

Introduction to Materials Characterization Techniques

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Designed as a quick-reference guide for students and professionals

1. Why Characterize Materials?

Goal	Typical Information Obtained
Identify composition	Elements, phases, chemical bonds
Determine structure	Crystallography, grain size, defects
Assess morphology	Surface topography, particle shape, porosity
Measure properties	Mechanical, electrical, magnetic, optical
Monitor changes	Aging, corrosion, heat-treatment effects

Understanding a material's structure-property relationships enables:

- Optimizing processing routes
 - Predicting performance in service
 - Ensuring quality control and compliance
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2. Classification of Techniques

Category	Primary Principle	Typical Output	Representative Methods
Chemical/Compositional	Interaction of radiation/particles with atoms	Elemental maps, spectra, stoichiometry	X-ray Fluorescence (XRF), Energy-Dispersive X-ray Spectroscopy (EDS), Inductively Coupled Plasma (ICP-OES/MS), X-ray Photoelectron Spectroscopy (XPS)

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Category	Primary Principle	Typical Output	Representative Methods
Structural/Crystallographic	Diffraction of waves by periodic lattices	parameters, phase identification, crystallite size	X-ray Diffraction (XRD), Electron Diffraction (SAED), Neutron Diffraction, Pair Distribution Function (PDF)
Microscopic/Morphological	Interaction of probe with surface or bulk	Images, 3D reconstructions, surface roughness	Optical Microscopy, Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM), Atomic Force Microscopy (AFM), Focused Ion Beam (FIB)
Thermal/Calorimetric	Heat flow or temperature change during transitions	Transition temperatures, enthalpy, heat capacity	Differential Scanning Calorimetry (DSC), Thermogravimetric Analysis (TGA), Differential Thermal Analysis (DTA)
Mechanical	Response to applied stress/strain	Elastic modulus, hardness, fracture toughness	Nanoindentation, Tensile/Compression testing, Dynamic Mechanical Analysis (DMA), Resonant Ultrasound Spectroscopy
Electrical/Magnetic/Optical	Interaction with electric, magnetic, or light fields	Conductivity, permittivity, magnetic hysteresis, band gap	Four-point probe, Hall effect, SQUID magnetometry, UV-Vis spectroscopy, Raman spectroscopy, FTIR

3. Core Techniques – How They Work & What They Reveal

3.1 X-ray Diffraction (XRD)

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- **Principle:** Bragg's law ($n\lambda = 2d\sin\theta$) describes constructive interference from crystal planes.

Techniques

- **Data:** 2θ vs. intensity plot (diffraction pattern).
- **Key Outputs:** Phase identification (match with database), lattice parameters, crystallite size (Scherrer equation), strain (peak broadening).

3.2 Scanning Electron Microscopy (SEM)

- **Principle:** Focused electron beam scans surface; secondary/ backscattered electrons generate contrast.
- **Data:** High-resolution grayscale images; optional EDS spectra for composition.
- **Key Outputs:** Surface topography, grain boundaries, fracture surfaces, elemental distribution (when coupled with EDS).

3.3 Transmission Electron Microscopy (TEM)

- **Principle:** Electrons transmitted through an ultra-thin specimen; diffraction and imaging occur simultaneously.
- **Data:** Bright-field/Dark-field images, selected-area electron diffraction (SAED),