Semiconductor Characterization Tools

Reading..............
Chapter-16: Semiconductor Characterization Techniques
Book: Fundamentals of Solid State Engineering By: *Manijeh Razeghi*

Why Semiconductor Characterization

Semiconductor characterization techniques are used in order to gain knowledge on the physical properties of a semiconductor crystal.

Semiconductor characterization is generally initiated immediately after the synthesis of a crystal.

The knowledge gained from the characterization process is essential in determining whether the semiconductor crystal probed is suitable for a particular device component with certain desired functionalities.

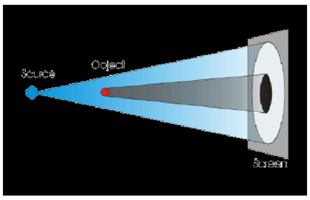
Types of Characterization

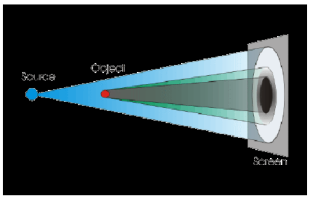
- Semiconductor characterization are of **three** types,
  - Sructural,
  - Optical and
  - Electrical.

1. Structural

The main purpose of structural analysis is to study the relationship between atomic structure, molecular structure, crystal structure and properties

History of X-ray and XRD

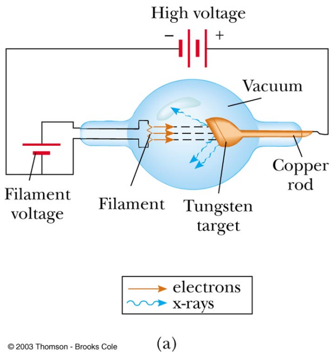




- **Radiographs like the ones in the last slide are simply shadowgrams.**
- **The X-rays either pass straight through or are stopped by the object. The diagram on the upper left illustrates the principle and shows a perfect shadow.**
- **In reality, a large fraction of the X-rays are not simply absorbed or transmitted by the object but are scattered. The diagram on the bottom left illustrates this effect and illustrates the fuzzy edge of the object that is produced in the image by the scattered X-rays.**

Production of X-rays

- X-rays are produced when high-speed electrons are suddenly slowed down
  - Can be caused by the electron striking a metal target
- A current in the filament causes electrons to be emitted
- These freed electrons are accelerated toward a dense metal target
- The target is held at a higher potential than the filament



X-Ray Tube

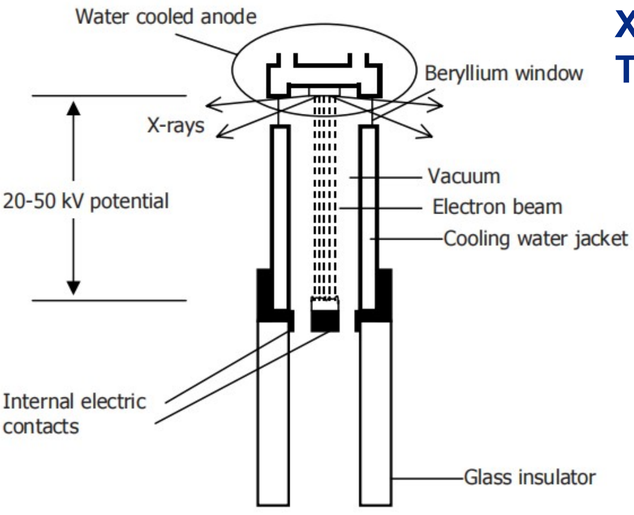
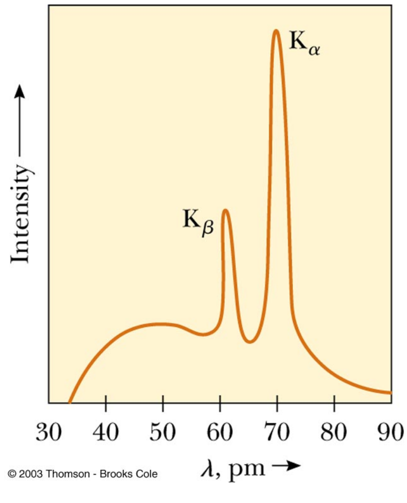


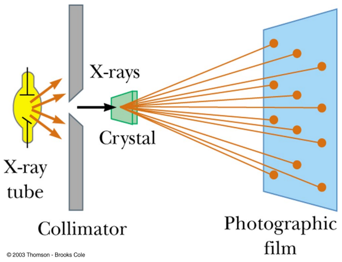
Fig. 16.1. Schematic diagram of an x-ray tube.

X-ray spectrum



Schematic for X-ray Diffraction

- A continuous beam of X-rays is incident on the crystal
- The diffracted radiation is very intense in certain directions
  - These directions correspond to constructive interference from waves reflected from the layers of the crystal
- The diffraction pattern is detected by photographic film



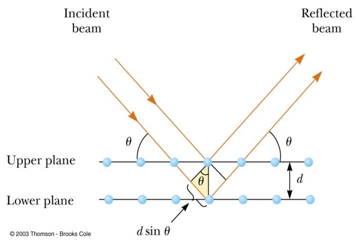
X-Ray Diffraction Applications

- Phase identification /transition
- Non-ambient studies (T, Rh, P) / in-situ reactions
- Crystallites sizes / micro-strain
- Crystallinity
- Crystal structure determination
- Texture/Stress (e.g. Polymers, Fiber, Thin
- Structure refinement and determination
- Epitaxy characterization
- Reflectometry

Bragg's Law

- The beam reflected from the lower surface travels farther than the one reflected from the upper surface
- If the path difference equals some integral multiple of the wavelength, constructive interference occurs
- *Bragg's Law* gives the conditions for constructive interference

$2d\sin\theta = n\lambda$, n = 1, 2, 3…



Diffracted waves from different atoms can **interfere with each other** and the resultant intensity distribution is strongly modulated by this interaction.

If the atoms are arranged in a **periodic** fashion, as in crystals, the diffracted waves will consist of **sharp interference maxima** (peaks) with the same symmetry as in the distribution of atoms. Measuring the diffraction pattern therefore allows us to deduce the distribution of atoms in a material.

The **peaks i**n an x-ray diffraction pattern are directly related to the **atomic distances.** For a given set of lattice planes with an inter-plane distance ***d***, the condition for a diffraction (peak) to occur can be found using **Bragg's law**.

Problem: X-ray diffraction

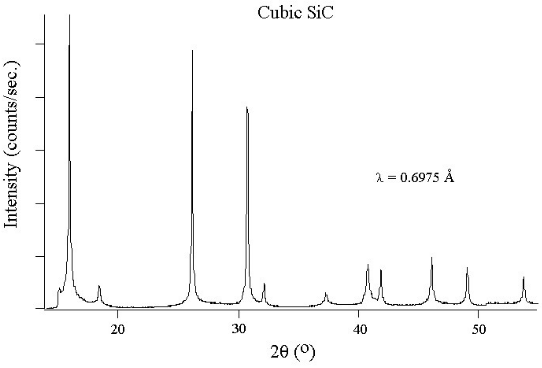
X-rays of wavelength 0.140 nm are reflected from a certain crystal, and the first-order maximum occurs at an angle of 14.4°. What value does this give for the interplanar spacing of this crystal?

Material's Information from the XRD Data

X-ray diffraction measurements on semiconductors can yield useful information such as:

- **Lattice constants**
  - The mismatch between the epilayer and the substrate perpendicular to the growth plane can be determined, which is also indicative of strain and stress.
- **Dislocation Density**
  - The width of the x-ray rocking curve, also called Full Width at Half Maximum (FWHM) is inversely related to the number of dislocations in the epilayer.
- **Thickness and quality of superlattices**
  - Thickness of the various layers in multi-layer structures like superlattices can be determined by the distance between the satellite peaks appearing on the sides of the main peak. Also the intensity and number of satellite peaks is a measure of the film quality.

Typical XRD



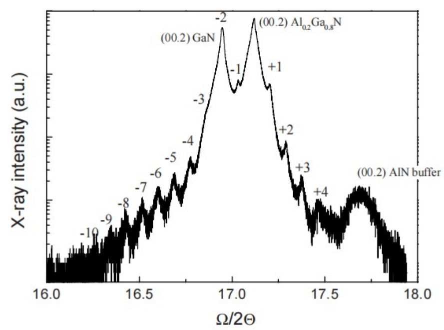


Fig. 16.3. X-ray curve of an $Al_{0.2}Ga_{0.8}N$/GaN superlattice grown on GaN/AlN buffer layer. The individual $Al_{0.2}Ga_{0.8}N$, GaN, and AlN peaks as well as the superlattice satellite peaks are clearly discernible on the graph.