

Commentary

Recent research and development on Quasicrystals †

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† A report on the “13th International Conference on Quasicrystals (ICQ13)” organized by Dr. Hem Raj Sharma (UK) and Prof. An Pang Tsai (Japan) during 18–23 September 2016, Kathmandu, Nepal

The 13th International Conference on Quasicrystals (ICQ13) was held during 18–23 September 2016 in Kathmandu, *Nepal*. This was one of the series following the 1st workshop in Les Houches, *France*, the 2nd in Beijing, *China*, the 3rd Meeting in Vista-Hermosa, *Mexico*, the 4th Conference in St. Louis, *USA*, the 5th in Avignon, *France*, the 6th in Tokyo, *Japan*, the 7th in Stuttgart, *Germany*, the 8th in Bangalore, *India*, the 9th in Ames, *USA*, the 10th in Zürich, *Switzerland*, the 11th in Sapporo, *Japan*, and the 12th in Cracow, *Poland*. Quasicrystals are a kind of unique materials and characterized by the discrete diffraction patterns which cannot be indexed with the conventional three indices but require additional ones [1,2]. They occur in almost every type of solid including organic and inorganic compounds, minerals, metals and alloys, macromolecules and oxides [3,4,5]. It is convenient to describe their structures in higher dimensional space, a conceptual environment, in which three-dimensional periodic crystals recover their periodicities [6]. The inconvenience of visualization due to extra dimensions is compensated by the mathematical elegance achieved through recovering periodicity. Studies of quasicrystalline structures have greatly enriched our understanding of the physics and chemistry of atomic orders, and have opened up new perspectives for correlating structure with the properties of complex materials.

The ICQ13 conference was attended by 134 participants from all over the world including two participants from India, T.P. Yadav (*Banaras Hindu University-Varanasi*) and R.R. Shahi (*Motilal Nehru National Institute of Technology Allahabad*). The details of the conference and the abstract of the papers presented in the conference can be found at <https://www.liverpool.ac.uk/conference-on-quasicrystals>. There were 15 technical sessions consisting of 56 presentations including three tutorial and 2 poster sessions of 39 papers.

There was an interesting public lecture on Quasi-Periodic Materials: A Paradigm Shift in Crystallography delivered by Professor Dan Shechtman, the 2011 Chemistry Nobel Laureate, who discovered the quasicrystal (QCs) in 1984 [7]. In addition to the public lecture, during the conference there were lively discussions on topics related to formation, growth and phase stability, structure and modeling, mathematics of quasiperiodic and aperiodic structures, physical properties (transport, magnetic, dynamical, mechanical etc.), surfaces and over layers, applications and new frontiers, metamaterials (polymer, macro molecules, photonic/phononic crystals, oxide etc.), incommensurate/modulated structures, metallic glass, complex metallic alloys, clathrate compound, clusters etc. Some of the issues emerging out of this conference are highlighted here which has been discussed by best scientists of the world to talk about the recent developments in the field quasicrystal.

The first tutorial was given by Joe Smerdon (*University of Central Lancashire, UK*) on “*Fibonacci, Penrose, Harry Potter: An introduction to the strange world of quasicrystals*”, second tutorial was given by Cesar Pay Gomez (*Uppsala University, Sweden*) on “*Structure analysis of icosahedral quasicrystals and approximants by X-ray diffraction*” and third tutorial was given by Noriaki K. Sato (*Nagoya University, Japan*) on “*Physics hidden in open space between heavy fermions and quasicrystals*”. Several workers presented on the formation, growth, soft Matter Quasicrystals. T. Dotera (*Kindai University, Japan*) discussed on the “*Bronze-mean hexagonal quasicrystal*” simulations of a particle system and obtained a random-tiling of the 6-fold quasicrystal. T. Ishimasa (*Hokkaido University, Japan*) presented on “*Dodecagonal quasicrystal in Mn-based alloy*” and has shown the first experimental indication of the presence of an acceptance domain in a dodecagonal quasicrystal viewpoint. P. Boulet (*Université de Lorraine, France*) shown “*Two types of QC approximant in the Ce-Au-Ge system*” where a non-centrosymmetric space group F-43m, pointing out the strong relationship of this structure with the gamma-brass structure type. R.R. Shahi (*Motilal Nehru National Institute of Technology, India*) presented on “*Synthesis characterizations and hydrogenation behavior of as quenched $Ti_{45+x}Zr_{38-x}Ni_{17}$ ($x = 3, 5, 8$) nano quasicrystalline ribbons*” and discussed the effect of various compositions of Ti and Zr on the structure, microstructure of QC ribbons and their correlation with hydrogen storage characteristics. The atomic structure of ternary Yb-Cd-Mg icosahedral quasicrystals was demonstrated by T. Yamada (*Tohoku University, Japan*). The “*Deformation of icosahedral quasicrystal in a composite of Mg-Zn-Y alloy during severe plastic deformation*” was discussed by Alok Singh (*National Institute for Materials Science, Japan*). He has demonstrated that in Mg-Zn-Y alloy, *i*-phase formed as eutectic phase in the interdendritic spaces of α -Mg phase with arm widths in the range of 10 to 20 μm . Due to HPT strain, severe deformation occurred in the Mg-matrix, as described in our earlier study on a Mg-3Zn-0.5Y alloy and recrystallization of α -Mg grains occurred over *i*-phase. No noticeable deformation was noticed in the *i*-phase until an applied strain of $N = 3$. Formation of planar low angle boundaries was observed on fivefold plane. C. Dong (*Dalian University of Technology, China*) dealt with the “*Quasicrystal composition formulas and the hardness evaluation via the cluster-plus-glue-atom model*”. It was shown within the framework of this model that the hardness of quasicrystals is determined by the number of the ruptured weakest bonds per unit cluster formula. Typically, theoretical hardness values of 8~9 GPa was obtained using ~18 broken inter-cluster bonds, which accounts for half of all the inter-cluster bonds. The statistical description of the Cd-Yb icosahedral quasicrystal with the application of the novel concept of the phason disorder correction and the fundamentals of statistical description of diffraction patterns of crystals was discussed by I. Buganski

and J. Wolny (*AGH—University of Science and Technology, Poland*) independently. The “*Structure and stability of γ -brass related complex phase in the Au-Zn System*” was discussed by P. Jana (*Lund University, Sweden and Indian Institute of Technology Kharagpur, India*). E. Abe (*University of Tokyo, Japan*) presented about the atomic-resolution scanning transmission electron microscopy combined with multivariate analysis for decagonal quasicrystals. K. Edagawa (*The University of Tokyo, Japan*) presented about the photonic band structure calculations done for a series of crystal approximants to a two dimensional dodecagonal quasicrystal. Further, properties of the six-fold symmetric photonic quasicrystal fibers were presented by C.S. Kee (*Gwangju Institute of Science and Technology, South Korea*). The “*Fibonacci Bloch function in the quasicrystal*” discussed by Ron Lifshitz (*Tel Aviv University, Israel*) where he was shown about the tight-binding model on the 1-dimensional Fibonacci quasicrystal. P. Subramanian (*University of Leeds, UK*) presented on “*Weakly nonlinear analysis of three-dimensional quasicrystals using homotopy continuation*”. R. Widmer (Paul Scherrer Institute, Switzerland) presented on “*Fermi states and anisotropy of Brillouin zone scattering in the decagonal Al-Ni-Co quasicrystal*” and “*Unified cluster-based description of valence bands in $AlIr$, $RuAl_2$, $RuGa_3$, and Al-TM quasicrystalline approximants*” was discussed by K. Kitahara (*The University of Tokyo, Japan*). A. Koga (*Tokyo Institute of Technology, Japan*) presented the extended Anderson lattice model on the Penrose lattice to discuss valence fluctuations at low temperatures combining the real-space dynamical mean-field theory with the continuous-time quantum Monte Carlo method, based on the f-electron number, spin correlations, and local magnetic susceptibility. K. Kimura (*The University of Tokyo, Japan*) presented semiconducting quasicrystal and high-performance thermoelectric material. J. Dolinšek (*Jožef Stefan Institute and University of Ljubljana, Slovenia*) presented extraction of the electronic properties of rare-earth-containing quasicrystals from their low-temperature specific heat in the presence of the Schottky effect. The “*Gap structure and topological indices on the Fibonacci quasicrystal*” was presented by Nicolas Macé (*Université Paris-Saclay, France*). K. Deguchi (*Nagoya University, Japan*) discussed on “*Magnetism and superconductivity in icosahedral quasicrystals and approximants with Tsai-type clusters*” and “*Phenomenological magnetic model in Tsai-type approximants*” was discussed by T. Sugimoto (*Tokyo University of Science, Japan*). “*Neutron-scattering study on the quasicrystal approximants Au-Si-R (R = rare-earths)*” was presented by T. Hiroto (*The University of Tokyo, Japan*). Anuradha Jagannathan (*Université Paris-Sud, France*) presented “*Screening of magnetic impurities in quasicrystals*”. R. Tamura (*Tokyo University of Science, Japan*) presented a detailed study on “*Magnetic properties of Au-based Tsai-type approximants*”. It was shown that an occurrence of a low temperature structural transition associated with the dynamical motion of a tetrahedron inside icosahedral clusters in Tsai cluster can be classified into “non-diffusive order-disorder transition”. In addition, a long-range magnetic order at low temperature was observed. The structural and magnetic ordering in Cd_6M approximants has been discussed. M. Mihalkovič (*Slovak Academy of Sciences, Slovakia*) presented “*Finite temperature structure and stability of $i-AlCuFe$ and $i-AlMnPd$ from realistic simulations*”. The different type of quasiperiodic tiling has been discussed by several authors including N. Fujita (*Tohoku University, Japan*), Shelomo I. Ben-Abraham (*Ben-Gurion University, Israel*), L. Boyle (*Perimeter Institute for Theoretical Physics, Canada*) and R. Ajlouni (*University of Utah, USA*). E. Gaudry (*CNRS Université de Lorraine, France*) presented surface structure determination of a quasicrystalline approximant using combined surface X-ray diffraction and ab-initio calculations and J. Ledieu (*CNRS-Université de Lorraine, France*) presented the surface studied of $Al_{13}Ru_4(010)$ using low energy electron diffraction

technique, scanning tunneling microscopy measurements and demonstrate that the superstructure consists of a network of well-separated lines running across terraces and appearing as “ditch” based on the site-isolation concept. A new result of 5-fold symmetric molecules which was trapped at 5-fold symmetric sites of the surface, enforcing long-range order in the molecular films was discussed by V. Fournée (CNRS—Université de Lorraine, France) and S. Coates (University of Liverpool, UK) separately. The occurrence of C₆₀ and C₂₀H₁₀ molecules on several quasicrystalline substrates including 5-fold Ag-In-Yb quasicrystalline surfaces was discussed in details. Coverage-dependent structural phase transformations in the adsorption of pentacene on an aperiodically modulated Cu film by density functional theory was presented by K. Pussi (Lappeenranta University of Technology, Finland). A new member in the family of quasicrystal, i.e., oxide quasicrystal which was characterized by scanning tunneling microscopy and low-energy electron diffraction measurements with in-situ low-energy electron microscopy studies was presented by S. Förster (Martin-Luther-Universität Halle-Wittenberg, Germany). Wolf Widdra (Max-Planck-Institut für Mikrostrukturphysik, Germany) presented structural analysis of approximants for the BaTiO₃-derived oxide quasicrystal. J.M. Dubois (Institut Jean Lamour, France) presented a complex self-lubricating, low-friction, wear-resistant Al-based quasicrystalline coatings. The D. Liu (Univ. Grenoble Alpes, France) presented “Diffuse scattering, phason fluctuations and atomic scale simulation in the Zn-Sc icosahedral quasicrystal”. The structure and growth model of quasicrystal was discussed by Walter Steurer (ETH, Switzerland) in details based on the two questions: (i) whether the state of the art in quasicrystal research is already comparable to that in complex intermetallics in general, (ii) what we could learn from the studies on mesoscopic quasicrystals for the structure formation of intermetallic quasicrystals. A.I. Goldman (Iowa State University, USA) presented the progress in the magnetism properties of quasicrystals and their related periodic approximants with the role of aperiodicity in shaping physical properties. Antoine Julien (Norwegian university of science and technology, Norway) presented the mathematics of the quasicrystal including mathematical theory of aperiodic order with group theory, number theory, and signal analysis. The bioactivity of quasicrystalline-reinforced composite materials for 3D printing of medical implants was discussed by G. Cini (CNRS—Université de Lorraine, France). This work opens new opportunities for medical applications of quasicrystalline alloys. Further, the microstructure and hydrophobic behavior of Al-Cu-Fe coating by plasma spraying was discussed by M.S. Leu (Industrial Technology Research Institute, Taiwan). T.P. Yadav (Banaras Hindu University, India) presented “Mechanical properties of carbon nano-variant reinforced quasicrystal composite” where the hardness of Al₆₅Cu₂₀Fe₁₅ icosahedral quasicrystal—mechanically activated carbon (graphite), carbon nano-tube, carbon nano-fiber and graphene nano-composite was communicated in details. Y. Chen (Dalian University of Technology, China) presented “Characteristic smearing wear behavior of quasicrystals as abrasive materials”. A unique surface flaw repairing effect was discussed in severe surface plastic deformation upon polishing using quasicrystal abrasives. The last lecture in the conference was given by Hari Dahal (American Physical Society, USA) on American physical society publications and peer review process in Physical Review B. The International Advisory Board of the Thirteenth International Conference on Quasicrystals has announced to award Prof. Marek Mihalkovič (Slovakia) the Jean Marie Dubois Award 2016 for Excellence in Quasicrystal Research in theoretical work that has enabled and demonstrated the simulation of thermodynamic and dynamic properties of quasicrystals, based on realistic atomic-scale models and energetic.

In the concluding remarks some major issues have emerged from this conference which is expected to dominate research in quasicrystal. These are: (i) structural refinement of quasicrystals by using electron diffraction and electron tomography, (ii) structural refinement of quasicrystals using the average lattice concept, (iii) application of quasicrystal at industrial scale.

It was announced by International Advisory Board of the International Conference on Quasicrystals that the next meeting on ICQ14 will be organized by Janez Dolinšek in the Slovenia in 2019.



Figure 1. The group photograph of 13th International Conference on Quasicrystals participants.

Conflict of Interest

The author declares that there is no conflict of interest regarding the publication of this paper.

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