Preface

Materials characterization is an ever-growing field in science since it plays a key role in the screening of electronic, mechanical, optical, and thermo properties of materials being incorporated in various industrial products that affect our daily life. In addition, analytical methods are being developed or modified in response to new demands for improved spatial resolution, detection limits of contents and impurities, atomic imaging contrast, device miniaturization, etc.

Rather than attempting to survey the hundreds of analytical methods currently being employed in various research fields, in this book we focus on five major analytical methods and their derivations. The methods presented here offer not only general applicability to most types of materials (ranging from hard coatings for tools to novel biological materials and nanoscaled devices) but also offer sufficient complexity that data analysis and interpretation can be far from trivial in many cases. In this aspect, we recruited contributors to this book who have demonstrated extensive hands-on experience with each of the techniques covered in the various chapters. All the authors in this book have 20+ years of experience in their respective field as materials analysts, with extensive exposure to industrial, academic, and advanced research environment.

The analytical methods presented here are based on interactions of ions, electrons, or photons (including visible light and X-rays) with the matter. Those species interact with the analyzed material and produce secondary ions, electrons, or photons through scattering processes. A multitude of material properties can be evaluated by studying those scattering processes under the proper environment (in some cases including vacuum systems) and the use of advanced instrument design and detection technologies.

X-ray analysis methods (including diffraction and reflectometry) described in Chap. 1 are the most widely used tools for the identification of crystalline properties of materials, in addition to materials strain, texture, stress, density, and surface roughness—properties that are key parameters for various industrial applications. Chapter 2 covers a wide range of optical characterization techniques with focus on ellipsometry, Raman scattering, Fourier transform infrared spectroscopy, and spectrophotometry. Those methods, covering a wide range of photon energy and laser technology, are broadly applied in academic and industrial laboratories to study many different material properties. They involve distinct physical phenomena driving the interaction between the photons and the material and here they are systematically compared with relevance to their strengths and limitations. Chapters 3 and 4 are devoted to mainstream surface analysis techniques. Chapter 3 covers X-ray photoelectron spectroscopy (XPS) and Auger electron spectroscopy (AES), which probe chemical states and chemical properties of materials. A large number of examples are presented where the same set of samples was analyzed by both techniques and comparative results are discussed. Chapter 4 covers secondary ion mass spectrometry (SIMS) and its variations. This is a technique with extreme sensitivity and very low detection limits in many materials (in many cases, parts per billion). Combined with depth profiling, SIMS is a powerful method in the investigation of composition and impurity contents as a function of depth in complex multilayered materials used, for example, in the optoelectronic industry. Finally, in Chap. 5 recent advances in transmission electron microscopy are presented by one of the world-class experts in the field. Various methods and strategies for sample preparation, smart procedures in instrumentation setup (such as the proper choice of lenses and apertures) are discussed with several examples involving novel materials. The foundations of the most spectacular developments in the area, such as sub-Angstrom spatial resolution and aberration correction microscopy are discussed with emphasis on basic principles.

Our foremost goal in this book was to produce a direct, modern review of selected, major analytical techniques of wide, general applicability in a textbook with emphasis on practical applications. A brief overview of the physical principles behind each technique is given but the emphasis is on modern, recent metrology advances. The complementarity of the various techniques became obvious as we reviewed the resolution and sensitivity limits of each technique. While a particular technique is useful in order to provide very high-resolution information on crystalline lattice distortions over large sample volumes (X-ray diffraction), other methods excel in probing small volumes at extremely high spatial resolution (transmission electron microscopy). Even when comparing two related surface analysis techniques, differences and complementarity are evident: for instance, XPS can provide more accurate information on the chemical state of near-surface species than SIMS, but if the research problem requires ultrahigh detection limits to species, SIMS is nearly unbeatable. In some cases, the same information can be probed by two competing techniques but the choice of the better method may depend on the details of the material. Thickness measurements of ultrathin layers of electronic materials can be done, for instance, by X-ray reflectivity or ellipsometry. However, while the first method (X-ray reflectivity) is limited to layers with relatively small interface roughness, ellipsometry might also require extensive modeling and several assumptions on the optical properties of the material being investigated. It is thus crucial for the materials scientist to being able to understand the strength and potential artifacts of each metrology being employed.

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