

The Properties and Applications of Quasicrystals

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In being relatively poor conductors of heat and electricity, quasicrystalline alloys, most of which contain about 70 atomic percent of aluminium, do not behave as one might expect. Other interesting properties involving, for instance, adhesion, corrosion, friction, and hardness, suggest that the industrial future of quasicrystals is promising while the present is already bearing its fruits, notably in coating applications.

Quasicrystals are materials having a new type of long-range order such that their diffraction patterns show Bragg reflections revealing symmetries which are incompatible with periodicity [1]. However, they are highly ordered systems [2] with correlation lengths of several tenths of a micrometer [3]. Large single crystals can be grown [4] whose quality is such that dynamical diffraction has been observed [5]. The atomic structure of quasicrystals can be reasonably well described in terms of a self-similar packing of atomic clusters using the techniques of high-dimensional crystallography [5, 6].

Aside from the peculiar structures, quasicrystals also exhibit very unexpected properties [7]. Perhaps their most intriguing feature is a very high electrical (and thermal) resistivity. Its value, which almost equals that of an insulator [8], is unexpected for a material containing about 70 atomic percent of aluminium. Fundamental physical characteristics of this type combined with other unusual properties mean that quasicrystals have emerged in a surprisingly short period of time since their discovery as rather useful materials having valuable existing and potential applications.

Very Different Structures

Differences between the crystallography of periodic crystals (PC) and quasicrystals (QC) can be examined in either real or reciprocal space. Both viewpoints are useful for understanding some of the properties of quasicrystals. To illustrate

schematically the real-space models of PC and QC, consider linear (one-dimensional) chains built up with sequences of two segments, one large (L) and one short (S). PC can be obtained via addition rules. For instance, adding strips LS over and over again gives the periodic chain LS LS LS LS LS LS To obtain a QC chain, substitution rules must be used instead. For instance, any given strip of LS segments can be grown by substituting L by LS and S by L in sequence; this results in the following successively grown strips:

- initial strip : L S
- plus 1 substitution : L S L
- 2 substitutions : L S L L S
- 3 substitutions : L S L L S L S L
- etc.

The result is a perfectly ordered, deterministic sequence of L and S segments without any indication of periodicity. For one-dimensional structures, it may be difficult to imagine why this awkward substitutional operation should be preferred instead of a straightforward periodic packing. Indeed, one-dimensional QC are expected to be unstable with respect to PC. But in two and three dimensions, substitution may be the only way to grow a structure. This is the situation, for instance, with pentagonal and icosahedral structural tiles (patterns of atoms), whose fivefold symmetries cannot be accommodated by periodicity. QC consequently become the stable structures as long as pentagonal or icosahedral atomic blocks can form.

In a monatomic PC such as a metal crystal, all atomic sites are strictly equivalent. If some electrons are loosely bonded to atoms they have no reason to locate on a particular site and can travel essentially freely through the bulk of the metal. The result is a high conductivity and isotropy, with all the well-known consequences for properties and their applications.

Conversely, in QC structures strictly equivalent sites cannot be found if the fully extended surroundings of the sites are considered. The "free" electrons, if there are any, are forced to "locate" preferably at low-energy sites within the constraints of the Coulomb interaction, although in reality this model must be somewhat smoothed out. QC structures are such that identical atomic clusters of any size can be found at distances apart of about twice the cluster size (Fig. 1). Conductivity is therefore reduced to a hopping or/and tunnelling communication between a hierarchy of almost identical sites, with bonding isotropy reduced to the preferred direction for hopping [9].

The reciprocal space description of QC adds to our understanding and supports similar conclusions. Both PC and QC structures can be analyzed in terms of their Fourier components in that the space dependence of their density can be expressed as a sum of density waves, i.e.,

$$\rho(r) = (1/v) \sum_G \rho(G) \exp(iG \cdot r).$$

For PC, the set of G vectors define a discrete reciprocal lattice in which each wave-vector can be written as an integer linear combination of three basis vectors a_i^* :

$$G = h a_1^* + k a_2^* + l a_3^* \quad (1).$$

For QC, the number of integer linearly independent vectors required to span the reciprocal space exceeds the spatial dimension. For instance, six basis vectors are required to span the reciprocal space for three-dimensional icosahedral QC, i.e., Eq. (1) must be replaced by:

$$G = n_1 a_1^* + n_2 a_2^* + n_3 a_3^* + n_4 a_4^* + n_5 a_5^* + n_6 a_6^*.$$

Many direct consequences follow:

- it is confirmed that the point symmetry is incompatible with periodic translational order in three-dimensions;
- the wavevectors G define a set of points which fill the space densely;
- there is a periodic image of the structure in a higher dimensional space (six dimensions for icosahedral structures) which can be used in quasicrystallography approaches [5, 10].

The inferred differences between the properties of PC and QC are basically contained in the analysis of wave propagation in the two types of structures. Plane waves with any wavevector k except for k vectors which satisfy the diffraction condition,

$$\pm G \cdot k \pm |G|^2 = 0 \quad (2)$$

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Jean-marie Dubois



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Quasicrystals 2003: Volume 805 E. Belin-Ferre, M. Feuerbacher, Y. Ishii, D. Sordelet, 2004-03-18 Twenty years after the discovery of a quasicrystalline compound the field of quasicrystals still raises interest and is continuously evolving. Quasicrystals display properties different from conventional crystals with small unit cells and present interesting potential for industrial purposes. This book offers an updated look into the field of quasicrystalline research. For example, a report on electrodeposited Al-Cu-Fe quasicrystals shows great promise for industry. It is also demonstrated that when Al-Cu-Fe quasicrystals are used as catalysts in particular at high temperatures such quasicrystals outperform conventional industrial catalysts. A new class of quasicrystal based on a novel type of local order differing from previously observed Mackay and Bergman type quasicrystals is featured. A detailed description of layer by layer growth of a Cu film on a quasicrystalline surface is also provided. Additional topics include synthesis and structure, transport properties, electronic properties, mechanical properties, quasicrystals from metallic glasses, surfaces and coatings, and applications and hydrogen storage.

Useful Quasicrystals Jean-Marie Dubois, 2005-04-20 The aim of this book is to acquaint the reader with what the author regards as the most basic characteristics of quasicrystals: structure, formation and stability, properties in relationship with the applications of quasicrystalline materials. Quasicrystals are fascinating substances that form a family of specific structures with strange physical and mechanical properties as compared to those of metallic alloys. This, on the one hand, is stimulating intensive research to understand the most basic properties of quasicrystals in the frame of a generalized crystallography. On the other hand, these properties open the way to technological applications, demonstrated or potential, mostly regarding energy savings. This valuable book discusses those various facets of quasicrystals in five chapters, ending with the author's own interpretation of the properties with respect to their unique structure.

Quasicrystals Hans-Rainer Trebin, 2003-07-07 A comprehensive and up-to-date review covering the broad range of this outstanding class of materials among intermetallic alloys. Starting with metallurgy and characterization, the authors continue on to structure and mathematical modeling. They use this basis to move on to dealing with electronic, magnetic, thermal, dynamic and mechanical properties, before finally providing an insight into surfaces and thin films. The authors belong to a research program on quasicrystals sponsored by the German Research Society and managed by Hans Rainer Trebin, such that most of the latest results are presented.

Quasicrystals: Current Topics - Proceedings Of The Spring School On Quasicrystals Esther Belin-Ferre, Claire Berger, Marianne Quiquandon, Anne Sadoc, 2000-07-31 This book focuses on current topics in quasicrystal science and research. Various themes are addressed, such as atomic structure, growth of quasicrystals, statistical physics and thermodynamics, magnetism, phasons, propagation of waves, surfaces and technological potential of quasicrystals. Insight into basics in physics and chemistry is also given, with examples from metallurgy, the surface of alloys, plasticity, etc., in order to point out the possible genuine aspects of quasicrystals and allow a better comparison with conventional alloys.

Quasicrystals, 2007-12-17 This book is aimed at

researchers who are working in a field of quasicrystals to provide a reference to recent developments and ideas in the field and also at graduate students who intend to study quasicrystals to provide introduction of ideas Topics in this book cover an entire field of quasicrystals both experimental and theoretical including new developments the state of the art in quasicrystallography new families of quasicrystals phasons in aperiodic solids ab initio studies on stability mechanism quantum transport phenomena elastic plastic properties and surface of quasicrystals Comprehensive reviews by experts in the field Complete reference of original papers and new topics Intelligible introduction of quasicrystals by experts

Quasicrystals - Proceedings Of The 5th International Conference C Janot,R Mosseri,1995-12-22 These proceedings cover topics related to Quasicrystals including tiling descriptions high dimensional crystallography structure studies metallurgy and phase diagrams and also properties with special emphasis on dynamics electronic and mechanical behaviour For the first time materials made of metals only that behave as insulators are presented For the first time also application focused research and processing of Quasicrystalline materials are addressed Invited speakers J Friedel D Shechtman M Baake D Basov C Berger M de Boissieu T Fujiwara S Khanna Y Meyer S J Poon C Sire H Trebin A P Tsai M Widdom M Wollgarten Z Zhang

New Horizons In Quasicrystals: Research And Applications - Proceedings Of The Conference Alan I Goldman,Jean-marie Dubois,Daniel J Sordet,Patricia Ann Thiel,1997-02-03 In this volume the following topics are discussed existing and potential applications of quasicrystals surface and interface properties of quasicrystals and potential new quasicrystalline materials It gathers contributions from world renowned researchers in the field of quasicrystals experts in fields such as surface science materials preparation and mechanical properties as well as representatives of industry to discuss possible directions for basic and applied programs of research for these novel materials

Quasicrystals: Proceedings Of The 6th International Conference (Yamada Conference XI Vii) Shin Takeuchi,Takeo Fujiwara,1998-01-22 This volume covers all scientific aspects relating to quasicrystals such as tilings generalized crystallography sample preparation structure determination the growth mechanism phase transition and physical and chemical properties including electronic dynamical and mechanical properties

Quasicrystals J.-B. Suck,M. Schreiber,P. Häussler,2013-04-17 Quasicrystals have been the object of intense research efforts for a good 16 years now In recent years this area of solid state physics and crystallography has grown into a mature field in its own right Hence several books on quasicrystals have appeared in the interim see Appendix and chapters on quasicrystals have been introduced into new books on solid state physics and into new editions of existing monographs However most of the former have been written for scientists specialised in this field rather than for students and the latter additions are often rather brief We therefore decided to fill the gap between these two extremes with a book which provides an introduction to the structure and physical properties of quasicrystals and covers in sufficient detail all important fields in quasicrystal research and even applications The chapters have been written by specialists and each is based on the author's insight into this field However much effort

has been put into achieving an introductory character and making the text accessible to newcomers to the field

Quasicrystals Esther Belin-Ferr², 2000 This book focuses on current topics in quasicrystal science and research Various themes are addressed such as atomic structure growth of quasicrystals statistical physics and thermodynamics magnetism phasons propagation of waves surfaces and technological potential of quasicrystals Insight into basics in physics and chemistry is also given with examples from metallurgy the surface of alloys plasticity etc in order to point out the possible genuine aspects of quasicrystals and allow a better comparison with conventional alloys Crystallography of Quasicrystals Steurer Walter, Sofia Deloudi, 2009-08-26 From tilings to quasicrystal structures and from surfaces to the n dimensional approach this book gives a full self contained in depth description of the crystallography of quasicrystals It aims not only at conveying the concepts and a precise picture of the structures of quasicrystals but it also enables the interested reader to enter the field of quasicrystal structure analysis Going beyond metallic quasicrystals it also describes the new dynamically growing field of photonic quasicrystals The readership will be graduate students and researchers in crystallography solid state physics materials science solid state chemistry and applied mathematics **Quasicrystals** Enrique Maciá-Barber, 2022-08 This is a complete guide to quasicrystals and next generation materials based on aperiodically ordered designs with potential uses in high performance technological devices It is an ideal introductory book for graduates senior scientists and researchers in physics chemistry materials science engineering *Quasicrystals - Proceedings Of China-japan Seminars* Ke-hsin Kuo, T Ninomiya, 1991-06-28 A decade has passed since the Asian crisis of 1997 1998 which decimated many of the regional economies While the crisis itself led to severe economic and political consequences its primary cause was an inappropriate mix of policies as regional economies attempted to simultaneously maintain fairly rigid exchange rates soft US dollar pegs and monetary policy autonomy in the presence of large scale capital outflows The chapters in this volume focus on selected exchange rate monetary and financial issues and policies that are of contemporary relevance and importance to Asia including choice of exchange rate regimes causes and consequences of reserve accumulation international capital flows macroeconomic synchronization and regional monetary and financial cooperation **Progress in Powder Metallurgy** Duk Yong Yoon, Suk-Joong L. Kang, Kwang Yong Eun, Yong Seog Kim, 2007-01-15 Proceedings of the 2006 Powder Metallurgy World Congress Exhibition PM 2006 held in Busan Exhibition Convention Center BEXCO Busan Korea September 24 28 2006 Wear Gwidon W. Stachowiak, 2006-08-14 Tribology is emerging from the realm of steam engines and crank case lubricants and becoming key to vital new technologies such as nanotechnology and MEMS Wear is an integral part of tribology and an effective understanding and appreciation of wear is essential in order to achieve the reliable and efficient operation of almost any machine or device Knowledge in the field has increased considerably over recent years and continues to expand this book is intended to stimulate its readers to contribute towards the progress of this fascinating subject that relates to most of the known disciplines in physical science Wear Materials Mechanisms and Practice provides

the reader with a unique insight into our current understanding of wear based on the contributions of numerous internationally acclaimed specialists in the field Offers a comprehensive review of current knowledge in the field of wear Discusses latest topics in wear mechanism classification Includes coverage of a wide variety of materials such as metals polymers polymer composites diamonds and diamond like films and ceramics Discusses the chemo mechanical linkages that control tribology providing a more complete treatment of the subject than just the conventional mechanical treatments Illustrated throughout with carefully compiled diagrams that provide a unique insight into the controlling mechanisms of tribology The state of the art research on wear and the mechanisms of wear featured will be of interest to post graduate students and lecturers in engineering materials science and chemistry The practical applications discussed will appeal to practitioners across virtually all sectors of engineering and industry including electronic mechanical and electrical quality and reliability and design

Shadows of Reality Tony Robbin, 2008-10-01 In this insightful book which is a revisionist math history as well as a revisionist art history Tony Robbin well known for his innovative computer visualizations of hyperspace investigates different models of the fourth dimension and how these are applied in art and physics Robbin explores the distinction between the slicing or Flatland model and the projection or shadow model He compares the history of these two models and their uses and misuses in popular discussions Robbin breaks new ground with his original argument that Picasso used the projection model to invent cubism and that Minkowski had four dimensional projective geometry in mind when he structured special relativity The discussion is brought to the present with an exposition of the projection model in the most creative ideas about space in contemporary mathematics such as twisters quasicrystals and quantum topology Robbin clarifies these esoteric concepts with understandable drawings and diagrams Robbin proposes that the powerful role of projective geometry in the development of current mathematical ideas has been long overlooked and that our attachment to the slicing model is essentially a conceptual block that hinders progress in understanding contemporary models of spacetime He offers a fascinating review of how projective ideas are the source of some of today's most exciting developments in art math physics and computer visualization *Zeitschrift Für Kristallographie*, 2009

Dislocations in Solids, 2007-05-16 Dislocations are lines of irregularity in the structure of a solid analogous to the bumps in a badly laid carpet Like these bumps they can be easily moved and they provide the most important mechanism by which the solid can be deformed They also have a strong influence on crystal growth and on the electronic properties of semiconductors Influence of dislocations on piezoelectric behavior New mechanisms for hardening in twinned crystals Bringing theories of martensite transformation into agreement Atomic scale motion of dislocations in electron microscopy Dislocation patterns deduced from X ray diffraction Role of dislocations in friction Dislocation motion in quasicrystals

Properties And Applications Of Complex Intermetallics Esther Belin-ferre, 2009-08-11 Complex metal alloys CMAs comprise a huge group of largely unknown alloys and compounds where many phases are formed with crystal structures based on giant unit cells containing atom clusters

ranging from tens of to more than thousand atoms per unit cell In these phases for many phenomena the physical length scales are substantially smaller than the unit cell dimension Hence these materials offer unique combinations of properties which are mutually exclusive in conventional materials such as metallic electric conductivity combined with low thermal conductivity good light absorption with high temperature stability high metallic hardness with reduced wetting by liquids etc This book is the second of a series of books issued yearly as a deliverable to the European Community of the School established within the European Network of Excellence CMA Written by reputed experts in the fields of metal physics surface physics surface chemistry metallurgy and process engineering this book brings together expertise found inside as well as outside the network to provide a comprehensive overview of the current state of knowledge in CMAs

Quasicrystals

Hans-Rainer Trebin, 2006-05-12 Quasicrystals form a new state of solid matter beside the crystalline and the amorphous The positions of the atoms are ordered but with noncrystallographic rotational symmetries and in a nonperiodic way The new structure induces unusual physical properties promising interesting applications This book provides a comprehensive and up to date review and presents most recent research results achieved by a collaboration of physicists chemists material scientists and mathematicians within the Priority Programme Quasicrystals Structure and Physical Properties of the Deutsche Forschungsgemeinschaft DFG Starting from metallurgy synthesis and characterization the authors carry on with structure and mathematical modelling On this basis electronic magnetic thermal dynamic and mechanical properties are dealt with and finally surfaces and thin films

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