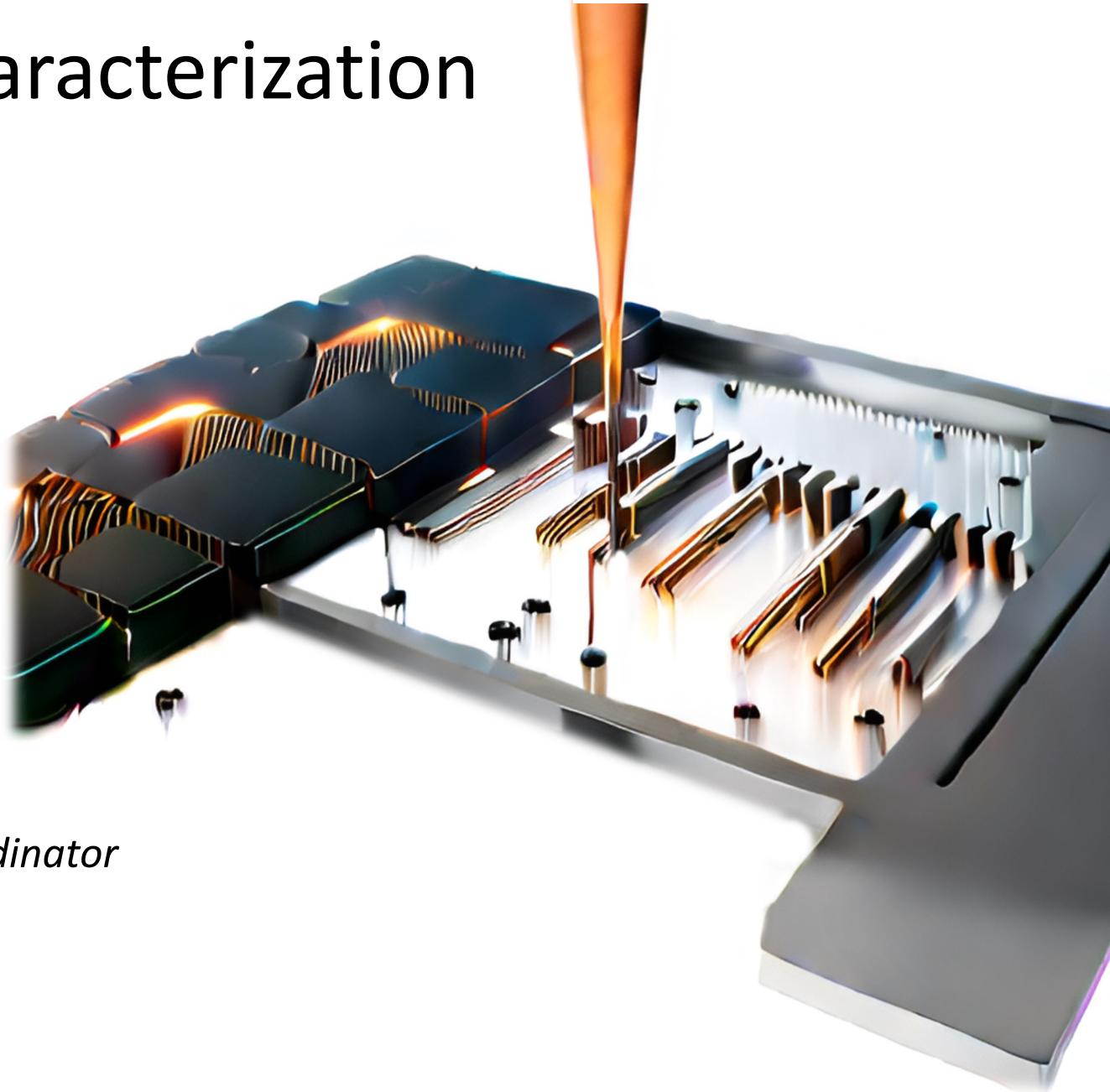


68320 Nanofabrication and Nanocharacterization Techniques



UNIVERSITY OF
TECHNOLOGY SYDNEY

Lecture 1 Introduction



Lecturer & Subject Coordinator

Prof Milos Toth

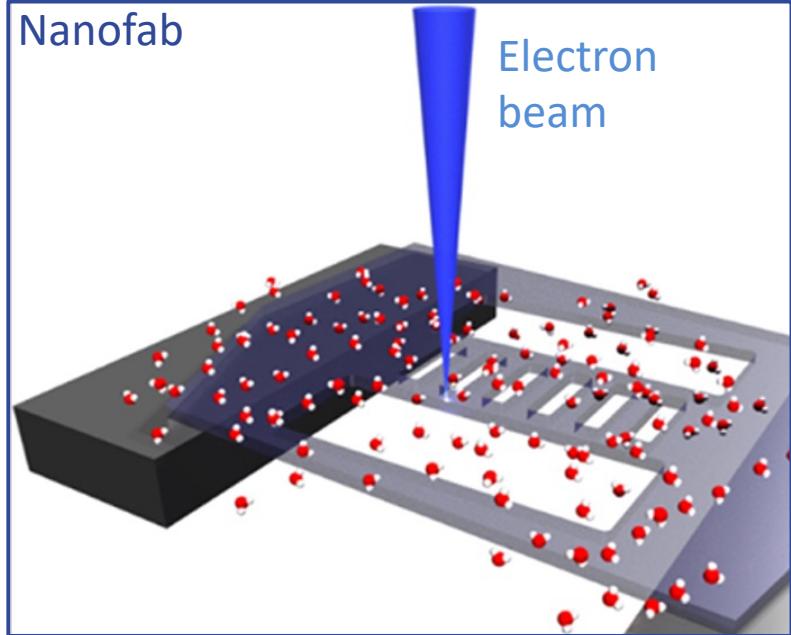
milos.toth@uts.edu.au

Brief introduction to electron, ion and laser beam techniques: imaging, analysis and nanofabrication

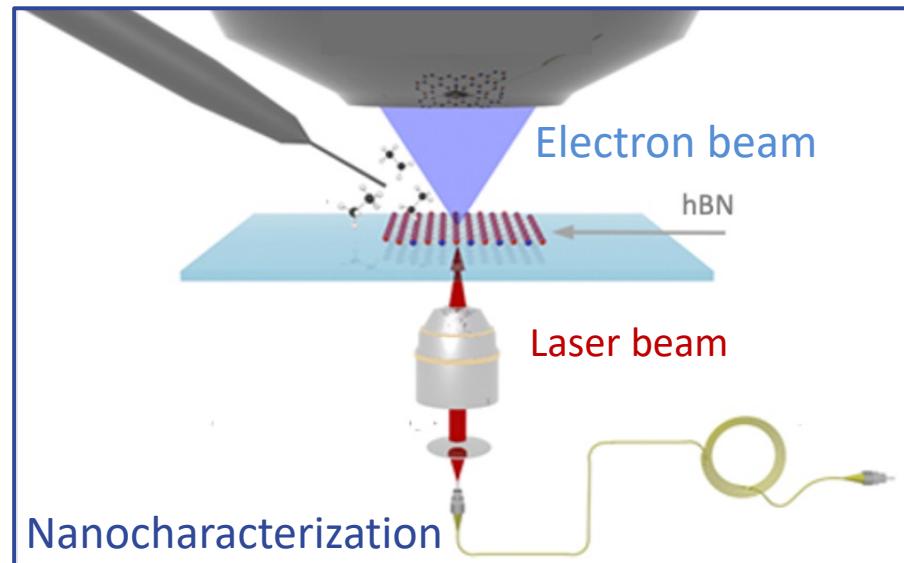
Overview

3D printing on the nanoscale

Nanofab



Electron beam



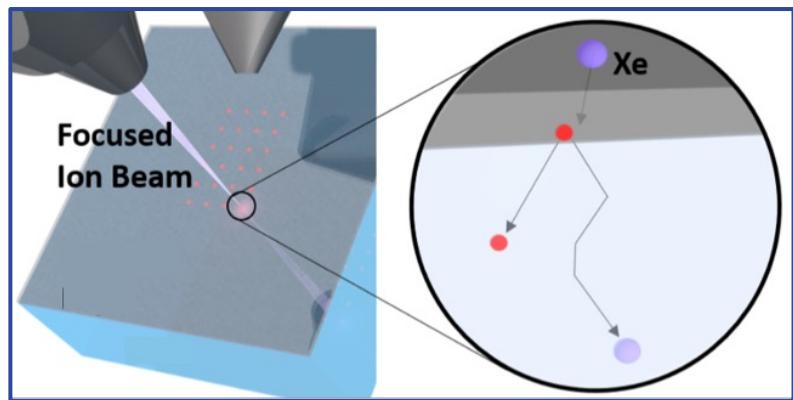
Electron beam

hBN

Laser beam

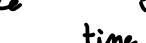
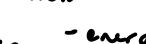
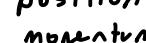
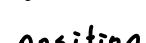
Nanocharacterization

light emitting diode



Material processing: Optical doping

Uncertainty Principle



- limited by size

- position & momentum

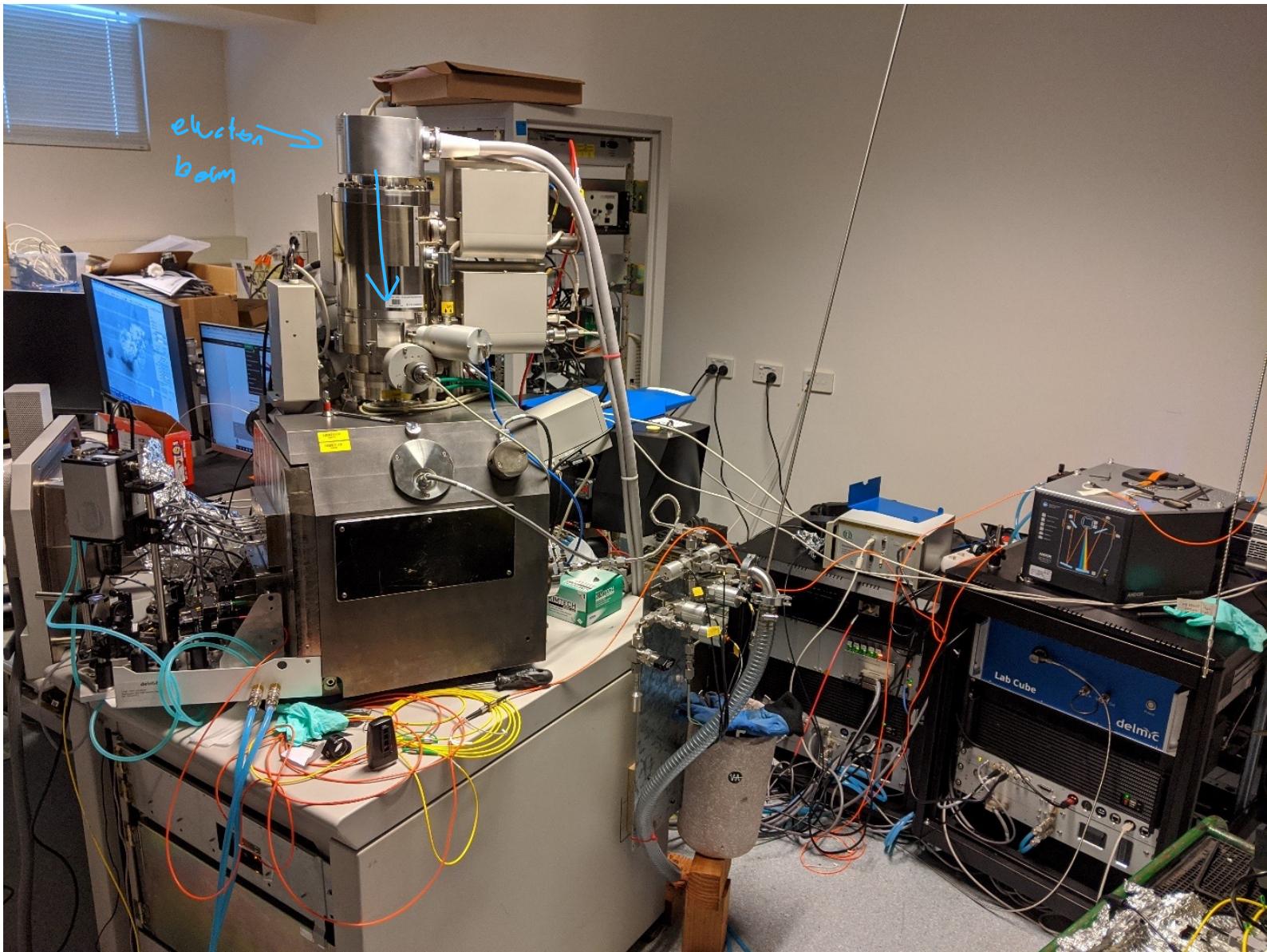
- energy & time

single photon

Quantum technologies → based on quantum interference

Lab: SEM, FIB, CL, PL

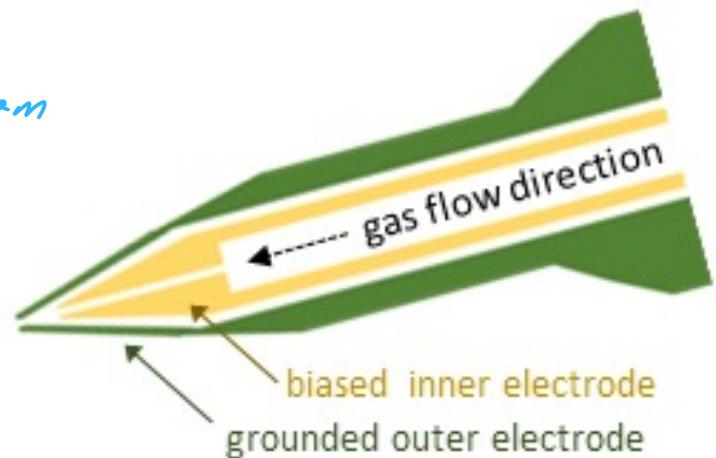
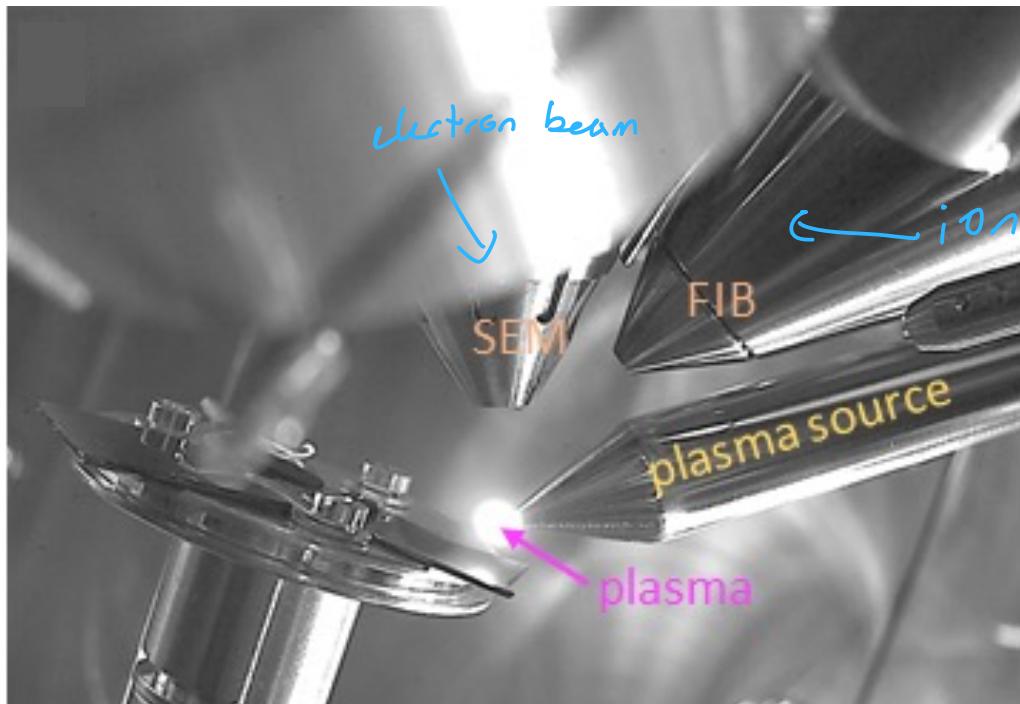
CHATGPT is
unreliable!



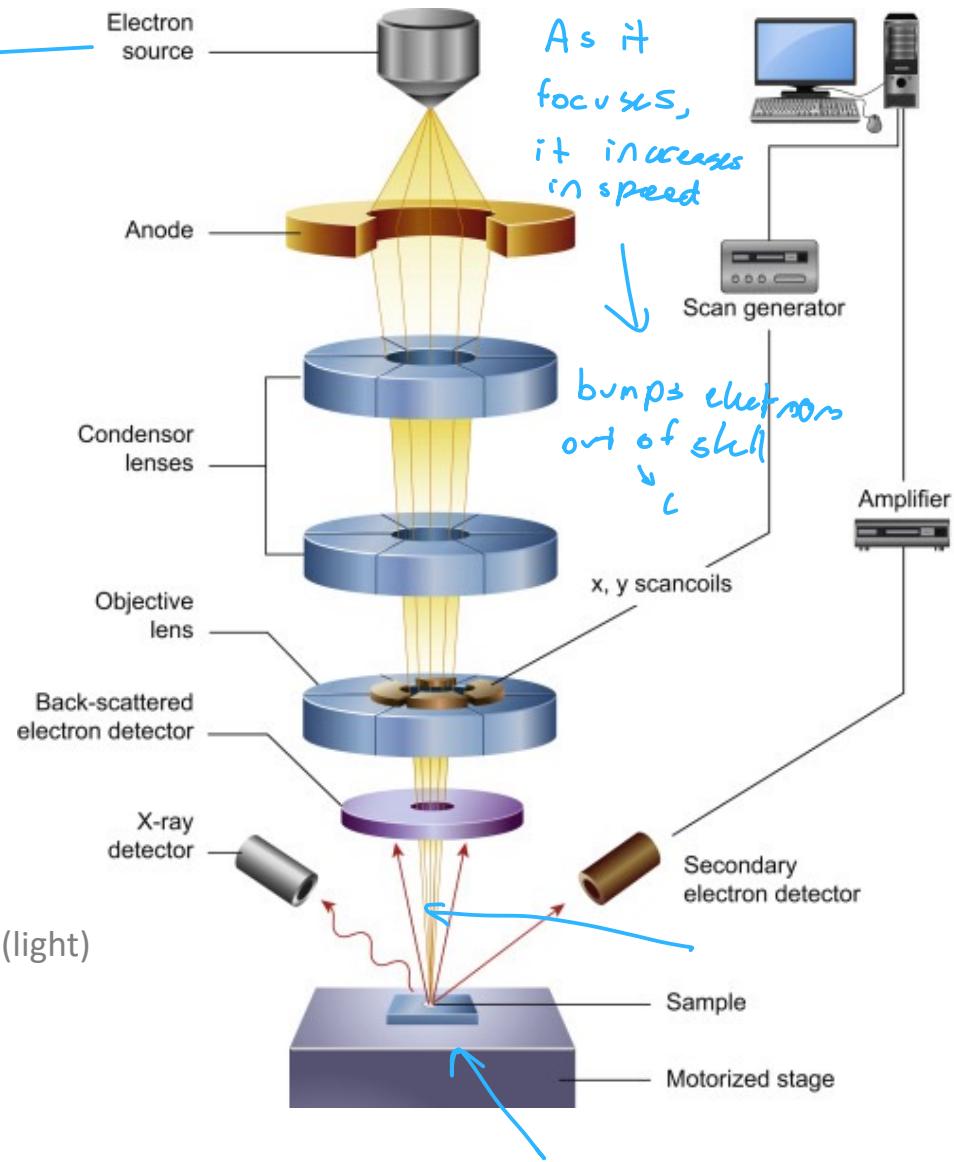
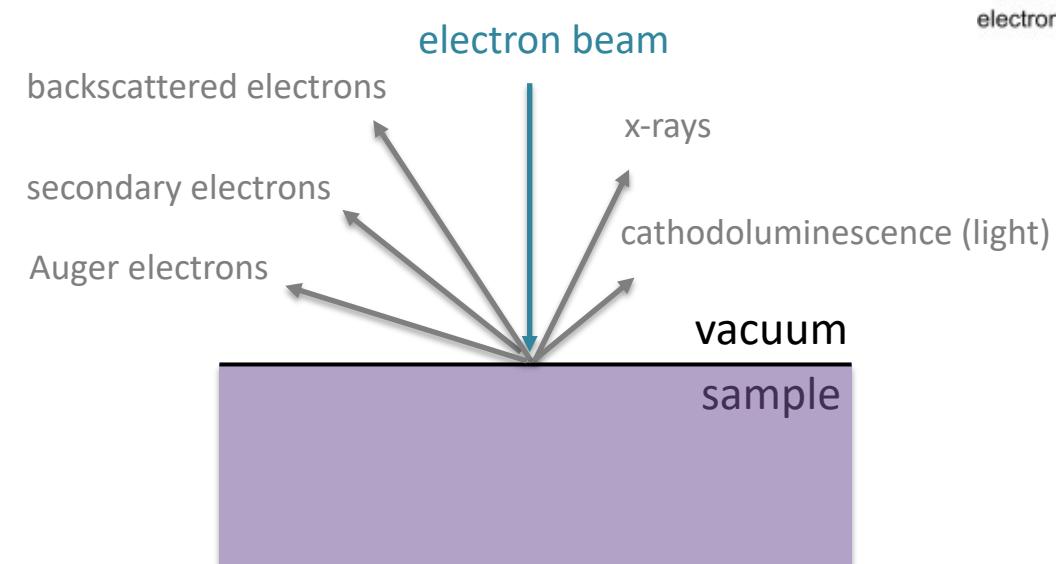
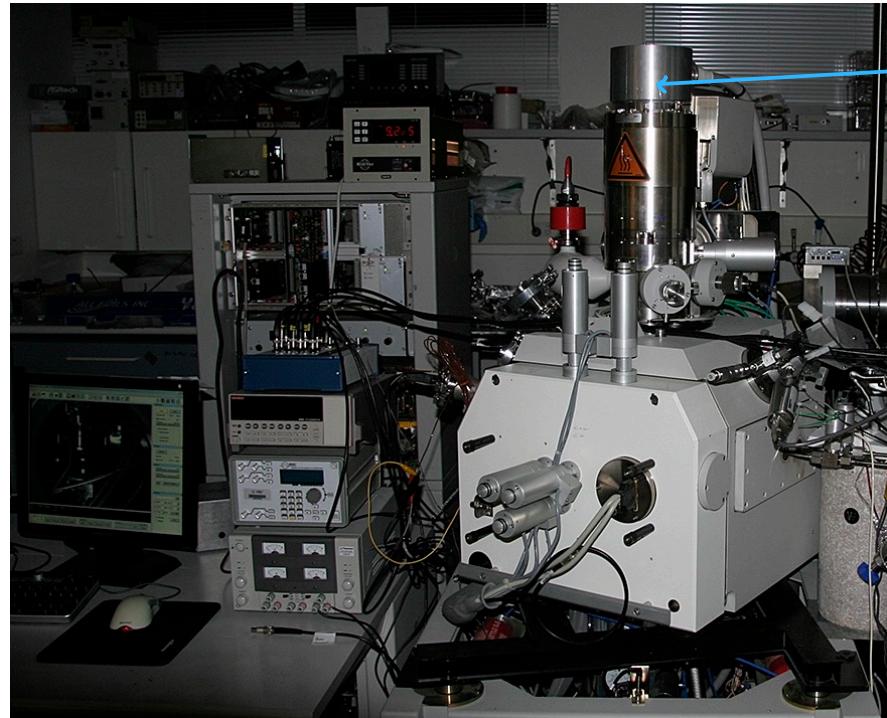
Lab: Inside one of these microscopes

→ scattering: bumps into particles in the air
- mass
- charge → causes interaction

This is under vacuum



Intro: Scanning electron microscope

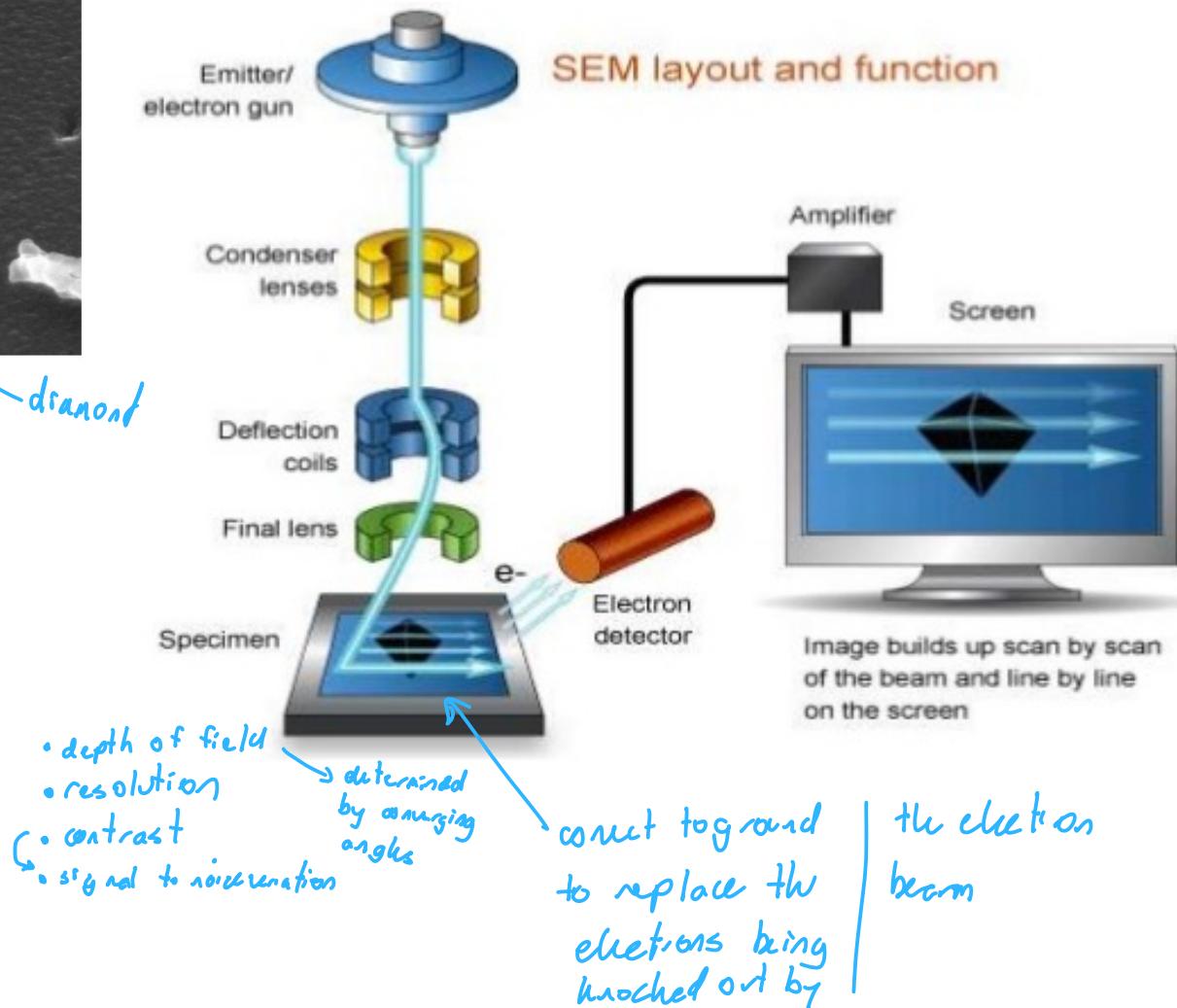
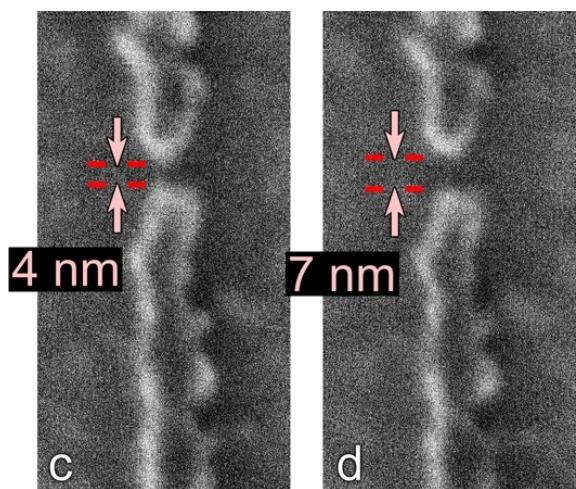
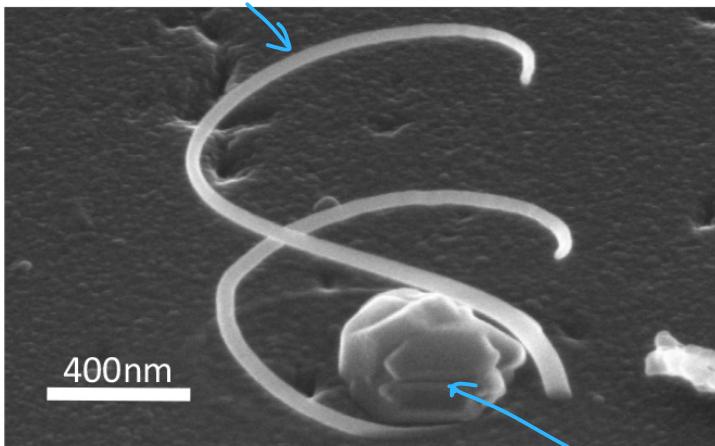


Intro: SEM image formation

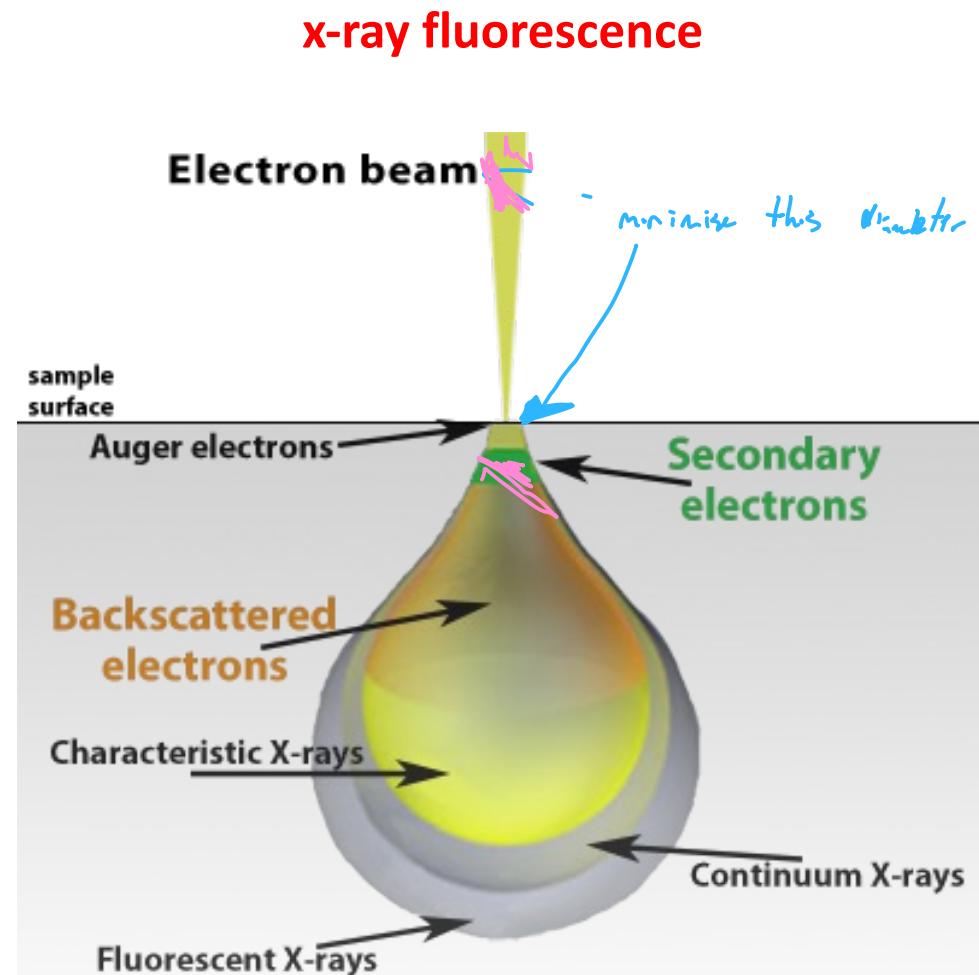
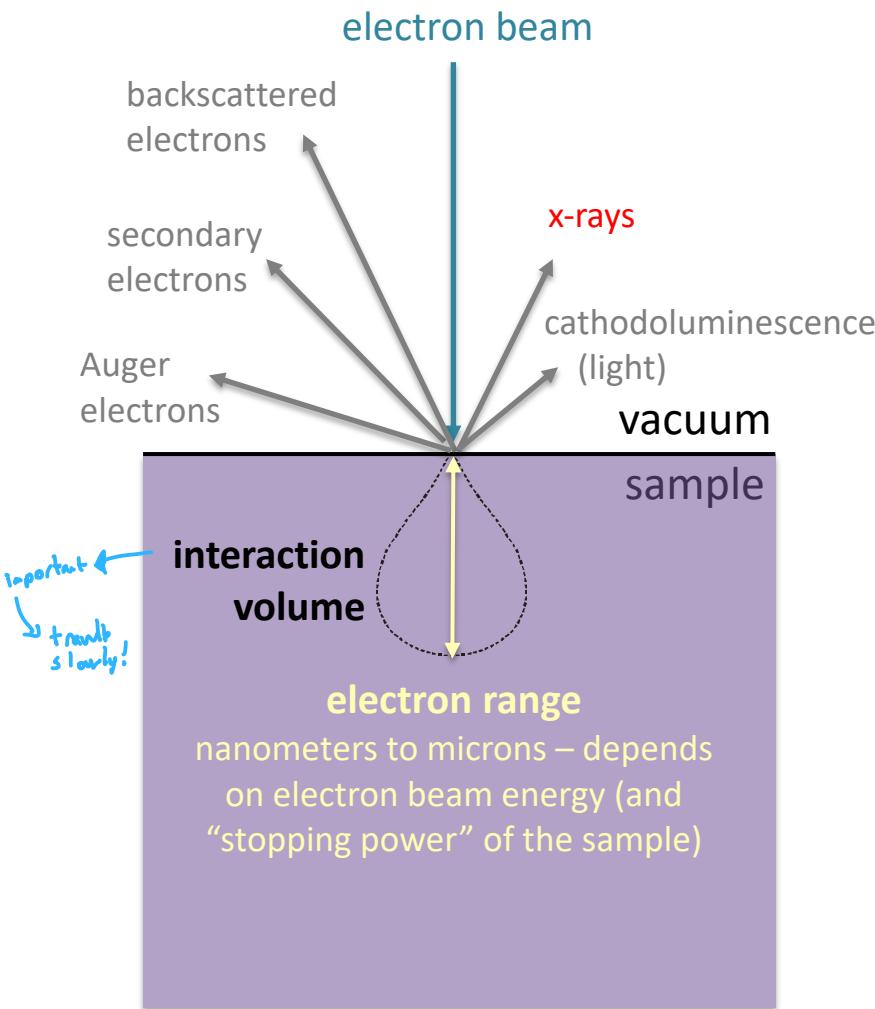
↳ scanning Electron Microscope

secondary electron images

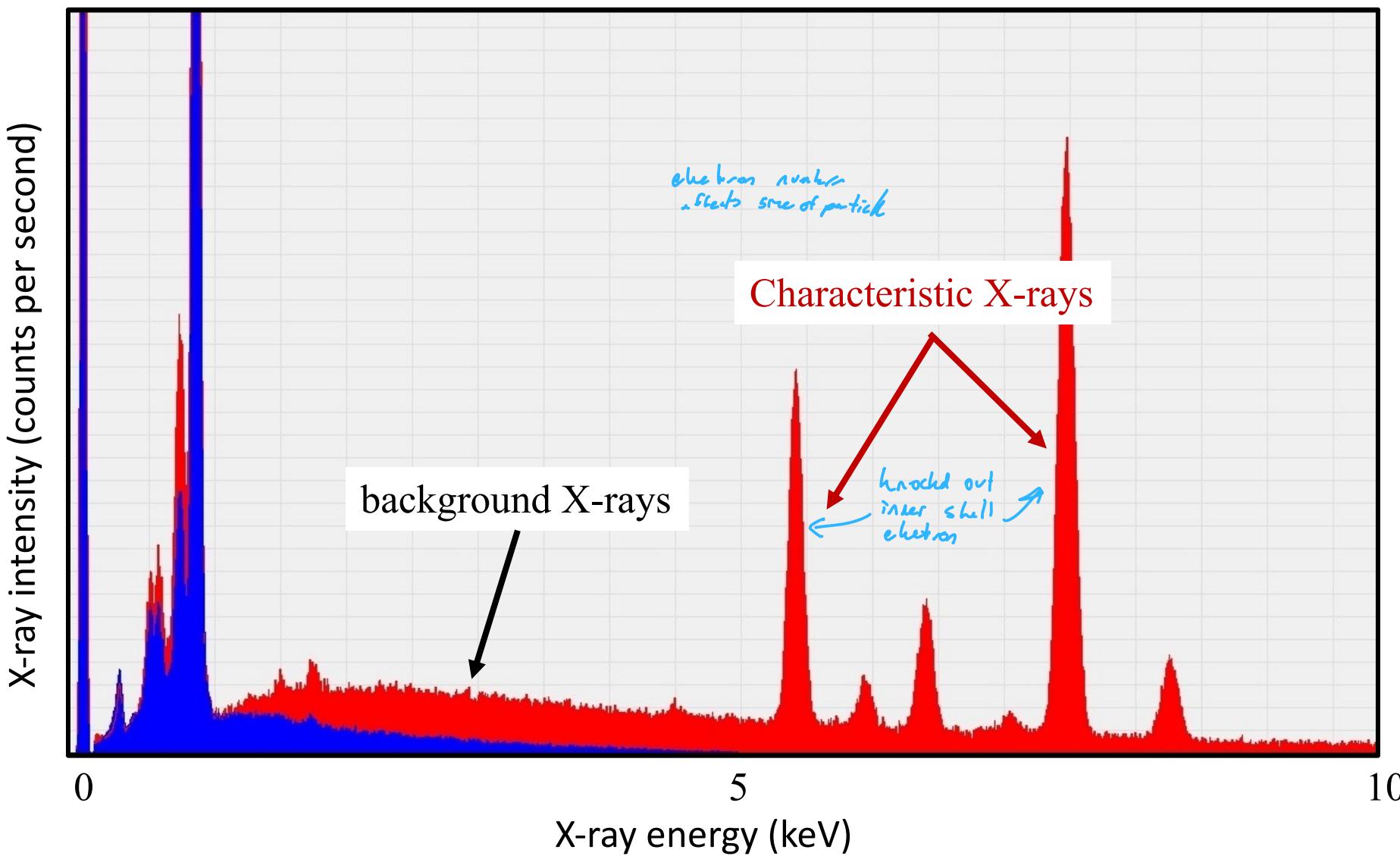
metallic nano antennas



SEM: imaging/analysis signals

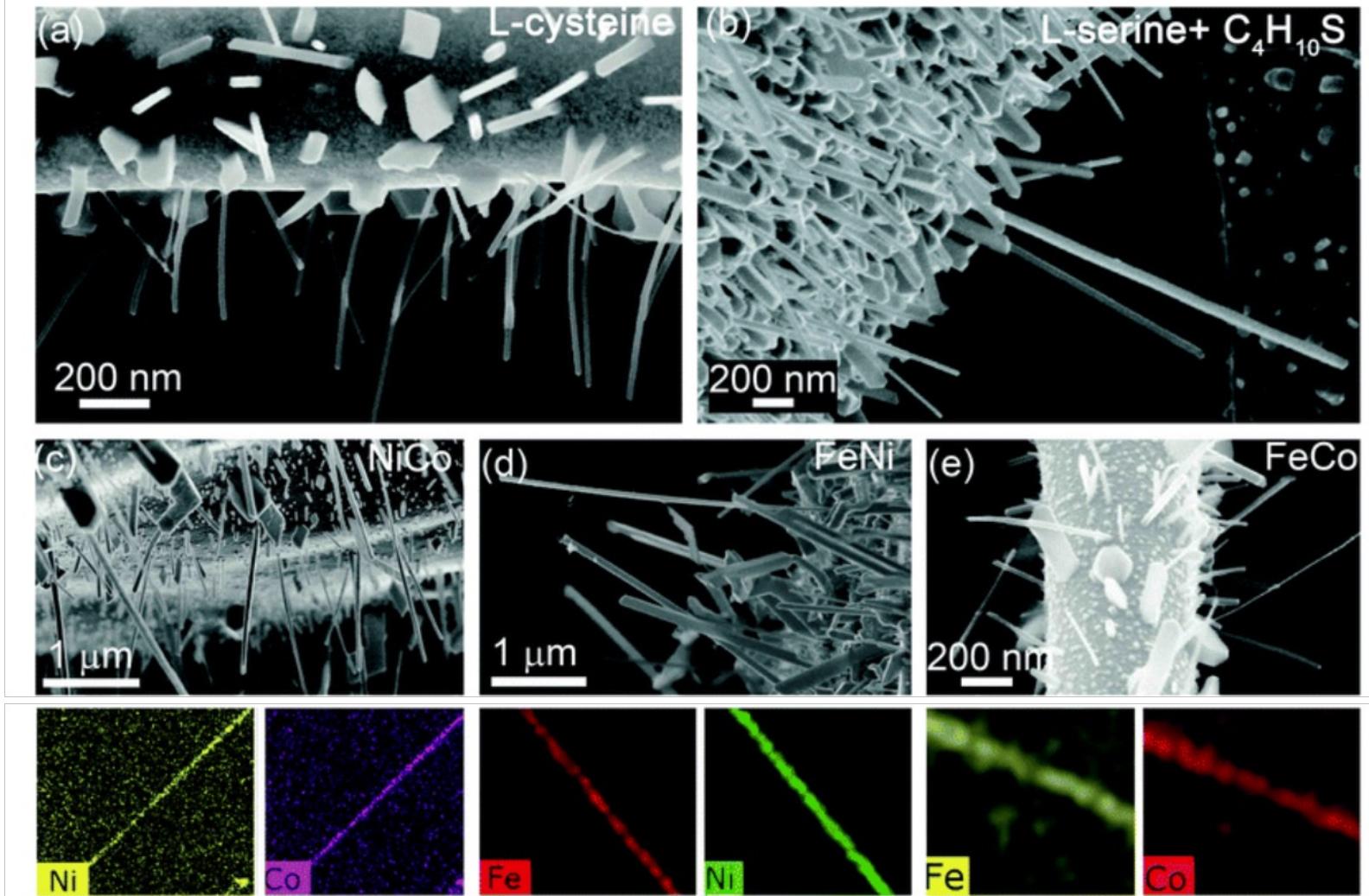


X-ray fluorescence: Spectroscopy



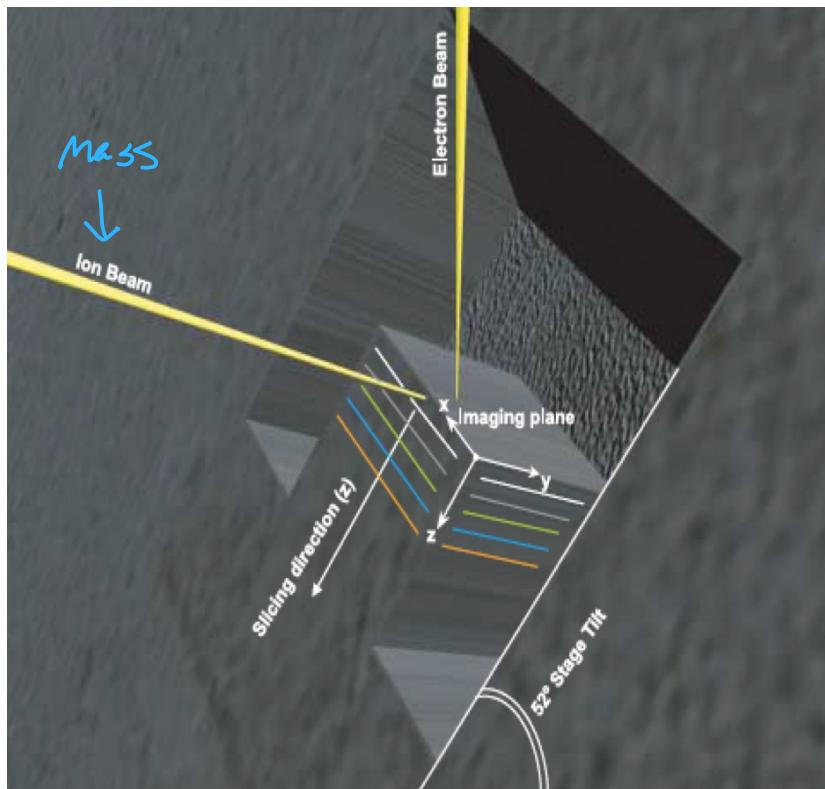
X-ray imaging (of nanowires)

SEM images show nanowire morphology

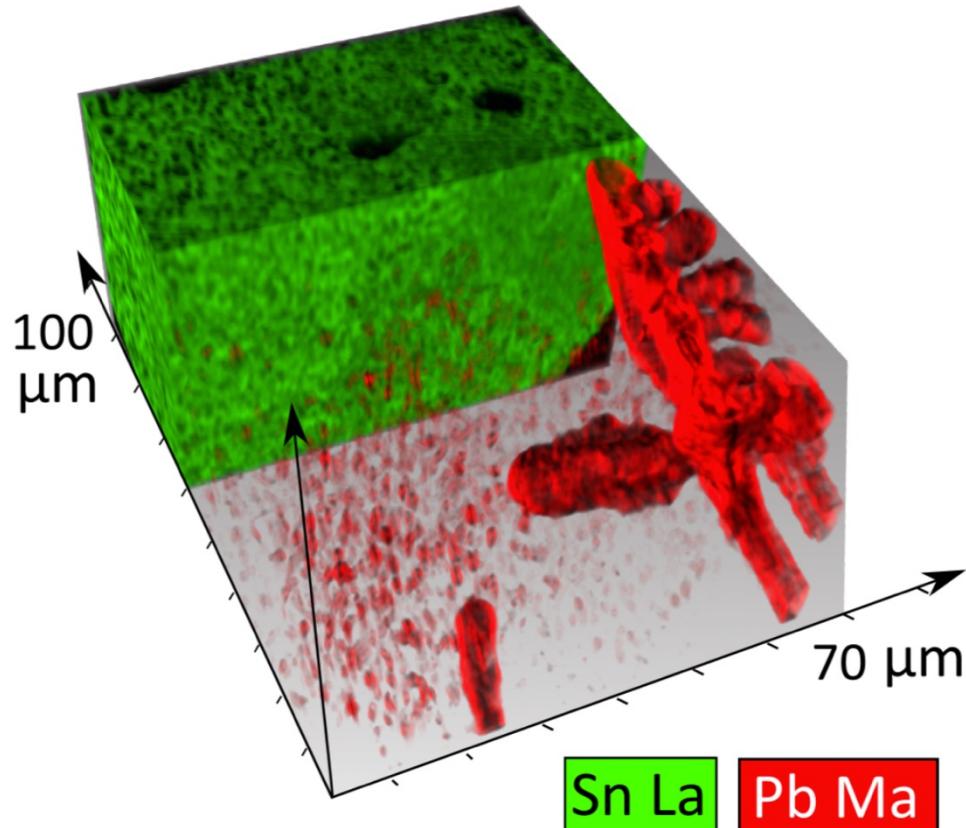


X-ray maps reveal elemental composition of individual nanowires

3D SEM & x-ray analysis: Focused ion beam (FIB) microscopy

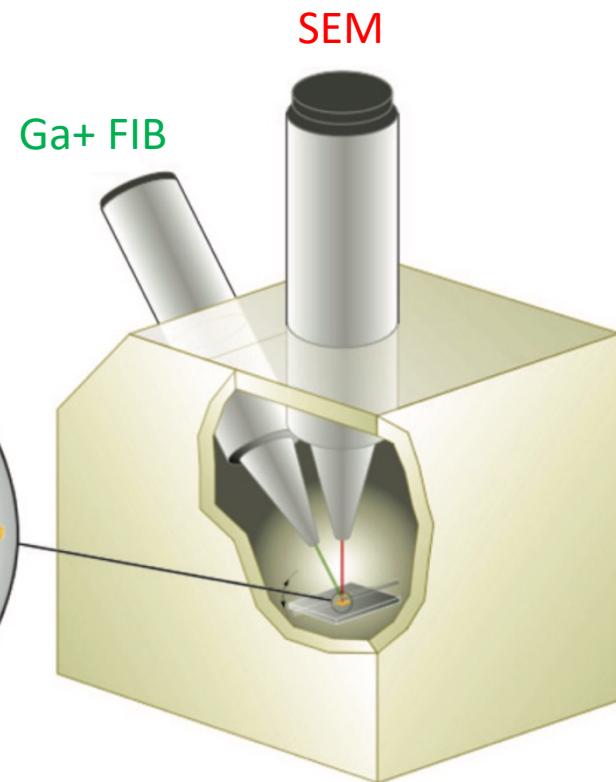
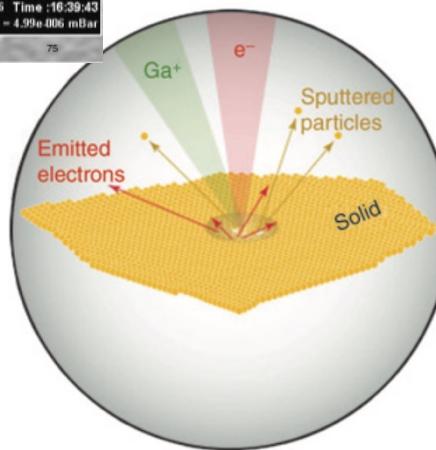
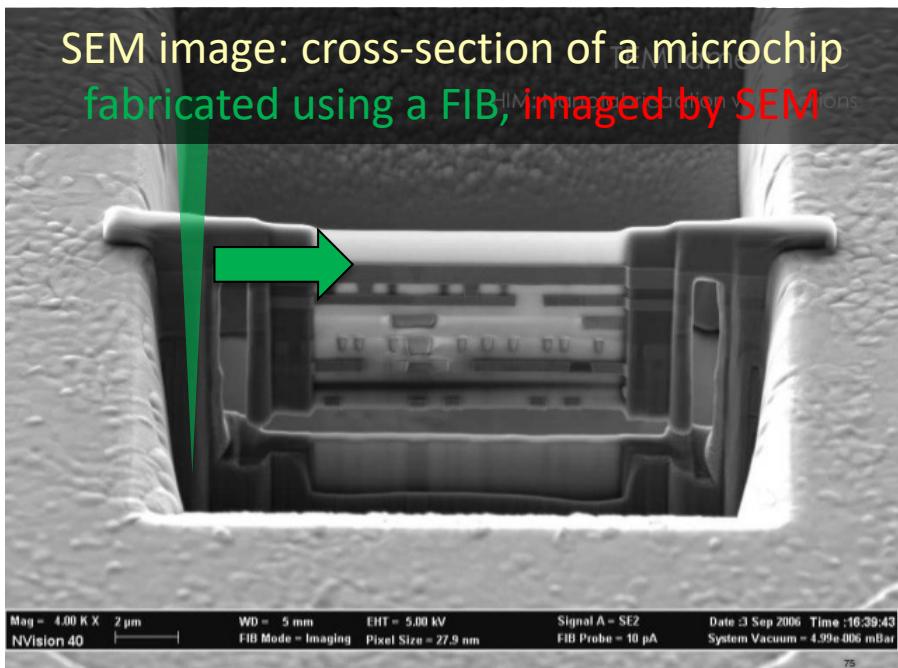


L. HOLZER, et al., *Journal of Microscopy*
Vol. 216, Pt 1 October 2004, pp. 84–95



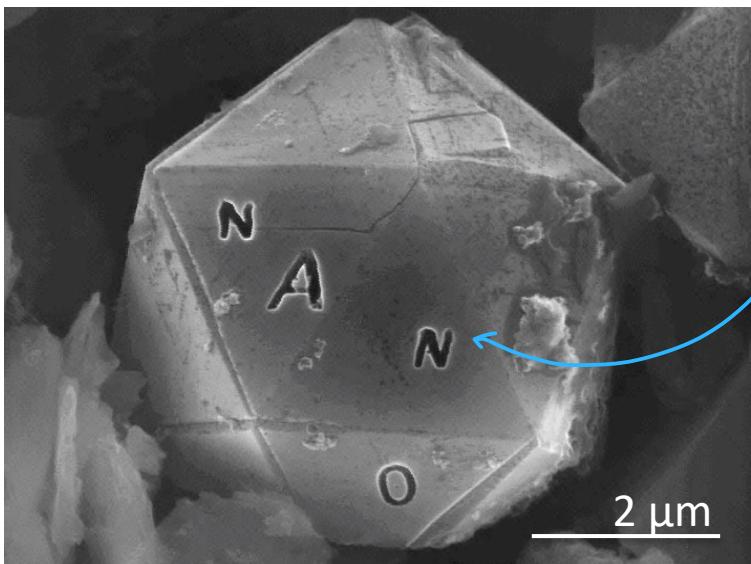
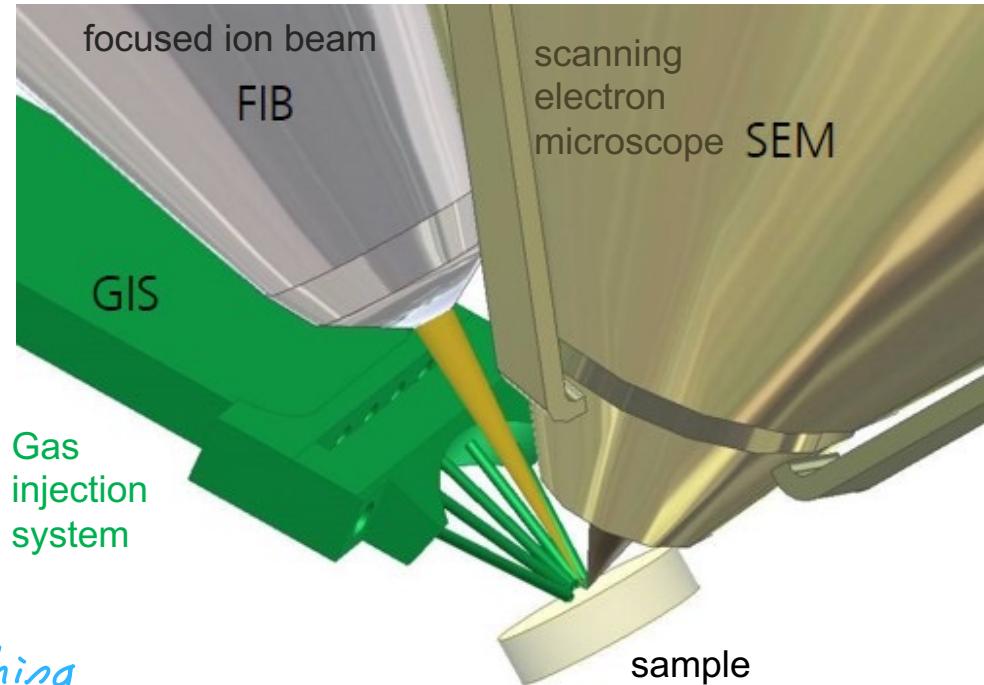
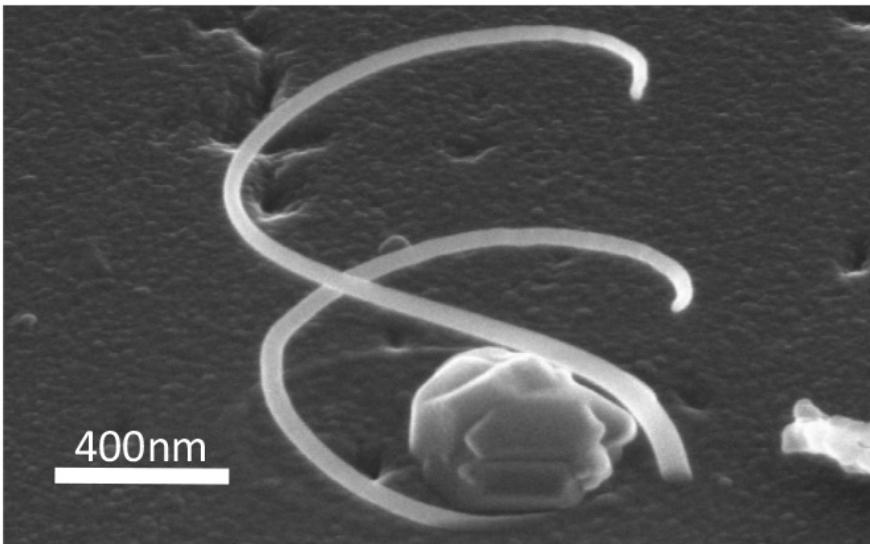
3D EDS reconstruction of
Sn₆₀Pb₄₀ solder (TESCAN)

SEM of cross-sections fabricated using a focused ion beam (FIB)



Gas-assisted nanofabrication

3D spirals grown by a (slowly) scanned electron beam



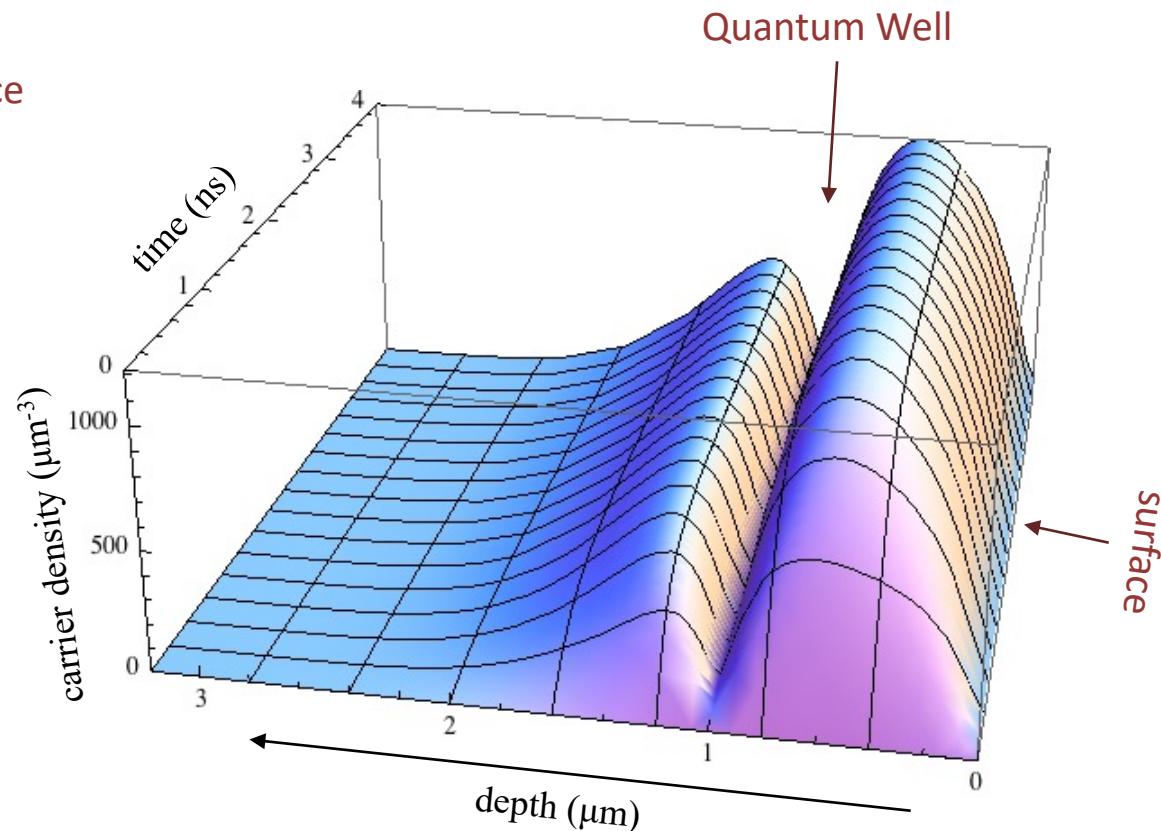
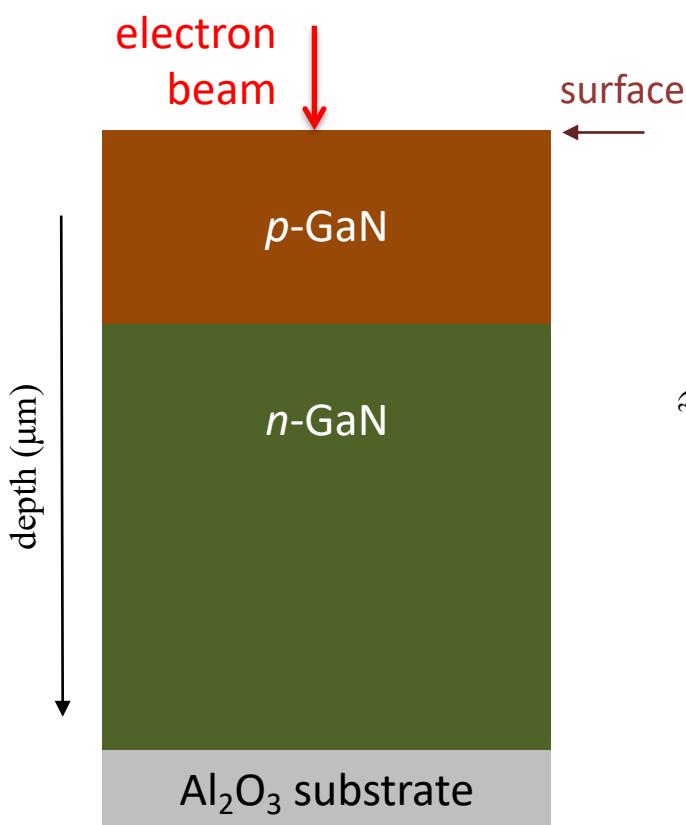
“NANO” etched into a microdiamond by an electron beam

Example of physics that we will cover

SEM & CL: rate of change of concentration of free carriers vs depth (z) & time (t)

$$\frac{\partial n}{\partial t}(t, z) = \frac{E_0(1 - \eta)}{E_{eh}} \frac{1}{\Lambda_1} \frac{\partial \Lambda}{\partial z} f - n \sum_i k_i + D_n \frac{\partial^2 n}{\partial z^2}$$

generation recombination diffusion



End of “brief introduction”/teaser

Calendar/timetable/assessments

Subject Outline → Canvas

UTS

68320 Nanofabrication and Nanocharacterization Techniq... > Subject Outline

Spring 2024 (City campus)

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Spring 2024 (City campus)

Note: Some Subject Outlines may be flagged as Unpublished. Where possible, students will always see the published Subject Outline that best matches their enrolment, or a published Standard Subject Outline if one is available. For more information, please refer to the [Subject Outline guide](#).

PDFs

1 / 8 | - 87% + | ↕ 🔍

SUBJECT OUTLINE

68320 Nanofabrication and Nanocharacterization Techniques

Course area UTS: Science
Delivery Spring 2024; City
Credit points 6cp
Result type Grade and marks
Attendance: 6hpw

Subject coordinator
Prof. Milos Toth
Email: milos.toth@uts.edu.au

Teaching staff
Prof Milos Toth
Email: milos.toth@uts.edu.au

Subject description
This subject addresses the high-precision techniques required for characterising and fabricating nano-materials and devices, which are core enablers of nanotechnology and materials physics. Students learn about nano-scale fabrication techniques, such as chemical vapour deposition, reactive ion etching, electron beam lithography, and focused ion beam microscopy. Students also learn about nano-resolution imaging and analysis such as electron microscopy, scanning tunnelling microscopy, and advanced fluorescence microscopy. They explore the application of these techniques in various scientific and technological fields, stay abreast of recent advancements, and gain hands-on experience with a range of imaging, analysis and nanofabrication methods.

Subject learning objectives (SLOs)

Upon successful completion of this subject students should be able to:

1. Apply theory and working principles to the practice of nano scale fabrication and analysis.
2. Competently operate a Scanning Electron Microscope.
3. Analyse experimental analytical microscopy results and prepare a formal scientific report.
4. Interpret data collected from nano scale analysis techniques.

Download Print

Calendar/timetable

weeks 1 – 9

Lectures

Tues 9 AM [CB05D.03.014]

Tutes & class tests

Tues 12 PM
[CB04.04.331_341]

Labs

Thurs 1 PM
[CB04.02.310]

"MAU lab", corner of Harris & Thomas St, building 4, street-level, opposite the gym]

close book

there is a revision lecture still

In the tutorials

• Multiple choice / must get 50%

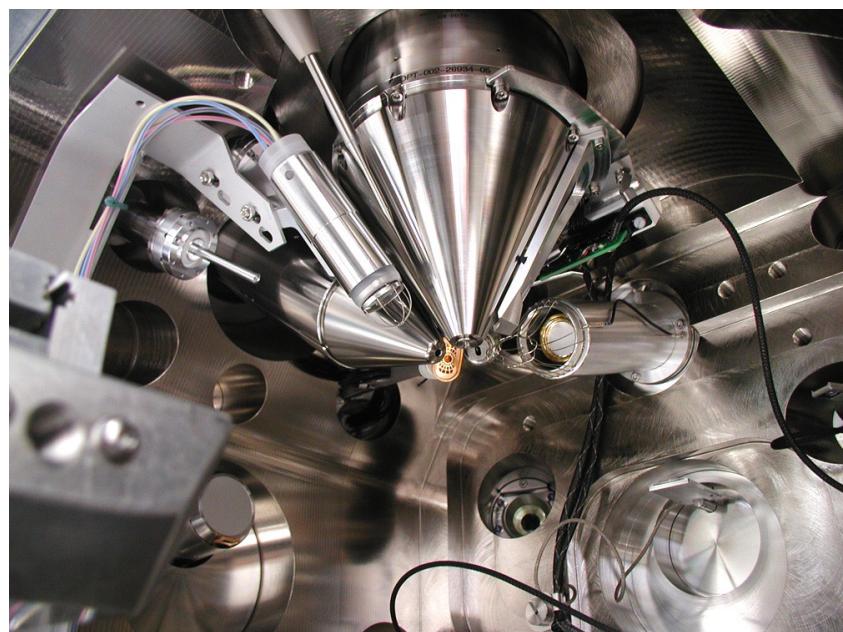
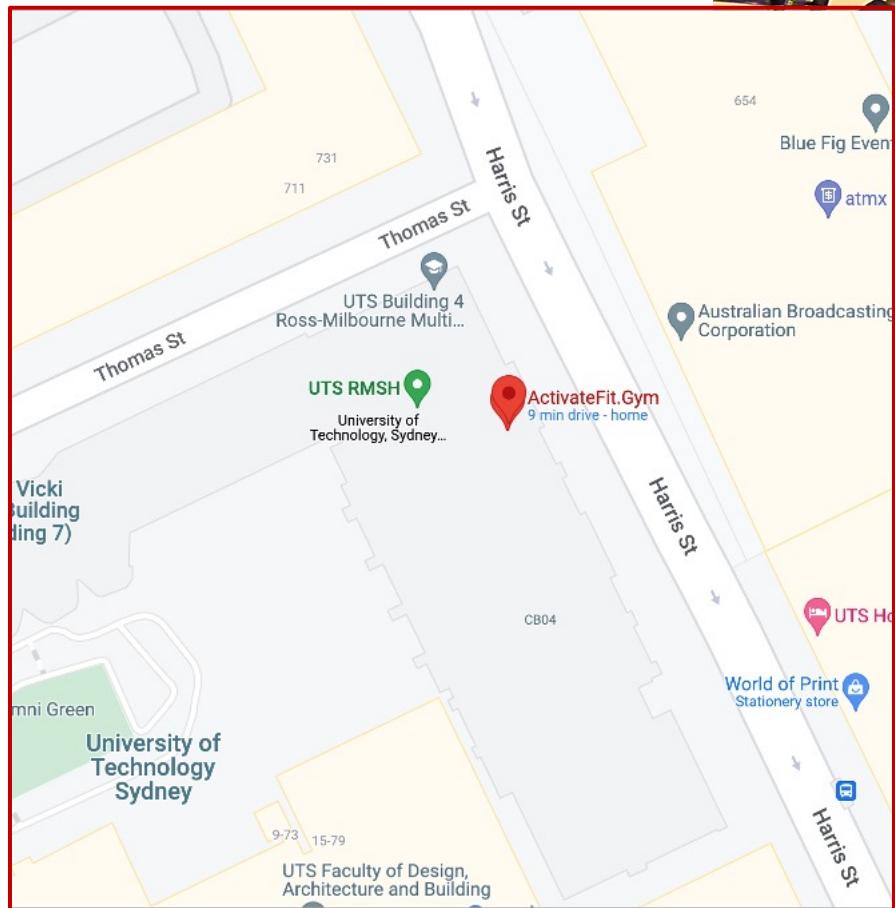
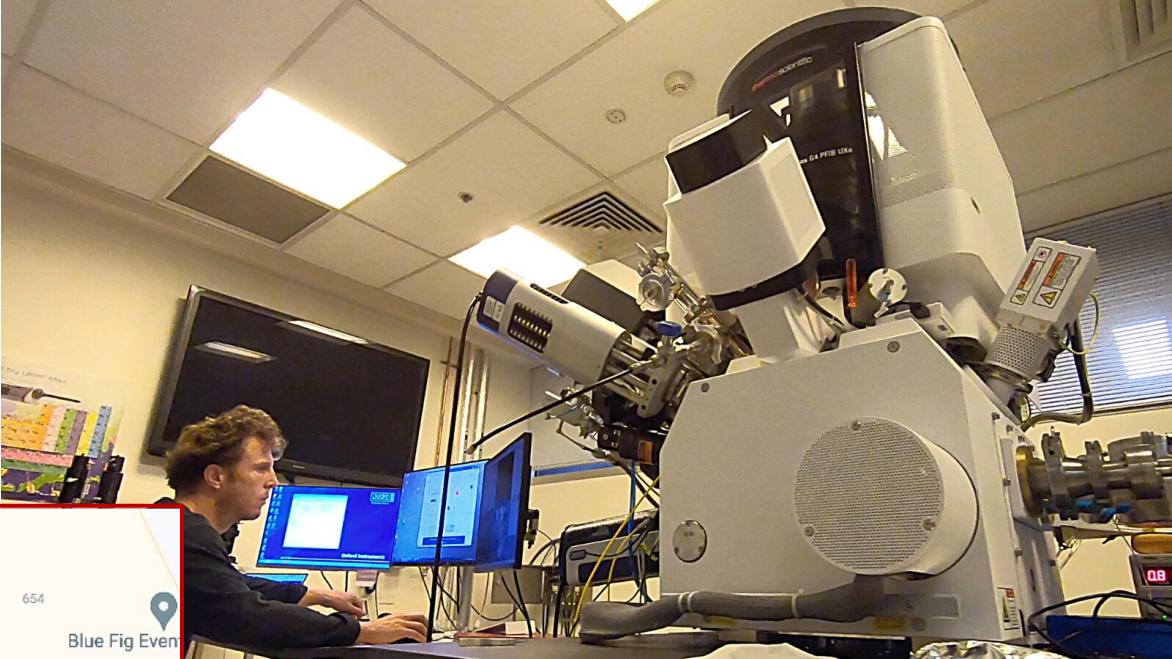
NOTE: tutes and labs are on some weeks, but not every week, as shown here

Program			
Week/Session	Dates	Description	
1	5 Aug	Lecture 1: Introduction	Tutorial 1: Nano-scale imaging basics
2	12 Aug	Lecture 2: Electron optics and electron-solid interactions	Tutorial 2: Electron-solid interactions Practical 1: Scanning electron microscopy
3	19 Aug	Lecture 3: Ion beams and electron/ion beam nanofabrication	Tutorial 3: Ion-solid interactions Practical 2: Electron/ion beam nanofabrication
4	26 Aug	CLASS TEST 1	• Multiple choice / must get 50%
5	2 Sept	Lecture 4: Cathodoluminescence & x-ray analysis	Tutorial 4: Cathodoluminescence simulations Practical 3: Nanocharacterisation techniques
6	9 Sept	Lecture 5: Advanced nanocharacterisation	Practical 4: Nanocharacterisation techniques
7	16 Sept	Lecture 6: Ion-solid interactions and gas-assisted nanofabrication (advanced)	Portfolio 1 due this week (practicals) Portfolio 2 due this week (tutorials)
8	23 Sept	CLASS TEST 2	
9	30 Sept	STUVAC	

Labs

CB04.02.310

Corner of Harris & Thomas St
Near the UTS gym



Reading material

The screenshot shows the UTS Learning Management System interface for Spring 2023 (City campus). The left sidebar includes links for Home, Subject Outline, Announcements, Search, People, and Modules. A red box highlights the 'Get started' section, which contains links to Welcome, Your teaching staff, How to be successful in this subject, Subject Outline, Assessment overview, Subject resources, Get started with UTS Library, and Study help and support. Below this is the 'LITERATURE' section, also highlighted with a green oval, containing a single link to LITERATURE.

- Read Up to introduction
 - Email
 - Ask questions
 - Will be referred to in lectures
- Start with these 3 papers

The screenshot shows the UTS Learning Management System interface for Spring 2023 (City campus). The left sidebar includes links for Home, Subject Outline, Announcements, Search, People, and Modules. A green box highlights the 'LITERATURE' section, which contains a list of 16 PDF files, each with a download icon. The first two items in the list are circled with a green oval. The list includes:

- 01A. FIB1.pdf
- 01B. FIB2.pdf
- 02. SEM - Low Voltage.pdf
- 03. cathodoluminescence.pdf
- 04. FIB and 3D SEM imaging.pdf
- 05. EDX Mapping.pdf
- 06. SEM Resolution.pdf
- 07. CASINO - intro.pdf
- 08. CASINO - 3D.pdf
- 09. CASINO - elastic.pdf
- 10. CASINO - inelastic.pdf
- 11. Gas-assisted nanofab - SEM and FIB.pdf
- 12. Models of e-beam nanofab.pdf
- 13. self-assembly.pdf
- 14. CL Depth profiling.pdf
- 15. Recoil Implantation.pdf
- 16. Recoil Implantation 2 - gas.pdf

Assessments

- 50% for Practical and Tutorial Work submitted in the form of **3 portfolios** throughout the semester
- 50% for Class Tests held on 3 dates throughout semester

The best way to prepare is to attend lectures and participate in discussions – I will ask many questions that are representative of what will be in the tests.

**Tests & Portfolio due dates are in the subject outline.
Reminders will be posted on Canvas.**

Assessments: Portfolios (assignments)

Portfolio 1 (16.7%)

Report based on lab work, written in the style of a scientific research paper (submitted as a PDF file in Canvas).

Portfolio 2 (16.7%)

4 assignments in Canvas, each of which covers one tute & is worth 4.17% of your total mark

Portfolio 3 (16.7%)

Assignment in Canvas based on tutes that will be done in the 2nd half of the semester.

68320 Nanofabrication and Nanocharacterization Techniq... > Assignments

Spring 2023 (City campus)

Search for Assignment

Assignments

Portfolio 1 [Pracs]: Formal report/paper
Practicals Module | Not available until Aug 15 at 9:00 | Due Sep 25 at 9:00 | 16.67 pts

Portfolio 2 [Tute 1]: SEM basics: magnification, resolution, signal-to-noise-ratio and contrast
Tutorials Module | Not available until Aug 8 at 9:00 | Due Sep 25 at 9:00 | 4.17 pts

Portfolio 2 [Tute 2]: Monte Carlo simulations of electron-solid interactions
Tutorials Module | Not available until Aug 15 at 9:00 | Due Sep 25 at 9:00 | 4.17 pts

Portfolio 2 [Tute 3]: Monte Carlo simulations of ion-solid interactions
Tutorials Module | Not available until Aug 22 at 9:00 | Due Sep 25 at 9:00 | 4.17 pts

Portfolio 2 [Tute 4]: Cathodoluminescence (CL) analysis
Tutorials Module | Not available until Sep 5 at 9:00 | Due Sep 25 at 9:00 | 4.17 pts

Portfolio 3 [SPM]
Tutorials 2 - SPM computer labs Module | Not available until Oct 10 at 9:00 | Due Nov 6 at 9:00 | 16.67 pts

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Outcomes

Each assignment will appear in Canvas at 9 AM on the Tuesday of the week when it will be covered in a tute/lab

Submission deadlines are the "Due Dates in Canvas"

Example: Week 1: Portfolio 2, Tute 1

Spring 2022 (City campus)



Account



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Portfolio 2 [Tute 1]: SEM basics: magnification, resolution, signal-to-noise-ratio and contrast

ⓘ This is a preview of the published version of the quiz.

Started: Aug 1 at 14:31

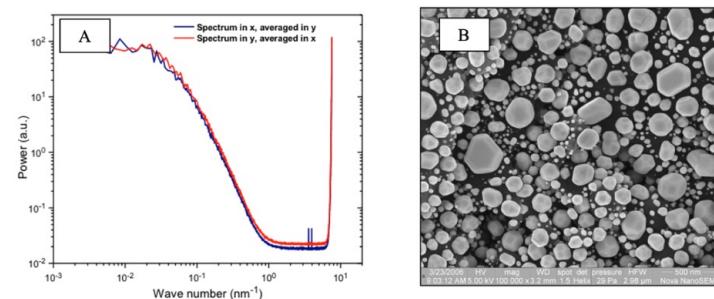
Quiz Instructions

Write up your answers on your computer and submit a single PDF file by the due date (hand-written, scanned answers will not be accepted).

Question 1

4.17 pts

- (1) The plot in A shows two power spectra of the image in B. Explain the physical meaning of the power spectra and calculate the image signal-to-noise ratio at a wave number of 10^{-1} nm^{-1} .



- (2) Image processing in the Fourier domain: Use ImageJ to perform the following:

- Open the image "balls1-2048x2048.tif" & calculate the 2D Fourier Transform.
- Explain how a Fourier transform can be used to apply a low pass filter to the image. Illustrate this graphically on the transform that you calculated in (a).
- Use the Fourier transform in (a) to apply a low pass filter to the image, calculate the inverse Fourier transform and show the resulting image in your portfolio.

Upload

Choose a File

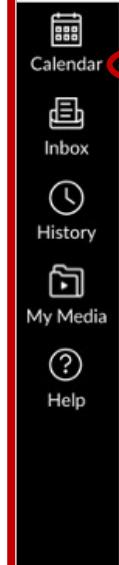
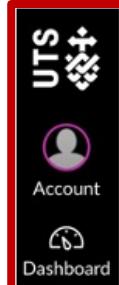


Typed on word
↳ upload as PDF

Type your answers and submit it as a PDF file in Canvas by the due date (see previous slide).

Photos of hand-written answers will not be accepted.

Software



68320 Nanofabrication and Nanocharacterization

Spring 2023 (City campus)

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Modules

- ▼ Get started
 - >Welcome
 - >Your teaching staff
 - How to be successful in this subject
 - Subject Outline
 - Assessment overview
- Subject resources
- Get started with UTS Library
- Study help and support

Subject resources and equipment

Some specialised (free) software packages will be used in the tutorials. These are installed on computers in the room that you will use for tutorials, and you can also install these on your own computers:

ImageJ/FIJI:

<https://fiji.sc/>

Tut 1

CASINO

<https://www.gegi.usherbrooke.ca/casino/What.html>

Tut 2 / Tut 4

SRIM

<http://www.srim.org/>

Tut 3

Gwyddion

<http://gwyddion.net/>

- Software you will use in tutorials.
- It's all free.
- You can install it on your computers or use it on UTS computers in the tutorial sessions.
- Check out the online documentation, YouTube tutorials...

Lecture notes, tutes, pracs

MUST GO TO

...all on Canvas, which will be updated each week

LECTURES!

Spring 2022 (City campus)

Get started

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LITERATURE

Lectures

Tutorials

Tute 1: SEM basics: magnification, resolution, signal-to-noise-ratio and contrast

- 68320 2022 Tute 1 - slides.pdf
- Portfolio 2 [Tute 1]: SEM basics: magnification, resolution, signal-to-noise-ratio and contrast
Sep 26 | 4.17 pts
- 06. SEM Resolution.pdf
- balls1-2048x2048.tif
- balls2-offset hor by 4 pixels.tif

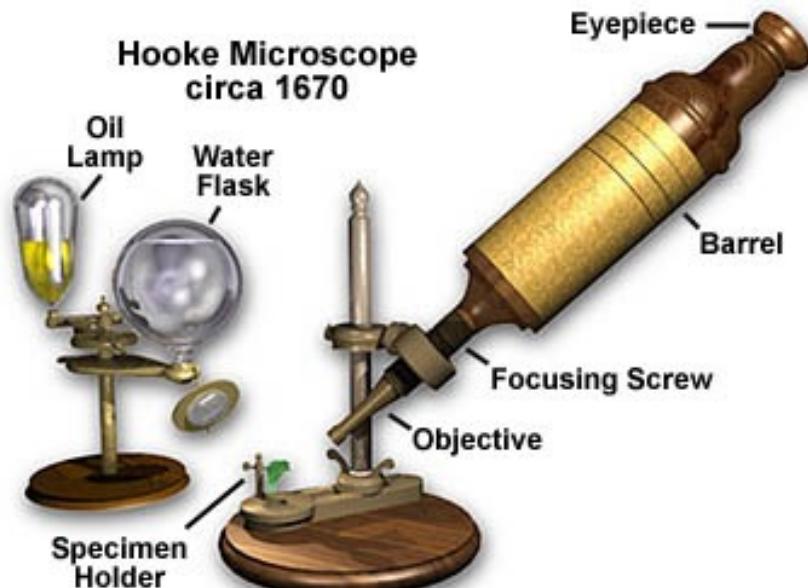
Tute 2: Electron-solid interactions

- 68320 2022 Tute 2 - Slides.ndf

Available on the Sunday before

Microscopy

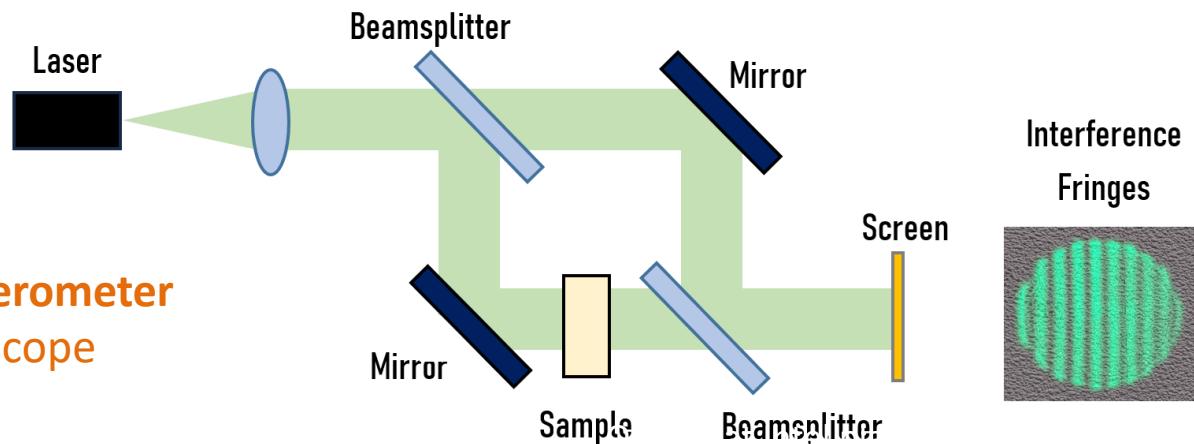
First Microscope (magnification ~270x)



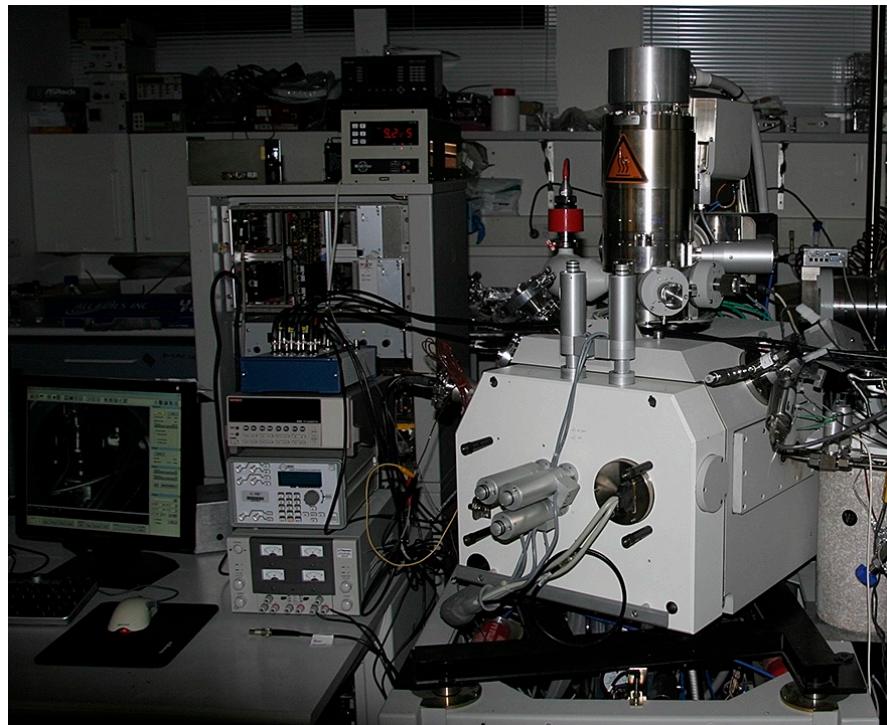
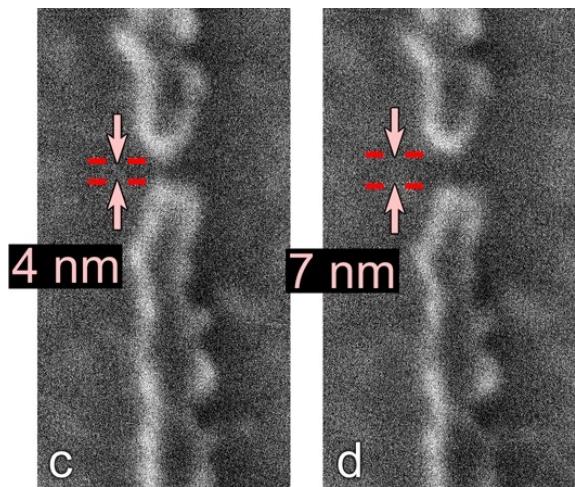
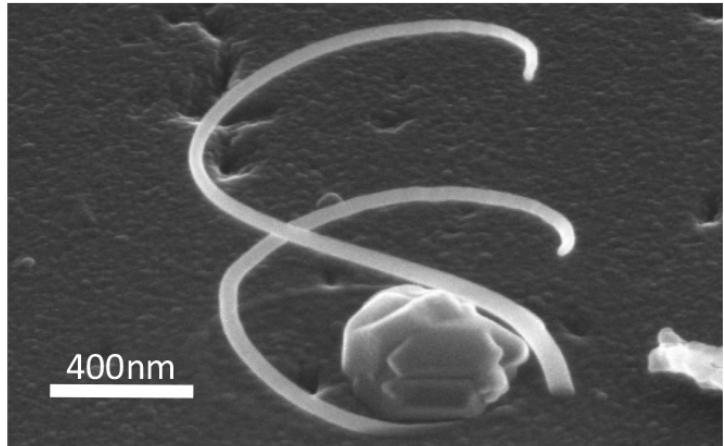
Transmission electron microscope
(magnification >10,000,000x)



Mach-Zehnder interferometer
phase contrast microscope

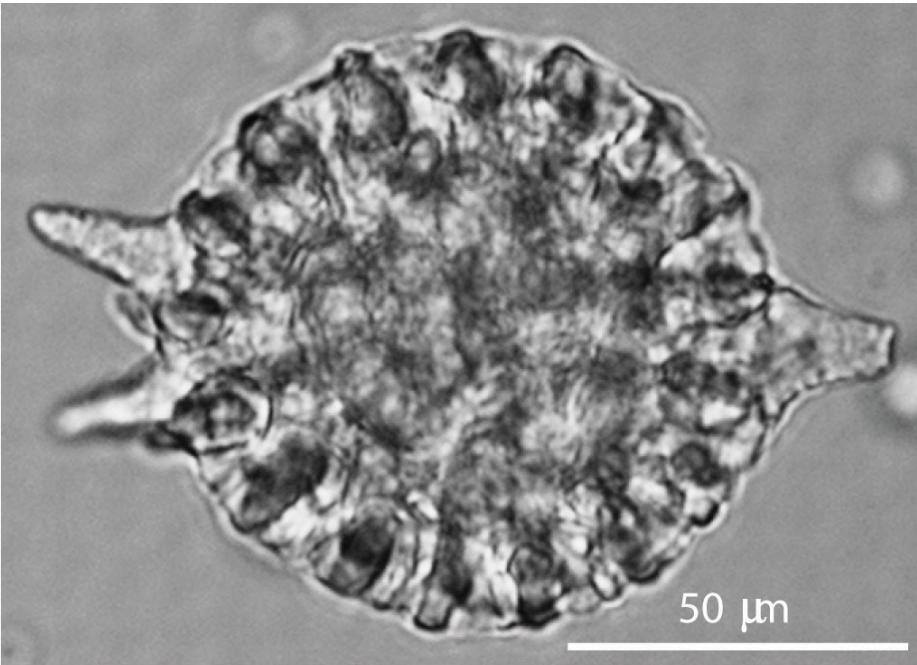


Scanning electron microscopy



Optical/light vs SEM/electrons

Light Microscope



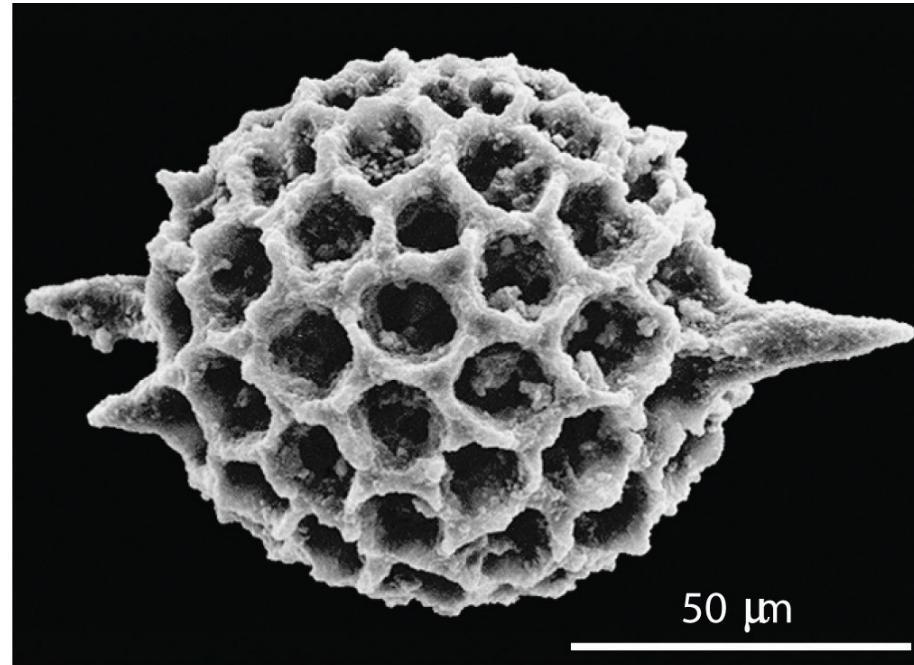
(a) Radiolarian under light microscope

low resolution
SEM: Improved “spatial detail”, sharper edges and contrast, field
no depth of field

larger depth of field

Quantifying : - signal to noise ratio
- contrast
Plot in one

Scanning Electron Microscope (SEM)



(b) Radiolarian under electron microscope

high resolution / angle / depth of field

The Radiolaria, also called Radiozoa, are protozoa of diameter 0.1–0.2 mm that produce intricate mineral skeletons, typically made of silica, and contain a central capsule dividing the cell into the inner and outer portions of endoplasm and ectoplasm.

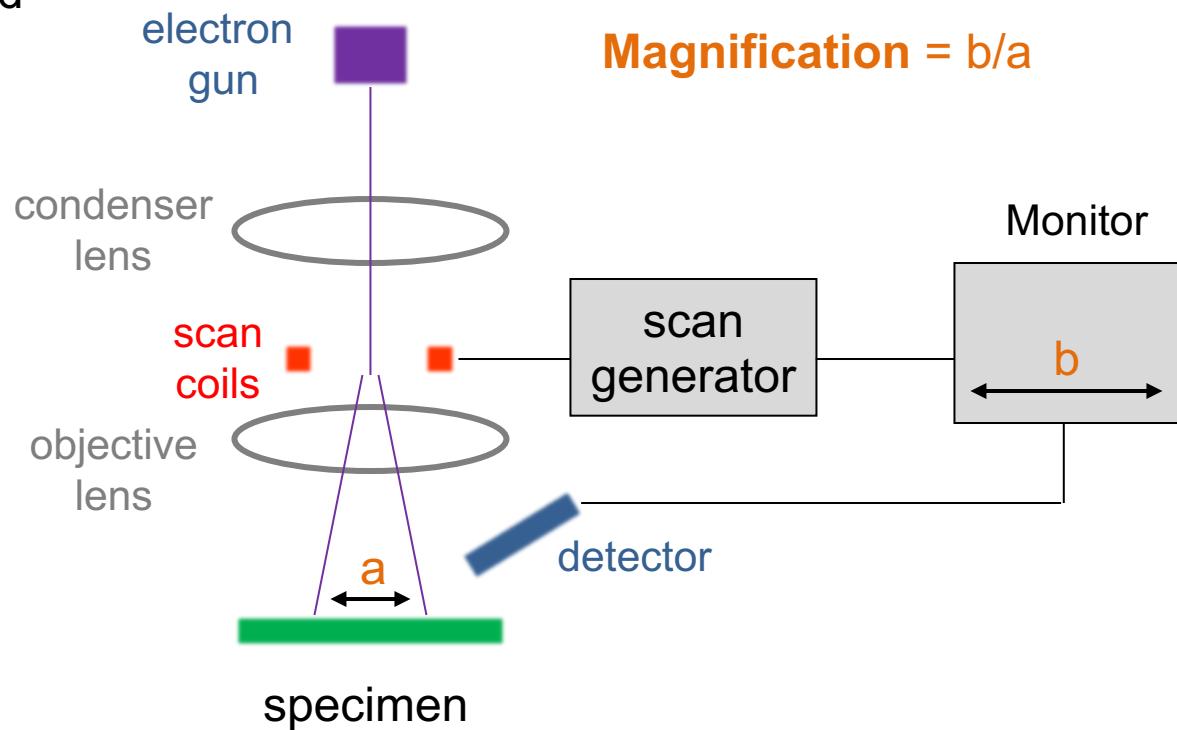
SEM basics & magnification

all SEMs operate by irradiating the specimen with a finely focussed beam of electrons, producing emission signals (SE, BSE, X-ray, etc.) that can be used to form an image

Electron Gun: used to produce electrons, pre-focus beam and accelerate to 1 - 30 keV

Electron Lens: used to provide a focussed, de-magnified spot at the specimen plane

Imaging System: used to scan the beam, achieve magnification, and produce image contrast



What limits spatial resolution?

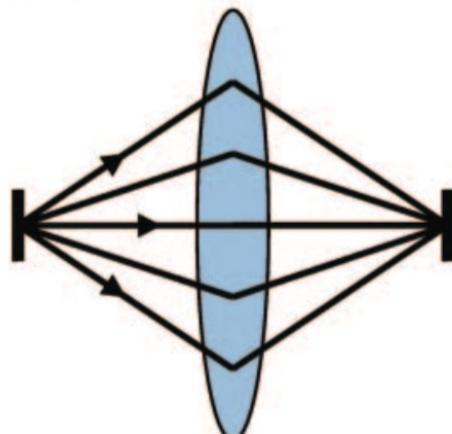
Resolution is limited by **aberrations** and by **diffraction** that cause blurring of images



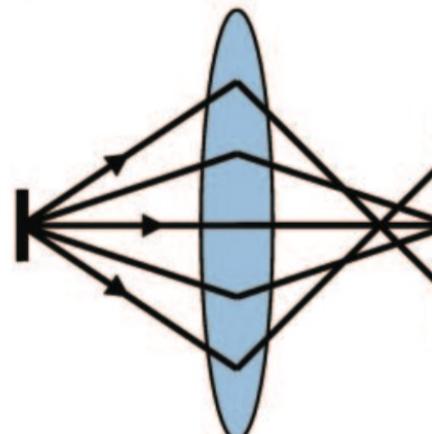
caused by imperfections of the imaging system

2 examples:

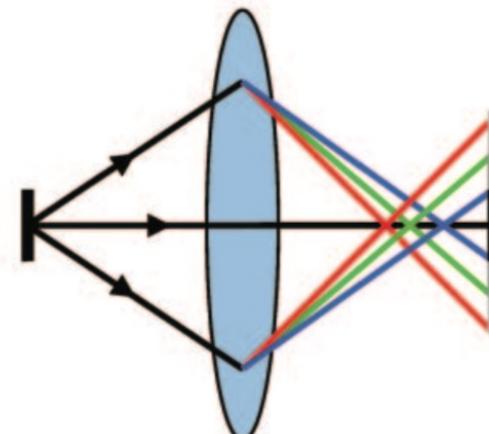
a perfect lens



b spherical aberration

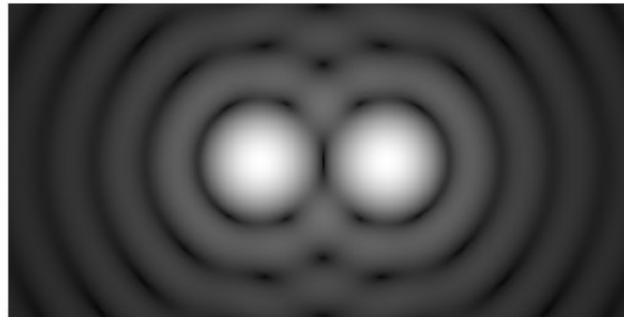


c chromatic aberration

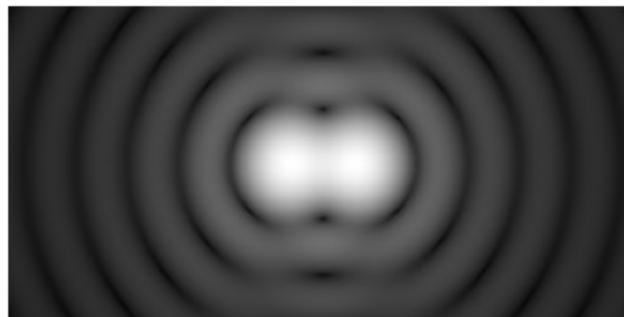


Diffraction aberration

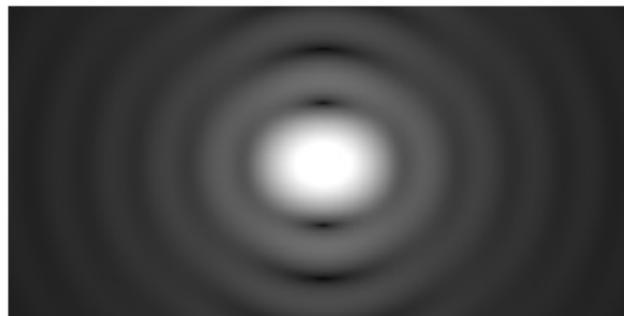
fundamental resolution limit imposed by the wave nature of particles (photons ,electrons and all other particles/objects)



2 objects far apart – well resolved



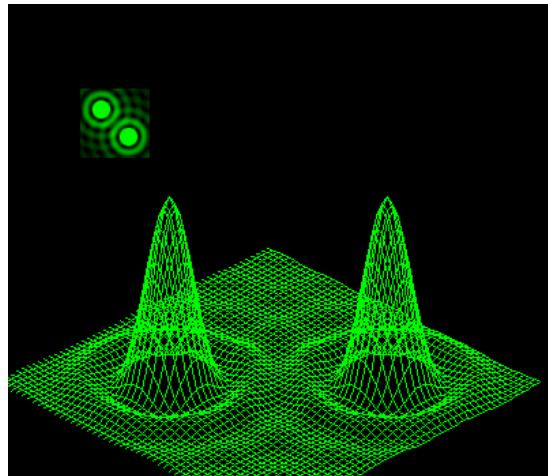
2 objects at the diffraction limit of resolution
defined by the Rayleigh criterion



2 objects close together – unresolved

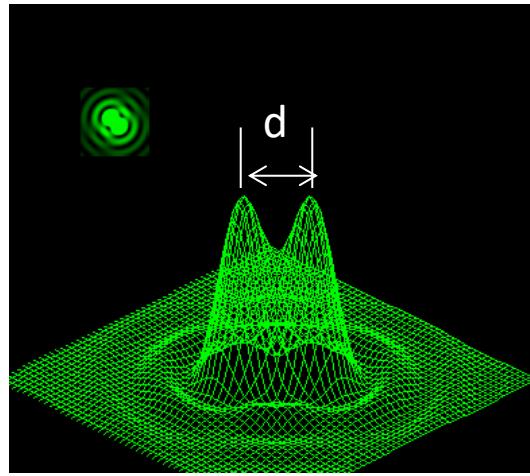
What is resolution?

resolved

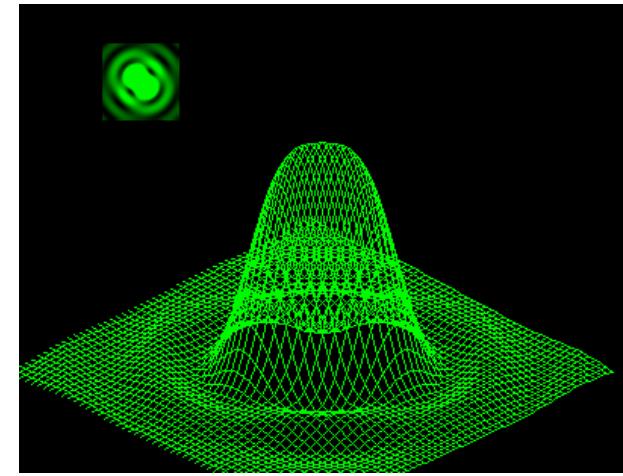


diffraction-limited image of 2
features much smaller than
the resolution

resolved



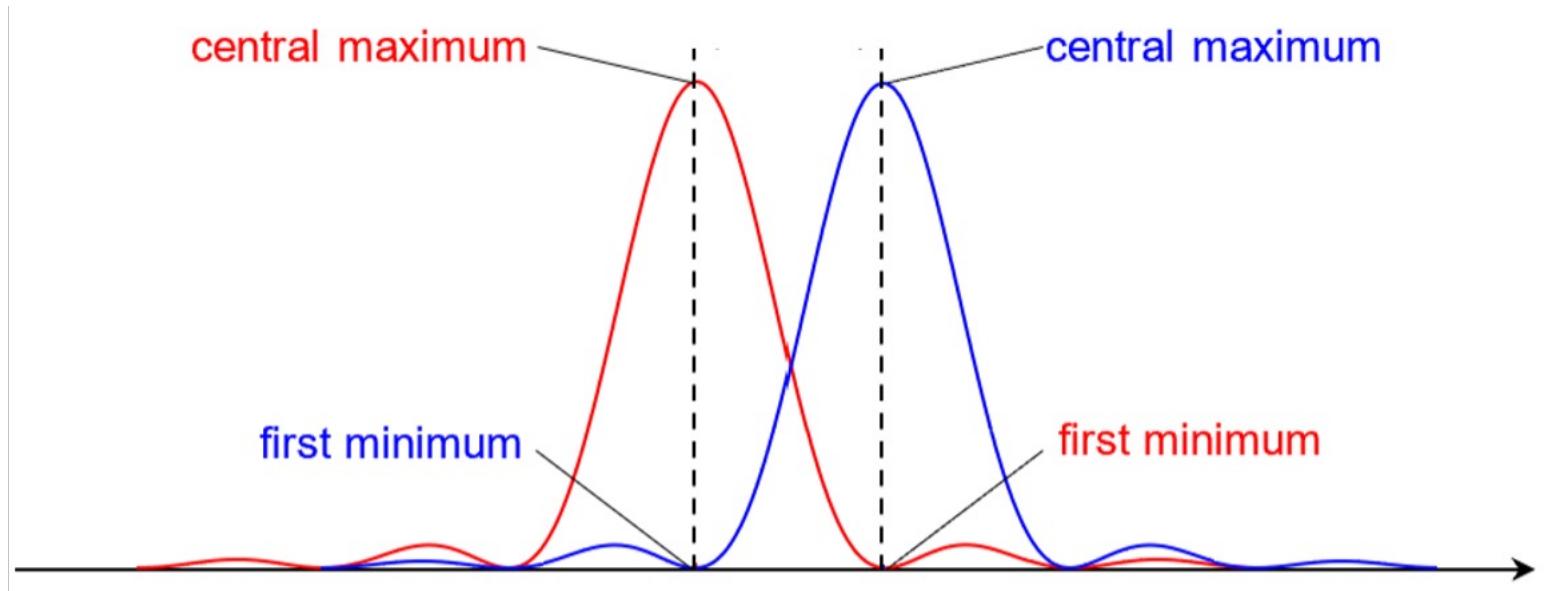
unresolved



is this an image of 1 broad
feature or 2 small features?

spatial resolution: smallest distance between two features
that can be distinguished as two separate entities

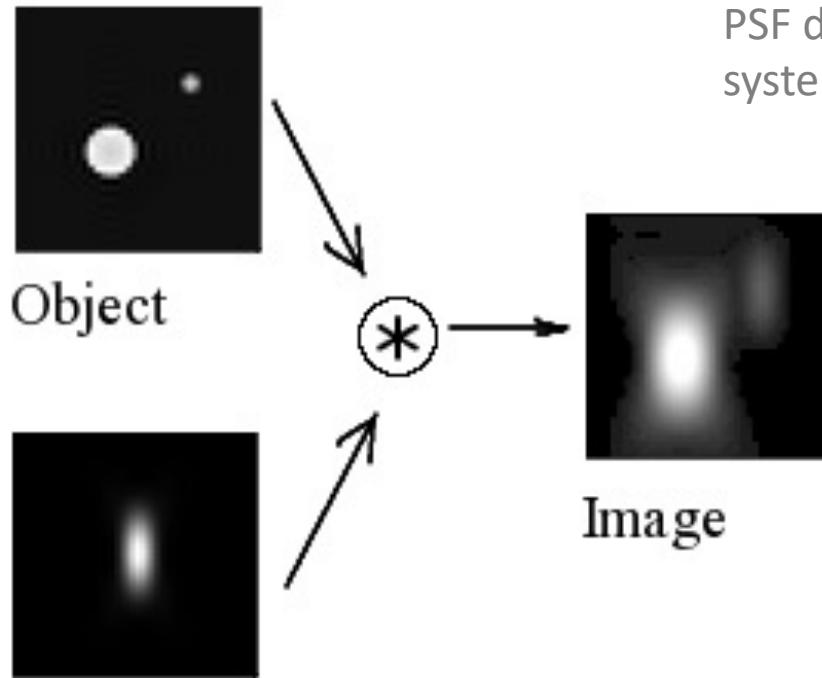
Rayleigh criterion



A generally accepted definition of the resolution of a diffraction-limited image:

The first diffraction minimum of the image of one source point coincides with the central maximum of another.

Point spread function (PSF)



PSF describes the response of an imaging system to a point source or point object.

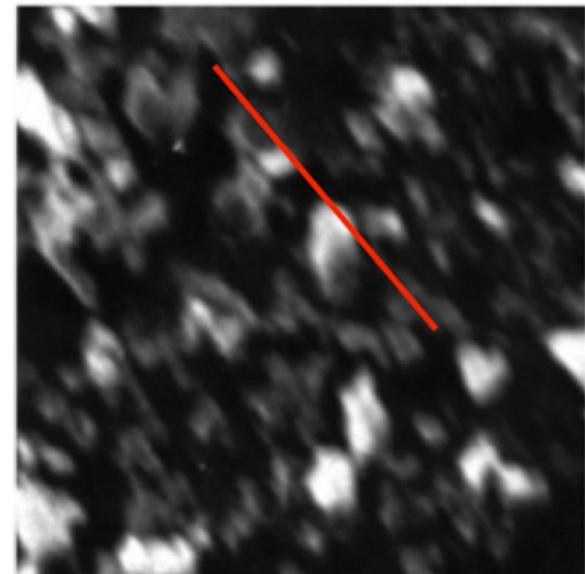
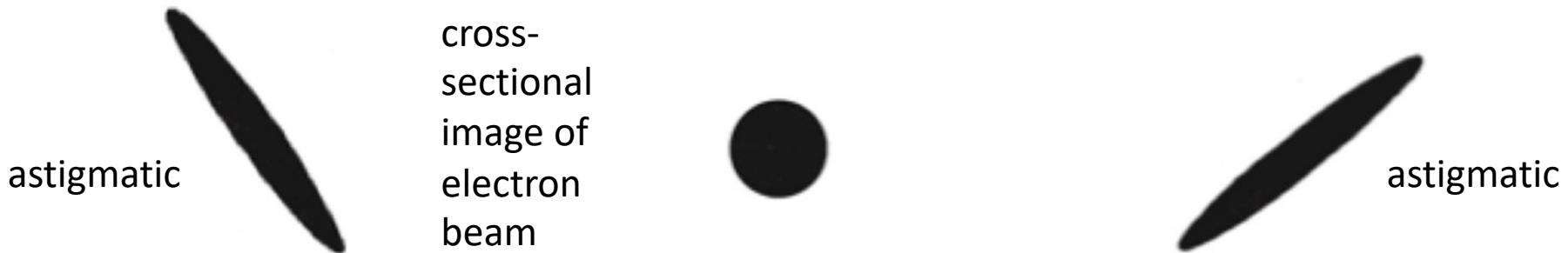
(here, $*$ is the convolution operator)

PSF

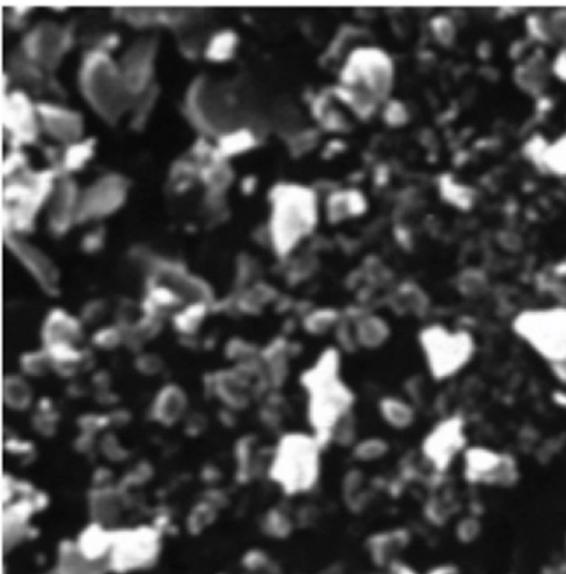
e.g., cross-sectional “shape” of the electron beam used in a scanning electron microscope

Useful concept in 2D (and 3D) microscopy as it describes all aspects of resolution in 2D (or 3D), as shown above by a 2D *astigmatic* PSF. Astigmatism is a type of aberration that makes the resolution of an imaging system anisotropic. It therefore makes the 2D PSF to be non-circular, and gives rise to geometric distortions in images.

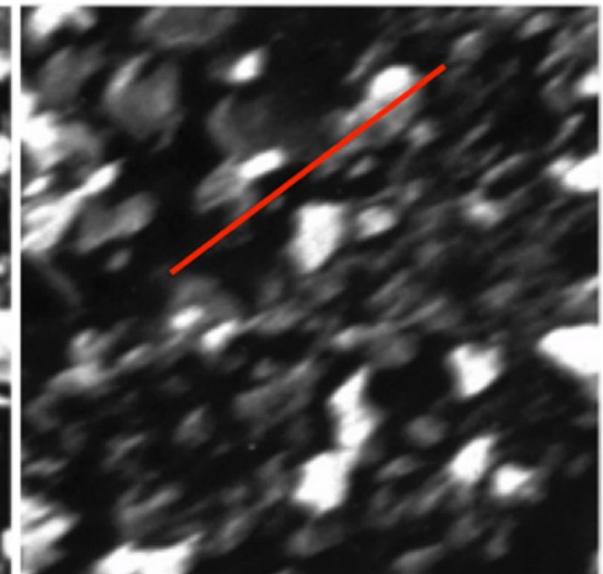
Astigmatism aberration



resolution is different in
different directions



resolution limit seen as
blurring of the image



resolution is different in
different directions

What's next?

Today, Aug 8

Tutorial 1: 12 PM

Next week

Lecture 2: Tues

Tutorial 2: Tues

Lab 1: Thurs

Program			
Week/Session	Dates	Description	
1	5 Aug	Lecture 1: Introduction	Tutorial 1: Nano-scale imaging basics
2	12 Aug	Lecture 2: Electron optics and electron-solid interactions	Tutorial 2: Electron-solid interactions Practical 1: Scanning electron microscopy
3	19 Aug	Lecture 3: Ion beams and electron/ion beam nanofabrication	Tutorial 3: Ion-solid interactions Practical 2: Electron/ion beam nanofabrication
4	26 Aug	CLASS TEST 1	
5	2 Sept	Lecture 4: Cathodoluminescence & x-ray analysis	Tutorial 4: Cathodoluminescence simulations Practical 3: Nanocharacterisation techniques
6	9 Sept	Lecture 5: Advanced nanocharacterisation	Practical 4: Nanocharacterisation techniques
7	16 Sept	Lecture 6: Ion-solid interactions and gas-assisted nanofabrication (advanced)	Portfolio 1 due this week (practicals)