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BOOK REVIEWS

4D Electron Microscopy: Imaging in Space and Time. By Ahmed H. Zewail (California Institute of Technology, Pasadena, USA) and John M. Thomas (University of Cambridge, UK). Imperial College Press: London. xiii + 348 pp. $48. ISBN 978-1-84816-400-9.

The main aim of the authors of this book is to describe the historical background behind imaging (real space), diffraction (reciprocal space), and spectroscopy (energy space) in the transmission electron microscopy (TEM) that has led to the development of the 4D TEM—the fourth dimension being the all important addition of temporal resolution. The impetus for the book is the pioneering development of ultrafast TEM by one of the authors that has generated fascinating new results in biology, chemistry, physics, and materials science over the past 2−5 years. In the postaberration correction era of electron microscopy (the development of corrective optics for electron microscopes ∼10 years ago improved the spatial resolution of images to ∼0.05 nm and increased the sensitivity of the methods significantly), this ability to perform ultrafast observations in a microscope may prove to be the most important and far-reaching development in electron optics. As would be expected from two scientists of the authors' stature, the book is full of historical perspectives and provides unique insights into the literature that has had the most effect on their research. Combining the authors' expertise in femtochemistry, catalysis, and electron microscopy has resulted in a book that conveys the excitement and potential for this new paradigm in electron imaging.

The book itself is effectively organized into three parts, with the first four chapters being devoted to a basic description of the underlying physics behind high-resolution coherent phase-contrast imaging in TEM and a review of potential applications of imaging in 2D and 3D—here 2D and 3D simply refer to the number of real-space dimensions—in both TEM and the Scanning TEM (STEM). Although the principles described in the book are highly selective, the authors frequently state that this is intentional and refer the reader to the major texts in electron microscopy for broader coverage. However, it does mean that a reader with minimal experience in TEM will require another book to understand the details of diffraction, phase-contrast imaging, and other high-resolution methods in STEM/TEM. This is particularly important, as the text is hard to follow in places because it switches back and forth between descriptions of phase-contrast imaging in TEM and discussion of incoherent Z-contrast imaging in STEM—in some cases with the figures not matching exactly with the discussion in the text (the figures themselves are also often small and contain many parts, making it hard to see the features being discussed). Additionally, because there is only a minimal, four-page discussion of spectroscopy in the first part of the book, this means that only one aspect of the "3D" possible in a conventional microscope, real-space imaging, is really addressed.

To some extent, the focus on real-space imaging is not a major limitation as coherent phase-contrast imaging in TEM is most important for the second part of the book, i.e., the two chapters dealing with the principles of temporal coherence, the physics of temporal measurements, and the examples of the results obtained using the microscope at Caltech. These two chapters make up almost half of the book and are really the "new" work that is contained in this volume. The discussions of the basic principles of temporal coherence and resolution are at a level that makes them accessible to nonexperts wishing to understand the basics of the measurements. The chapter in which examples are covered summarizes the many papers published by the Caltech group over the past few years. Having them all collected together gives a great overview of the status of the field and provides a clear picture of the potential of the new instrument for the characterization of both inorganic and organic systems on the ultrafast time scale.

Although these two chapters are impressive, this section was missing a chapter on the practical performance of the methods in TEM. It is well-known that the stability of the sample, e.g., drift, charging, beam damage, etc., and the environment in which electron microscopes are housed are very important for the quality of the final result. Because the authors make it clear that the benefit of the ultrafast 4D approach is that the full spatial resolution of the microscope is available, it is important that the factors known to control conventional TEM are accounted for in the 4D microscope. A discussion of these factors would allow the book to go beyond the information available in journals, which often do not have the space to allow experimental details, and thereby permit scientists interested in the methods to evaluate setting up a similar capability for themselves.

The final part of the book is aimed at relating the perspective of the new advancements to future applications and comparing these developments with other methods for time-resolved studies. Obviously with such a new technique, the future applications are not fully established, but it was at times disappointing to have references given to calculations that have been performed with respect to a particular new application that was possible using the 4D microscope and yet not have those calculations available. The potential of the technique is clear for all to see, so it makes the discussion weaker to have such hinted references, particularly given the unique nature of the experiments. The stroboscopic method of acquiring images makes all the results a sum of millions of experiments, all with the same time delay, thus making them completely different from a standard TEM image (a single image of a particular structure at a given point in space and time) and more like a synchrotron (an average of the structure at a given time after an excitation). For this book, it would therefore have been nice for the discussion to focus on where the technique was unique, rather than to try and force it into one camp (microscopy) or another (synchrotron). Nonetheless, the discussion is thought provoking and does convey that microscopy is moving forward in leaps and bounds to characterize materials on the ultrafast time scale.

In summary, there is no doubt that the development of the 4D microscope has introduced a new paradigm for characterization by TEM. Taken together with introductory texts covering TEM, it provides the understanding necessary for the reader to appreciate the principles of this brand new field.

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