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Book Review

Principles of Materials Characterization and Metrology, by Kannan M. Krishnan, Oxford University Press, Oxford, UK, 2021

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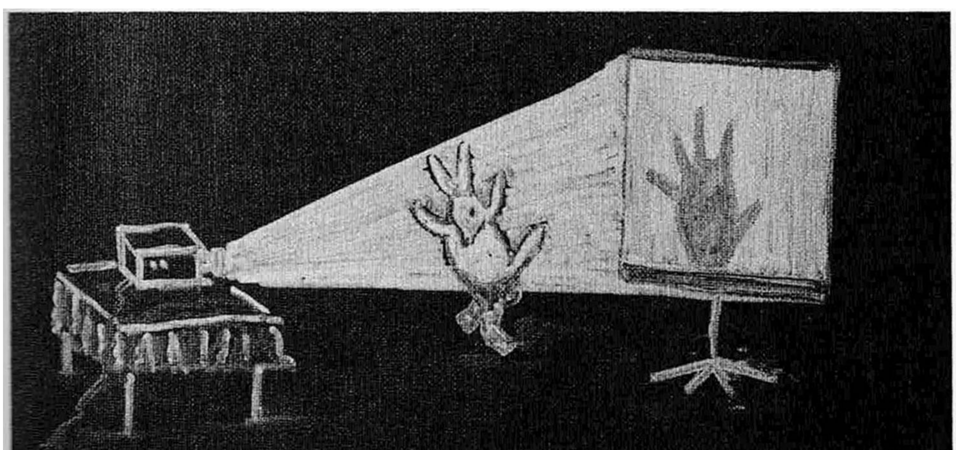

This illustration, by the author, based on a cartoon by John O'Brien (*The New Yorker*, February 25, 1991), succinctly describes the challenges in materials characterization. We are often called upon to describe the material microstructure (rabbit) based on the measured signals (hand) in diffraction, spectroscopy, or imaging methods. Needless to say, a poor understanding of the fundamental principles underlying the characterization methods generally lead to bad experimental design, hasty interpretations, and/or erroneous conclusions.

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Material Scientists and Engineers depend on understanding the relationships between processing, structure, properties and finally performance, daily. Structure is one important aspect of these relationships and is determined by using materials characterization methods. There is currently a plethora of materials characterization methods available to the materials engineer or scientist and it would be nearly impossible for someone to be an expert in all of them. This is where **Principles of Materials Characterization and Metrology** by Kannan M. Krishnan comes into play as it presents reviews of many of the most common (and some not so common) materials characterization methods that a materials engineer may be asked to interpret while making important decisions about a given use of a material.

Professor Kannan Krishnan is in the Materials Science and Engineering Department at the University of Washington, Seattle where his current research focuses on the intersection of magnetism, materials and medicine and in the area of nanoscale magnetic and transport phenomenon. Dr. Krishnan is a Fellow of the American Association for the Advancement of Science. Professor Krishnan has recently published **Fundamentals and Applications of Magnetic Materials** [1, 2]. He has also published over 200 papers in peer reviewed journals and has received numerous awards and honors. Professor Krishnan is well known for his work in materials characterization.

Principles of Materials Characterization and Metrology comprises 846 pages divided into 11 chapters. The author has intentionally limited this book to a discussion of probe-based techniques in order to keep the length manageable, thus leaving out some useful techniques like thermal characterization and mechanical testing. Professor Krishnan states that this book builds on concepts that should be familiar to upper-division students in any branch of science or engineering. Later it is stated in the Preface that Principles of Materials Characterization and Metrology is meant for undergraduate or early graduate level course work in Materials Science and Engineering. This book reads like a compendium of lectures assembled by the author and then reassembled into book chapters. Each Chapter does include listings of further reading, references and example questions for the student to work through.

Chapter 1 is an introductory chapter that discusses the connections between synthesis and processing, structure, properties and performance with characterization central to all of these. This chapter provides an excellent introduction to materials characterization and provides a few nicely chosen examples of the application of materials characterization. Following these examples, the concept of wave-particle duality is introduced and a discussion of electromagnetic waves. The concepts of Spectroscopy, Diffraction and imaging are also introduced. There is a lot of information here and some of it may require the student or reader to have some background knowledge to make the discussion useful. The chapter wraps up with a discussion of digital imaging, which to this reviewer, seems to be out of place and would probably be better placed later in the book as a full chapter. The use of image processing was introduced, but there was not any discussion of the ethics of image manipulation and what information to disclose once an image is processed.

Chapter 2 introduces atomic structure and spectra. This is a good discussion with a few rather glaring issues. The chapter discusses X-ray emission from atoms and how these X-rays can be detected. The discussion of Bremsstrahlung radiation is referred to incorrectly as "breaking radiation" rather than the correct braking radiation. The chapter then goes into great detail about various transitions that can be used for characterization. The discussion of X-ray detectors seems quite outdated. The discussion of energy dispersive X-ray spectrometers is limited to the obsolete Li-drifted silicon detectors that have a been completely replaced in recent years by silicon drift detectors. This is a major oversight and might be a clue as to the vintage of this chapter and that it has not been updated in the last 5 years. Here we also find discussions of the electron probe microanalysis (EPMA) and this again seems out of place in this chapter. These topics could have been better incorporated into later chapters.

Chapter 3 is a comprehensive discussion of molecular bonding and spectra from molecules. There are discussions of Fourier transform infrared (FTIR) spectroscopy, Raman spectroscopy X-ray photoemission spectroscopy (XPS) and X-ray absorption spectroscopy (XAS). Chapter 4 is a typical approach to the subject of crystallography and diffraction. This chapter also introduces X-ray and electron diffraction, and this is done in the context of the transmission electron microscope (TEM) before the instrument is discussed in a later chapter. One complicated example of diffraction from quasicrystals is given at the end of the chapter. Perhaps the reader would have been better served with examples from more easily understood conventional crystals.

Chapter 5 introduces probes and their interactions with matter. It was somewhat surprising that interaction volumes with respect to X-rays and electrons were already discussed way back in Chap. 2. Chapter 5 attempts to discuss how the various light, electron and ion probes or beams are generated. I would have preferred that each of these discussions occur within the chapter where the tools and the techniques are discussed. The subject matter is adequately addressed but there are some missing discussions of important modern developments. There is a discussion of lasers (incorrectly called "simulated emission") but in that discussion there is no mention of the latest femtosecond lasers and the important uses in materials characterization. This again points to the age of this chapter and for a book published in 2021 is a glaring omission. The following discussions of probe sample interactions should have been separated and discussed in the specific chapter where they apply. For example, there is a discussion of electron beam broadening that would have been better placed in Chap. 9 that discusses Transmission Electron Microscopy/Scanning Transmission Electron Microscopy (TEM/STEM). This chapter ends with a discussion of ion-based characterization methods which to this reader seemed out of place.

Chapter 6, Optics, Optical Methods and Microscopy starts with an image of Robert Hooke's book Micrographia. I thought this would be a good chapter on basic optical microscopy. However, the chapter then delves into the wave nature of light (I thought this was covered or could have been covered in an earlier chapter). There is advanced math used here in this discussion that seems a bit too much. Eventually, about 30 pages later, we finally get to learn about optical microscopy! Unfortunately, these discussions cover optical microscopy, metallography, confocal microscopy and ellipsometry in only 19 pages, leaving little room for in-depth discussion of each technique.

Chapter 7 is a typical introduction and discussion of X-ray diffraction. Later in this chapter x-ray diffraction methods are introduced and cover the typically used geometries and samples used. A large amount of information is covered here in a few short pages, but I was rather dismayed to not see a single mention of crystallographic texture. The chapter covered single crystal, powder diffraction and thin film techniques but no discussion of texture methods or applications. Chapter 8 continues with a discussion of diffraction of neutrons and electrons. The author starts with the basics and builds on and repeats some of the information from Chap. 3. There is a discussion of surface electron diffraction that completely leaves out any of the methods used in the scanning electron microscope (SEM), like channeling patterns or electron backscatter diffraction (EBSD). The surface electron diffraction methods are well covered otherwise. The chapter then spends the next 30 pages delving into transmission high-energy electron diffraction as applied to TEM, before the TEM has been fully discussed. These 30 pages contain a lot of information, but this seems out of place and should have been held until the actual technique of TEM has been covered.

Chapter 9 Transmission and Analytical Electron Microscopy is the longest chapter in the book extending to 141 pages which is nearly twice the length of any other chapter. Perhaps this is the authors favorite method. The optics of the TEM and how the instrument functions are nicely covered. Unfortunately, the chapter gives a very short cursory discussion of one development and totally leaves out two other major developments, and these together have contributed to a renewal in the interest in TEM/STEM. Aberration correction is handled in one paragraph, and it is this development that really began the new interest in TEM/STEM. There is no mention of any of the cryo-microscopy methods that have become hugely important in both biological and materials science applications. The exciting developments and research being conducted using the environmental TEM (ETEM) are not found in this Chapter or in this book which is a great shame.

Chapter 10 covers Scanning Electron Microscopy (SEM) of materials. There is discussion of how the SEM functions and a repeat of the electron beam/matter interactions from a previous chapter and the various signals that are generated. There are the typical discussions of beam size and resolution etc. However, once again there are some outdated discussions of resolution. The section on Channeling and EBSD is mostly incorrect. There are a few electron channeling patterns shown but these are mislabeled as EBSD patterns, which is disappointing as EBSD has become one of the most important methods currently available for characterization of crystalline materials. Here I also must digress for a moment. I note that many of the images shown in this chapter and the previous chapter were obtained from a book that was published in 1991 [3]. I would have expected that a book published in 2021 could come up with some beautiful newer examples of the current state of the art in materials characterization. Getting back to Chap. 10, there is a brief (maybe two pages) discussion of focused ion beam (FIB) tools and how they are used, but there is a rather complete discussion of spin polarized scanning electron microscopy, a somewhat narrowly focused specialized technique for magnetic imaging. It would not be unreasonable to expect a full chapter on FIB considering the immense number of applications of FIB in both materials and biological sciences.

The final chapter in the book discusses scanned probe microscopy (SPM). The basics of SPM are covered in this chapter, but it leaves out some of the more exciting applications of SPM, like capacitance methods for electrical characterization of samples.

Final thoughts. The combination of materials characterization and metrology in a single volume is quite useful and refreshing. **Principles of Materials Characterization and Metrology** is very generously illustrated throughout. Although this book reads very much like a compendium of university lectures that have not all been updated consistently it is a useful introduction to materials characterization. There are many references given as well as interesting example problems for the student. The recommend further reading lists are also welcome but should be updated to include newer editions of the texts [4, 5]. The reader would be well advised to use this book as an introduction to materials characterization and then study some of the more focused texts that are available to delve deeper into the techniques of interest. The depth and quality of coverage from chapter-to-chapter varies, most likely due to the interests and biases of the author. The first five chapters are well done and are an excellent, although advanced, explanation of the physics of materials characterization. If one is looking for an overview of materials characterization methods, this book delivers with a few exceptions as noted.

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