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**Elastic and Inelastic Scattering in Electron Diffraction and Imaging , Zhong Lin Wang Plenum Press, 1995. 448 pp.**

Scientists and engineers often need to quantify the properties of solids at the microscopic level, and electron scattering is frequently the method of choice. This book is a noteworthy contribution to the literature of electron microscopy. It is intended for the advanced student or the practicing microscopist and is not a text for an introductory course. As the author points out, there is an enormous variety of theories of limited scope, mainly involving elastic scattering, published in this field. Each theory tackles a special case, and each is presented in a variety of forms, uses different sets of units and symbols, and is based on somewhat different approximations. Summarizing them in a coherent manner not only is an overwhelming task, it may not be productive. The author therefore selects a single starting point, the Schr”dinger equation, and summarizes the elastic scattering theory succinctly in the first quarter of the book. The coverage is consistent, the mathematics are given in detail, and all theories are linked. They are also presented in a convenient form for numerical calculation. Units are consistently noted according to the International System, except for the occasional angstrom used for convenience. A notable inclusion in Part I is Chapter 5, devoted to the dynamic theories of reflected high-energy electron diffraction (RHEED) from crystal surfaces. Although RHEED is commonly used to monitor surface structural evolution during thin-film growth, quantitative analysis of RHEED patters is far from settled. This comprehensive review, the only one so far, is therefore a valuable contribution. As the author points out, there is a real need for further theoretical work on RHEED. Most of the book, Chapters 6 to 15, is devoted to the dynamic theory of diffraction and imaging by inelastically scattered electrons. This is the first book to cover this subject so comprehensively, which makes it a most useful contribution to the scientific literature. As the author emphasizes, if electron microscopy is to become truly a quantitative technique, inelastic scattering must be included quantitatively in the theory of diffraction and imaging. Energy filtering, although an indispensable experimental adjunct, is not a substitute for a quantitative theory of inelastic scattering. Inelastic scattered electrons are a part of every spectrum or image and must be understood quantitatively. Chapters 6 through 15 provide an excellent, and so far unique, summary of our present knowledge, and present it in a useful and consistent format for numerical calculations. Chapter 6 begins with a formal derivation of the imaginary potential that describes the scattering processes, fundamental to all numerical calculations. Yoshioka's coupled equations are the basis for the derivation and indeed for the book's entire Part II. The various inelastic scattering processes are described in detail, as well as the contribution of each to the absorption potential. Chapter 7 is a review of classical thermal diffuse scattering (TDS) theory. Absorption coefficients are calculated and diffuse scattering from multiphonon processes is treated on both a two-beam and multibeam basis. The importance of coherent TDS on Z-contrast images and of Huan scattering on dark field scanning transmission electron microscopy (STEM) images is addressed. Chapter 8 utilizes the dynamic Bloch wave theory to treat single and double inelastically scattered electrons. Contrast features in Kikuchi patterns are qualitatively interpreted, and the theory is extended to calculate images from defects. Chapter 9 proves the reciprocity theorem for transmission electron microscopy (TEM) and STEM. The results are exact for elastically scattered electrons, but are exact only for the intensity of those inelastically scattered electrons with small energy loss. These results are then employed in Chapters 10 through 13 to understand diffraction and imaging. In Chapter 10, the author presents Green's function theory as best suited to treat dynamic inelastic electron scattering for numerical calculations. The most important advantage is that all possible multiphonon processes can be included in a single formula, and the results should be valid for both low- and high-angle TDS. The solutions, however, for double-inelastic scattering can be obtained easily only for zero-order Laue zone reflections. In Chapter 11 multislice theories are introduced to approach multiple elastic and inelastic scattering in crystals containing defects. Some examples that conform with experimental images are given. The last part of Chapter 10 describes the real-space multislice theory, most powerful for calculating diffraction patterns and images of TDS electrons. Exact theories are introduced for simulating Z-contrast images formed by TDS electrons in STEM and TEM. Chapter 12 presents a simplified formalism for treating dynamic elastic rescattering of inelastically scattered electrons. Useful analytic solutions for TDS electrons are obtained, and a simple rule to predict TDS streaks in electron diffraction is presented and tested. The conditions under which equivalent results are obtained from either frozen-lattice or quantum mechanical phonon-excitation theories are derived and provide a theoretical basis for treating TDS based on the frozen-lattice model. Chapter 13 treats inelastic scattering in high-resolution TEM images, as follows: A time-averaged crystal potential results in a Debye-Waller factor. An absorption function can be introduced to account for inelastic scattering and a loss of elastic scattering intensity. Additional effects included within the objective aperture, include chromatic effects resulting from the energy spread. The final image becomes a sum from electrons with differing energy losses and momentum transfers weighted by the double-differential scattering cross section. If specimens are thin, valence loss electrons, assumed to occur at the entrance face, can be considered as elastic scattering of incident inelastic electrons. In principle, the contribution of loss electrons of more than a few electron volts can be removed by an energy filter, leaving only the inelastic component of TDS electrons in the high-resolution transmission electron microscopy (HRTEM) images. Simulations are presented to support these conclusions. Because of requirements for coherency, arguments can be made to suggest that quantitative analysis of electron holograms may be easier to analyze than HRTEM images. In the final section of the book, some simplified approaches to calculate diffraction patterns from thick specimens are presented in Chapter 14. A one-particle density matrix theory is used to describe multiple inelastic scattering. However, more than one type of inelastic event, such as coupled phonon-electron excitation, cannot be handled. A modified multislice theory permits a greatly simplified and useful simulation of elastic rescattering of electrons after inelastic excitation. Finally, in Chapter 15, the author tackles the issues of inelastic excitations occurring in thermal equilibrium with the environment. Since the time-independent Schr”dinger equation is only valid for an isolated system, the actual fluctuation of energy between the environment and the specimen affects the scattering behavior of electrons. An outline of a first-principles approach to inelastic electron scattering of a crystal in thermal equilibrium with its environment is presented. The chapter and text concludes with the observation that even in the case of no energy transfer, thermal equilibrium influences the image and diffraction patter intensities, presenting a daunting challenge for the future. Without question this book, particularly the treatment of inelastic scattering, is a noteworthy achievement and a valuable contribution to the literature. John J. Hren, Materials Science & Engineering, North Carolina State University

## BOOK REVIEW by C. Humphreys, Professor and Head, Department of Materials Science and Metallurgy, University of Cambridge University, Pembroke St., Cambridge CB2 3QZ, UK

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Elastic and Inelastic Scattering in Electron Diffraction and Imaging by Zhong Lin Wang, Plenum Press New York and London (1995).

This is an excellent and comprehensive book describing the theory of the elastic and inelastic scattering of electrons by crystals. The book is divided into two parts: Part I covers the diffraction and imaging of elastically scattered electrons; Part II is devoted to inelastically scattered electrons. This book fills a gap in the existing books on electron microscopy because it discuss in considerable depth inelastic scattering in electron diffraction and microscopy. It is also an excellent survey of elastic scattering. The book is particularly good at referencing the major publications in the field from around the world. it is therefore very useful both as a text book and as a reference book. Part I of the book on elastic scattering starts by describing basic kinematic electron diffraction. It then moves on to describe in detail various dynamical electron diffraction theories: the Bloch wave approach, multislice theory and other methods including scattering matrix theory, Green's function theory, etc. The different methods are compared and contrasted. Applications to convergent beam electron diffraction (CBED) and to scattering by imperfect crystals are considered. Finally, Part I ends with a chapter on RHEED (reflection high energy electron diffraction) from bulk crystal surfaces. Part I is a very comprehensive and useful treatment of elastic scattering. It is very clearly written with many diagrams and some excellent electron micrographs. Part II, on inelastic scattering, starts by considering Kikuchi patterns and Yoshioka's treatment of inelastic scattering. Inelastic scattering processes due to phonon scattering, valence excitations and single core electron excitations are described in detail. Dynamical theories of inelastic electron scattering are described based on Bloch wave theory, Green's function theory and multislice theory. Multiple inelastic scattering is treated in detail. Applications to annular dark field (ADF) contrast in scanning transmission electron microscopy (STEM), energy-filtered imaging, electron holography, etc., are discussed. Part II of this book is the most comprehensive treatment of inelastic scattering to appear in any book. If you are interested in electron scattering by crystals, in the theory underlying the interpretation of electron micrographs, or in the theory of the inelastic scattering of fast electrons then you should buy this book. it is comprehensive and right up to date, with many very recent references as well as references to classical papers. It is suitable for scientists ranging from research students to real experts in the field. It is written with great clarity. I shall take great care when handing out my copy to my research group since I fear I will not get it back!

## BOOK REVIEW by C. Colliex, Professor and Director, Laboratorie de Physique des Solides Bldg 510, Universite Paris-Sud, 91405 Orsay France

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Elastic and Inelastic Scattering in Electron Diffraction and Imaging by Zhong Lin Wang, Plenum Press New York and London (1995).

A few months ago arrived on my desk a book with a yellow and black cover illustrated with an image of a diffraction pattern. The colour was not very encouraging but I opened it, there was a hand-written dedication signed by the author, Zhong Lin Wang whom I had advised in Arizona during his first year of Ph. D. preparation. It was not that far ago, less than a decade I am sure. The title was more appealing than the cover, a very general title corresponding to one of my persistent interests since I have been involved in electron microscopy. In particular, mentioning explicitly inelastic scattering was quite stimulating.

"The aim of the book is to explore the physics in electron diffraction and imaging and related applications for materials characterization", Wang writes in his Preface. The author is then more explicit in the introduction of the book. He explains his deep interest in the theoretical tools necessary for understanding the basic mechanisms in elastic and inelastic electron diffraction and imaging and their applications in quantitative electron microscopy. This is the key word. Progress in instrumentation, energy filtering, image recording open a new era in quantitative electron microscopy. The data delivered by the different elastic and inelastic channels can now be discriminated and have to be compared with the relevant simulations in order to extract the new level of information (concerning the disorder, the chemistry or the electronic properties) which they carry. The book is thus devoted to a complete synthesis and description of these theoretical tools. It cannot easily be understood and followed at the first glance. On the contrary a detailed reading is required to grasp its deep content and I must confess that I have not found the time to do it. However it is obvious that I keep the book on the first row of my shelves to consult it more thoroughly in any case when I shall have to understand inelastic images or to prepare advanced lectures on that topic.

The content of the book is divided in two major parts dealing respectively with the elastically and inelastically scattered electrons from crystalline specimens. The first part consists of an elegant synthetic survey of well established material, comparing the Bloch wave, multislice and different other approaches (with a short introduction to the case of reflected high-energy electrons from bulk crystal surfaces). The second part is much more original and contains a lot of information either completely new or originating from isolated papers of restricted access. In this domain the effort developed by the author is quite impressive. He covers a lot of different aspects and I am pretty sure that everybody concerned with these subjects will find his own point of interest, even if he does not agree with everything. I must confess that my own preference goes to chapters with more restricted mathematics and an effort to interprete complex effects in simple terms. I can therefore recommend chapter 6 for his general description of inelastic scattering, pointing out the equivalency of the dynamic form factor in inelastic scattering with the potential in elastic scattering, and calculating this dynamic form factor for the different types of excitations (phonons, valence excitations, atomic inner shell excitations). I have also selected the elegant discussion of reciprocity in chapter 9, the complete discussion of the origin of the contrast in HAADF mode in the STEM mentioning clearly that Huang scattering on defects can also be relevant... Finally my favourite chapter may be chapter 13 dedicated to inelastic scattering in HREM imaging. The authors shows in particular that for a specimen thinner than the localization of valence electrons, the image made with the valence-loss electrons can be treated as if the loss has occurred at the entrance face of the crystal. It reminds me some old observations by Castaing and his coworkers, more than 20 years ago and reported in "Physical aspects of Electron Microscopy and Microbeam Analysis" (B. Siegel and D. Beaman eds. John Wiley and Sons). The last chapter of the book points out a rather poorly investigated subject, the influence of the environment and its consequences on the fact that it may introduce fluctuations of the total energy of the system. Unluckily contrary to all the previous chapters which are concluded by a clear summary, this last chapter has no summary and it is not straightforward to extract the major consequence of this environmental factor.

Let us conclude with some of the assertions of the author in the final lines of his introduction which I fully support : "The quantitative analysis of energy-filtered elastic and inelastic diffraction patterns and images is the future direction of TEM". We have been fully convinced of that in Orsay for years and even decades, but it took quite a long time for this message to spread over the whole EM community. Better late than never! The second remark of Wang is the enormous variety of existing theories to deal with these complex effects. I can compliment him for the huge effort he has accomplished to make all of them classified and accessible to us. And I am convinced that his book is quite important for anyone wishing to cleverly use the new TEMs equipped with energy filtering devices.

Finally I cannot help quoting these words of the author : "This book was written in my spare time after working hours". Everybody who knows Zhong Lin Wang is well aware that his working hours are rather long and can imagine how little time he has devoted to his nice family.