

# CACTUS: A Computational Framework for Generating Realistic White Matter Microstructure Substrates

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## ABSTRACT

Monte-Carlo diffusion simulations are a powerful tool for validating tissue microstructure models by generating synthetic diffusion-weighted magnetic resonance images (DW-MRI) in controlled environments. This is fundamental for understanding the link between micrometre-scale tissue properties and DW-MRI signals measured at the millimetre-scale, optimising acquisition protocols to target microstructure properties of interest, and exploring the robustness and accuracy of estimation methods. However, accurate simulations require substrates that reflect the main microstructural features of the studied tissue. To address this challenge, we introduce a novel computational workflow, CACTUS (Computational Axonal Configurator for Tailored and Ultradense Substrates), for generating synthetic white matter substrates. Our approach allows constructing substrates with higher packing density than existing methods, up to 95 % intra-axonal volume fraction, and larger voxel sizes of up to  $(500\mu\text{m})^3$  with rich fibre complexity. CACTUS generates bundles with angular dispersion, bundle crossings, and variations along the fibres of their inner and outer radii and g-ratio. We achieve this by introducing a novel global cost function and a fibre radial growth approach that allows substrates to match predefined targeted characteristics and mirror those reported in histological studies. CACTUS improves the development of complex synthetic substrates, paving the way for future applications in microstructure imaging.

**Keywords:** microstructure imaging, diffusion MRI, brain imaging, white matter, Monte Carlo simulations, numerical phantom, synthetic substrates, high packing density.

## 1 INTRODUCTION

Diffusion-weighted magnetic resonance imaging (DW-MRI) is a non-invasive technique used to study the microscopic structure of biological tissues *in vivo*. It is sensitive to the ensemble of water molecules

# Microstructure Of Matter

**James C. M. Li**

## Microstructure Of Matter:

**Microstructure of Matter** Clifford E. Swartz,1965

**Microstructure of Matter** Clifford E. Swartz,1969

Microstructure And Properties Of Materials, Vol 2 James C M Li,2000-10-09 This is the second volume of an advanced textbook on microstructure and properties of materials The first volume is on aluminum alloys nickel based superalloys metal matrix composites polymer matrix composites ceramics matrix composites inorganic glasses superconducting materials and magnetic materials It covers titanium alloys titanium aluminides iron aluminides iron and steels iron based bulk amorphous alloys and nanocrystalline materials There are many elementary materials science textbooks but one can find very few advanced texts suitable for graduate school courses The contributors to this volume are experts in the subject and hence together with the first volume it is a good text for graduate microstructure courses It is a rich source of design ideas and applications and will provide a good understanding of how microstructure affects the properties of materials Chapter 1 on titanium alloys covers production thermomechanical processing microstructure mechanical properties and applications Chapter 2 on titanium aluminides discusses phase stability bulk and defect properties deformation mechanisms of single phase materials and polysynthetically twinned crystals and interfacial structures and energies between phases of different compositions Chapter 3 on iron aluminides reviews the physical and mechanical metallurgy of Fe3Al and FeAl the two important structural intermetallics Chapter 4 on iron and steels presents methodology microstructure at various levels strength ductility and strengthening toughness and toughening environmental cracking and design against fracture for many different kinds of steels Chapter 5 on bulk amorphous alloys covers the critical cooling rate and the effect of composition on glass formation and the accompanying mechanical and magnetic properties of the glasses Chapter 6 on nanocrystalline materials describes the preparation from vapor liquid and solid states microstructure including grain boundaries and their junctions stability with respect to grain growth particulate consolidation while maintaining the nanoscale microstructure physical chemical mechanical electric magnetic and optical properties and applications in cutting tools superplasticity coatings transformers magnetic recordings catalysis and hydrogen storage

Understanding the Atom: Microstructure of Matter U.S. Atomic Energy Commission,1969

Fundamentals of Materials Science Eric J. Mittemeijer,2022-01-01 This textbook offers a strong introduction to the fundamental concepts of materials science It conveys the quintessence of this interdisciplinary field distinguishing it from merely solid state physics and solid state chemistry using metals as model systems to elucidate the relation between microstructure and materials properties Mittemeijer's Fundamentals of Materials Science provides a consistent treatment of the subject matter with a special focus on the microstructure property relationship Richly illustrated and thoroughly referenced it is the ideal adoption for an entire undergraduate and even graduate course of study in materials science and engineering It delivers a solid background against which more specialized texts can be studied covering the necessary breadth of key topics such as crystallography structure defects phase equilibria

and transformations diffusion and kinetics and mechanical properties The success of the first edition has led to this updated and extended second edition featuring detailed discussion of electron microscopy supermicroscopy and diffraction methods an extended treatment of diffusion in solids and a separate chapter on phase transformation kinetics In a lucid and masterly manner the ways in which the microstructure can affect a host of basic phenomena in metals are described By consistently staying with the postulated topic of the microstructure property relationship this book occupies a singular position within the broad spectrum of comparable materials science literature it will also be of permanent value as a reference book for background refreshing not least because of its unique annotated intermezzi an ambitious remarkable work G Petzow in International Journal of Materials Research The biggest strength of the book is the discussion of the structure property relationships which the author has accomplished admirably In a nutshell the book should not be looked at as a quick cook book type text but as a serious critical treatise for some significant time to come G S Upadhyaya in Science of Sintering The role of lattice defects in deformation processes is clearly illustrated using excellent diagrams Included are many footnotes Intermezzos Epilogues and asides within the text from the author s experience This soon becomes valued for the interesting insights into the subject and shows the human side of its history Overall this book provides a refreshing treatment of this important subject and should prove a useful addition to the existing text books available to undergraduate and graduate students and researchers in the field of materials science M Davies in Materials World **Microstructure of Matter** ,1965

*Vocational Instructional Materials Available from Federal Agencies* Northwest Regional Educational Laboratory,1970

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broad spectrum of comparable materials science literature it will also be of permanent value as a reference book for background refreshing not least because of its unique annotated intermezzi an ambitious remarkable work G Petzow in International Journal of Materials Research The biggest strength of the book is the discussion of the structure property relationships which the author has accomplished admirably In a nutshell the book should not be looked at as a quick cook book type text but as a serious critical treatise for some significant time to come G S Upadhyaya in Science of Sintering The role of lattice defects in deformation processes is clearly illustrated using excellent diagrams Included are many footnotes Intermezzos Epilogues and asides within the text from the author s experience This soon becomes valued for the interesting insights into the subject and shows the human side of its history Overall this book provides a refreshing treatment of this important subject and should prove a useful addition to the existing text books available to undergraduate and graduate students and researchers in the field of materials science M Davies in Materials World [Microstructural Characterization of Materials](#) David Brandon, Wayne D. Kaplan, 2013-03-21 Microstructural characterization is usually achieved by allowing some form of probe to interact with a carefully prepared specimen The most commonly used probes are visible light X ray radiation a high energy electron beam or a sharp flexible needle These four types of probe form the basis for optical microscopy X ray diffraction electron microscopy and scanning probe microscopy Microstructural Characterization of Materials 2nd Edition is an introduction to the expertise involved in assessing the microstructure of engineering materials and to the experimental methods used for this purpose Similar to the first edition this 2nd edition explores the methodology of materials characterization under the three headings of crystal structure microstructural morphology and microanalysis The principal methods of characterization including diffraction analysis optical microscopy electron microscopy and chemical microanalytical techniques are treated both qualitatively and quantitatively An additional chapter has been added to the new edition to cover surface probe microscopy and there are new sections on digital image recording and analysis orientation imaging microscopy focused ion beam instruments atom probe microscopy and 3 D image reconstruction As well as being fully updated this second edition also includes revised and expanded examples and exercises with a solutions manual available at <http://develop.wiley.co.uk/microstructural2e> Microstructural Characterization of Materials 2nd Edition will appeal to senior undergraduate and graduate students of material science materials engineering and materials chemistry as well as to qualified engineers and more advanced researchers who will find the book a useful and comprehensive general reference source **Random Heterogeneous Materials** Salvatore Torquato, 2013-04-17 The interdisciplinary subject of random heterogeneous materials has experienced remarkable growth since the publication of the well known monograph Statistical Continuum Theories by Beran 1968 Many of these advances especially those concerning the statistical characterization of the microstructure and its effect on the physical properties of the material have not been treated fully in any book One of the intents of the present book is to fill this gap This book also distinguishes itself in that it provides a unified rigorous

framework to characterize the microstructures and macroscopic properties of the widely diverse types of heterogeneous materials found in nature and synthetic products Emphasis is placed on providing foundational theoretical methods that can simultaneously yield results of practical utility This book treats a wide breadth of topics but the choice of subjects naturally reflects my own interests The sheer enormity of the field has prevented me from covering many important topics I apologize to those colleagues known and unknown who may not find enough of their own work cited in the ensuing pages

**Vocational Education : State Instruction Materials for ...** Oklahoma. State Department of Vocational and Technical Education. Curriculum and Instructional Materials Center,1974     *Solid Oxide Fuel Cells 12 (SOFC-XII)* S. C. Singhal,K. Eguchi,2011-04-25 This issue of ECS Transactions contains papers from the Twelfth International Symposium on Solid Oxide Fuel Cells SOFC XII a continuing biennial series of symposia The papers deal with materials for cell components and fabrication methods for components and complete cells Also contained are papers on cell electrochemical performance and its modelling stacks and systems and prototype testing of SOFC demonstration units for different applications

*Solid-fluid Mixture Microstructure Design of Composite Materials with Application to Tissue Engineering Scaffold Design* Cheng-Yu Lin,2005     **Microstructure and Properties of Materials** James C. M. Li,1996-01-01     Microstructure and Texture in Steels Arunansu Haldar,Satyam Suwas,Debashish Bhattacharjee,2009-09-03 Microstructure and Texture in Steels and Other Materials comprises a collection of articles pertaining to experimental and theoretical aspects of the evolution of crystallographic texture and microstructure during processing of steels and some other materials Among the topics covered is the processing microstructure texture property relationship in various kinds of steels including the latest grade Special emphasis has been given to introduce recent advances in the characterization of texture and microstructure as well as modeling The papers included are written by well known experts from academia and industrial R and D which will provide the reader with state of the art in depth knowledge of the subject With these attributes Microstructure and Texture in Steels and Other Materials is expected to serve the cause of creating awareness of current developments in microstructural science and materials engineering among academic and R and D personnel working in the field

**Properties and Microstructure** R. K. MacCrone,2013-10-22 Treatise on Materials Science and Technology Volume 11 Properties And Microstructure covers the parameters important to understanding microstructural effects The book discusses the direct observation and characterization of defects in materials the cause and effect of crystal defects in silicon integrated circuits as well as the microstructure of some noncrystalline ceramics The text also describes microstructural defects in the important semiconductors silicon and germanium microstructural effects in glasses microstructural effects on the mechanical properties of ceramics and finally microstructures in ferrites Materials scientists materials engineers and graduate students taking related courses will find the book invaluable

Phase Diagrams and Microstructure ,1973-01-01     **Design of Microstructures of Periodic Composite Materials** Jun Sérgio Ono Fonseca,1997     **The Quantitative Description of**

**the Microstructure of Materials** Krzysztof Jan Kurzydlowski, Brian Ralph, 1995-07-21 This book the product of a deep collaboration between the two authors strikes a balance between the traditional approach and newly emerging techniques used to obtain a quantitative description of the microstructure of materials The Quantitative Description of the Microstructure of Materials has a unique format that sets it apart from other books The first half of the book gives a comprehensive account of the entire quantification process and presents material in a pedagogical style Numerous examples appear throughout text to illustrate the methodology A general introduction to the subject and basic concepts definitions techniques and relationships are provided Aspects of modern stereology are described in detail Image processing computer aided procedures of data analysis and the elements of a system for image analysis also are discussed at length The remaining chapters treat a series of significant examples in much more detail This part of text offers information in an easy to access reference style making it extremely useful as a guide to active researchers in the quantification guide Topics include dislocations internal and external surfaces and quantitative characterization of thin film structures The book covers geometry of grains and its effect on the properties of polycrystals Particles pores and other isolated volumetric elements of the microstructure also are discussed

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