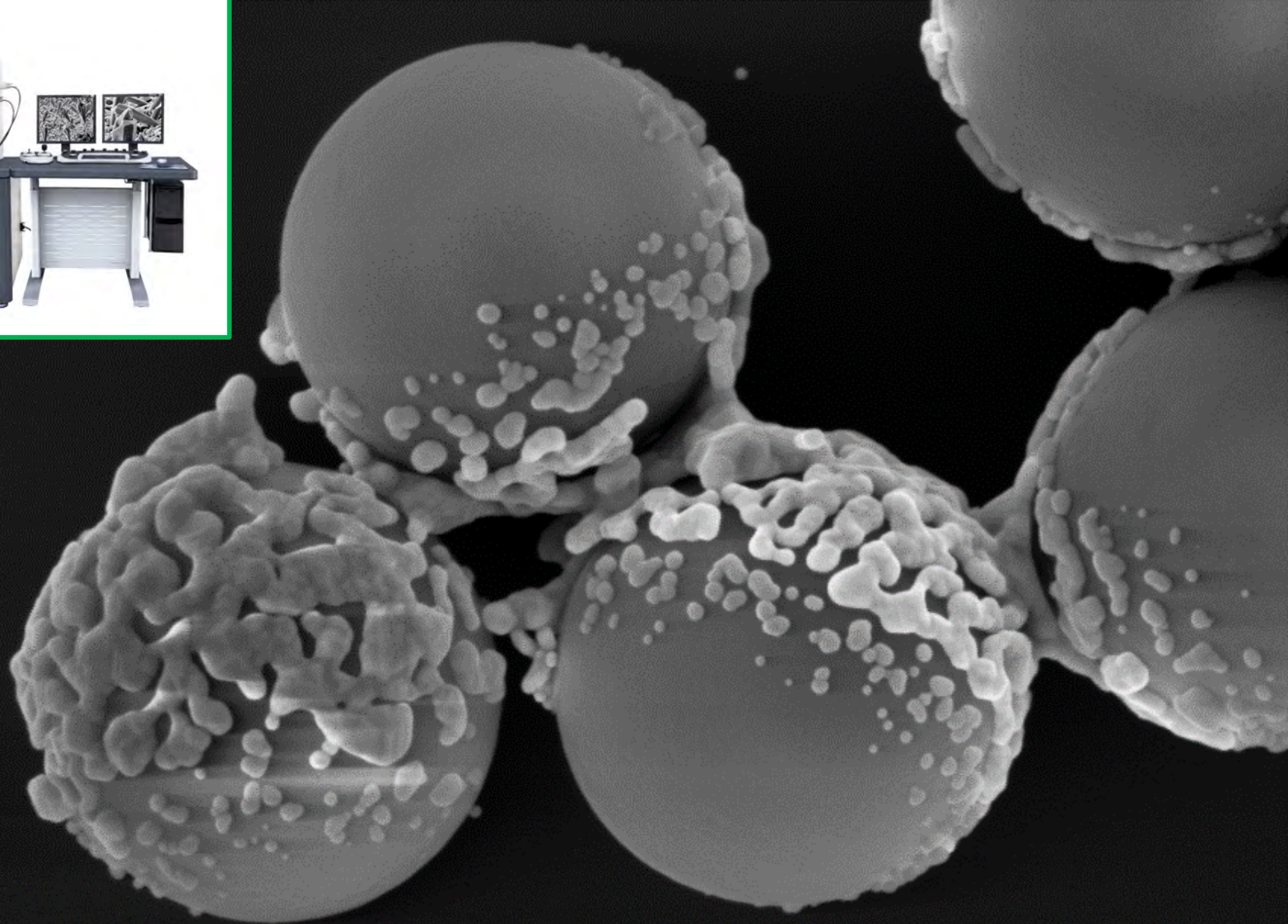
Low KV minimizes beam damage and the high resolution allows us to see the small features, in this case, nm size nucleation sites, which are barely visible on the left image taken on Merlin.

GEMINI I column (G500)



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

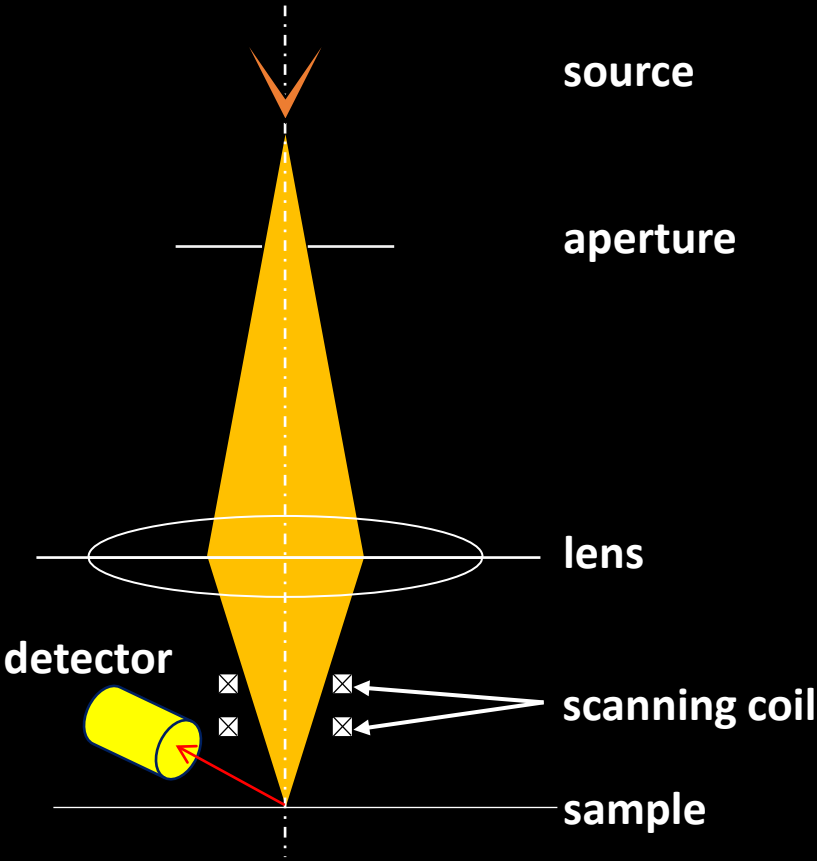
Signal A = InLens
ESB Grid = 0 V

Time :17:38:43
Date :12 Jul 2010

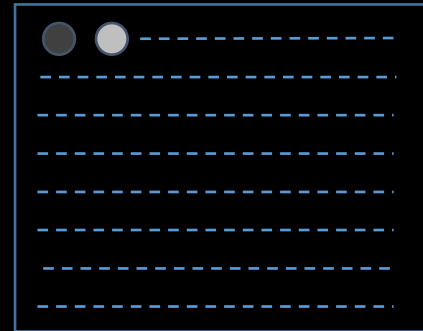
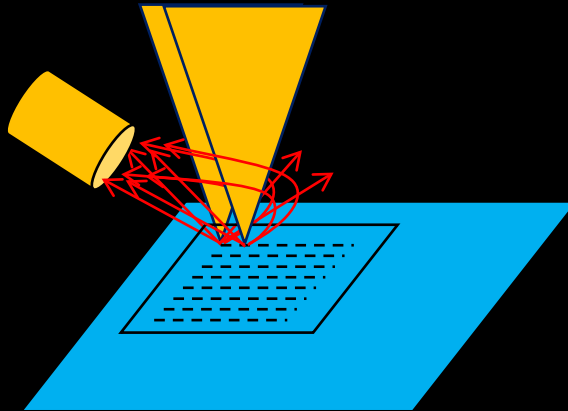
Outline

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

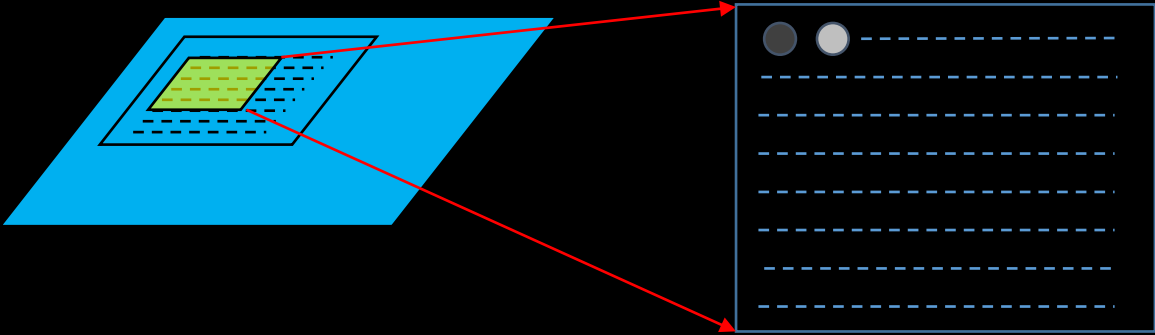
A simplified ray diagram of SEM



Scanning->move the beam!



Magnification?



Merlin: Large field of view

V1 = 4.075 mm

H1 = 3.054 mm

5.00 kV

28X

200 μ m

WD = 6.4 mm

SE2

ESB Det = 700V

3 May 2021

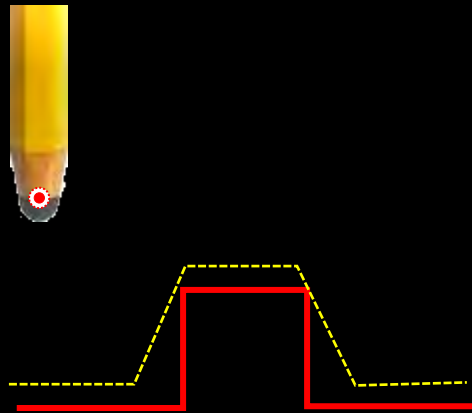
TiltAngle = 10°

Zeiss Merlin

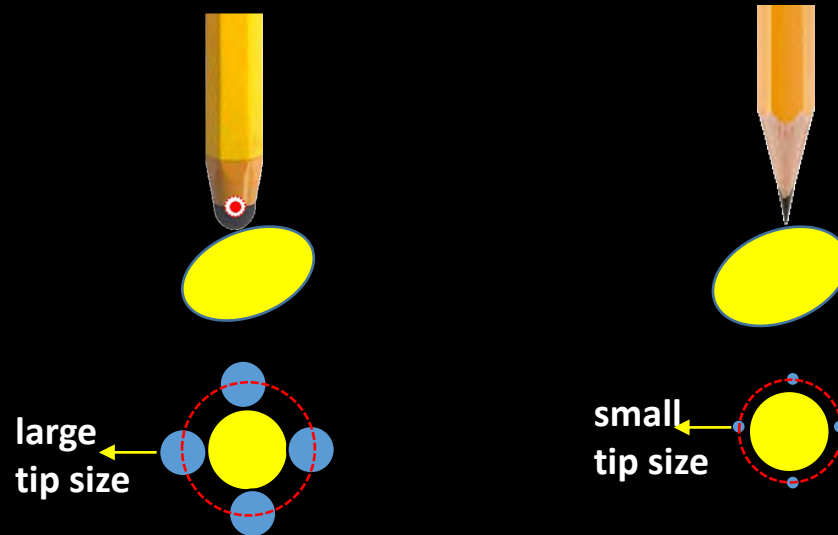
Penn State Nanofab

Ideal beam?

Electron beam is a probe, just like your pencil

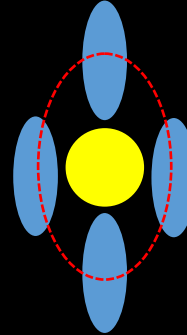
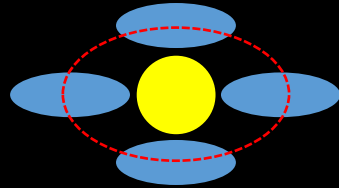


Tip size matters!

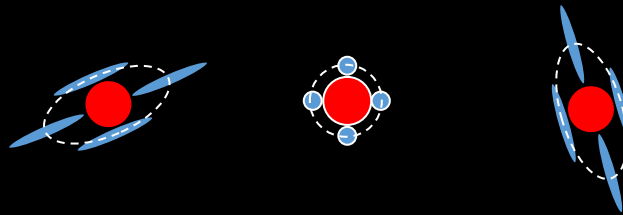
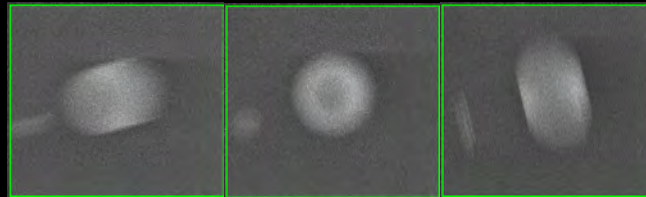


Smaller tip size -> better resolution

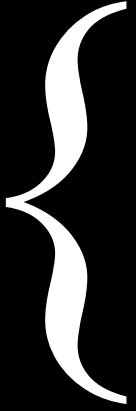
Tip shape matters too!



How does the beam shape affect SEM image?

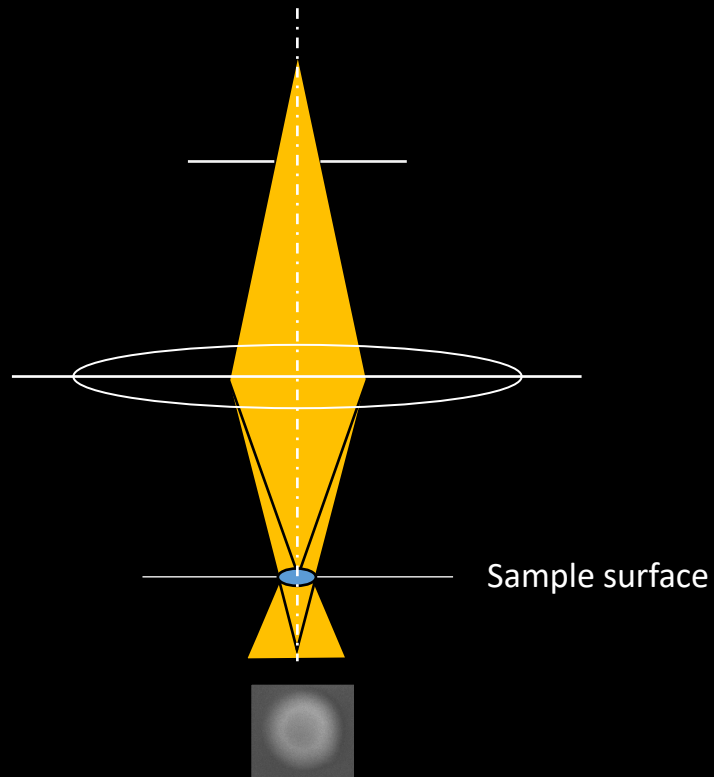


Ideal beam?

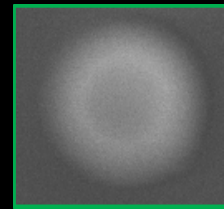


Small
Round
Straight

How to achieve sharp beam on FESEM?

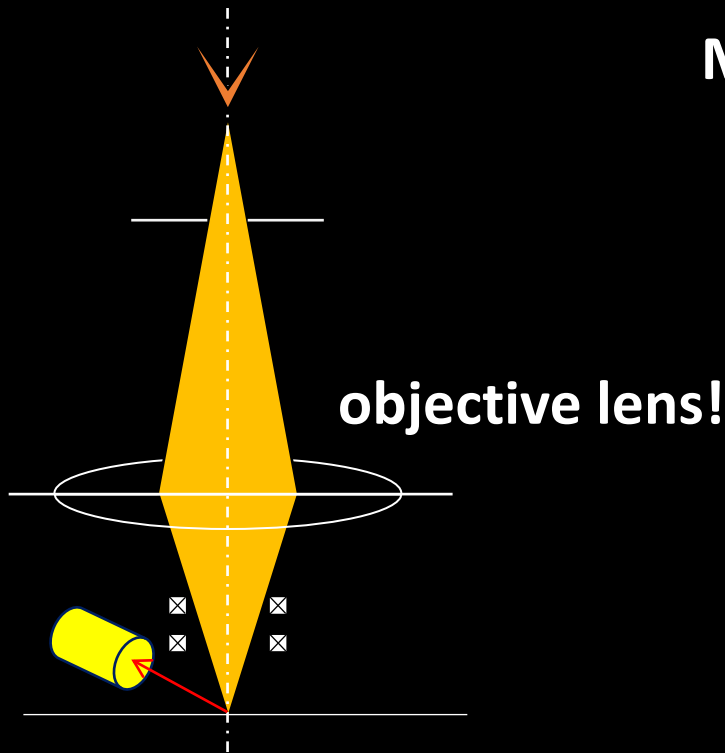


Varying focus changes beam size !

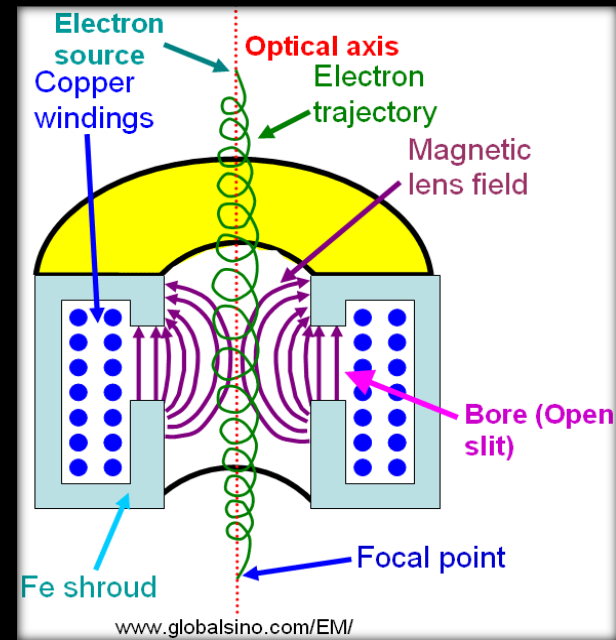


{ Small -> focus
Round ?
Straight

Which component control beam shape?



Magnetic lens or pole piece

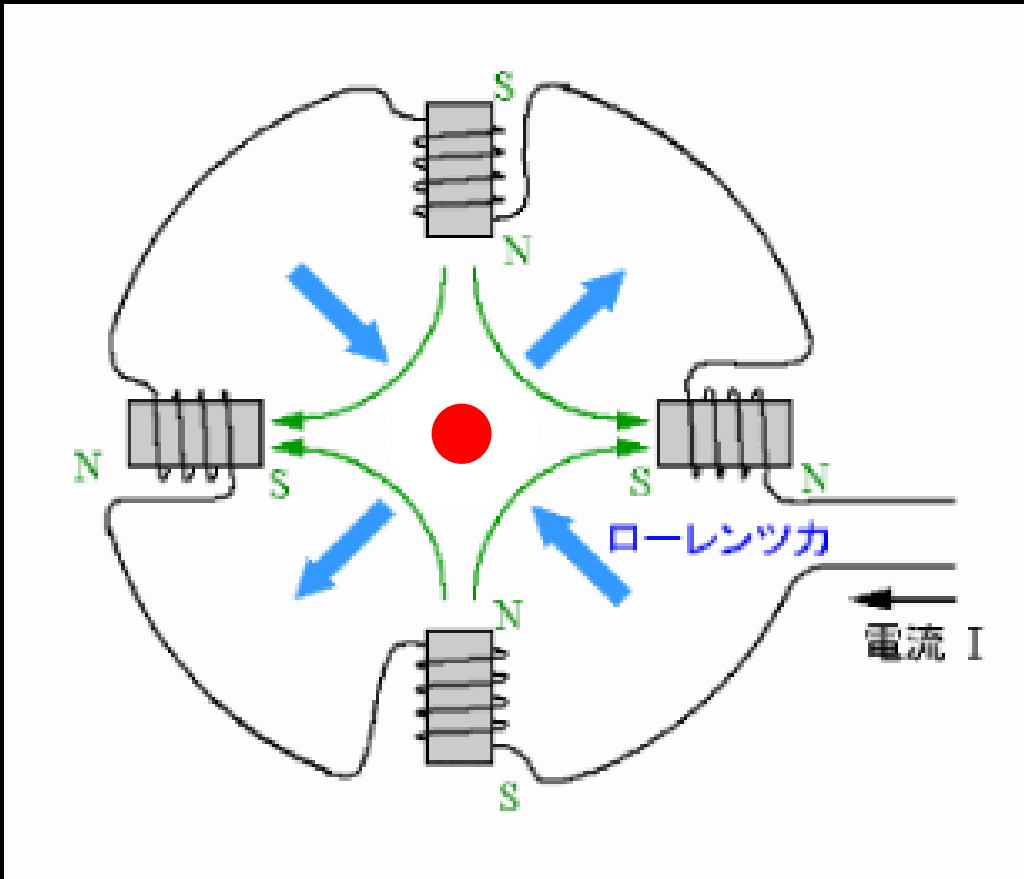


Field is not symmetrical -> lens is not round

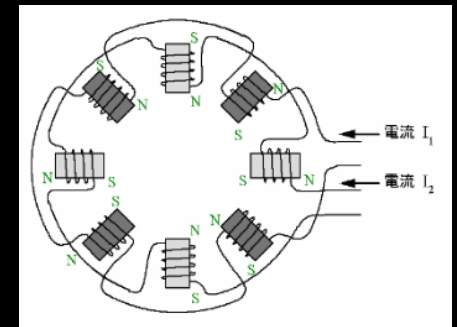
{ Small -> focus
Round -> Stigmation/stigmatism
Straight

Mechanism to correct stigmation

Stigmators x/y



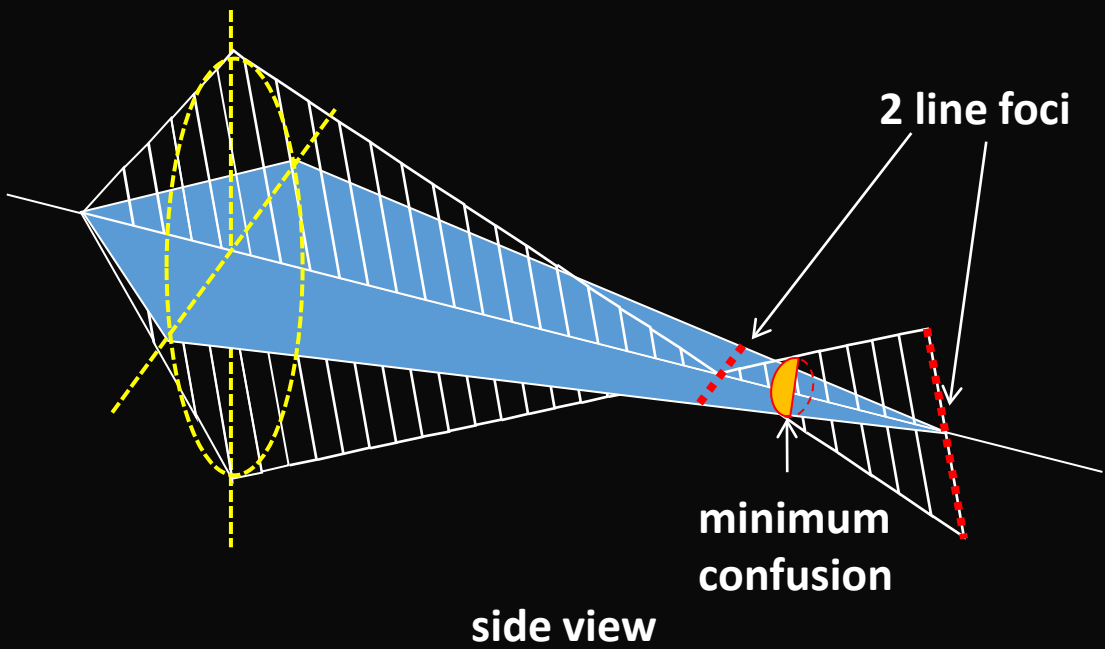
quadrupole stigmator

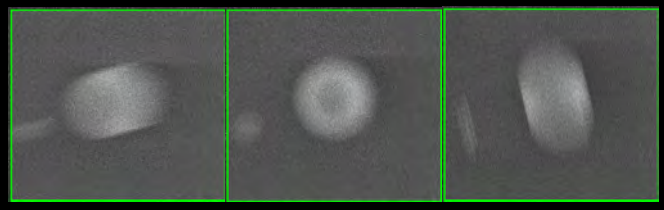
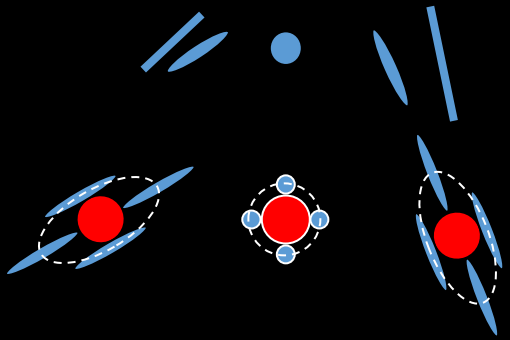
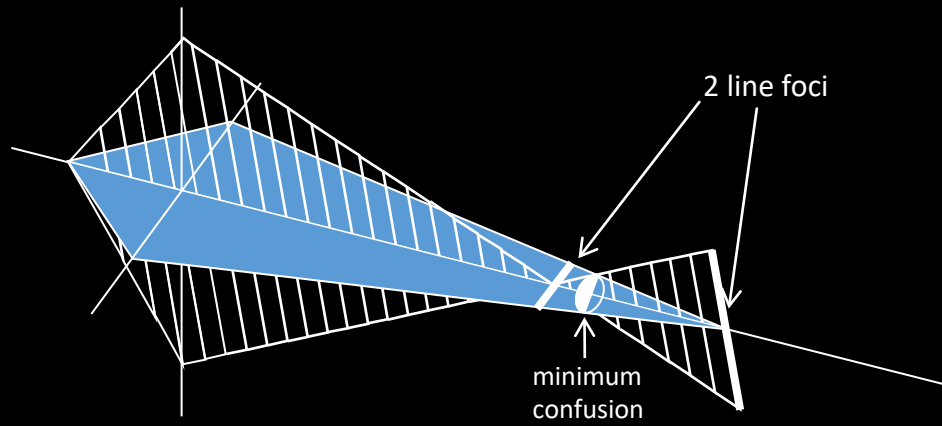


two sets of quadrupole

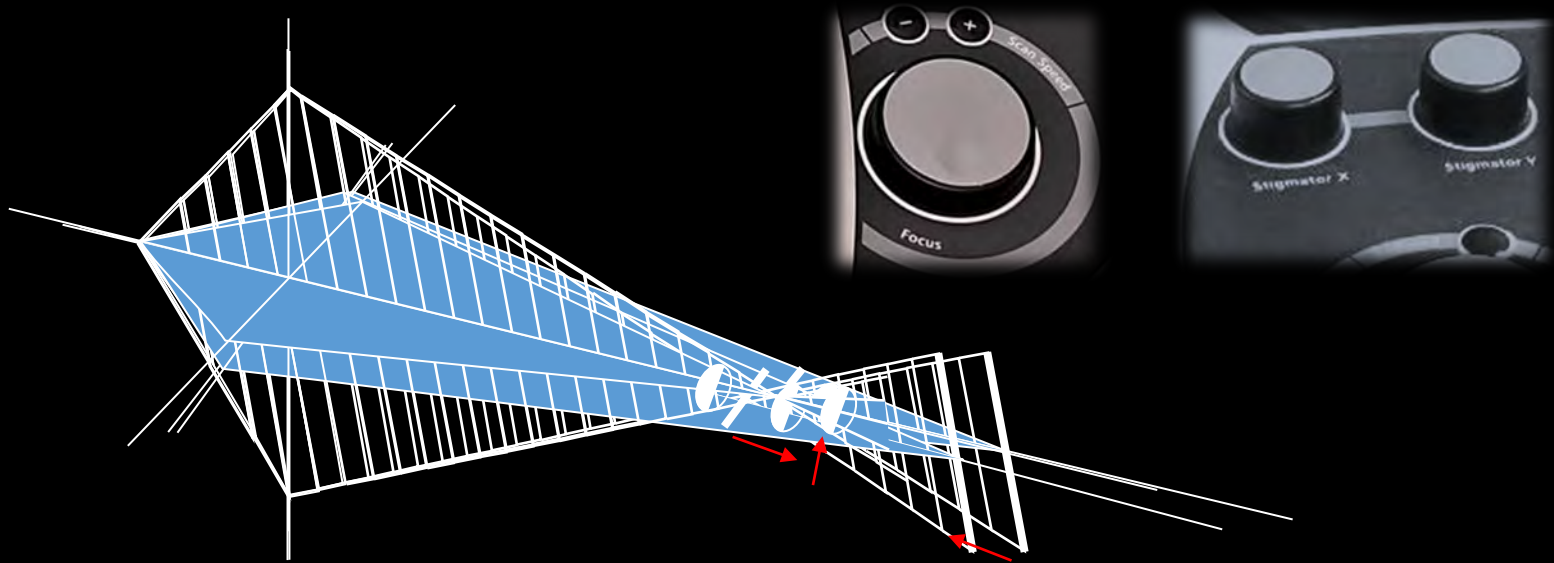
<https://www.jeol.co.jp/>

Ray diagram of a stigmated lens





How to correct stigmation



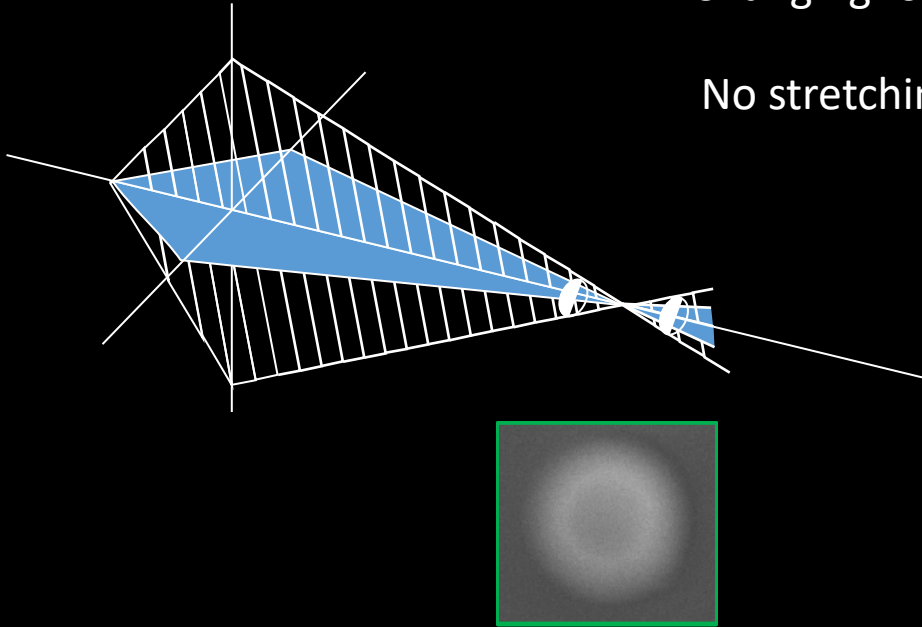
Repeating process:

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

How to test when stigmatism is corrected?

Changing focus again!

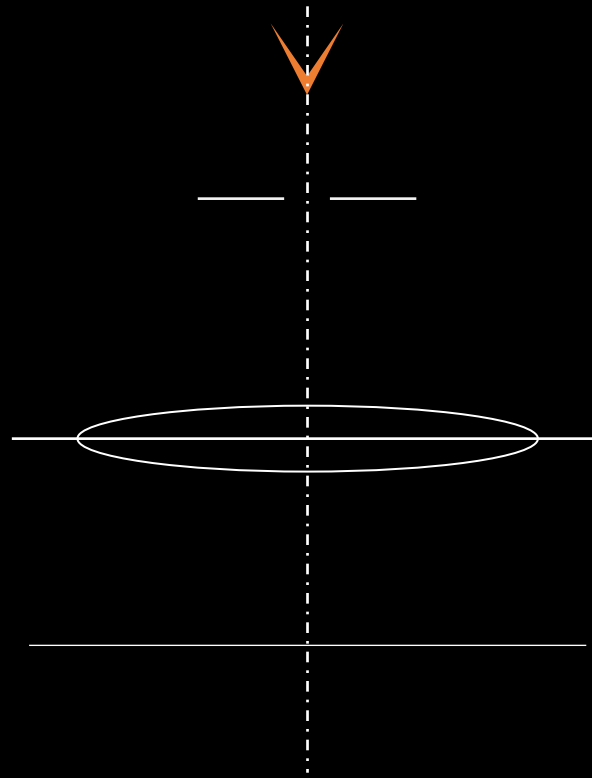
No stretching should be observed



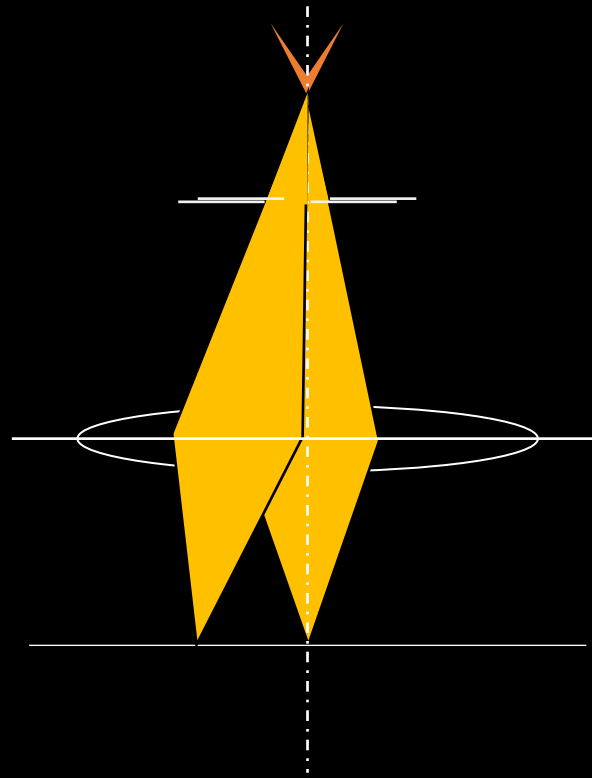
 **Small** -> **focus**
Round -> **stigmation**
Straight ?

Why straight beam?

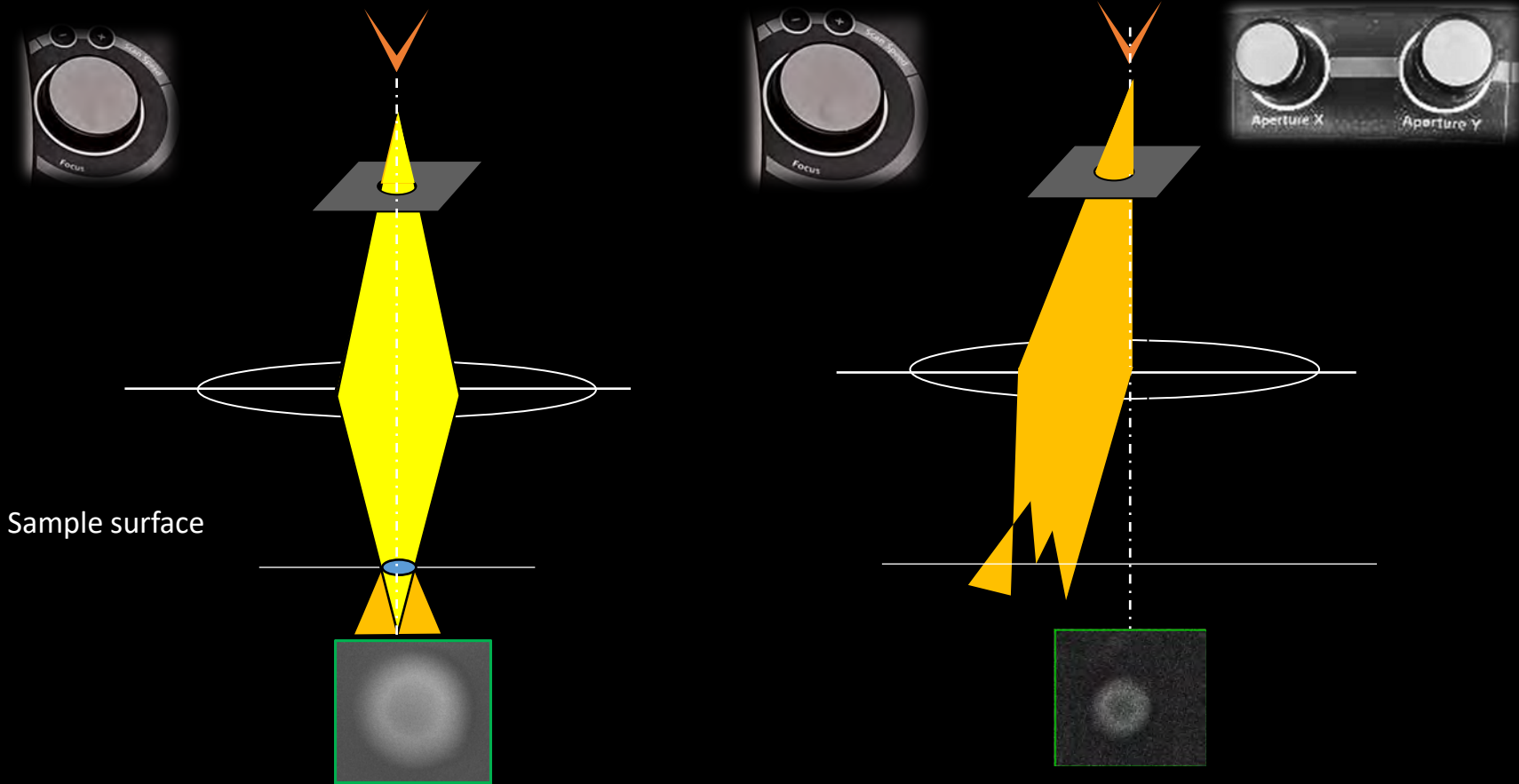
{ source
aperture
lens



What happens when aperture is off?



How do you know when aperture is off?



Small -> focus
Round -> x/y stigmatism
Straight -> x/y alignment

5 controls needed to correct the beam

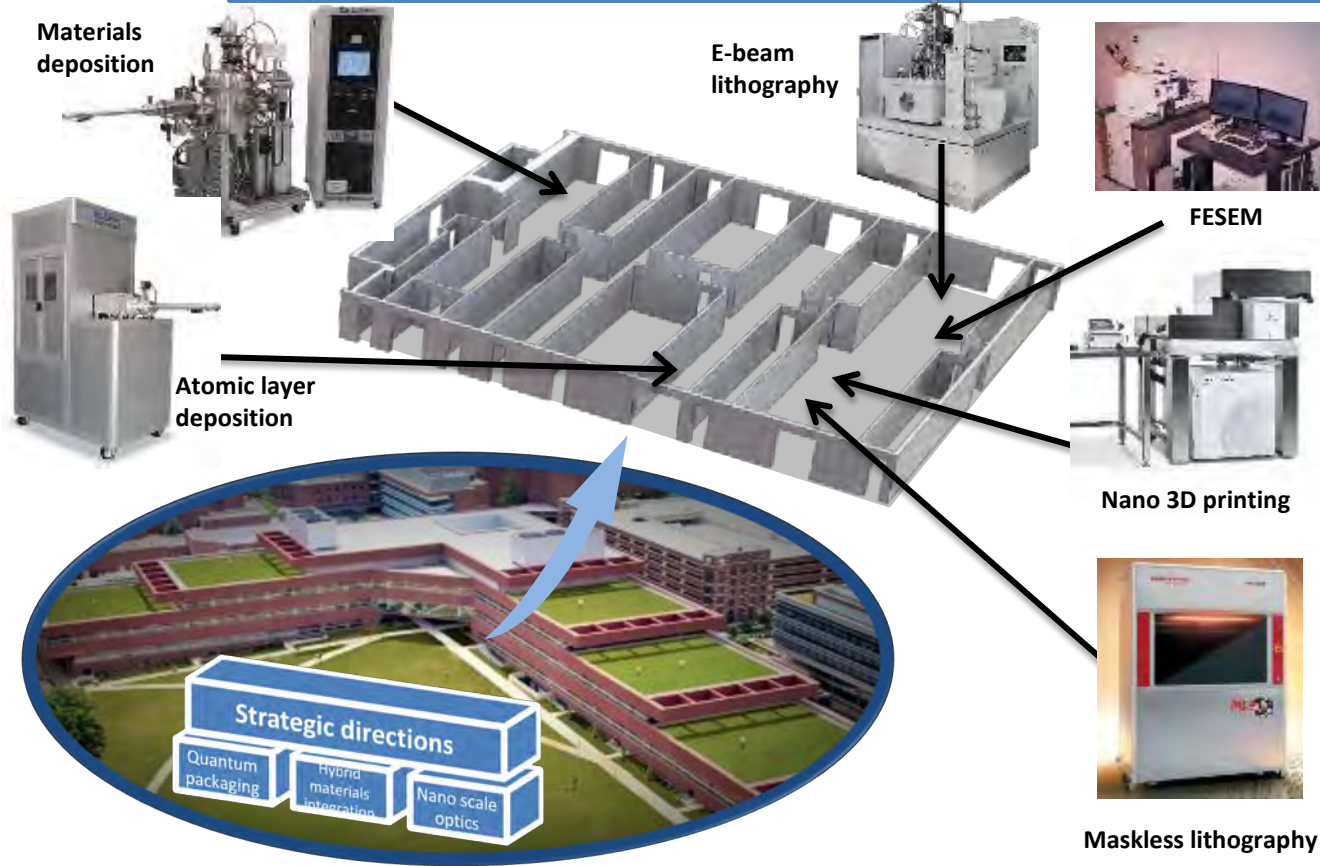




Questions?

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.

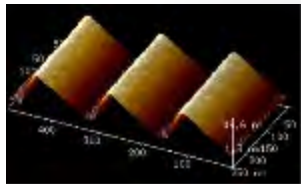
Lithography Suite:
Electron beam, ion beam, direct write optical, stepper, and contact lithography capabilities.

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

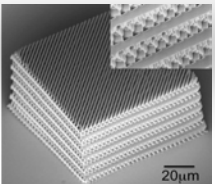
Etching Suite:
Plasma, high density plasma, and deep reactive ion etching of dielectrics and metals.

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)



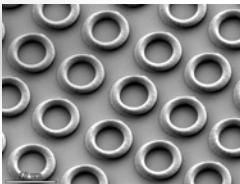
Reflection gratings for X-ray radiation



Photonic bandgap structures



Nanostructured optics



Array of toroidal nanostructures



Atomic vapor cells



Nanostructured surfaces

