Scanning electron microscope

5th CEMM workshop

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Outline

- The basic principle?
- What is an electron?
- Parts of the SEM
  - Electron gun
  - Electromagnetic lenses
  - Apertures
  - Detectors
- Electrons and their interactions with the specimen
- SEM settings and how we observe it on the image
  - Voltage
  - Current
  - WD and apertures
  - Scanning speed

What is it?

By using a focused beam of electrons, we can see otherwise invisible worlds on the microscale and nanoscale.

SEM advantages over LM:

- Resolution at high magnification
- Depth of focus (field, depth)
- Microanalysis

In LM: the specimen is unchanged by observation
In EM: interaction can have more serious consequences (heated and chemical changes)

Figure removed for copyright reasons.

But must be vacuum compatible and conductive!

(Images: ammrf)

Figure removed for copyright reasons.

Magnification is the enlargement of an image, or portion of an image. In a SEM this is achieved by scanning a smaller area. In the images, the beam is indicated by arrows on a sample.

Resolution? The ability to distinguish closely spaced points as separate points.

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(Image: ammrf)

Basic principle of SEM operation

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What is an electron?

Ambiguity: a woman's face or a man playing a saxophone

Electrons are small subatomic particles (small and firm, like a ball).

In the 1920 in Bell laboratories an experiment was made were the beam of electrons passed a double slit and was observed on the screen

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Quantum mechanics: Niels Bohr

Wave – particle duality

Example: Analogy with a spinning coin.

Image: getmedic.ru

(Images: physics.stackexchange.com*)*

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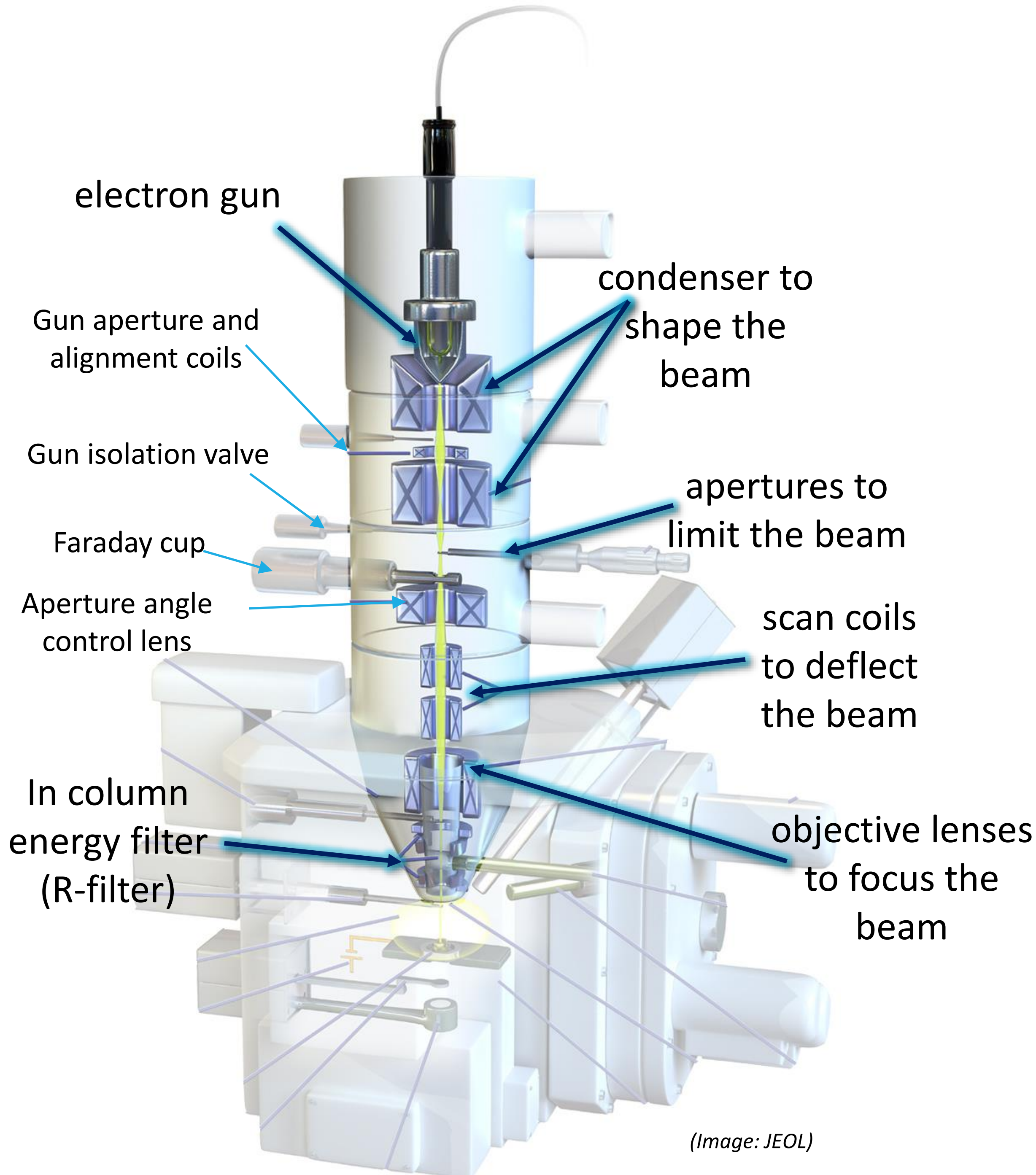
Parts of the SEM

Microscope (column and chamber), computer and other parts (vacuum system, water chilling system, microanalysis)

Microscope column



(Image: JEOL)

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Electron gun

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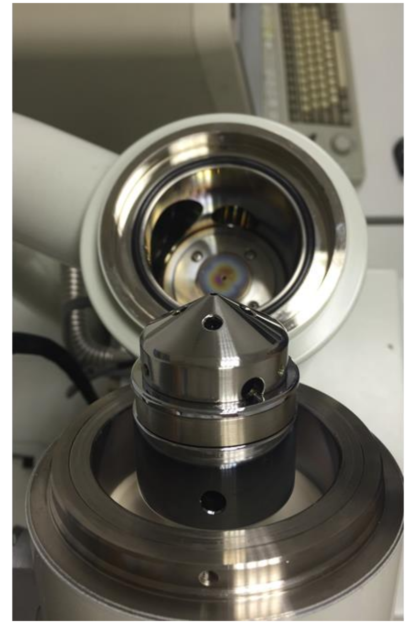
Thermionic emission

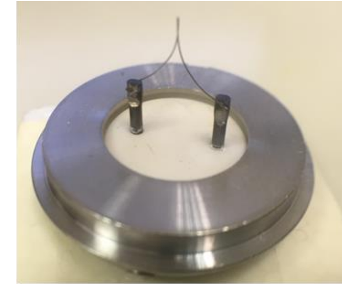
The components to produce an electron beam:

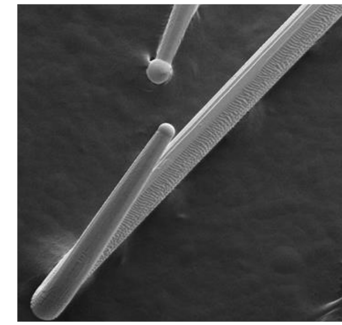
an **emitter** (electrode W or LaB6)

a surrounding cathode (**Wehnelt** cylinder/ grid cap)

an **anode** with a central hole.







JSM-5800

Figure removed for copyright reasons.

(Image: ammrf)

$$E = E_w - E_F$$

Emission current density

Tungsten: $J_{th} = 3{,}4\ A/cm^2$

$T = 2700\ K,\ E_w = 4{,}5\ eV$

LaB_6: $J_{th} = 40\ A/cm^2$

$T = 1800\ K,\ E_w = 2{,}5\ eV$

Figure removed for copyright reasons.

(Image: Goldstein)

Field emission

The FE gun consists of:

Emitter

cathode - tungsten with a very sharp point <100nm

Suppresser anode

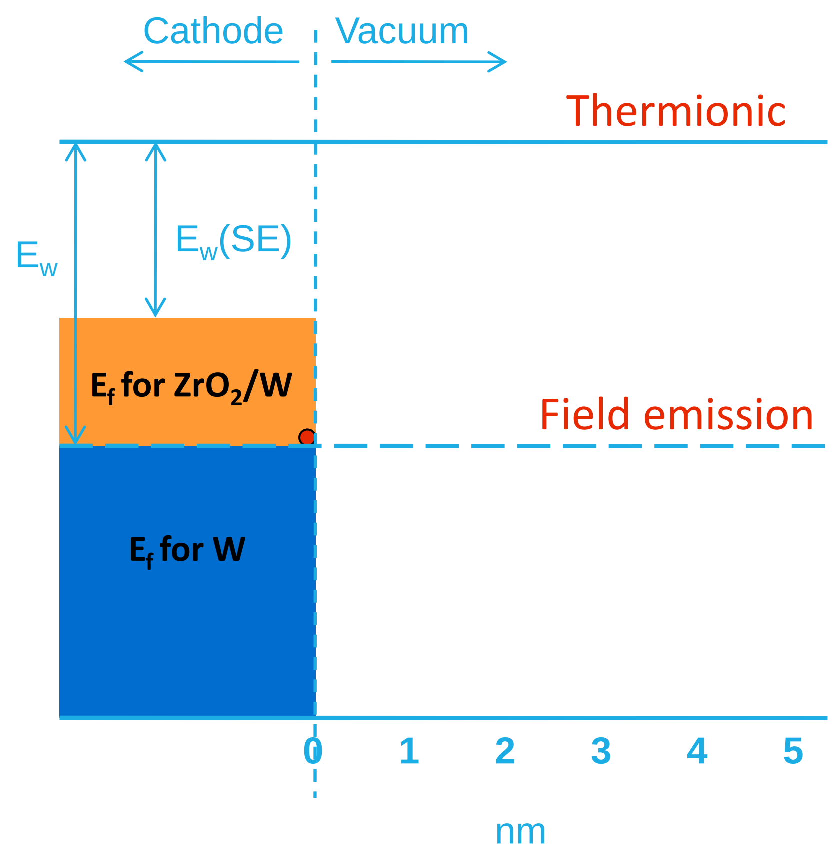
(only Schottky – field assisted thermionic emitter)

Extraction anode

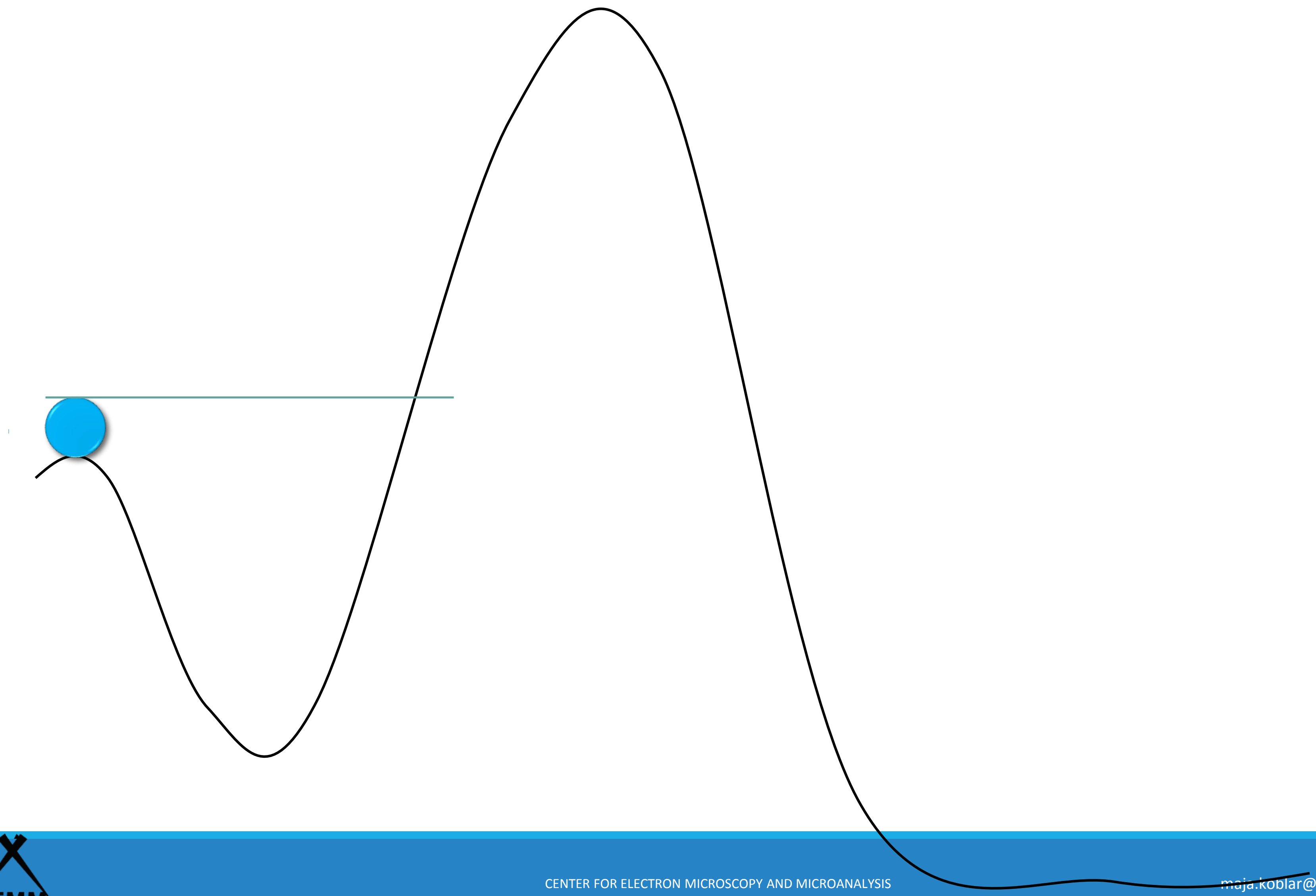
(a very strong field at the tip $>10^7$ V/cm)

Accelerating anode

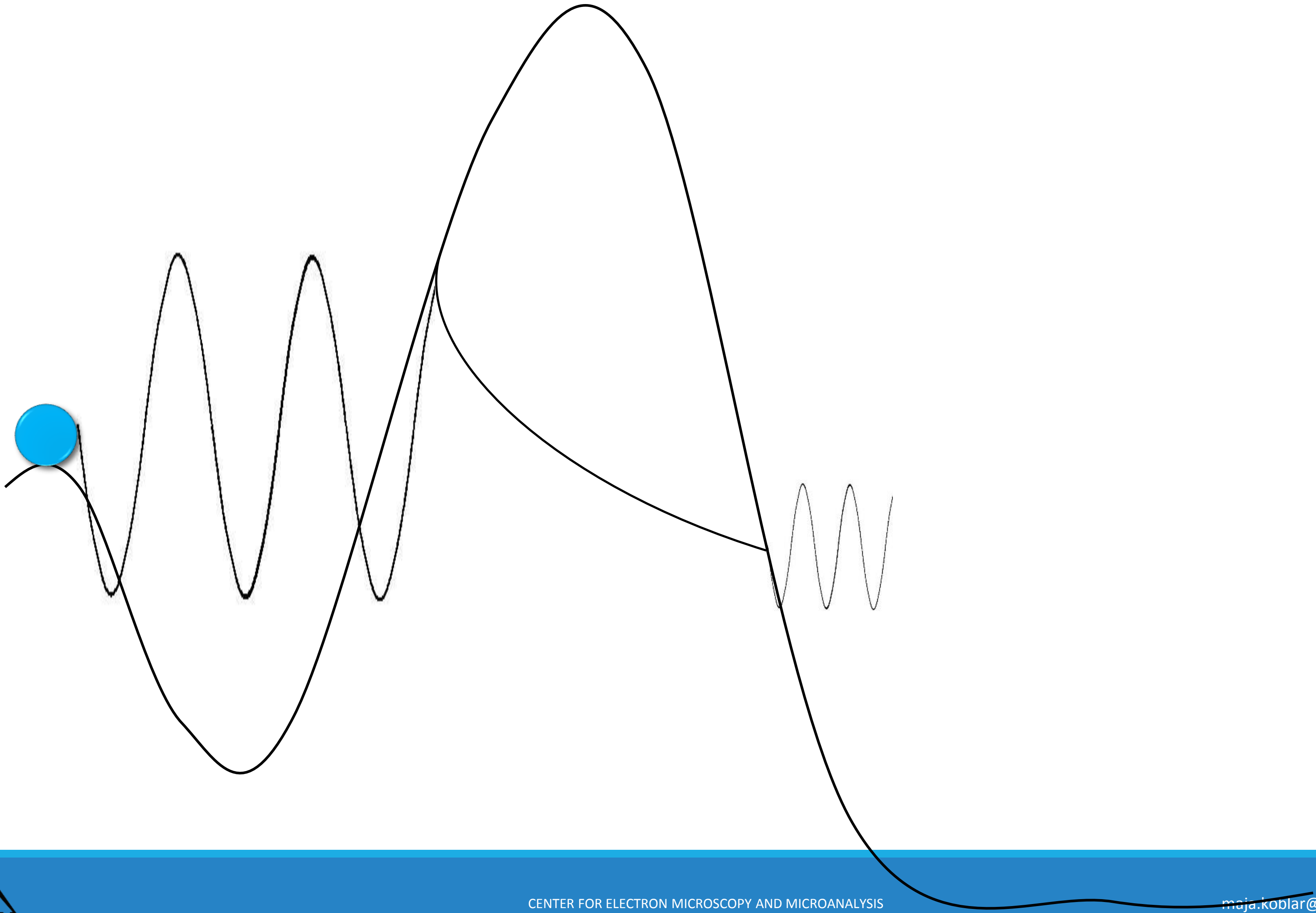
(final accelerating)



Quantum tunnelling



Quantum tunnelling



Schottky FEG

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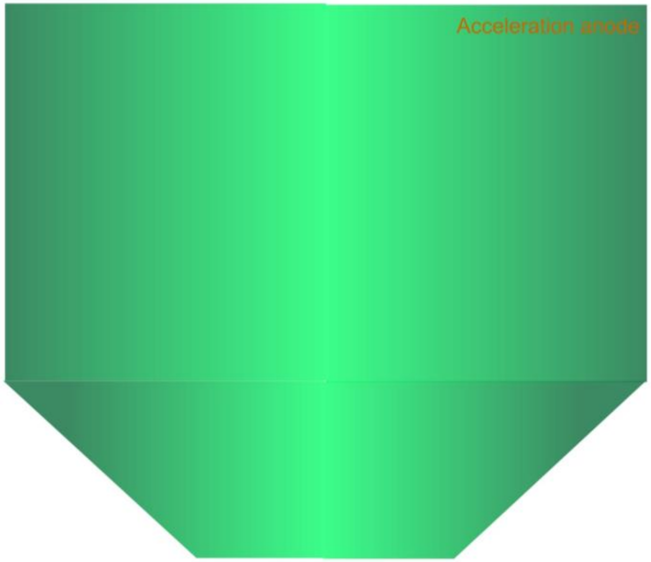
(Image: tnw.tudelft)



(Image: JEOL)

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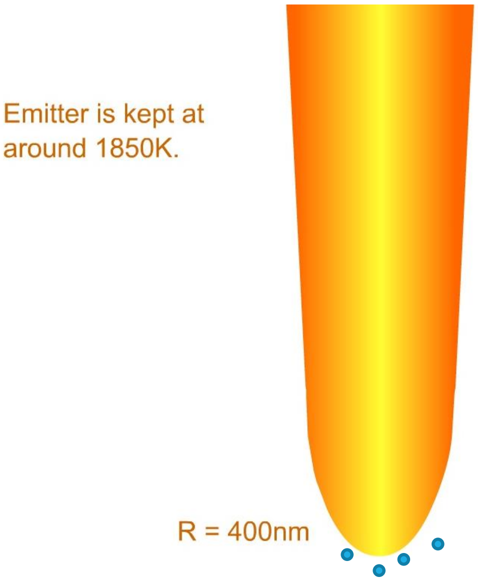

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Comparison of electron guns

Emitter Type Cathode material	Thermionic W	Thermionic LaB_6	Schottky FEG ZrO/W (100)	cold FEG W(310)
Operating temperature [K]	2,800	1,900	1,800	300
Cathode radius [nm]	60,000	10,000	< 1,000	< 100
Effective source radius [nm]	15,000	5,000	15	2.5
Emission current density [A/cm^2]	**3**	30	**5,300**	17,000
Total emission current [µA]	200	80	200	5
Normalized brightness [A/cm^2.sr.kV]	**1×10^4**	1×10^5	**1×10^7**	2×10^7
Maximum probe current [nA]	1000	1000	10 - 100	0.2
Energy spread @ cathode [eV]	0.59	0.40	0.31	0.26
Energy spread @ gun exit [eV]	**1.5 - 2.5**	1.3 - 2.5	**0.35 - 0.7**	0.3 - 0.7
Beam noise [%]	1	1	1	5 - 10
Emission current drift [%/h]	**0.1**	0.2	**< 0.5**	5
Operating vacuum hPa/mbar[1]	**$< 1 \times 10^{-5}$**	$< 1 \times 10^{-6}$	**$< 1 \times 10^{-9}$**	$< 1 \times 10^{-10}$
Typical Cathode life [h]	**100**	> 1000	**> 5000**	> 2000
Cathode regeneration	not required	not required	not required	every 6 to 8 hours
Sensitivity to external influence	minimal	minimal	low	high

(Table: tedpella)

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Electromagnetic lens system

Condenser lens, objective lens and scanning coils.

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EM lenses

Similar to glass lenses in optical microscopes.

Main role of EM lenses is to demagnify the source of electrons to form a much smaller diameter probe.

Two main lenses used in SEM:

- Condenser lenses
- Objective lenses

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(Images: ammrf)

EM lenses

CONDENSER LENS

The main role of the condenser lens is to control the size of the beam and determines the number of electrons in the beam which hit the sample.

OBJECTIVE LENS

Focuses electrons on the sample at the working distance.

(Images: ammrf)

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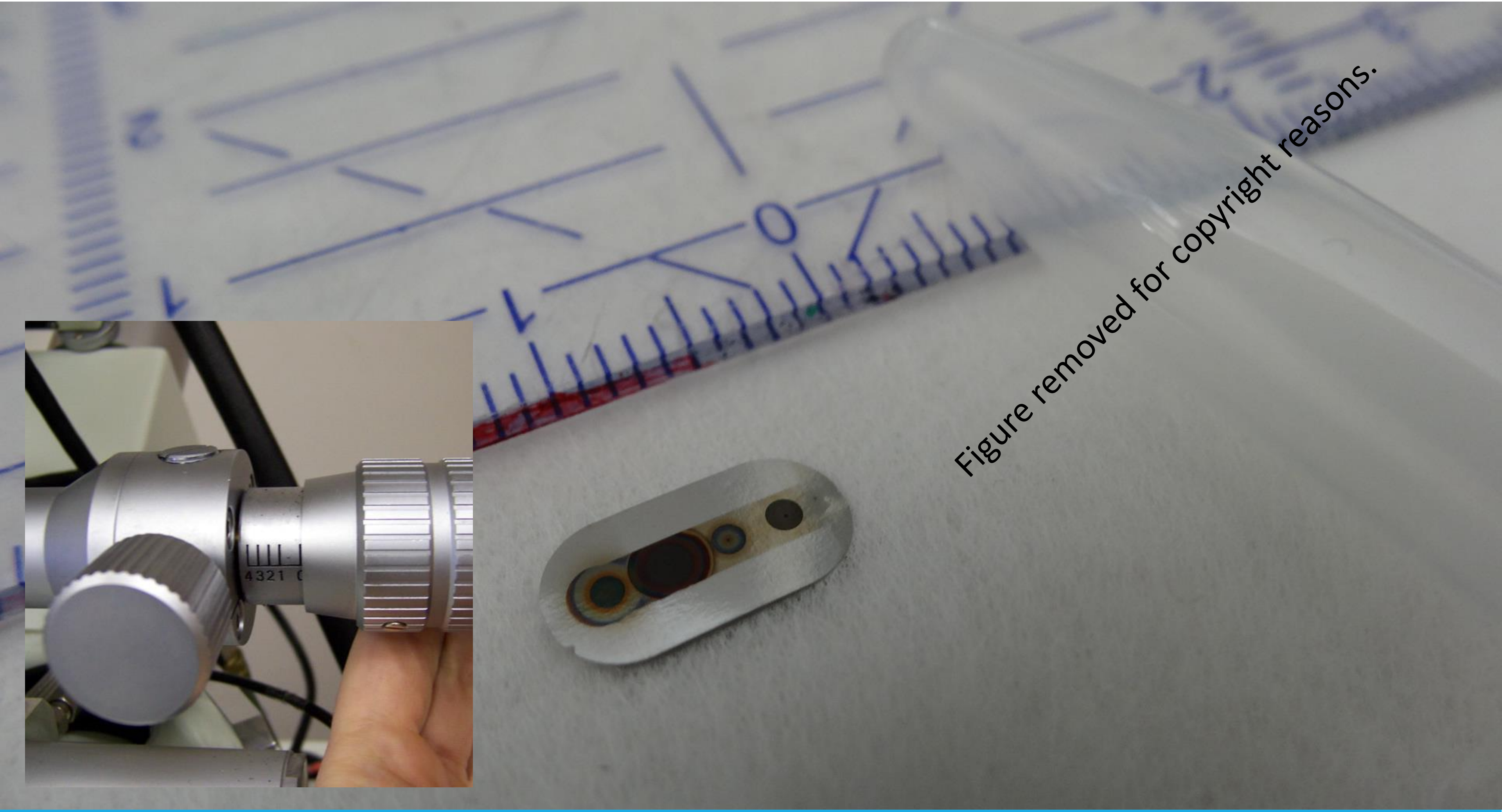

Apertures to limit the beam

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Apertures

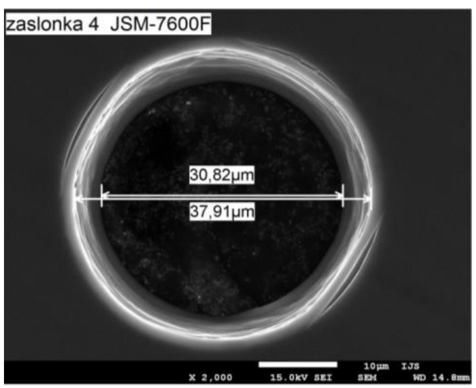
For ultra high resolution – use the smallest 30 µm (smaller probe, low current, large depth of focus).

For microanalysis – use the largest 110 µm (observation at high currents, shallow depth of focus, higher statistics).

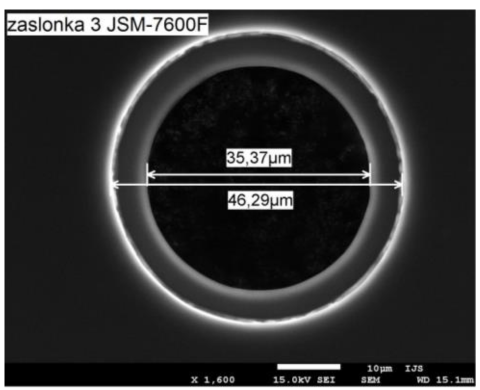
For usual observation – use 50 µm.

To work with high probe current, but still good resolution – use 70 µm.

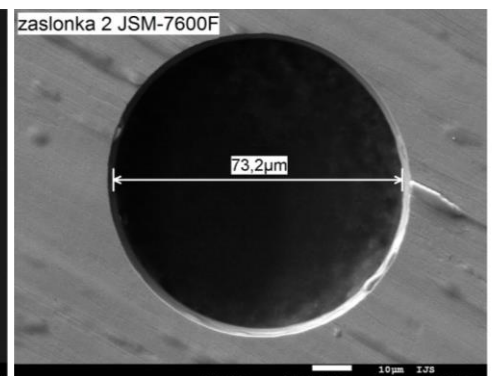
Needs to be changed regularly.



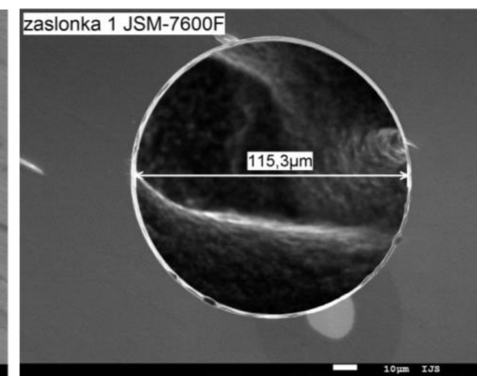
30 µm



50 µm



70 µm



110 µm

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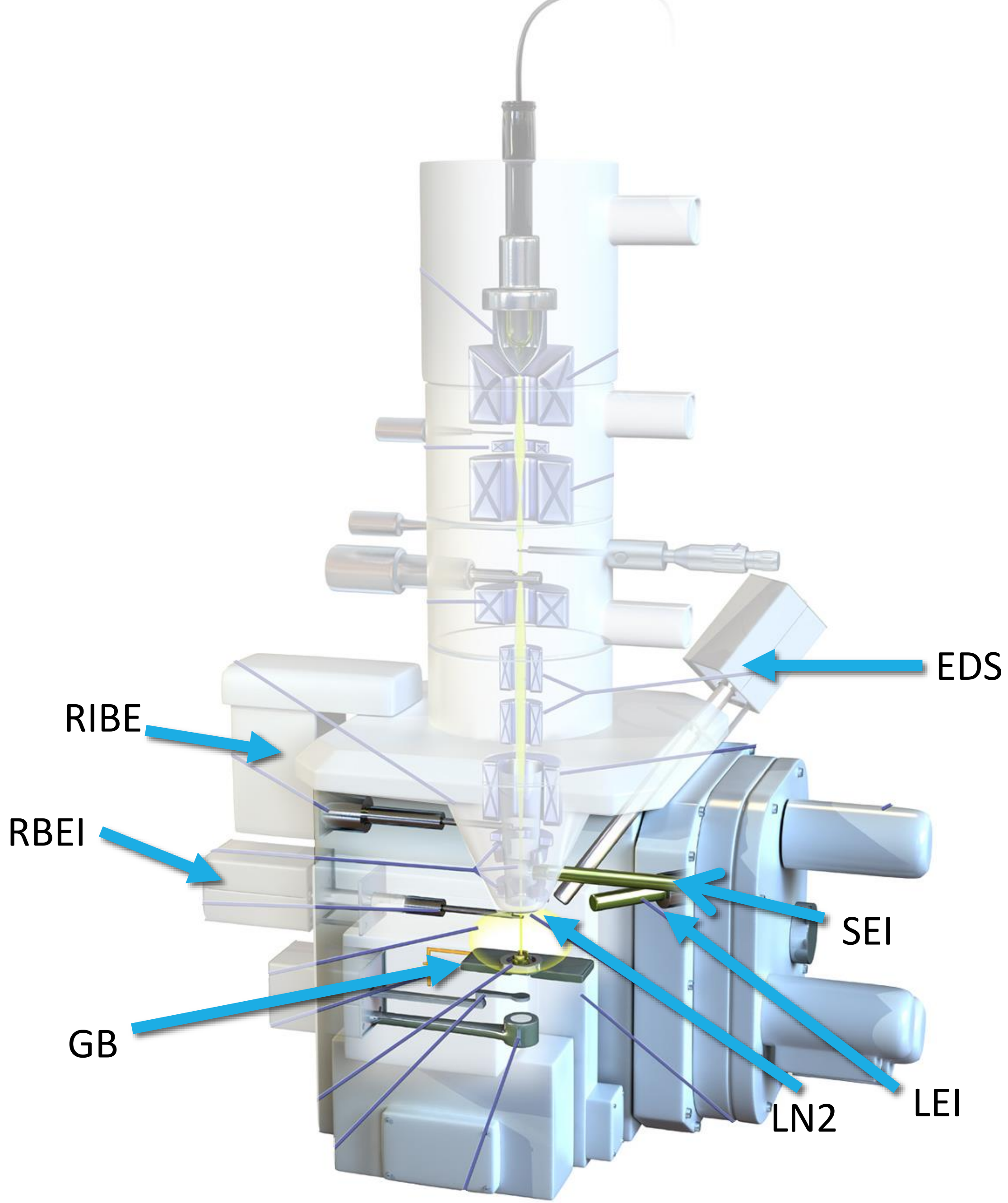
Sample chamber

motorized stage (x,y,z,t,r)

detectors



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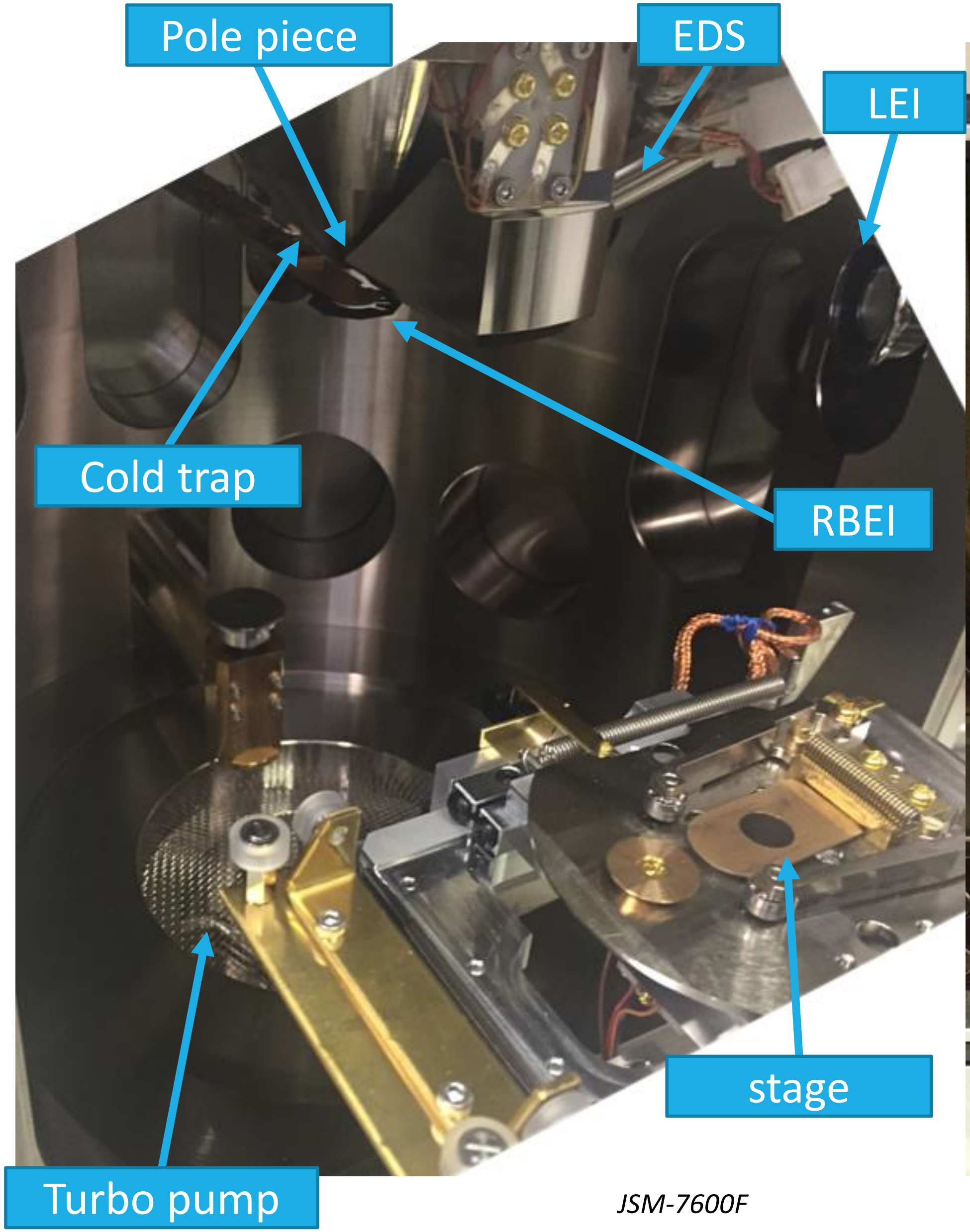
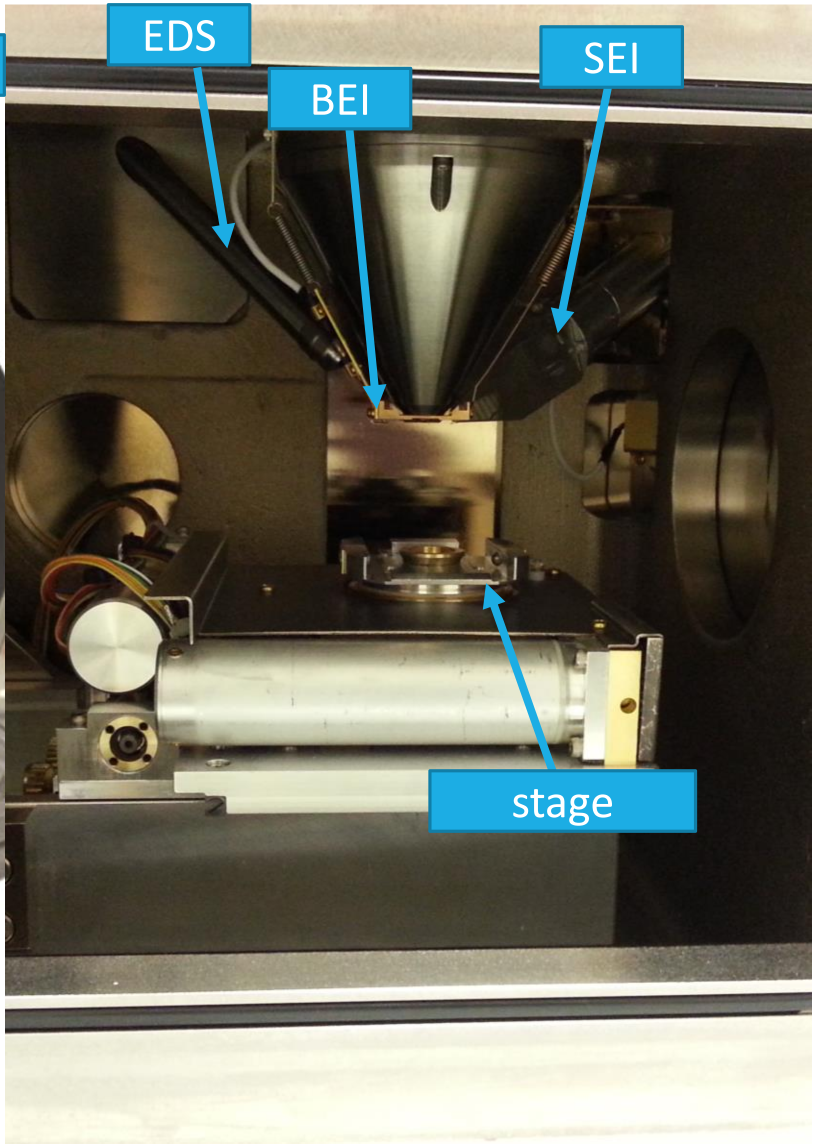


JSM-7600F



JSM-5800

Electrons and their interactions with the specimen

But we will not talk about excitation, we will talk about ionization.

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Interactions

Electrons:

- Secondary (low energy)
- Backscattered (high energy)
- Transmitted
- Auger electrons
- Beam current

Photons

- X-rays
- cathodoluminescence

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SEM

TEM

(Images: Low Voltage Electron Microscopy: Principles and Applications)

SEM signal

Secondary electrons (SE)

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Backscattered electrons (BSE)

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Primary incident beam of electrons of sufficient energy, hits a surface (SEM) or passes through some material (TEM) and induces the emission of secondary particles.

Total electron yield: $\sigma = \delta + \eta$

SE yield (δ)

the number of secondary electrons emitted per incident particle is called secondary emission yield

Figure removed for copyright reasons.

BSE yield (η)

the number of backscattered electrons emitted per incident particle is called backscattered emission yield

Figure removed for copyright reasons.

CEMM

Signal

Secondary electrons

- High resolution
- Strongly topography sensitive
- Little element sensitive
- Sensitive to charging

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Backscattered electrons

- Lower resolution
- Atomic number contrast in particular strong signal to heavy atoms
- Less sensitive to charging

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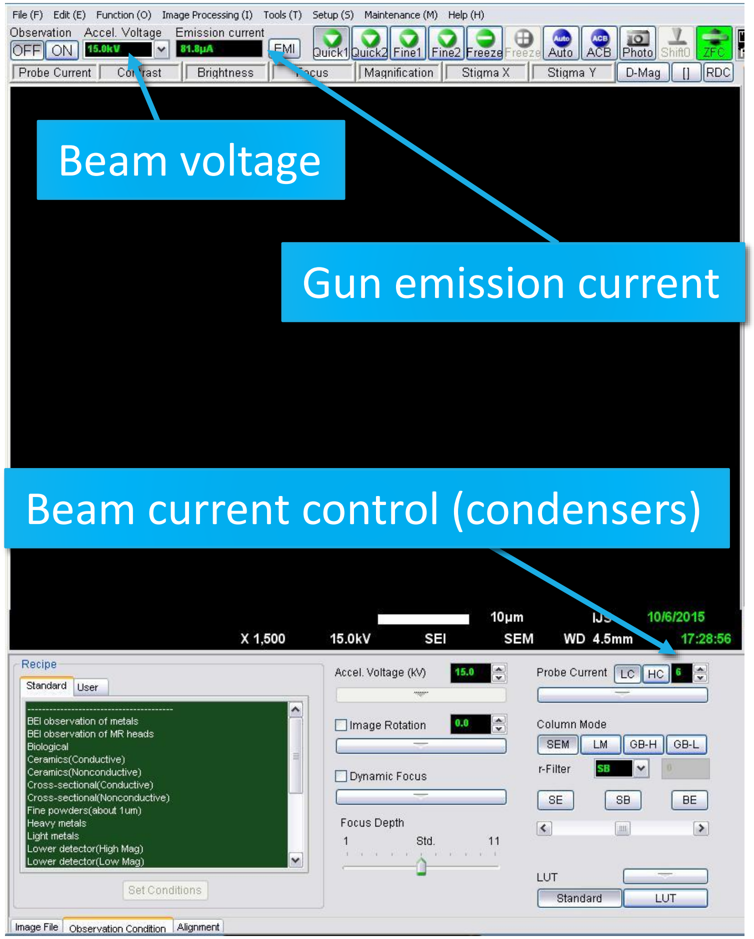
SEM settings

Voltage (electrical potential)
- Consider as the spread or energy of electrons
- Typically 1-30 kV or keV

Current (number of electrons/unit time (amps))
- 1 coulomb ~ 6 x 10^{18} electrons
- 1 A = 1 C/s
- Typically from 10^{-12} A to 10^{-9} A
- So 1 nA~ 9 x 10^{9} electrons/sec

WD and apertures



Voltage

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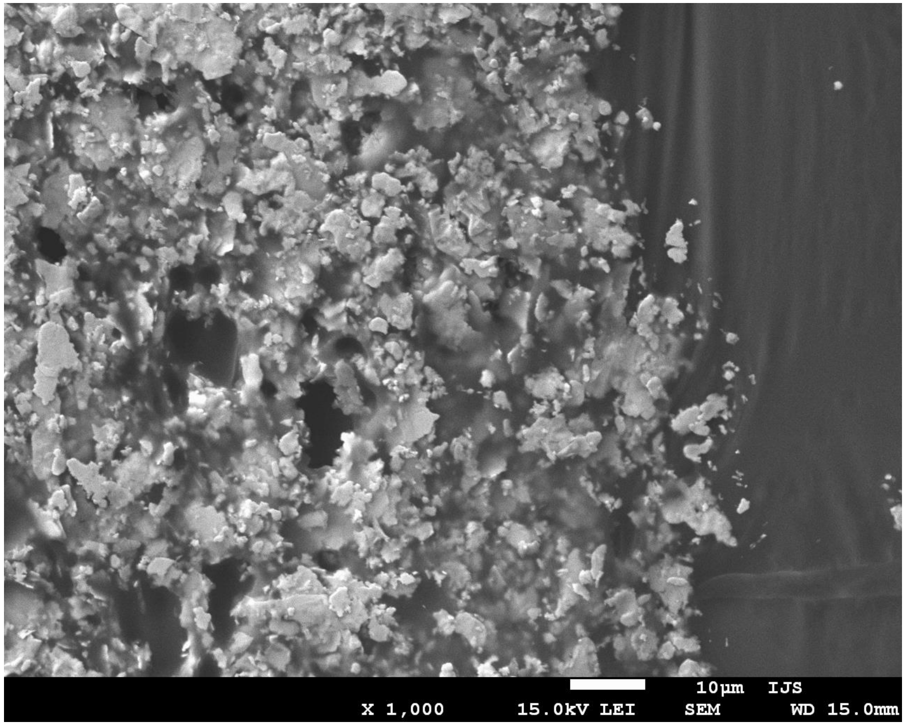
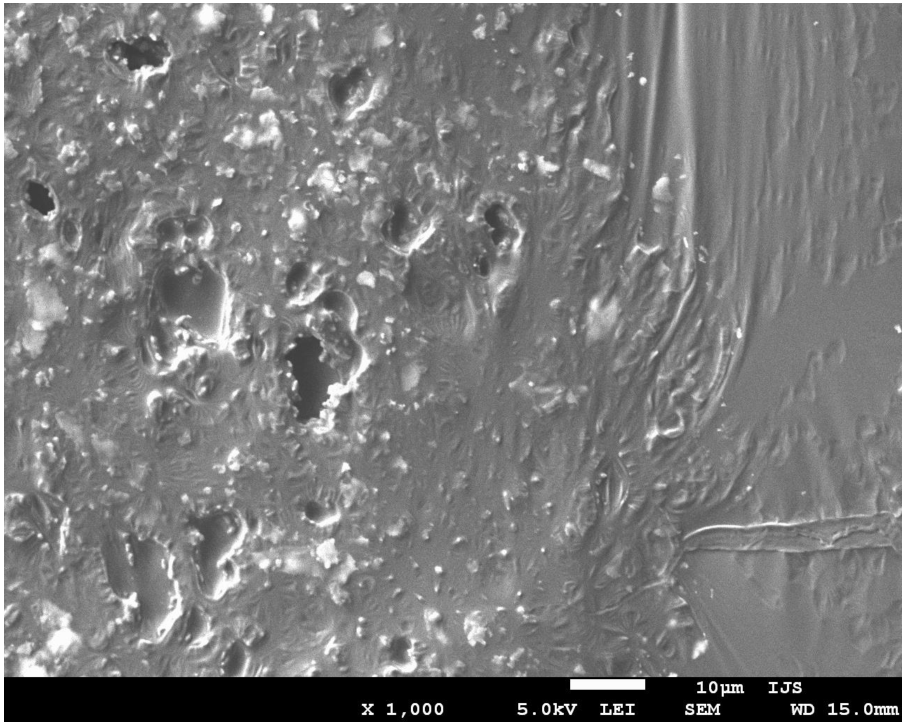
(Images: ammrf)

Voltage

15 kV



5 kV



Probe current

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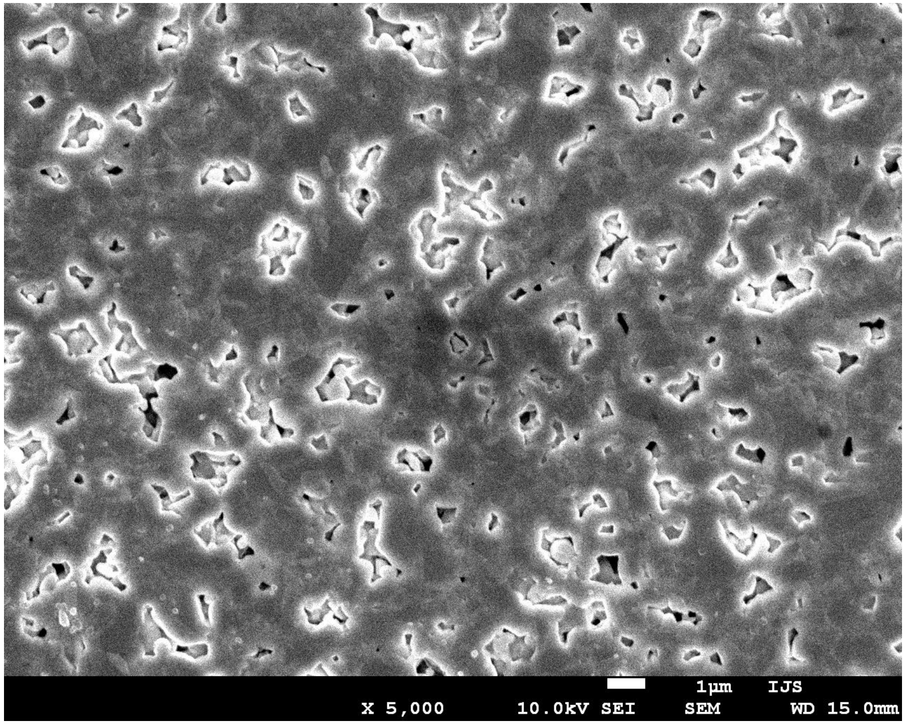
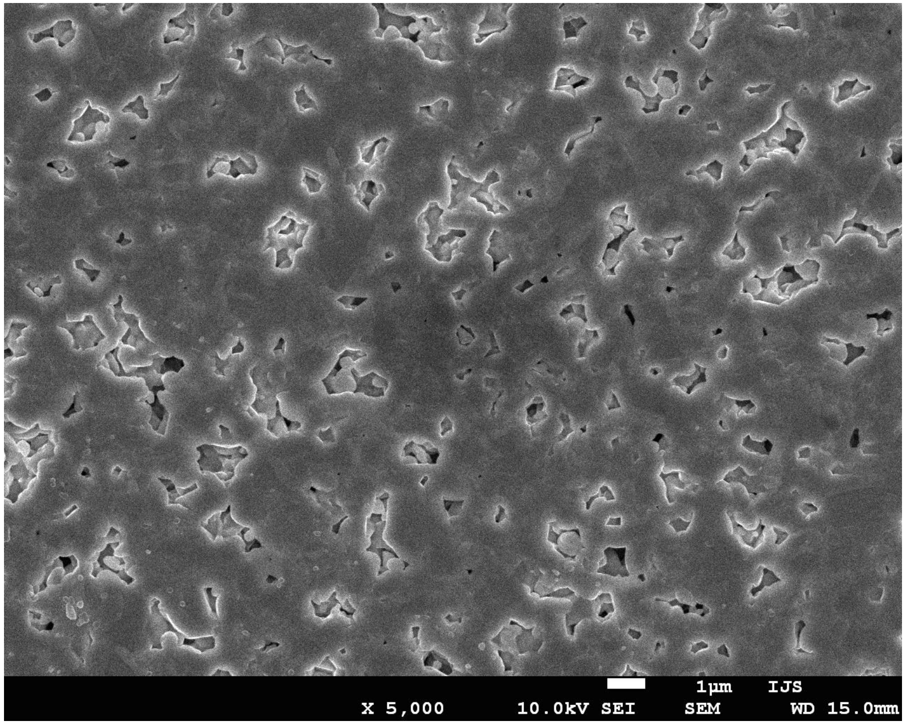
(Images: ammrf)

Probe current

PC 8 → 0,35 nA



PC 6 → 0,08 nA



Depth of focus

The WD and the aperture impacts on the **depth of field** and **resolution** of the SEM image

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(Images: ammrf)

High DOF:

use smaller aperture and larger WD

Low DOF:

use bigger aperture and smaller WD

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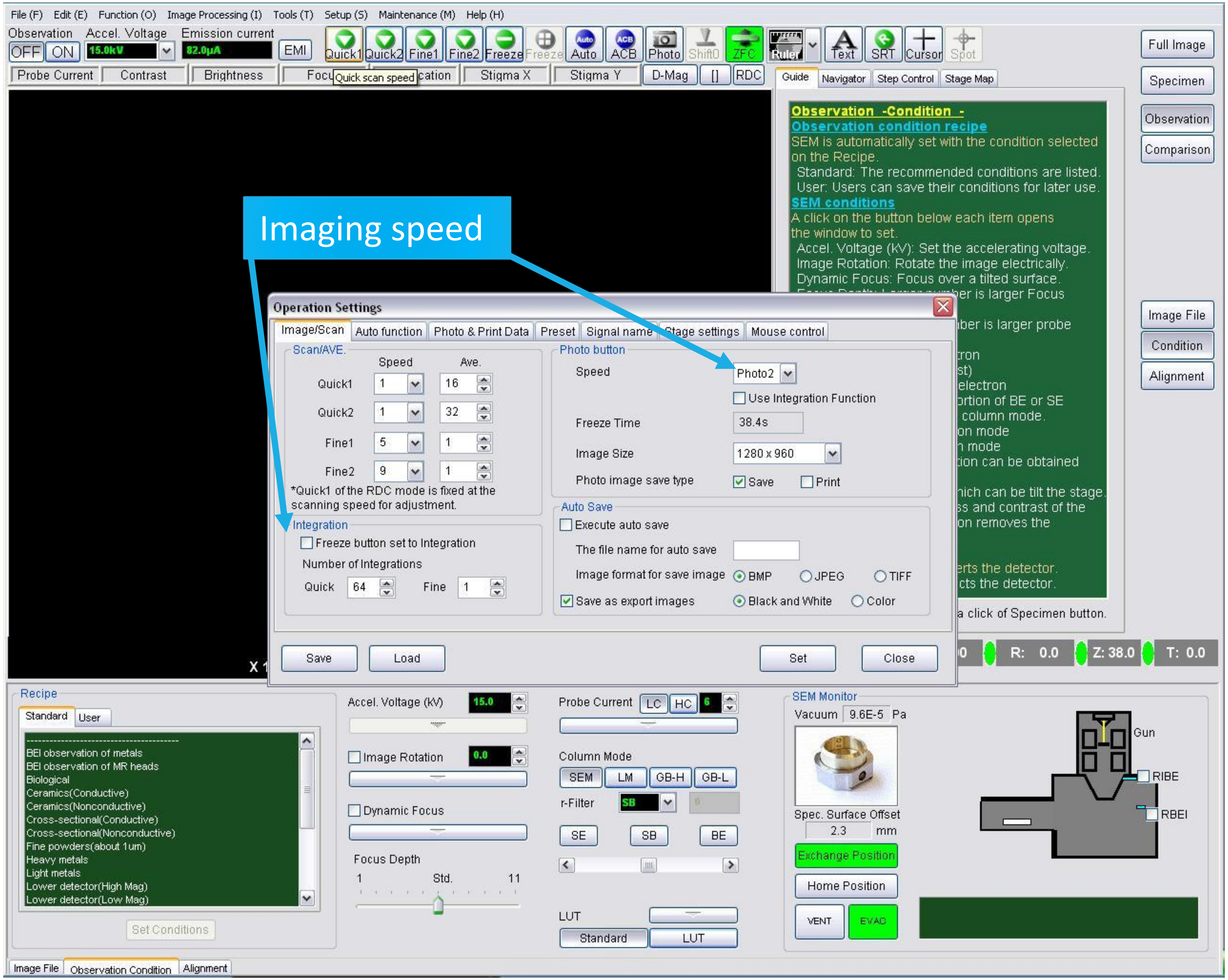

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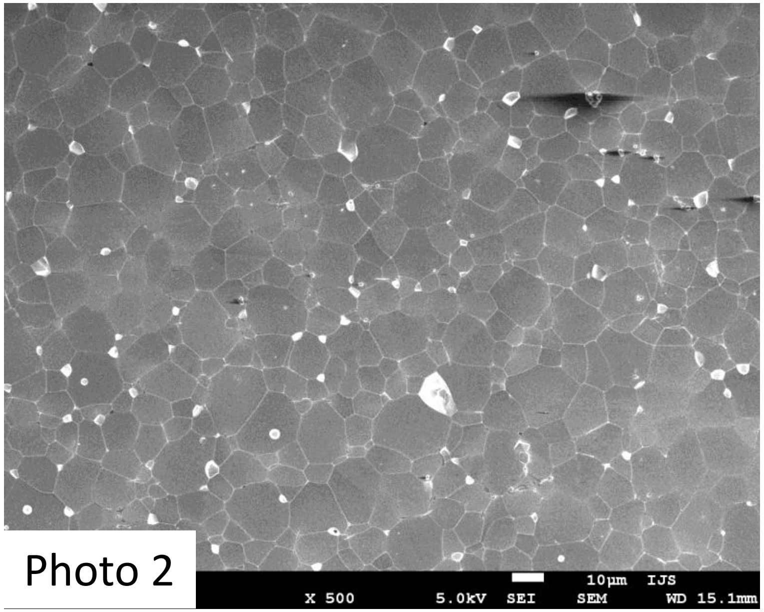
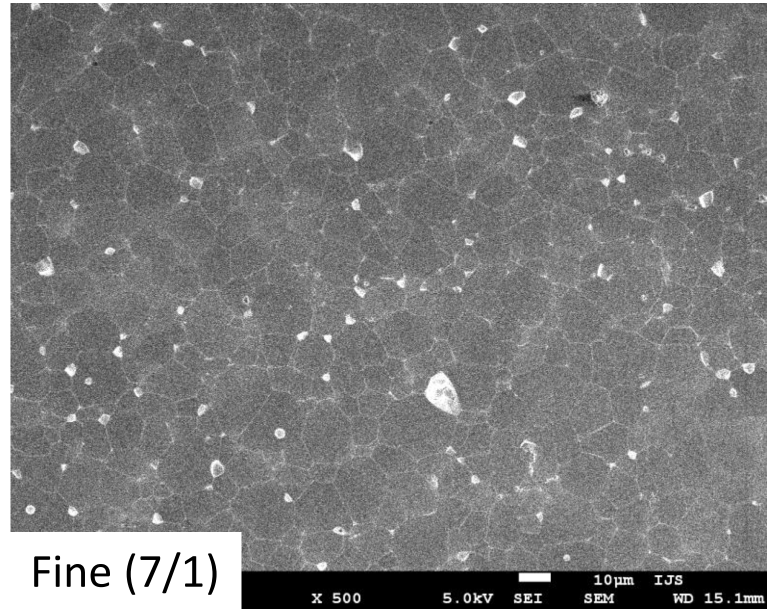
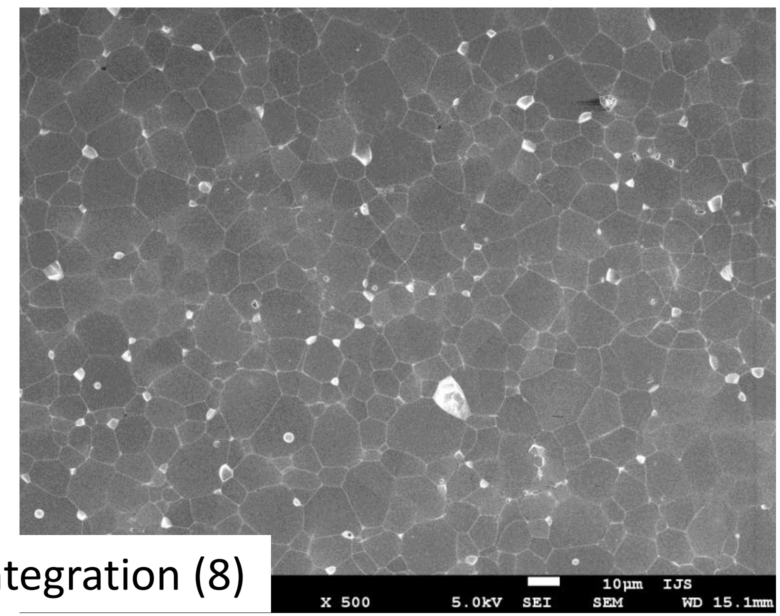


Photo 2



Fine (7/1)



Fine (7/1) + integration (8)

What is the working distance?

A. The seated distance between the microscopist and the microscope

B. The distance from the specimen to the secondary electron detector

C. The distance from the specimen to the objective lens pole piece

D. The distance from the specimen to X-ray detector

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JSM-5800 and JSM-7600F

Different height of samples

BSE on 5800 damaged!!
BSE on 7600F carbon tape on it!!

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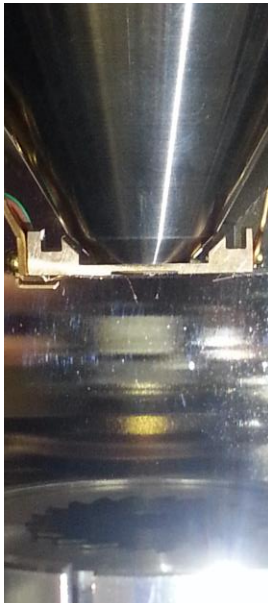
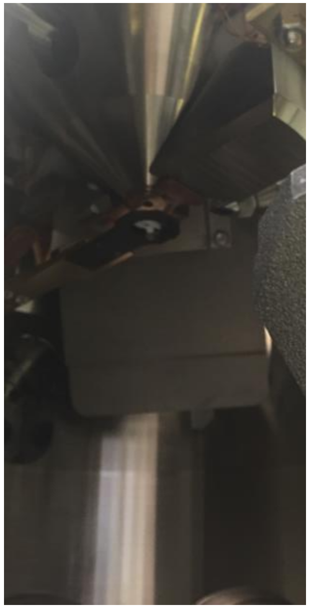
(Image: ammrf)





Magnetic samples

A) minimal amount as possible!

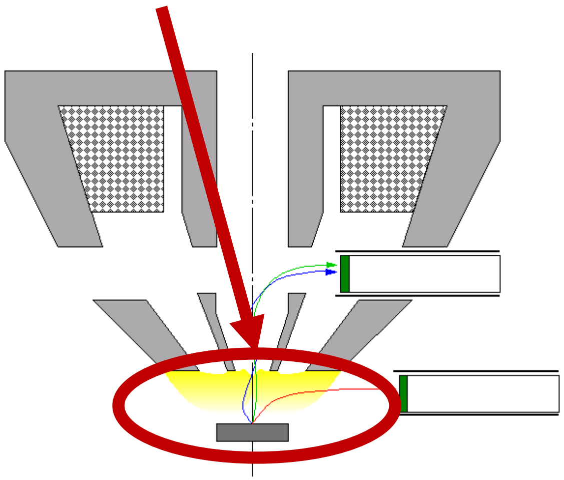
- **Bulk - less force**
- **Powder – to avoid flying of the holder**

B) mount it very good! Use special holder

C) use slow movement (x, y and z) under the objective lens!

- **Turn on LM mode**
- **Be further away from the pol piece**

D) focus, stigmatizm … very slowly!



Take home information

- The SEM works differently than LM
  - But there are some similarities
- Why is it possible to image with electrons
  - The wave particle duality and the scanning mode makes it possible
- Different parts of the SEM and what is the difference between them
  - Why we have different types of electron gun (W, FE)
  - How the electromagnetic lenses work and why magnetic samples are a problem
  - Why we need Apertures
  - Detectors
- Electrons and their interactions with the specimen and what kind of information we get from SE and BSE image
  - SE yield
  - BSE yield
- SEM settings and how we observe it on the image
  - What is the difference in image depending on the
    - Voltage
    - Current
    - WD and apertures
    - Scanning speed

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QUESTIONS?
COMMENTS?
CONCERNS?

Next workshop on 7.8.2017:

- EDS,
- WDS,
- EBSD,

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