

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

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James C M Li

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Microstructure of Matter Clifford E. Swartz,1965 **Microstructure of Matter** Clifford E. Swartz,1969

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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

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Northwest Regional Educational Laboratory,1971 *Fundamentals of Materials Science* Eric J. Mittemeijer,2021 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 *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 *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 *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 *Solid-fluid Mixture Microstructure Design of Composite Materials with Application to Tissue Engineering Scaffold Design* Cheng-Yu Lin,2005

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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 **Materials for the Mining Industry** ,1974

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