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ENR116 Engineering Materials

Module 2 Material Properties

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Welcome to ENR116 Engineering Materials Module 2 Material Properties

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Imperfections

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Intended Learning Outcomes

At the end of this section, students will be able to:-

- Identify the types of defects in solids.
- Understand how defect type and density can be manipulated.
- How defects affect material properties.

The intended learning outcomes from this presentation
Identify types of defects in solids
Understand how defect type and density can be manipulated
How defects affect material properties

Point Defects - Vacancies

Point defects may be vacancies or self-interstitials

Vacancy: - vacant lattice site, one that is normally occupied but from which an atom is missing.

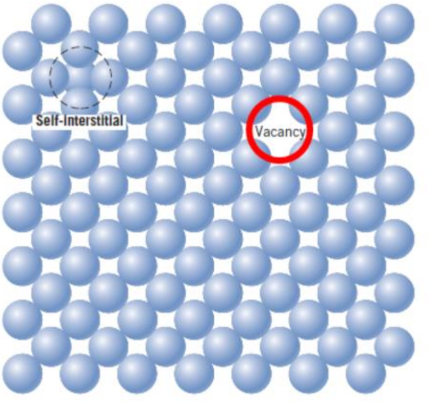

Fig. 4.01, *Callister & Rethwisch 8e.*

Vacancy = vacant lattice site

Occurs in all solids

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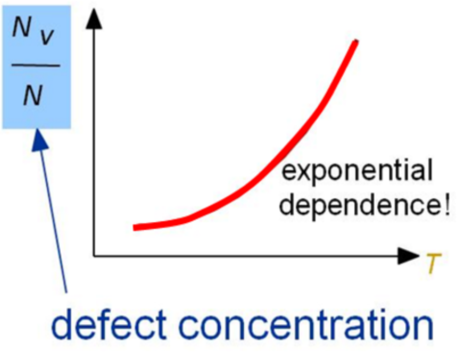
Point Defects - Vacancies

The number of vacancies increases exponentially with temperature.



Number of vacancies increases with T

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Point defects - vacancies

Example: Iron

"Iron electrolytic and 1cm³ cube" by Alchemist-hp (talk) (www.pse-mendelejew.de) - Own work. Licensed under FAL via Wikimedia Commons

Consider 10g of iron

Atomic mass = 55.85 g/mol

Therefore ~10^{23} atoms in sample

Just below melting temperature:

Number of vacancies is of the order of 10^{19}

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Point Defects - Vacancies

N_v: Equilibrium number of vacancies

$$N_V = N \exp\left(-\frac{Q_v}{kT}\right)$$

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Point Defects – Self-interstitials

Self-interstitial: an atom crowded into an interstitial site a small void space that under ordinary circumstances is not occupied.

- Introduces relatively large distortions, because the atom is substantially larger than the interstitial position
- Formation of this defect is not highly probable
- Exists in significantly lower concentrations than vacancies.

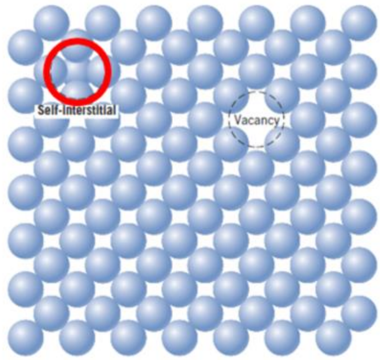

Fig. 4.01, *Callister & Rethwisch 8e.*

Self-interstitial = an atom in an interstitial void

Highly unlikely

Impurities in solids

A pure metal consisting of only one type of atom simply does not exist.

- Most familiar metals are not highly pure - they are alloys.
- Impurity atoms have been added intentionally to impart specific characteristics to the material.
    - Mechanical strength
    - Corrosion resistance

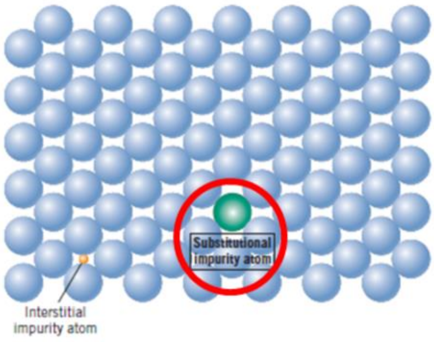

Fig. 4.02, *Callister & Rethwisch 8e.*

Pure metals DO NOT exist

Most metals are alloys

Impurities can be used to improve material properties

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Impurities in solids

Solid solution - the addition of impurity atoms to a metal.

Solvent - represents the element or compound that is present in the greatest amount.

Solute - element or compound present in a minor concentration.

A solid solution forms when, as the solute atoms are added to the host material, the crystal structure is maintained, and no new structures are formed.

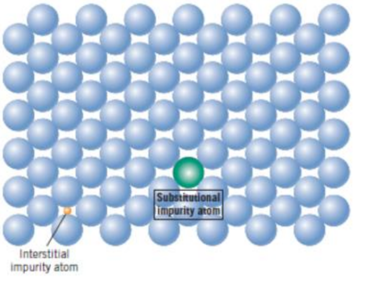

Fig. 4.02, *Callister & Rethwisch 8e.*

Solid solution = addition of impurity atoms to a metal

Solvent = more abundant element

Solute = less abundant element

Crystal structure must be maintained

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Impurities in solids

Two types: **Substitutional** and Interstitial

Substitutional - solute or impurity atoms replace or substitute for the host atoms.

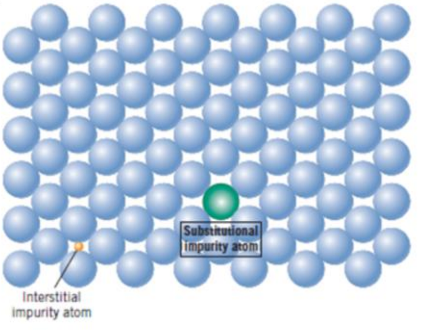

Fig. 4.02, *Callister & Rethwisch 8e.*

Depends on:

Substitutional impurities are where impurity atoms replace host atoms

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Impurities in solids

Interstitial - impurity atoms fill the voids or interstices among the host atoms.

The atomic diameter of an interstitial impurity must be substantially smaller than that of the host atoms.

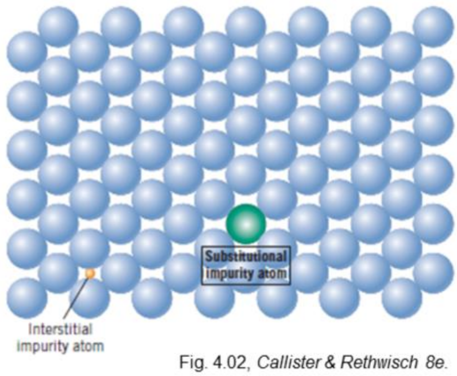
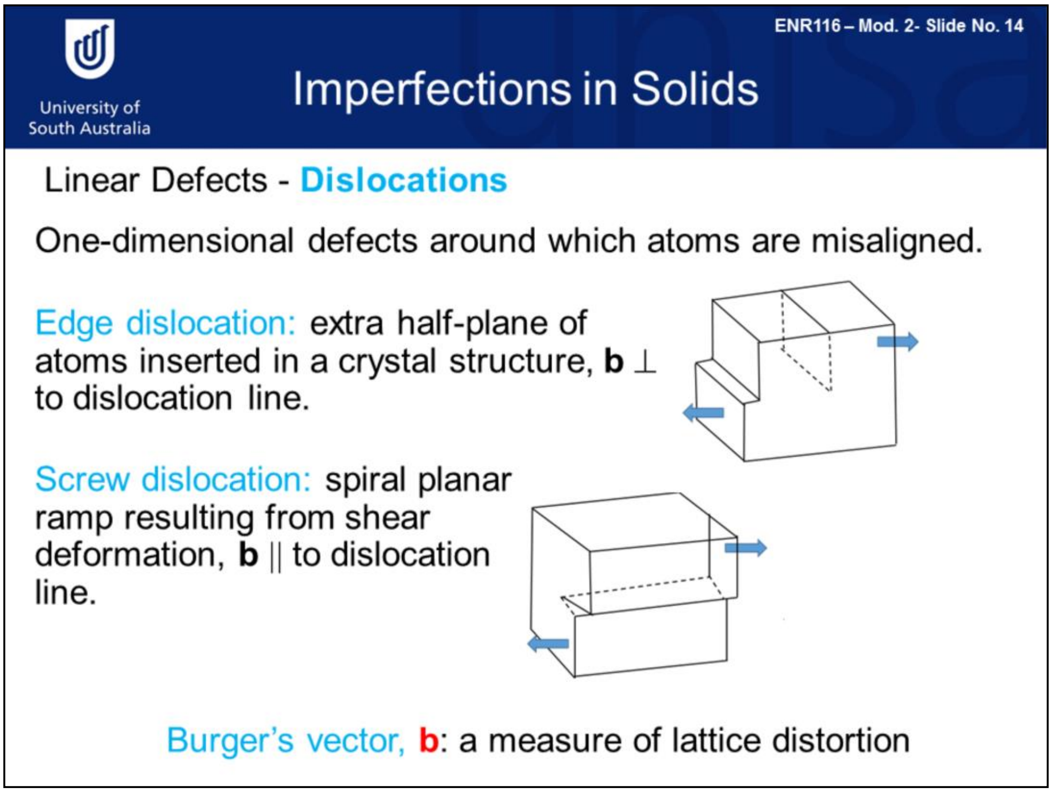


Fig. 4.02, *Callister & Rethwisch 8e.*

Interstitial impurities are where the impurity atoms fill voids

Must be small diameter atoms



Two types of Dislocations

Edge dislocation = extra half-plane of atoms inserted into crystal structure

Screw dislocation = spiral planar ramp from shear deformation

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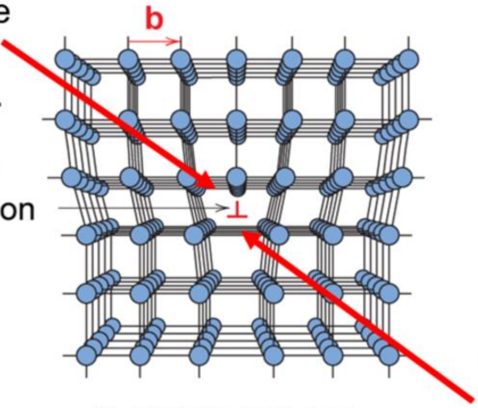
Imperfections in Solids

Edge Dislocation: An extra portion of a plane of atoms, or half-plane, the edge of which terminates within the crystal.

Burgers vector

The atoms above the dislocation line are squeezed together…

Edge dislocation line



…Those below are pulled apart.

Fig. 4.03, *Callister & Rethwisch 8e.*

Edge dislocation results in localized lattice distortion

Burgers vector, b = a measure of lattice distortion

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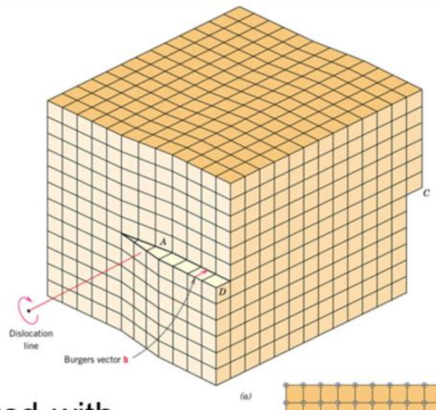
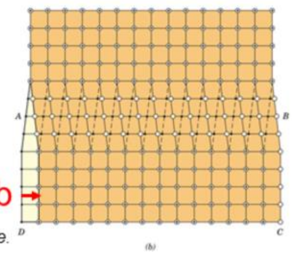
Imperfections in Solids

Screw Dislocation: The upper front region of the crystal is shifted one atomic distance to the right relative to the bottom portion.

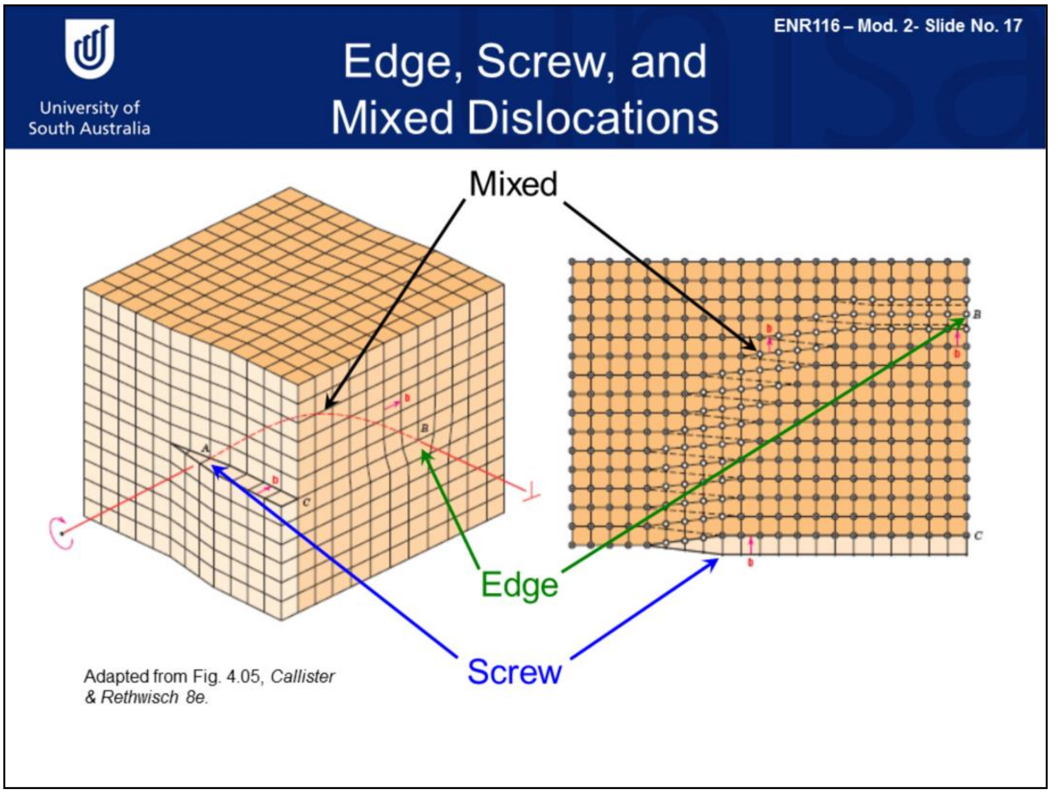


The atomic distortion associated with a screw dislocation is also linear and along a dislocation line.



Adapted from Fig. 4.04, *Callister & Rethwisch 8e.*

Screw dislocation = upper planes shifted relative to lower planes of atoms



3 types of dislocations (Edge, Screw and Mixed)

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Imperfections in Solids

Dislocations are visible in electron microscopy.

A transmission electron micrograph of a titanium alloy in which the dark lines are dislocations.

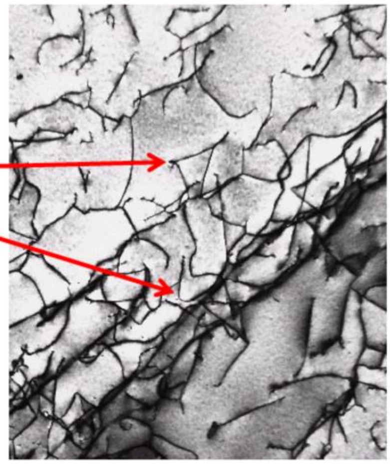

Fig. 4.06, *Callister & Rethwisch 8e.*

Dislocations are visible in electron microscopy (shown as dark lines)

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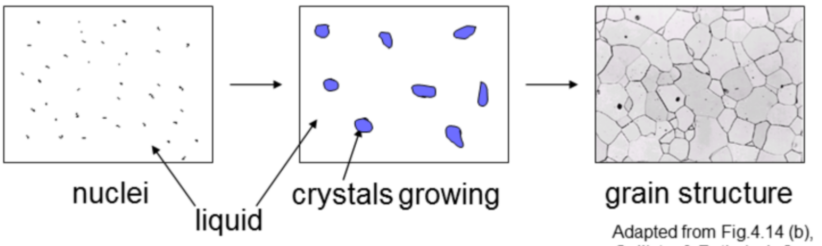
Imperfections in Solids

Solidification: The result of casting molten material.

2 steps

Nuclei form

Nuclei grow to form crystals – grain structure



Adapted from Fig.4.14 (b), *Callister & Rethwisch 8e.*

Crystals grow until they meet each other

Imperfections occur during solification

Crystal grow into each other and form grain boundaries

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Polycrystalline Materials

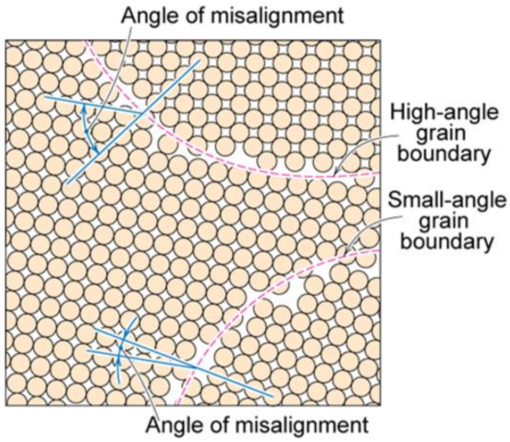
Grain Boundaries

Regions between crystals.

Transition from lattice of one region to that of the other is slightly disordered.

Low density in grain boundaries.

Atoms have:



Adapted from Fig.4.17, *Callister & Rethwisch 8e.*

Grain boundaries are the regions between crystals

Grain boundaries have low density, and the atoms have high mobility, diffusivity and reactivity

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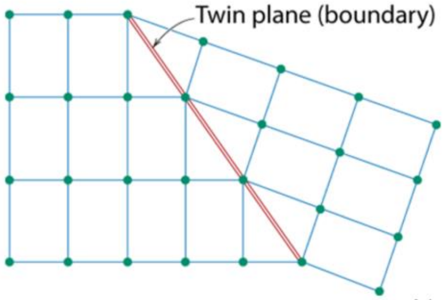
Planar Defects in Solids

One case is a twin boundary (plane)

Essentially a reflection of atom positions across the twin plane. There is a specific mirror lattice symmetry.



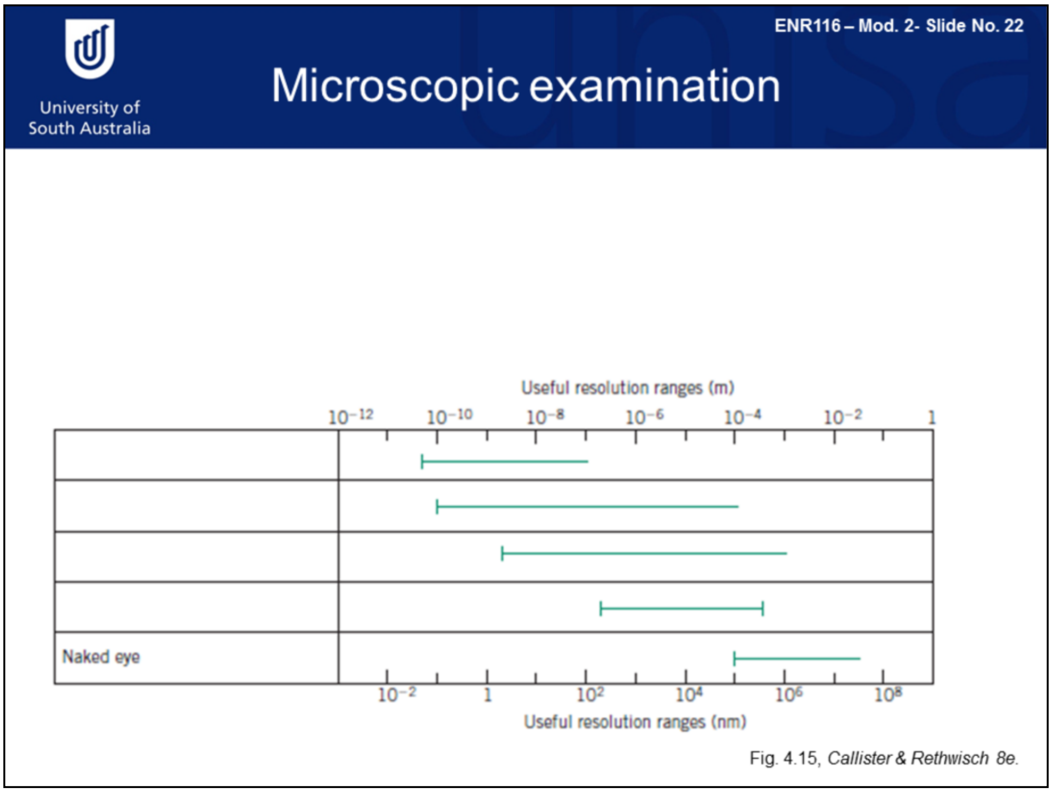
Adapted from Fig.4.19, *Callister & Rethwisch 8e.*

Stacking faults

For FCC metals an error in ABCABC packing sequence
For example: ABCABABC

Planar Defects

- Twin Planes
- Stacking Faults (eg ABCABABC)



4 Types of Microscopy will be covered

Naked eye resolution = 0.1mm approx

Optical microscopy resolution = 300nm

Scanning electron microscopy resoltuion = 1nm

Transmission electron microscopy and scanning probe microscopy resolution < 1 Angstrom

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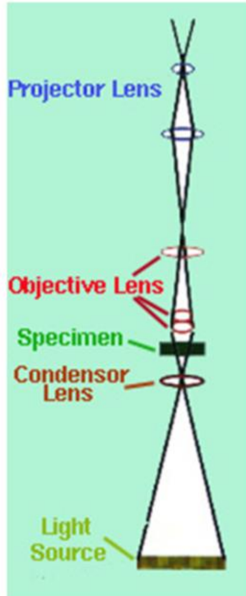
Optical microscopy

Optical microscopes consist of an arrangement of optical elements (mostly lenses and mirrors).

Light coming from the observed object Leads directly into the observer's eye or any other light detecting device.



Optical microscopy utilises light waves

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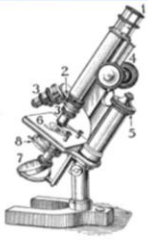
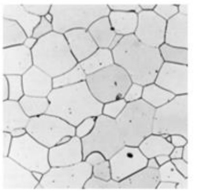
Optical microscopy

Advantages:





Adapted from Fig. 4.14b, *Callister & Rethwisch 8e.* Courtesy of L.C. Smith and C. Brady, the National Bureau of Standards, Washington, DC [now the National Institute of Standards and Technology, Gaithersburg, MD].)

Limitation:

Resolution – diffraction limited, which is roughly half of the wavelength of light.
Max resolution: 300 – 400 nm

Advantages = Cheap, Fast, Non-invasive and Easy

Limitation = max resolution = 300nm

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Optical Microscopy

Useful up to 2000X magnification.

Useful when observing large features, such as scratches

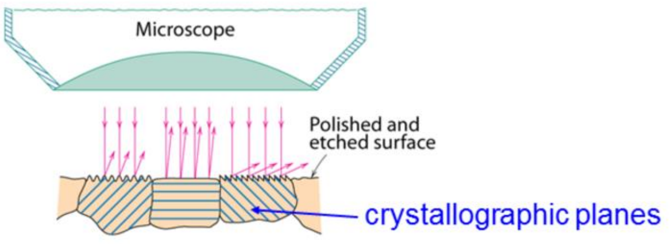

Fig. 4.13a, *Callister & Rethwisch 8e.*

Fig. 4.13b, *Callister & Rethwisch 8e.*

Micrograph of brass (a Cu-Zn alloy)

Etching changes reflectance, depending on crystal orientation.

Can be used to observe scratches, etching of surfaces and large grains

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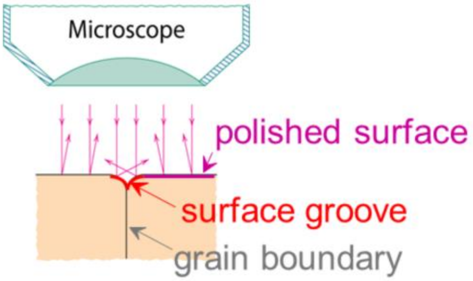
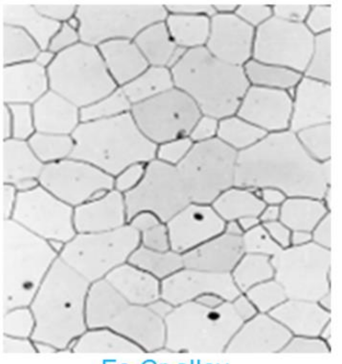
Optical Microscopy

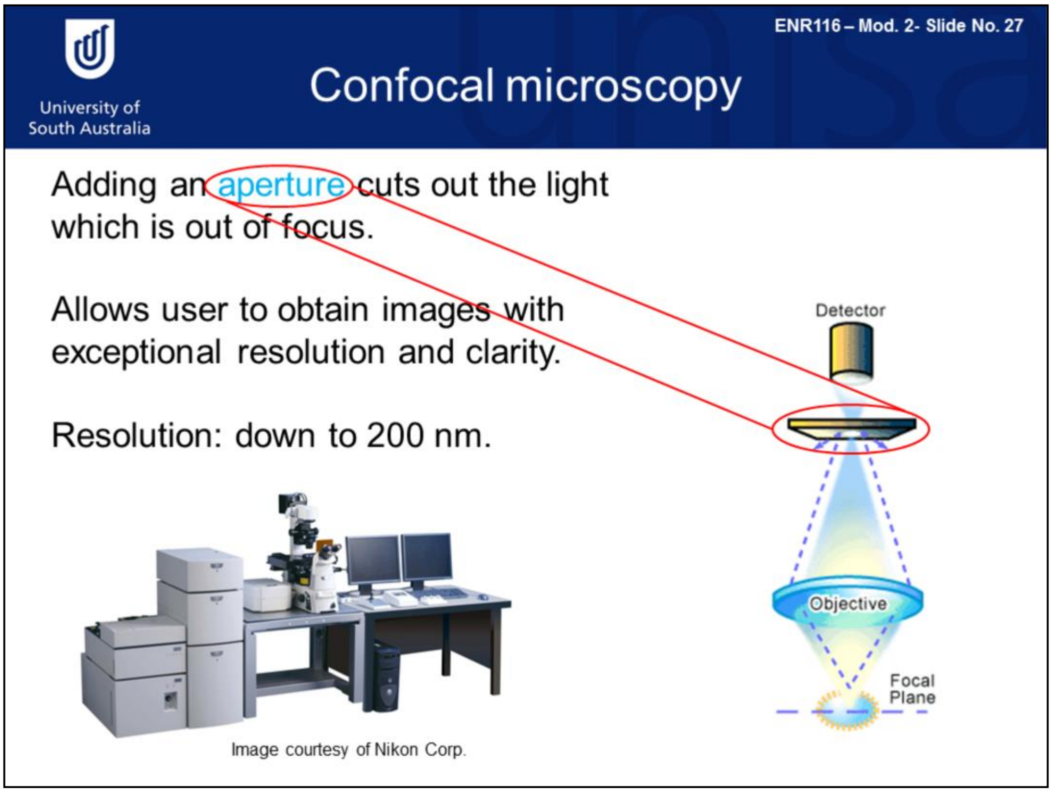
Grain boundaries:




Fe-Cr alloy

Adapted from Fig. 4.14(a) and (b), *Callister & Rethwisch 8e.* (Fig. 4.14(b) is courtesy of L.C. Smith and C. Brady, the National Bureau of Standards, Washington, DC [now the National Institute of Standards and Technology, Gaithersburg, MD].)

Grain boundaries are easily etched and show up as dark lines



Confocal microscopy uses an aperture to cut out of focus light

Improved resolution down to 200nm

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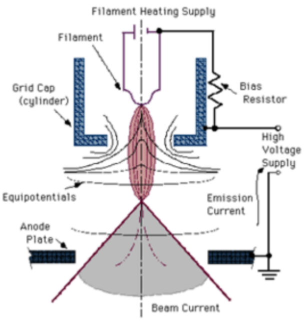
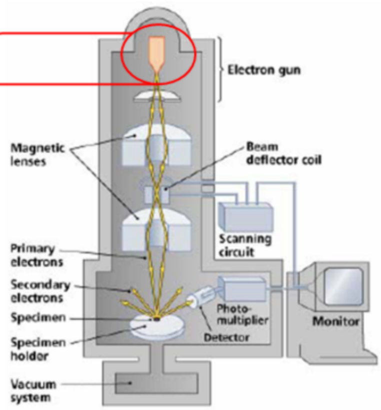
Scanning electron microscopy (SEM)

The Scanning Electron Microscope (SEM) is a microscope that uses electrons rather than light to form an image.

Electron gun:
Tungsten
Lanthanum hexaboride





Scanning Electron Microscopy uses electrons rather than light

Electrons have very low wavelengths

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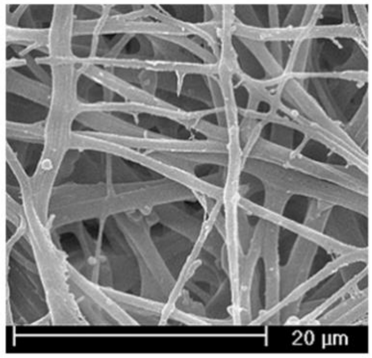
Scanning electron microscopy (SEM)

Secondary electron image of the inside of an eggshell.



BSE image of an Al-Cu alloy. The light area is mostly Cu and the dark area is mostly Al.

Can easily see features below 1 micron

Back scattered electron image can be used to show chemical differences

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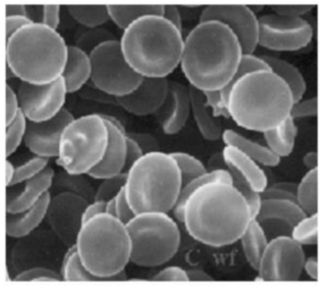
Scanning electron microscopy (SEM)



SEM of red blood cells

SEM advantages – High resolution, quantitative, elemental mapping

SEM disadvantages – vacuum, destructive, biological samples need special preparation

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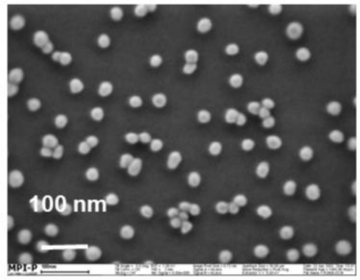
Scanning electron microscopy (SEM)

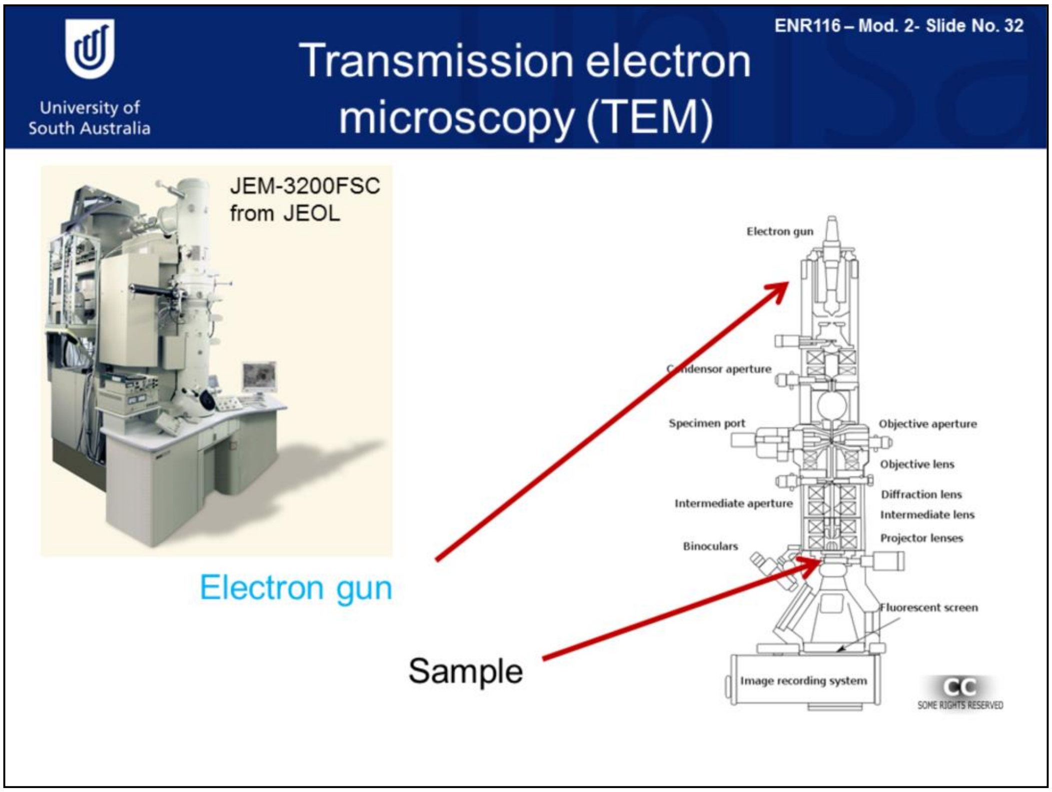
Applications: - very broad

Materials science
Semiconductor industry
Biology
Nanotechnology
….all related disciplines



SEM image of gold nanoparticles

Very broad range of applications



Transmission electron microscopy measures transmitted electrons rather than scattered electrons

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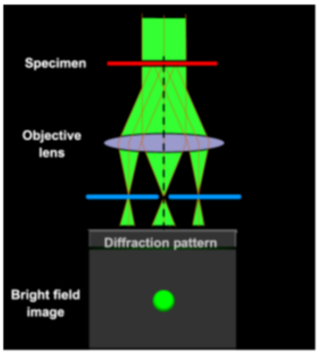
TEM modes of operation



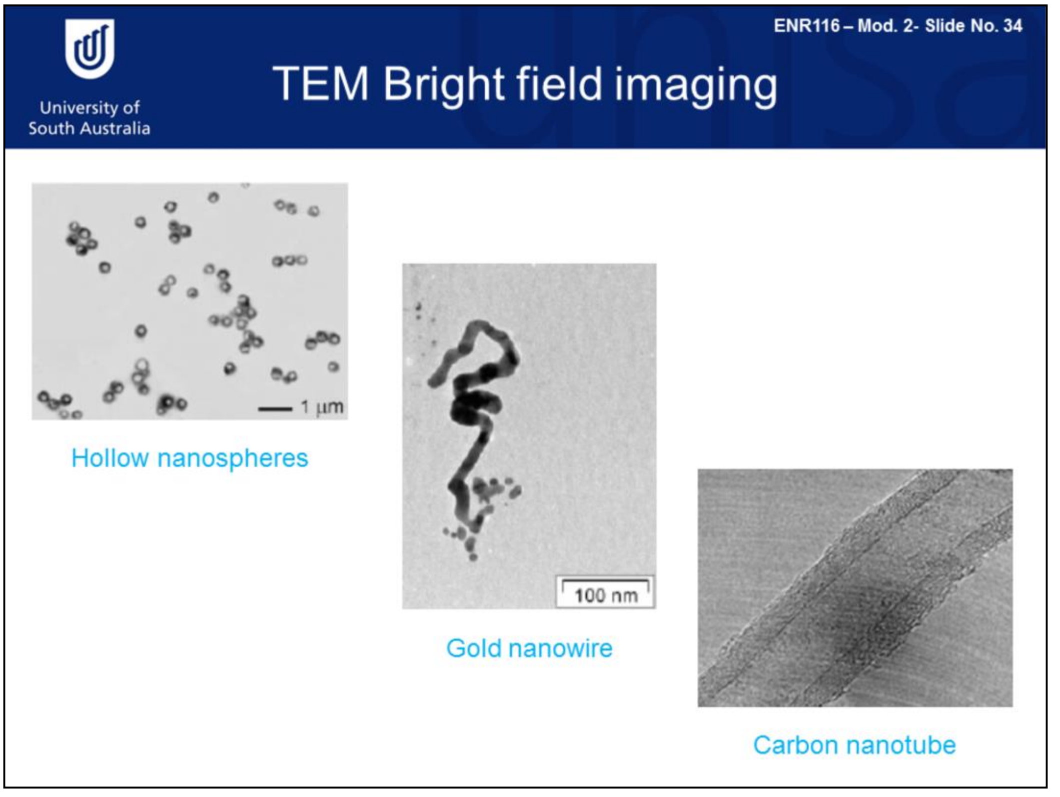
Bright field

3 Modes of operation

Bright field – transmitted electrons

Dark field – electron beam tilted and scattered electrons collected

Diffraction – gives atomic arrangement information



TEM Bright field images

Solids show up as dark areas, due to no electrons being transmitted

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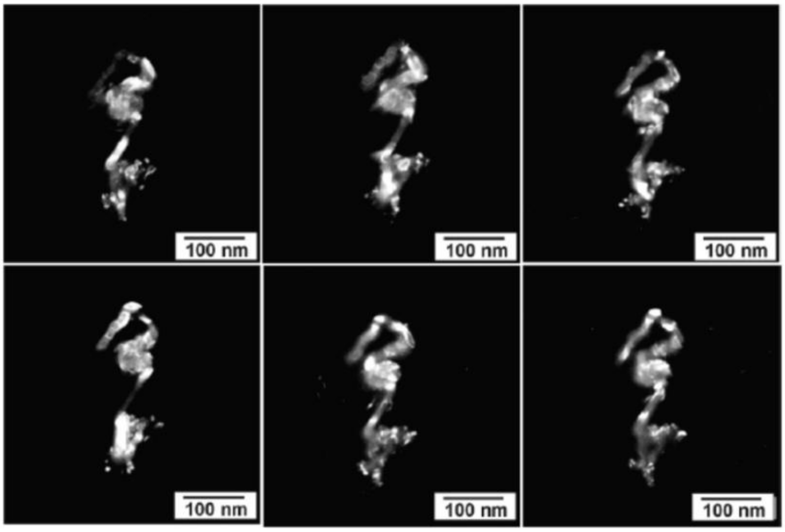
TEM Dark-field imaging



Images from Vasilev et al. Langmuir **2005**, 21 (26): 12399-12403

TEM Dark field

Images changes as angle of electron beam is changed

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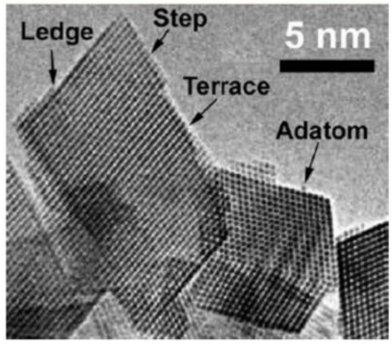
Transmission electron microscopy (TEM)



High-resolution transmission electron micrograph that shows single crystals of $(Ce_{0.5}Zr_{0.5})O_2$; this material is used in catalytic converters for automobiles.

Fig. 4.11, *Callister & Rethwisch 8e.*

TEM advantages – resolution 0.2nm, and info regarding crystal structure

TEM disadvantages – require vacuum, very thin sample required

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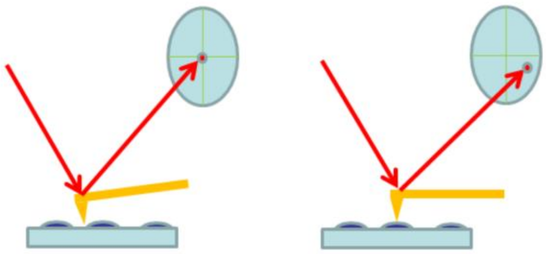
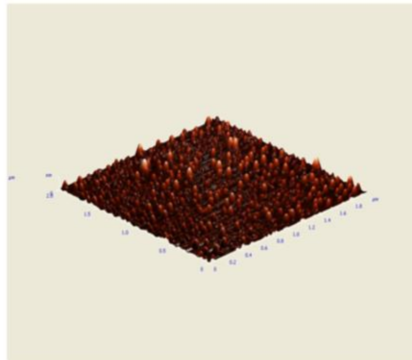
Scanning probe microscopy (SPM)

Atomic force microscopy (AFM)

Works by scanning a sharp probe over the surface of a sample in a raster pattern. By monitoring the movement of the probe, a 3-D image of the surface can be constructed.





Scanning Probe Microscopy uses sharp probe to raster over surface.

Movements in probe over topographical features are measured by movement of a reflected laser beam.

Can generate 3D images

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Summary

- Point, line, and area defects exist in solids.
- Temperature controls the number and type of defects.
- Defects affect material properties (e.g., grain boundaries control crystal slip).

Summary
Point, line and area defects in solids
Temperature controls number and type of defects
Defects affect material properties

Thank you