

5. Normal Modes of a Three-Dimensional Crystal

Consider a face-centered cubic monatomic Bravais lattice in which each ion interacts only with its (twelve) nearest neighbors. Assume that the interaction between a pair of neighboring ions is described by a pair potential ϕ that depends only on the distance r between the pair of ions.

(a) Show that the frequencies of the three normal modes with wave vector \mathbf{k} are given by

$$\omega = \sqrt{\lambda/M} \quad (22.96)$$

where the λ are the eigenvalues of the 3×3 matrix:

$$\mathbf{D} = \sum_{\mathbf{R}} \sin^2(\tfrac{1}{2}\mathbf{k} \cdot \mathbf{R}) [A\mathbf{1} + B\hat{\mathbf{R}}\hat{\mathbf{R}}]. \quad (22.97)$$

Here the sum is over the twelve nearest neighbors of $\mathbf{R} = 0$:

$$\frac{a}{2}(\pm\hat{x} \pm \hat{y}), \quad \frac{a}{2}(\pm\hat{y} \pm \hat{z}), \quad \frac{a}{2}(\pm\hat{z} \pm \hat{x}); \quad (22.98)$$

$\mathbf{1}$ is the unit matrix $((1)_{\mu\nu} = \delta_{\mu\nu})$, and $\hat{\mathbf{R}}\hat{\mathbf{R}}$ is the diadic formed from the unit vectors $\hat{\mathbf{R}} = \mathbf{R}/R$ (i.e., $(\hat{\mathbf{R}}\hat{\mathbf{R}})_{\mu\nu} = \hat{R}_\mu\hat{R}_\nu$). The constants A and B are: $A = 2\phi'(d)/d$, $B = 2[\phi''(d) - \phi'(d)/d]$, where d is the equilibrium nearest-neighbor distance. (This follows from Equations (22.59) and (22.11).)

(b) Show that when \mathbf{k} is in the (100) direction ($\mathbf{k} = (k, 0, 0)$ in rectangular coordinates), then one normal mode is strictly longitudinal, with frequency

$$\omega_L = \sqrt{\frac{8A + 4B}{M}} \sin \tfrac{1}{4}ka, \quad (22.99)$$

and the other two are strictly transverse and degenerate, with frequency

$$\omega_T = \sqrt{\frac{8A + 2B}{M}} \sin \tfrac{1}{4}ka. \quad (22.100)$$

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SJ Ball



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Simulations for Solid State Physics Hardback with CD-ROM Robert H. Silsbee, Joerg Draeger, Jörg Dräger, 1997-06-28 Interactive resource centering around fourteen high quality computer simulations covering essential topics in solid state physics **Solid State Physics** Neil W. Ashcroft, N. David Mermin, 1976 This book provides an introduction to the field of solid state physics for undergraduate students in physics chemistry engineering and materials science **Introduction to Lattice Dynamics** Martin T. Dove, 1993-10-21 The vibrations of atoms inside crystals lattice dynamics is basic to many fields of study in the solid state and mineral sciences This book provides a self contained text that introduces the subject from a basic level and then takes the reader through applications of the theory **The Specific Heat Of Matter At Low Temperatures** Ahmet Tari, 2003-08-12 Recent discoveries of new materials and improvements in calorimetric techniques have given new impetus to the subject of specific heat Nevertheless there is a serious lack of literature on the subject This invaluable book which goes some way towards remedying that is concerned mainly with the specific heat of matter at ordinary temperatures It discusses the principles that underlie the theory of specific heat and considers a number of theoretical models in some detail The subject matter ranges from traditional materials to those recently discovered heavy fermion compounds high temperature superconductors spin glasses and so on and includes a large number of figures tables and references The book will be particularly useful for advanced undergraduate and postgraduate students as well as academics and researchers a **Understanding Solid State Physics** Jacques Cazaux, 2016-03-23 The correlation between the microscopic composition of solids and their macroscopic electrical optical thermal properties is the goal of solid state physics This book is the deeply revised version of the French book Initiation a physique du solide exercices commentés avec rappels de cours written more than 20 years ago It has five sections **Carbon Nanotube and Graphene Nanoribbon Interconnects** Debaprasad Das, Hafizur Rahaman, 2017-12-19 An Alternative to Copper Based Interconnect Technology With an increase in demand for more circuit components on a single chip there is a growing need for nanoelectronic devices and their interconnects a physical connecting medium made of thin metal films between several electrical nodes in a semiconducting chip that transmit signals from one point to another without any distortion Carbon Nanotube and Graphene Nanoribbon Interconnects explores two new important carbon nanomaterials carbon nanotube CNT and graphene nanoribbon GNR and compares them with that of copper based interconnects These nanomaterials show almost 1 000 times more current carrying capacity and significantly higher mean free path than copper Due to their remarkable properties CNT and GNR could soon replace traditional copper interconnects Dedicated to proving their benefits this book covers the basic theory of CNT and GNR and provides a comprehensive analysis of the CNT and GNR based VLSI interconnects at nanometric dimensions Explore the Potential Applications of CNT and Graphene for VLSI Circuits The book starts off with a brief introduction of carbon nanomaterials discusses the latest research and details the modeling and

analysis of CNT and GNR interconnects It also describes the electrical thermal and mechanical properties and structural behavior of these materials In addition it chronicles the progression of these fundamental properties explores possible engineering applications and growth technologies and considers applications for CNT and GNR apart from their use in VLSI circuits Comprising eight chapters this text Covers the basics of carbon nanotube and graphene nanoribbon Discusses the growth and characterization of carbon nanotube and graphene nanoribbon Presents the modeling of CNT and GNR as future VLSI interconnects Examines the applicability of CNT and GNR in terms of several analysis works Addresses the timing and frequency response of the CNT and GNR interconnects Explores the signal integrity analysis for CNT and GNR interconnects Models and analyzes the applicability of CNT and GNR as power interconnects Considers the future scope of CNT and GNR Beneficial to VLSI designers working in this area Carbon Nanotube and Graphene Nanoribbon Interconnects provides a complete understanding of carbon based materials and interconnect technology and equips the reader with sufficient knowledge about the future scope of research and development for this emerging topic

Ferroelectricity in Doped Hafnium Oxide Uwe Schroeder,Cheol Seong Hwang,Hiroshi Funakubo,2019-03-27 Ferroelectricity in Doped Hafnium Oxide Materials Properties and Devices covers all aspects relating to the structural and electrical properties of HfO₂ and its implementation into semiconductor devices including a comparison to standard ferroelectric materials The ferroelectric and field induced ferroelectric properties of HfO₂ based films are considered promising for various applications including non volatile memories negative capacitance field effect transistors energy storage harvesting and solid state cooling Fundamentals of ferroelectric and piezoelectric properties HfO₂ processes and the impact of dopants on ferroelectric properties are also extensively discussed in the book along with phase transition switching kinetics epitaxial growth thickness scaling and more Additional chapters consider the modeling of ferroelectric phase transformation structural characterization and the differences and similarities between HfO₂ and standard ferroelectric materials Finally HfO₂ based devices are summarized Explores all aspects of the structural and electrical properties of HfO₂ including processes modelling and implementation into semiconductor devices Considers potential applications including FeCaps FeFETs NCFETs FTJs and more Provides comparison of an emerging ferroelectric material to conventional ferroelectric materials with insights to the problems of downscaling that conventional ferroelectrics face

Nano-Electronic Devices Dragica Vasileska,Stephen M. Goodnick,2011-06-10 This book surveys the advanced simulation methods needed for proper modeling of state of the art nanoscale devices It systematically describes theoretical approaches and the numerical solutions that are used in explaining the operation of both power devices as well as nano scale devices It clearly explains for what types of devices a particular method is suitable which is the most critical point that a researcher faces and has to decide upon when modeling semiconductor devices

Meeting Abstracts Electrochemical Society. Meeting,1999

An Experimental and Theoretical Study of Furan Decomposition on Pd(111) Using Scanning Tunneling Microscopy and Density

Functional Theory Albert Loui, 2005 *Whitaker's Books in Print* ,1998 **Soviet Electrochemistry** ,1984 *Helium Three* W. P. Halperin, Lev Petrovich Pitaevskiĭ, 1990 Introducing the subject of superfluid helium three and polarized liquid helium three this book is devoted to modern problems in many body physics specific to the quantum fluid helium three Relationships between properties of helium three and topics in other fields are established including superconductivity non linear dynamics acoustics and magnetically polarized quantum systems Among the chapters in this collection one finds valuable reference material and original research not published elsewhere Advanced research topics are presented in a pedagogical manner in considerable depth and with appropriate introductory material sufficiently general to be suitable to the non specialist **Microdosimetry** H. G. Menzel, 1994 *British Books in Print* ,1979 **Studies of Phase Transitions and Critical Phenomena** Raymond Ethan Goldstein, 1988 *Subject Guide to Books in Print* ,1975

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