# IMPERFECTIONS IN SOLIDS

Subject: Material Science - Lecture #10

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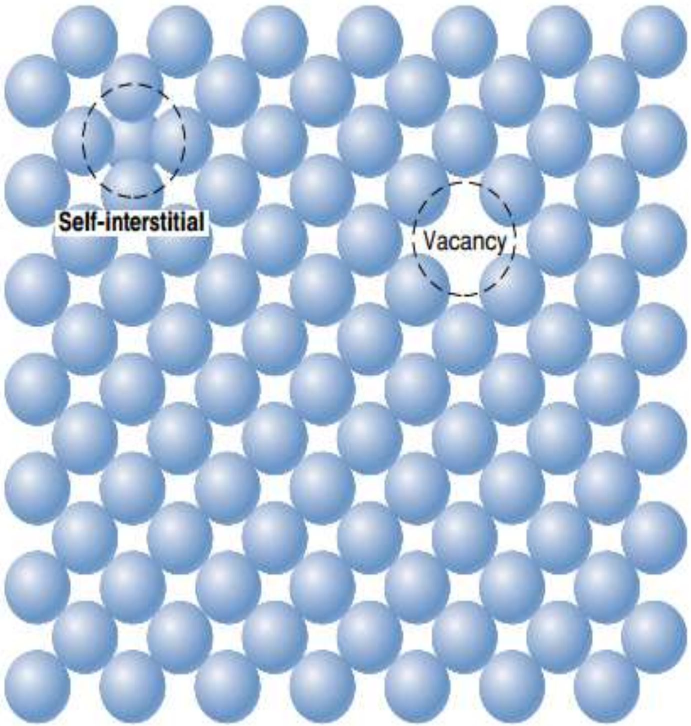
# INTRODUCTION

- previous chapter assumed that perfect order exists throughout crystalline materials on an atomic scale. However, such an idealized solid does not exist; all contain large numbers of various defects or **imperfections**.
- many of the properties of materials are sensitive to deviations from crystalline perfection.
- Classification of crystalline imperfections is frequently made according to the geometry or dimensionality of the defect.

Several different imperfections are discussed in this chapter,

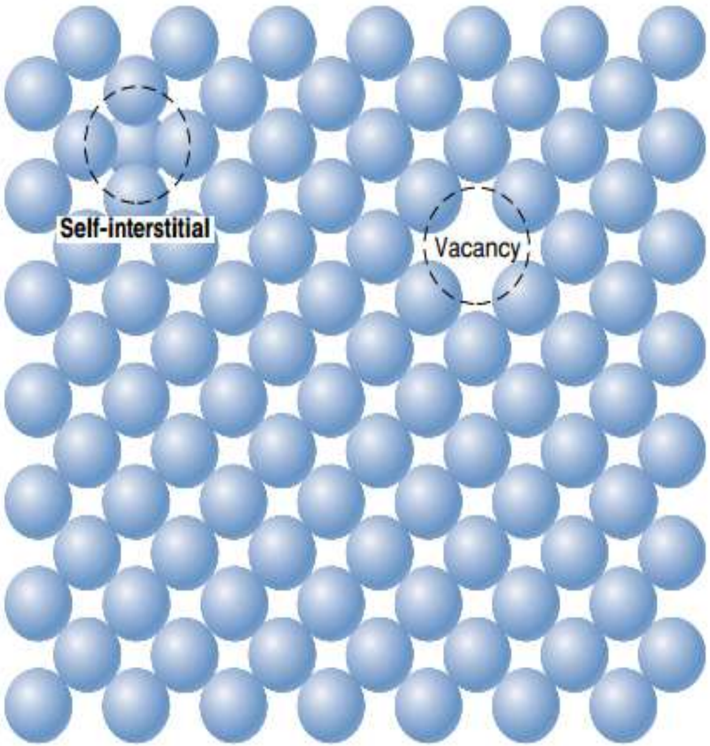
# Point Defects
## VACANCIES AND SELF-INTERSTITIALS

- The simplest of the point defects is a **vacancy**, or vacant lattice site (missing atom)




- All crystalline solids contain vacancies, and, in fact, it is not possible to create such a material that is free of these defects.

- A **self-interstitial** is an atom from the crystal that is crowded into an *interstitial site* (a small void space that under ordinary circumstances is not occupied).



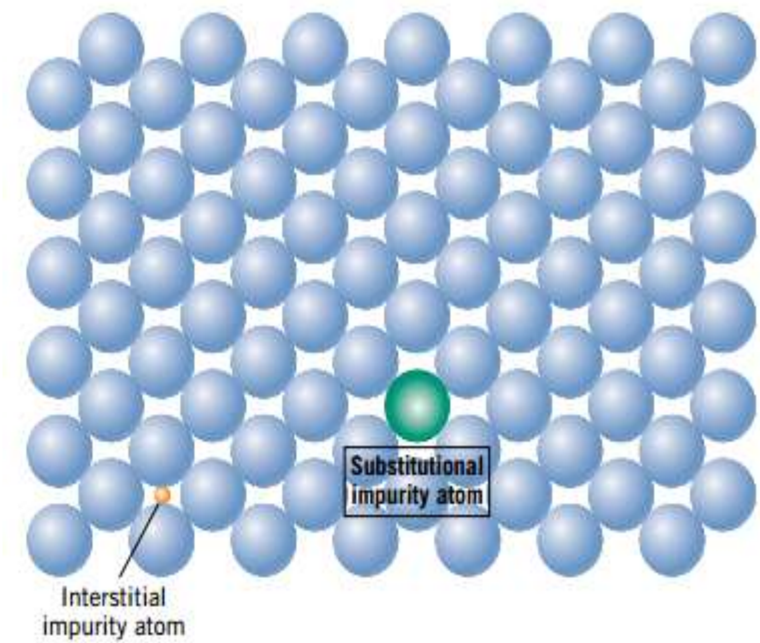
# IMPURITIES IN SOLIDS

- A pure metal consisting of only one type of atom just isn't possible;
- impurity or foreign atoms are always present, and some exist as crystalline point defects.
- In fact, even with relatively sophisticated techniques, it is difficult to refine metals to a purity in excess of 99.9999%. At this level, on the order of $10^{22}$to $10^{23}$ impurity atoms are present in $1m^3$ of material.
- Most familiar metals are not highly pure; rather, they are **alloys**, in which impurity atoms have been added intentionally to show a specific characteristics to the material.

- Ordinarily, alloying is used in metals to improve mechanical strength and corrosion resistance.
- For example, sterling silver is a 92.5% silver/7.5% copper alloy. In normal ambient environments, pure silver is highly corrosion resistant, but also very soft. Alloying with copper significantly enhances the mechanical strength without depreciating the corrosion resistance appreciably.

- The addition of impurity atoms to a metal results in the formation of a **solid solution** and/or a new *second phase,* depending on the kinds of impurity, their concentrations, and the temperature of the alloy.

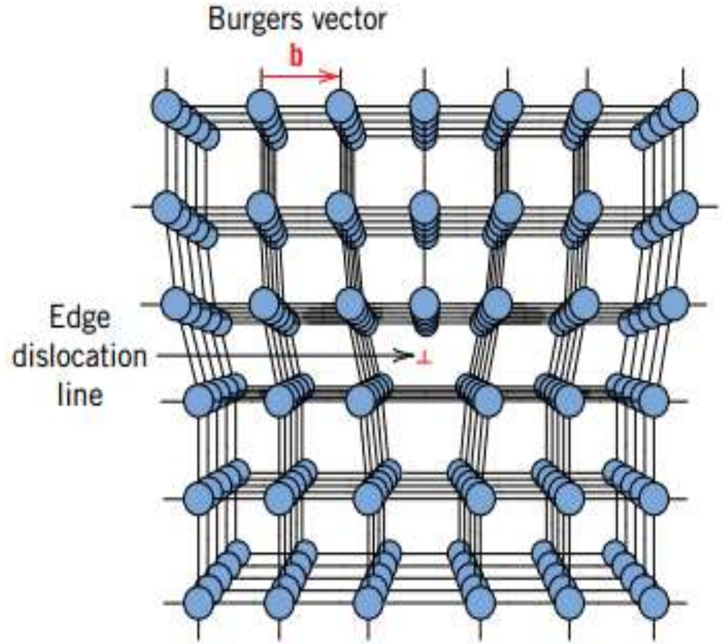
- Impurity point defects are found in solid solutions, of which there are two types: **substitutional** and **interstitial**.



# Miscellaneous Imperfections
# **DISLOCATIONS—LINEAR DEFECTS**

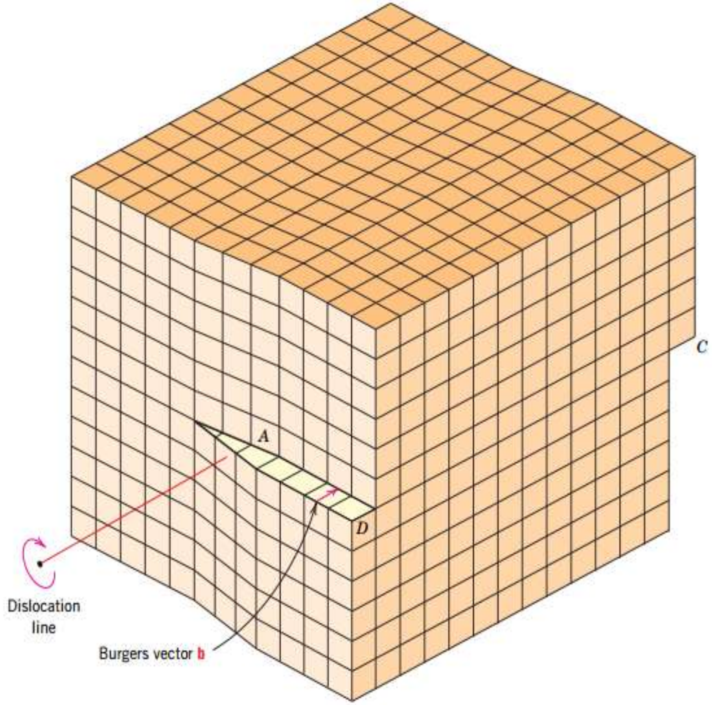
A *dislocation* is a linear or one-dimensional defect around which some of the atoms are misaligned. There are several linear defect:

- One type of dislocation is represented in Figure; an extra portion of a plane of atoms, or half-plane, the edge of which terminates within the crystal. This is termed an **edge dislocation**



- Another type of dislocation, called a **screw dislocation**, may be thought of as being formed by a shear stress that is applied to produce the distortion shown in Figure

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

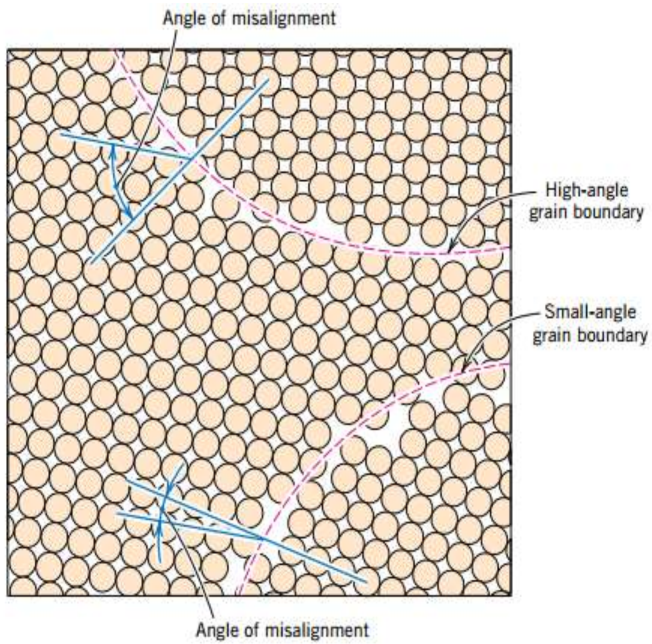


- Most dislocations found in crystalline materials are probably neither pure edge nor pure screw but exhibit components of both types; these are termed **mixed dislocations**.

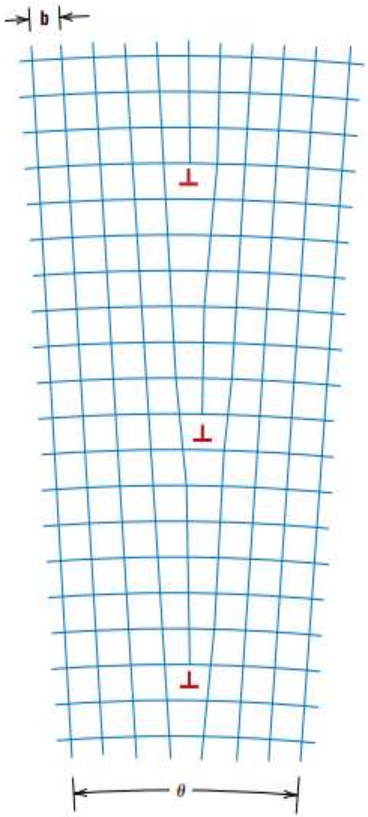
# INTERFACIAL DEFECTS

Interfacial defects are boundaries that have two dimensions and normally separate regions of the materials that have different crystal structures and/or crystallographic orientations.

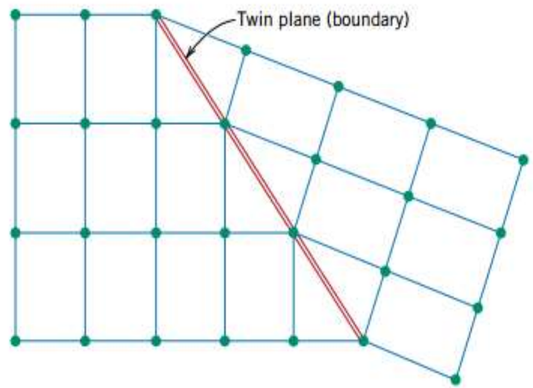
These imperfections include external surfaces, grain boundaries, phase boundaries, twin boundaries, and stacking faults.




grain boundaries




tilt boundary




Twin plane or boundary

# BULK OR VOLUME DEFECTS

- Other defects exist in all solid materials that are much larger than those discussed. These include pores, cracks, foreign inclusions, and other phases. They are normally introduced during processing and fabrication steps.

# ATOMIC VIBRATIONS

- Every atom in a solid material is vibrating very rapidly about its lattice position within the crystal. In a sense, these **atomic vibrations** may be thought of as imperfections or defects.
- At any instant of time, not all atoms vibrate at the same frequency and amplitude or with the same energy.
- At a given temperature, there exists a distribution of energies for the constituent atoms about an average energy. Over time, the vibrational energy of any specific atom also varies in a random manner. With rising temperature, this average energy increases, and, in fact, the temperature of a solid is really just a measure of the average vibrational activity of atoms and molecules.

- At room temperature, a typical vibrational frequency is on the order of $10^{13}$ vibrations per second, whereas the amplitude is a few thousandths of a nanometer.
- Many properties and processes in solids are manifestations of this vibrational atomic motion. For example, melting occurs when the vibrations are vigorous enough to rupture large numbers of atomic bonds.

# Microscopic Examination
# BASIC CONCEPTS OF MICROSCOPY

- It is necessary or desirable to examine the structural elements and defects that influence the properties of materials.
- Some structural elements are of *macroscopic* dimensions; that is, they are large enough to be observed with the unaided eye. For example, the shape and average size or diameter of the grains for a polycrystalline specimen are important structural characteristics.
- large grains having different textures are clearly visible on the surface of the sectioned copper ingot shown in Figure. The small, needle-shape grains may be observed, which extend from the center radially outward.

- However, in most materials the constituent grains are of *microscopic* dimensions, having diameters that may be on the order of microns, and their details must be investigated using some type of microscope.
- Grain size and shape are only two features of what is termed the **microstructure**.
- Optical, electron, and scanning probe microscopes are commonly used in **microscopy**. These instruments aid in investigations of the microstructural features of all material types.
- Some of these techniques employ photographic equipment in conjunction with the microscope; the photograph on which the image is recorded is called a **photomicrograph**. In addition, many microstructural images are computer generated and/or enhanced.

- Microscopic examination is an extremely useful tool in the study and characterization of materials:

- ➢ to ensure that the associations between the properties and structure (and defects) are properly understood.
- ➢ to predict the properties of materials once these relationships have been established.
- ➢ to design alloys with new property combinations.
- ➢ to determine whether a material has been correctly heat-treated.
- ➢ to ascertain the mode of mechanical fracture.

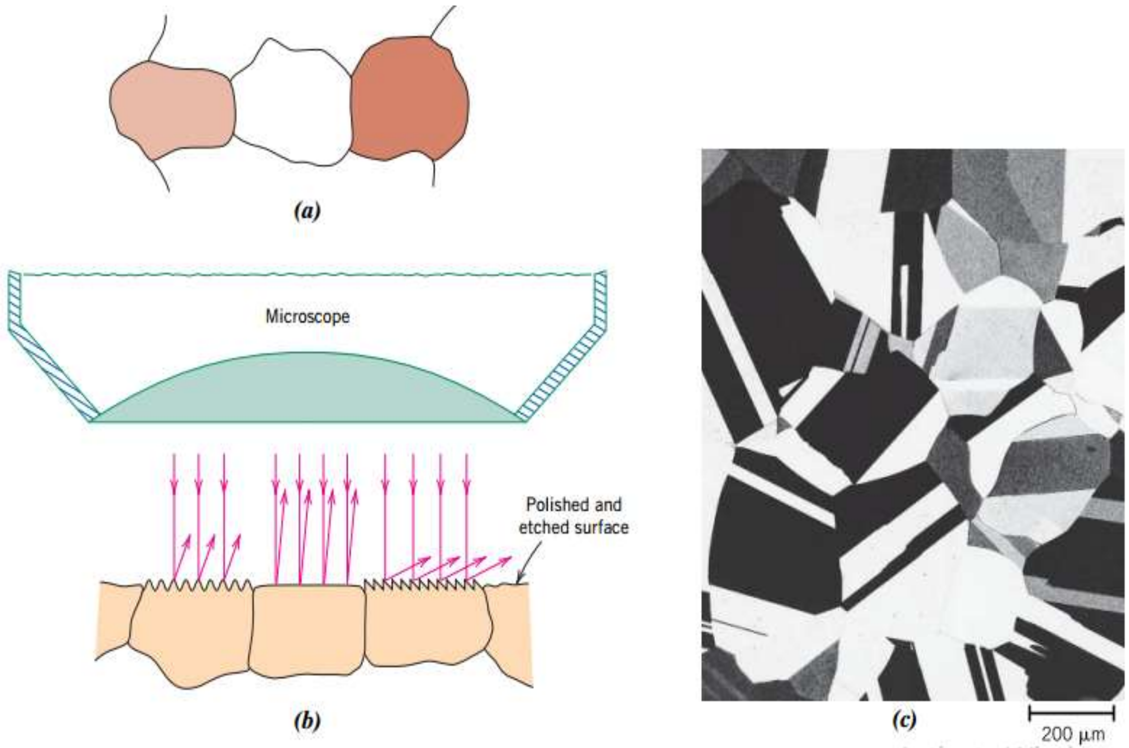
Several techniques that are commonly used in such investigations are discussed next.

# MICROSCOPIC TECHNIQUES

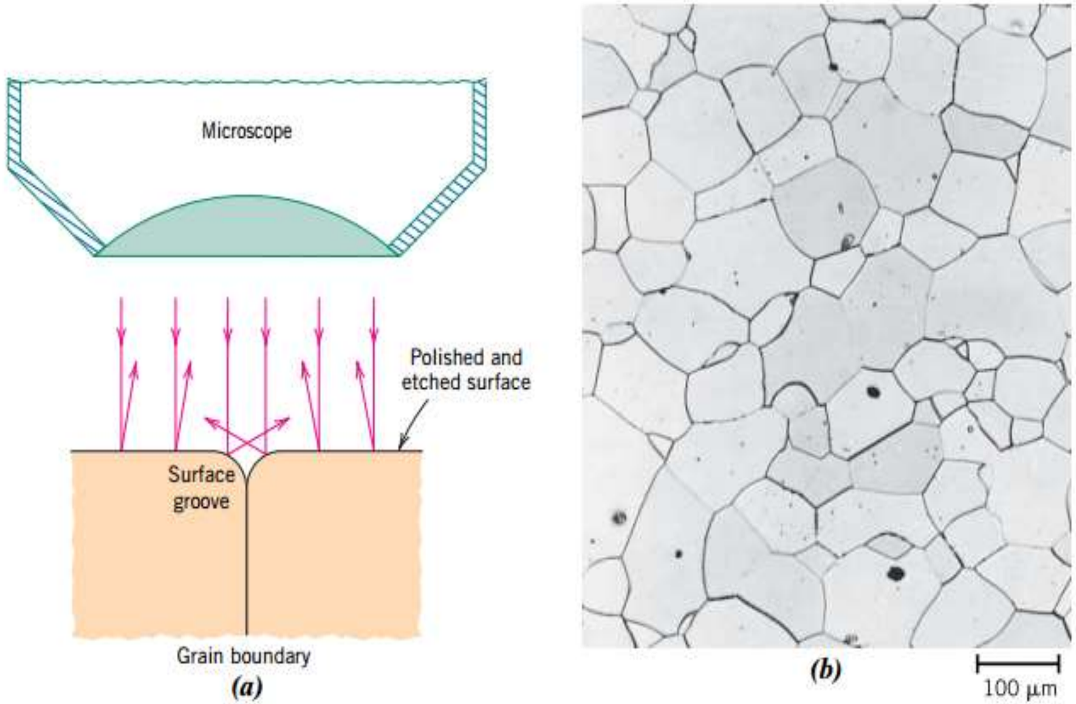
## Optical Microscopy

With *optical microscopy*, the light microscope is used to study the microstructure; optical and illumination systems are its basic elements.

For materials that are opaque to visible light (all metals and many ceramics and polymers), only the surface is subject to observation, and the light microscope must be used in a reflecting mode. Contrasts in the image produced result from differences in reflectivity of the various regions of the microstructure. Investigations of this type are often termed *metallographic* because metals were first examined using this technique.




(a) Polished and etched grains as they might appear when viewed with an optical microscope. (b) Section taken through these grains showing how the etching characteristics and resulting surface texture vary from grain to grain because of differences in crystallographic orientation. (c) Photomicrograph of a polycrystalline brass specimen. 60 x




(*a*) Section of a grain boundary and its surface groove produced by etching; the light reflection characteristics in the vicinity of the groove are also shown. (*b*) Photomicrograph of the surface of a polished and etched polycrystalline specimen of an iron–chromium alloy in which the grain boundaries appear dark, 100 ×.

## Electron Microscopy

- The upper limit to the magnification possible with an optical microscope is approximately $2000\times$. Consequently, some structural elements are too fine or small to permit observation using optical microscopy. Under such circumstances, the electron microscope, which is capable of much higher magnifications, may be employed.
- An image of the structure under investigation is formed using beams of electrons instead of light radiation.
- According to quantum mechanics, a high-velocity electron becomes wavelike, having a wavelength that is inversely proportional to its velocity. When accelerated across large voltages, electrons can be made to have wavelengths on the order of 0.003 nm. High magnifications and resolving powers of these microscopes are consequences of the short wavelengths of electron beams. The electron beam is focused and the image formed with magnetic lenses; otherwise, the geometry of the microscope components is essentially the same as with optical systems.

- Both transmission and reflection beam modes of operation are possible for electron microscopes.

➢ **transmission electron microscope (TEM)** Magnifications approaching 1,000,000 × are possible

➢ **scanning electron microscope (SEM)** Magnifications ranging from 10 × to in excess of 50,000 × are possible

## Scanning Probe Microscopy

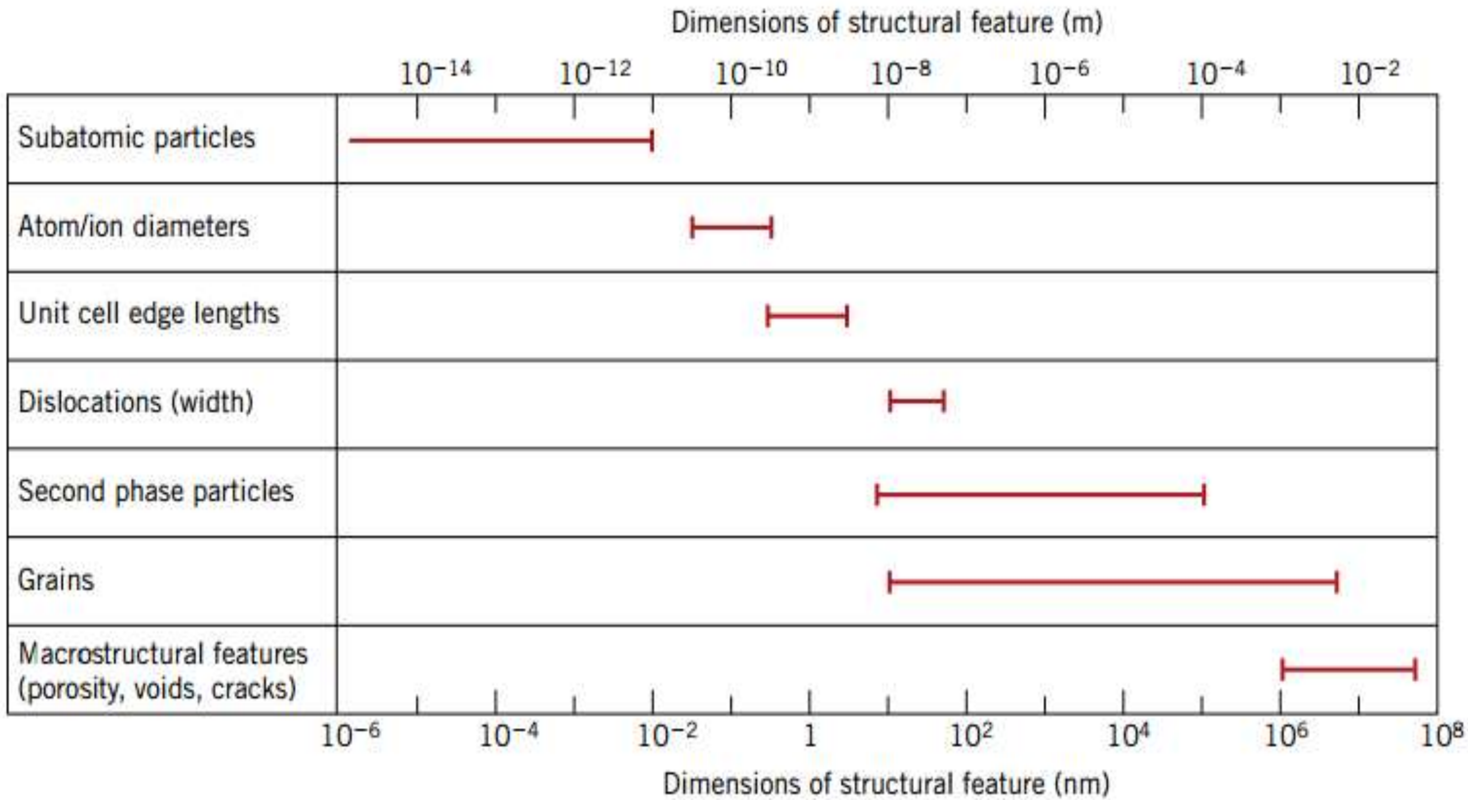
- The **scanning probe microscope (SPM)**, of which there are several varieties, differs from optical and electron microscopes in that neither light nor electrons are used to form an image.
- The microscope generates a topographical map, on an atomic scale.
- Some of the features that differentiate the SPM from other microscopic techniques are as follows:

➢ Examination on the nanometer scale is possible inasmuch as magnifications as high as $10^9 \times$ are possible; much better resolutions are attainable than with other microscopic techniques.

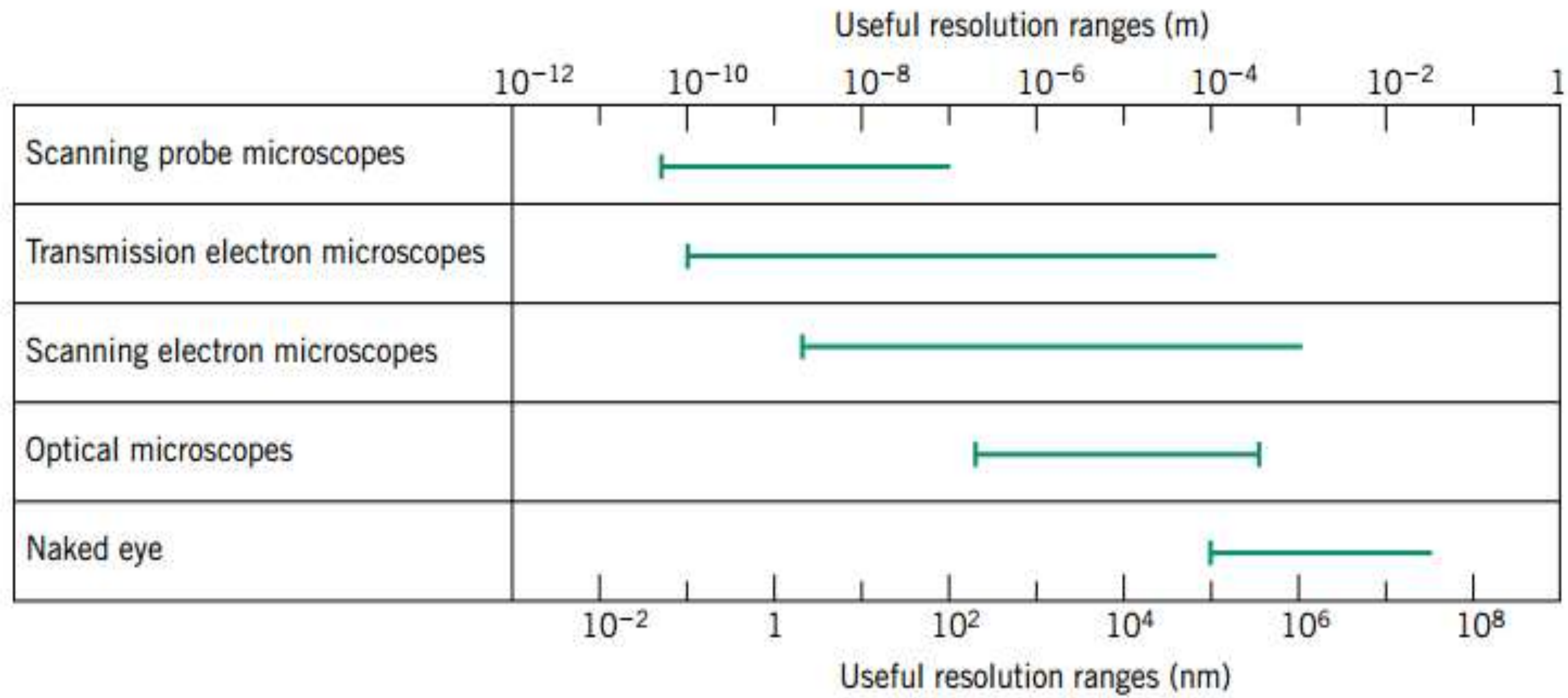
➢ Three-dimensional magnified images are generated that provide topographical information about features of interest.

➢ Some SPMs may be operated in a variety of environments (e.g., vacuum, air, liquid); thus, a particular specimen may be examined in its most suitable environment.

- Scanning probe microscopes employ a tiny probe with a very sharp tip that is brought into very close proximity (i.e., to within on the order of a nanometer) of the specimen surface. This probe is then raster-scanned across the plane of the surface. During scanning, the probe experiences deflections perpendicular to this plane in response to electronic or other interactions between the probe and specimen surface. The in-surface-plane and out-of plane motions of the probe are controlled by piezoelectric ceramic components that have nanometer resolutions. Furthermore, these probe movements are monitored electronically and transferred to and stored in a computer, which then generates the three dimensional surface image.




Bar chart showing size ranges for several structural features found in materials (note that the axes are scaled logarithmically).




Bar chart showing the useful resolution ranges for four microscopic techniques discussed in this chapter, in addition to the naked eye.

Thank you for your attention

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