aerosols, and concluded that higher refractive index and smaller size are important for larger deflection of sunlight. However, S. N. Tripathi (IIT, Kanpur) in his review of the various aerosols for geoengineering (sulphates, tin oxide, alumina, diamond, calcium carbonate, etc.), showed that smaller-sized particles have larger surface area and hence could accelerate ozone loss. R. Ramesh (National Institute of Science Education and Research, Bhubaneswar) made a brief review of the CDR method of ocean iron fertilization for sequestering carbon in the ocean and its potential limitations.

The second technical session, chaired by Prodipto Ghosh (MoEF&CC) and moderated by Akhilesh Gupta (DST) discussed the following science and policy issues of geoengineering.

(1) Will geoengineering adversely impact India?

(2) Will it impact monsoon rainfall in India and cause severe droughts?

(3) Will there be benefits for India? If yes, what are they? For example, will it reduce the heat wave related deaths in India?

(4) Do we believe that our climate would be controlled and manipulated by other countries through geoengineering?

(5) Should India consider joining a 'coalition' of countries that support geoengineering?

(6) What are the international protocols and agreements that are relevant to geoengineering experiments and implementation?

(7) What should be the role of India in developing the global governance framework on geoengineering (for laboratory research, field experiments, and large-scale deployment)?

(8) Should India develop a national network of geoengineering research programmes?

(9) What mechanisms are needed to increase the capacity of a national programme?

(10) Should India develop international joint research programmes with other countries, taking into account research capacities, funding mechanisms, liability rules and intellectual property rights?

(11) What should be India's stand on geoengineering, nationally and internationally?

Valuable comments and suggestions on the above questions were provided by several participants. In the concluding session, the following recommendations that emerged from the discussion session were presented by Akhilesh Gupta.

(i) DST may encourage various research groups to undertake geoengineering research in the country through a network programme.

(ii) DST may foster research on unintended consequence of geoengineering on physical and biological systems (e.g. acid rain, coral, fisheries) by employing sophisticated earth system models.

(iii) Geoengineering research should be largely funded by GoI. However, international collaboration may be encouraged.

(iv) Circumstances need to be identified and defined for deployment of field experiments, if any, in the long run.

(v) Need for mapping of groups/researchers/institutions doing or willing to take up geoengineering research and policy in India and abroad.

(vi) Need to set up a Global Technology Watch Group on geoengineering.

(vii) Development of a national strategy on geoengineering research.

(viii) Organize a national conclave on climate change with a special session on climate modelling.

(ix) Bring out a detailed report on the theme of the roundtable at the earliest.

(x) MoEF&CC and DST may jointly develop a policy paper on 'Geoengineering and India'.

(xi) IISc may go ahead with the implementation of MRDP supported by DST and study the impact of geoengineering on monsoon circulation and rainfall, extreme events, cyclones, drought, floods, heat waves, etc.

(xii) IISc may organize the next roundtable in Bengaluru after a year to discuss the initial results from the project.

(xiii) Involve a few other relevant ministries such as the Ministry of External Affairs, Ministry of Agriculture, Ministry of Water, etc.

In his valedictory address, V. K. Gaur (CSIR 4th Paradigm Institute) characterized the roundtable discussion on geoengineering as a visionary step to safeguard India's independent initiatives by high reliability knowledge and capability against possible adventurist climate interventions. He remarked that geoengineering has thrown up a challenge to Indian scientists to empower the nation while forging constructive engagements with global partners and stakeholders.

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MEETING REPORT

# Latest trends in quasicrystal research*

A publication in *Physical Review Letters* by Shechtman *et al.*[1] in 1984 announcing the discovery of a new and unusual quasiperiodic atomic order in solids led to excitement in the scientific community, especially among mathematicians, physicists, crystallographers and materials scientists. It resulted in a race to describe the structure of quasicrystals, development of higher dimensional crystallography, prediction of its properties and potential applications. It also resulted in a new series of conferences on quasicrystals. The 13th international conference on quasicrystals was held in 2016. It was attended by 134 participants from all over the world. The biggest challenge has been to describe the structure of quasicrystals. While challenges still remain, by now there is a good idea of how the

*A report on the 13th International Conference on Quasicrystals (ICQ13) held at Kathmandu, Nepal, during 18–23 September 2016.

atoms are arranged in these materials, thanks to intense interdisciplinary efforts. The problems related to full understanding of quasicrystals continue to excite scientists. Highlights of the conference are presented in this report.

A wide range of theoretical topics was covered in the conference, including quasicrystal structure model, magnetic properties and electronic profiles in the quasiperiodic system. These can be classified into three categories. First, since the detailed crystal structure of icosahedral quasicrystals has not been established, there were several talks about quasiperiodic geometry. One of the candidates is canonical cell tiling consisting of four polyhedrons, proposed by C. L. Henley. In the Chris Henley Memorial Session, Nobuhisa Fujita (Tohoku University, Japan) showed that canonical cell tiling holds subgroup $m\bar{3}$ of the full icosahedral group symmetry $\bar{5}\bar{3}2/m$. In the opening talk of the conference, Tomonari Dotera (Kindai University, Japan) provided a new quasiperiodic structure with hexagonal rotational symmetry. This finding may broaden the series of the quasiperiodic system since this system is often referred to as holding rotational symmetry other than 2, 3, 4 and 6-fold rotational symmetry. In such a unique system without translational symmetry, electronic structure is highly non-trivial since a conventional picture of the crystal cannot be applied. Ron Lifshitz (Tel Aviv University) challenged the fundamental tenet that the Bloch wave function can exist in the 1D quasiperiodic system. Nicolas Macé (Universite of Paris-Sud) reconsidered the gaps in the Fibonacci quasicrystal from the point of view of topology.

There were some theoretical studies motivated by recent synthesis of the first strongly correlated icosahedral quasicrystal $Au_{51}Al_{34}Yb_{15}$. It has been reported that the valence of Yb ions in these compounds is intermediate $Yb^{2\sim3+}$, which indicates that Yb atoms supply both localized and itinerant electrons. Moreover, the quasicrystal $Au_{51}Al_{34}Yb_{15}$ shows interesting low-temperature properties. The susceptibility exhibits non-trivial power-law behaviour $\chi \propto T^{\sim 0.5}$ and specific heat coefficient shows logarithmic divergence $\gamma \propto \ln T$ at low temperatures. This fact indicates that quantum critical behaviour appears in the quasicrystal $Au_{51}Al_{34}Yb_{15}$, which does not vanish with the application of pressure. In contrast, the quantum critical behaviour does not appear in approximant $Au_{51}Al_{35}Yb_{14}$. These findings suggest that electron correlations and the quasiperiodic/quasicrystal nature play a crucial role in destabilizing ordered phases even at very low temperatures. Motivated by these facts, Anuradha Jagannathan (Universite Paris-Sud) claimed that the experimentally observed non-trivial Fermi liquid behaviour can be explained by a dilute alloy system. Nayuta Takemori (RIKEN, Japan) developed real-space dual fermion approach so as to describe non-local correlation effects in the general inhomogeneous system. Furthermore, Elena Y. Vedmedenko (University of Hamburg) focused on magnetic structures in a frustrated quasiperiodic system, which can be useful when the magnetic quasicrystal is synthesized.

There was an experimental–theoretical collaboration of recent neutron diffraction study, which revealed the existence of a ferromagnetism in Au–Si–RE (RE = Gd, Tb, Dy and Ho) and Au–Al–RE approximants with an anisotropy of magnetic moments of rare-earth atoms. Takanori Sugimoto (Tokyo University of Science) proposed an effective model which reproduces the magnetic structure and showed that a local symmetry of icosahedral cluster in body-centred cubic structure plays a crucial role.

The existence of quasicrystals is now widely known, after Dan Shechtman was awarded a Nobel Prize in Chemistry in 2011. However, many physical properties of quasicrystals still remain controversial. As for the first theoretical topic in the conference, fundamental problems such as 'where are the atoms?', need be investigated steadily in the future. In addition, we would like to mention that the field is not just grounded but also broadened since the second and third topics described above are motivated by recent experimental data, obtained after the Nobel Prize award to Shechtman. It is hoped that more young theoreticians would join this area of research, which has a large potential, and reveal unique physical characteristics that will change the present concepts.

The experimental studies reported can be broadly categorized into structural studies on quasicrystals and their approximants, surface structures and their use as templates for growth of other compounds, magnetic and related properties, and quasicrystals materials for practical applications. Studies on samples of two different Yb–Cd–Mg quasicrystals by X-ray diffraction were presented by Tsunetomo Yamada (Tohoku University), focusing on relative occupancies of Cd and Mg in terms of the shell structure of Tsai-type cluster. Two types of approximants were reported in the Ce–Au–Ge system by P. Boulet (CNRS-Universite de Lorraine, France), a body-centred $Im\bar{3}$ and a face-centred $F\bar{4}3m$ type. Structural studies on recently discovered dodecagonal Mn–Cr–Ni–Si quasicrystals with five-dimensional space group $P12_6/mmc$ alloys, employing high-angle annular dark-field scanning transmission electron microscopy (HAADF-STEM) were presented by Tsutomu Ishimasa (Hokkaido University, Japan). Observation along 12-fold axis reveals a non-periodic tiling consisting of an equilateral triangle and a square of edge length 4.560 Å, which tend to form a network of decagons of 17 Å diameter in size. HAADF-STEM technique is well suited for two-dimensional quasicrystals because of two-dimensional samples and imaging of individual atom columns. This technique is complementary to, and can validate the bulk techniques such as diffraction, as shown by Eiji Abe (University of Tokyo) in a study of decagonal quasicrystals by ultra-high resolution STEM.

Among the studies on magnetism and related properties, Kazuhiko Deguchi (Nagoya University, Japan) showed that Au–Al–Yb quasicrystal exhibits novel quantum critical behaviour, which may correspond to an electronic state unique to quasicrystals compared to its approximants. Superconductivity has been shown in Au–Al–Yb approximants by a substitution of Al atoms with Ge atoms. A complex magnetic order in $TbCd_6$ approximant was reported by neutron diffraction studies using $^{112}Cd$ isotope by Andreas Kreyssig (Iowa State University, USA). Phenomenological magnetic model in Tsai-type Au–Si–RE and Au-Al–RE approximants was reported by Takanori Sugimoto (Tokyo University of Science) and Takanobu Hiroto (University of Tokyo). Local symmetry of icosahedral clusters results in peculiar magnetic structure.

Interesting development in the study of surfaces is the self-assembly of molecular films resulting in new fivefold symmetric molecules, such as of $C_{60}$ and $C_{20}H_{10}$ on fivefold surfaces of Ag–In–Yb quasicrystals (Vincent Fournee, Universite

Lorraine, France) and pentacene molecules adsorbed on aperiodic Cu surface (K. Pussi, Lappeenranta University of Technology, Finland). Further excitement is from aperiodic oxides that grow as two-dimensional quasicrystal on periodic single-element substrates – two-dimensional oxide quasicrystals, such as dodecagonal $BaTiO_3$ and $SrTiO_3$ on Pt(111) surface, reported by Stefan Forster (Martin-Luther-Universitat Halle-Wittenberg, Germany), Wolf Widdra (Martin-Luther-Universitat Halle-Wittenberg and Max-Planck-Institut fur Mikrostrukturphysik, Germany) and Junji Yuhara (Nagoya University).

Quasicrystal materials have several applications, many of them related to technologies for most urgent issues such as the environment. One of them is hydrogen absorption in Ti-based quasicrystals. This issue is important from the point of view of hydrogen-based fuel for automobiles, etc. Rohit R. Sahi (Motilal Nehru National Institute of Technology, India) talked about the effect of nanocrystallinity and composition of the quasicrystal phase on hydrogen storage capacity. Several of the applications depend upon the surface properties of the quasicrystals. A prime example is a self-lubricating, low-friction and wear-resistant coating, discussed by Jean-Marie Dubois (Universite de Lorraine, France). Other examples are hydrophobic coatings by Ming-Sheng Leu (Industrial Technology Research Institute, Taiwan), and soft metal abrasive material by Yongjun Chen (Dalian University of Technology, China). Another application of quasicrystals is as a reinforcement in composites, such as in lightweight magnesium alloys or with polymers. The latter can be used for 3D printing and medical implants. A bioactivity study of such a composite was shown to be most suitable for bio-implants by Guillaume Cini (Universite de Lorraine). Mechanical property study of another such composite was presented by Thakur P. Yadav (Banaras Hindu University, India). A study of deformation behaviour of quasicrystal particles in a magnesium matrix was presented by Alok Singh (National Institute for Materials Science, Japan), showing them to be very strong.

Details of the conference and abstracts of all presentations can be found at https://www.liverpool.ac.uk/conference-onquasicrystals.

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MEETING REPORT

# Shallow subsurface investigations for resource exploration and hazard estimation*

The international workshop which held at ISR, Gandhinagar encompassed five major themes, namely: (i) Exploration of groundwater and minerals; (ii) Geothermal resource mapping; (iii) Air and space-borne geophysical investigations; (iv) Active fault mapping; (v) Seismic hazard assessment (SHA): macro–micro and site specific and societal impact of SHA.

Welcoming the delegates the Director General, ISR emphasized the need for shallow subsurface mapping. Understanding the top 1 km of the earth's crust is critical for sustenance of mankind. In view of the many challenges involved in probing this layer with high resolution, multidisciplinary investigations are required to decipher useful information about the mineral resources which can bring economic benefits to the society. The keynote address was delivered by Arun Kumar (Western onshore Basin, ONGC). He informed the delegates about the activities of ONGC in resource exploitation. He opined that ONGC has acquired enormous data through geophysical investigations, which contains a wealth of information about the shallow surface. This information can be further used according to the needs of various stake holders.

During the first plenary session, S. K. Biswas presented a glimpse of the genesis of active faults of Kachchh region and their implications towards seismic hazard. Antonella Pearesan talked about assessing performances of seismic hazard maps, their reliability and comprehensive characterization of expected seismic ground shaking. She opined that after every major earthquake, we need to examine the existing hazard maps, validate and periodically update them as and when new information is available. Yi-Ching Lo delivered a talk on shallow surface tomography and topography effect on ground motion in northern Taiwan region. V. P. Dimri presented a talk on the investigation of scaling sources of geophysical anomalies for exploration.

The second session was devoted to advantages of time domain electromagnetic methods for resource exploration. S. K. Verma provided an overview and advantages of airborne EM surveys and presented the results of identification of palaeochannels in Rajasthan. Pavan Kumar discussed the ground-based TDEM surveys and presented a case study on the results of delineation of deep aquifers in the Kachchh region of Gujarat. Shakeel Ahmed emphasized the need for airborne resisitivity surveys for delineating aquifers in an urban area where ground-based surveys cannot be carried out. Kapil Mohan discussed the efficacy of MT method in delineating geothermal zones. Hirok Chaudhuri

*A report on the International workshop on 'Shallow Subsurface Investigations for Resource Exploration and Hazard Estimation' organized by the Institute of Seismological Research (ISR) and the Department of Science and Technology (DST), Government of Gujarat, India, in collaboration with the National Hydropower Corporation, during 19–20 January 2017, at ISR, Gandhinagar.