transportation in restricted areas such as university campuses, hospitals, airports, theme parks, industrial parks, holiday resorts, residential complexes and city centres.

The above situation does not imply that there are no legitimate uses of pure battery-powered electric cars today as fleet vehicles, as community cars and as second cars for families that already own a gasoline automobile for long-distance travel. One solution to this enigma might be to take the pure battery-powered electric cars out of the development laboratories and put them in the hands of the real drivers. Some will find these vehicles inadequate, but many others may not. With this proposition in mind, Saturn, in partnership with General Motors Advanced Technology Vehicles, now offers GEN II EV1 to consumers through a lease-only programme. Select Saturn retail facilities in California and Arizona distribute and service EV1. Saturn believes that this is the best way to ensure total customer enthusiasm for the early customers in their vehicle. Leasing will provide the customers with a known, consistent cost of ownership. Saturn covers all routine maintenance and service under the terms of 3-year/36000-miles new-vehicle limited warranty. This includes everything from batteries to tyres. Saturn also provides a 24-hour roadside assistance programme, to make every aspect of EV1 lease trouble-free.

While the fate of pure battery-powered electric cars hangs in limbo, the last five years has seen a dramatic development in fuel cells which have advanced to the point where manufacturers believe that the technology is commercially viable and capable of delivering sufficient energy for running the cars. Among various types of fuel cells, the low-operating temperature and rapid start-up characteristics, together with its robust solid-state construction give the Polymer Electrolyte Fuel Cells (PEFCs) a clear advantage for application in cars. The energy conversion efficiency of PEFCs is much higher than both Otto and Diesel versions of internal combustion engines.

The preferred fuel for PEFCs is hydrogen. Various strategies for providing hydrogen to PEFCs are presently being evaluated. Broadly speaking, these strategies could be divided into two categories: (a) to generate hydrogen on-board and on-demand from liquid hydrocarbon or methanol, and (b) to directly fuel hydrogen from a storage tank containing compressed/liquid hydrogen. Experts believe that for Fuel Cell Vehicles (FCVs) with an on-board fuel processor, it would be difficult to exceed the performance of the future ICEVs in terms of emission, efficiency, drivability, maintenance and first cost. By contrast, if the FCVs are powered by a directly-fuelled fuel cell, then there is every prospect that the performance of such vehicles will exceed that of the ICEVs, but not the first cost. However, given the recent rate of progress in PEFC technology, we expect a significant reduction in the cost of directly-fuelled fuel cells.

For direct-hydrogen FCVs, the main task is to develop a cost-effective, reliable and safe method of storing sufficient hydrogen on-board. Particularly, with buses, where there is more room for storage of hydrogen as a compressed gas, there are good prospects that commercial fuel-cell powered versions will be on the roads within 2 to 3 years. Such vehicles are centrally refuelled and therefore hydrogen-distribution infrastructure is not a critical issue.

Some car manufacturers undertaking the development of FCVs are Daimler–Chrysler who have a joint venture with Ballard, EXCELLSIS, Ecostar and Ford, General Motors with Opel, Honda, Mazda, Nissan, Renault, Toyota, Volkswagon and ZeTech. While some of these manufacturers are attempting to develop pure fuel-cell powered FCVs, others are attempting to develop vehicles either with a fuel cell–battery hybrid system or with a fuel cell–supercapacitor hybrid system. The problems that remain to be tackled are reduction in cost, weight and volume of fuel-cell systems, further improvements in driving dynamics, durability and reliability, development of cost-effective production technologies and installation of refuelling infrastructure for methanol and hydrogen. Although each of these problems represents a big challenge, FCV developers look committed to commercialize FCVs, and some of them as early as the middle of this decade.

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Quasicrystals–2001*

The first conference on quasicrystals (QCs) in the new millennium had A. Yamamoto and A. P. Tsai as its Chairpersons. The aim of the conference was to bring scientists from various fields to have new views on QCs, to share recent excitements and achievements, and to gain new insight linking fundamental research with practical applications. There were nearly 140 participants from more than fifteen countries, mainly from Japan, Germany, France, Korea, India, China, UK, USA, The Netherlands and Switzerland. There were four participants from India – S. Ranganathan (IISc), N. K. Mukhopadhyay (BHU), Alok Singh (Kalpakkam) and M. Abu Shaz (BHU). S. Ranganathan chaired one technical session. The scientific programme consisted of 60 oral presentations in 16 sessions and 70 poster presentations in two sessions, totalling 130 papers, which covered many important issues in QCs, including applications, metallurgy, crystallography, phase stability, structure, dynamics and defects. In the following we will highlight some important and interesting discussions.

*A report on the International Conference on Quasicrystals, 'Quasicrystals–2001', sponsored by CREST, Japan Science and Technology Corporation and National Institute for Materials Science (NIMS) Japan, and held during 24–28 September 2001 in Sendai, Japan.

Applications

It is important to note that the first session after the welcome address, was on the issue of application of QCs. In this session, development of two QC

composite materials was discussed. V. V. Shears *et al.* (USA) reported new polymer–QC composite materials with a unique combination of super high hardness and extraordinarily low abrasion. In fact, the wear properties of the polymer–QC composites are significantly improved over the polymer alone. These properties are superior to other polymer–hard filler composites containing silicon carbide and aluminum oxide, presumably due to the low surface energy and high hardness of QCs. In the area of bio-implant materials, the polymer–QC composite materials appear to have the potential to replace the polyethelene materials, which are being currently used for bone and joint replacements, although extensive studies must be conducted before this application is realized.

D. H. Kim (Korea) discussed the development of composites of Mg–Zn–Y alloy, where QC particles are distributed in microscale as reinforcing agents. The quasiperiodic lattice structure of icosahedral (I) QC phase was found to be stable under deformation up to the test temperature of 0.93 T_m, (where T_m is the alloy's absolute melting temperature), confirming that the icosahedral phase thermally equilibrates with Mg-rich solid solution in the alloy. The alloy exhibits greater strengths and larger elongations and fails without the formation of particle-matrix debonding at elevated temperatures. E. Macia (Spain) presented a theoretical study on the possible use of QC as potential thermoelectric materials. By comparing the theoretical results with available experimental data, it has been suggested that icosahedral Cd–Yb and the dodecagonal Ta–Te binary phases are two promising candidates for thermoelectric applications. M. Yoshimura and A. P. Tsai (Japan) showed that QC can be used as precursor of a catalyst making use of its brittleness and thermal stability. Al–Cu–Fe-stable QC has been used for methanol steam-forming reaction ($CH_3OH + H_2O = 3H_2 + CO_2$). The catalyst was prepared by ball milling and leaching with NaOH to attain high surface area. The catalyst exhibited activity (235 H_2 ml/g min at 553 K), which is comparable to that of Cu-based industrial catalyst.

Synthesis

Though QCs have been synthesized in a number of alloys classified into three important categories, namely Al-based, Ti-based and Mg-based QCs, there were excitements in this conference about the discovery of many new types of QC. There are also attempts to understand the basis for the synthesis of quasicrystalline materials. A. P. Tsai's group has synthesized a number of new QCs in Cd–Mg–Re (Re = Y, Nd, Sm, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ca) and binary Cd–Ca and Cd–Yb systems. Electron diffraction studies have confirmed that these Cd-based QCs are primitive type, with a quasilattice constant $a = 0.5571$–0.5816 nm and proportional to a weighting Goldschmidt atom diameter of QC by a factor of 1.75. Composition ranges of some QCs are very wide; for example, Cd–Mg–Yb QC exists in the range of 25–85% Cd, 0–60% Mg and 10–20% Yb. Valence electron number per atom of the Cd-based QC, e/a is found to be 2.0–2.2, indicating that this is a new class of QC. Ishimasa (Japan) reported new QCs in $Zn_{85}Mg_5Sc_{15}$ and $Zn_{84}Mg_8Ti_8$ with the average $e/a = 2.15$, and 6-d lattice parameter 0.7023 nm, which apparently indicates that this class is of the Bergman type. It has been shown that this new type of QC is close to $Zn_{17}Sc_3$ 1/1 cubic approximant phase ($a = 1.3822$ nm). This phase consists of triple shell cluster very similar to that of Cd_6Yb crystal. These evidences suggest that Zn–Mg–Sc and Zn–Mg–Ti icosahedral QCs belong to the same structure type as the Cd-based icosahedral QC. However, Zn–Mg–Ti system shows *P*-type QC as well as *F*-type QC, exhibiting a very weak superlattice reflection. QCs in both these systems have common features with regard to diffraction intensity, stoichiometric composition and average concentration of valence electrons. It should be noted that Zn–Mg–Ti is the first example of a QC containing an element with four valence electrons (such as in Ti) in Zn–Mg-based alloys. This may become a guide to find new alloy systems forming an icosahedral QC.

J. Saida *et al.* (Japan) have found a nano IQC phase during primary crystallization from the amorphous phase in melt-spun $Zr_{70}Pd_{30}$ and $Zr_{80}Pt_{20}$ binary alloys. These QC phases can also be synthesized in melt-spun ribbon form by controlling quenching parameters. The formation of nano IQC phase has been attributed to diffusion-controlled growth. The medium-range order with icosahedral atomic configuration has been observed in HREM images. S. Ranganathan has studied the formation of IQC and other crystalline phases from Hf-based glassy alloys such as Hf–PM–TM–Al, Hf–PM–NI and Hf–PM–PM, where PM = Pd, Pt, Ag, Au; TM = Ni, Cu, Co, Fe. The formation of the primary IQC phase has been observed in definite composition ranges in alloys containing PM, Al, Ni or Cu. The replacement of Ni and Cu by Fe or Co as well as exclusion of Al led to the appearance of Fd3m cF96 phase in preference to the IQC. Alok Singh *et al.* (India) showed the formation of nano QC of 50 nm size from Zn_2Mg-type hexagonal phase in $Mg_{60+x}Cd_{25-x}Yb_{15}$ alloy matrix with a definite orientation relationship, viz. hexagonal axis along two-fold axis of the IQC phase. New stable IQC have been reported by S. Takeuchi and co-workers (Japan) in Al–Pd–Ru and Al–Pd–Os systems, who have also compared their electrical properties with those of crystalline approximants. Many crystalline approximants to decagonal QC in Al–Rh–Si ternary systems were also presented during the poster session by N. Koshikawa *et al.* (Japan). M. Abu Shaz *et al.* (India) synthesized the nano QC in Ti–Zr–Ni and studied the microindentation behaviour of this material. It was demonstrated that the fracture toughness improves due to the formation of nano-scale microstructure.

Stability and structure

K. Edagawa (Japan) presented a video recording of *in situ* high temperature high resolution transmission electron microscopy (HRTEM), showing the thermal fluctuation of phasons in Al–Cu–Co decagonal QC. A tiling pattern with edge length of 2 nm was constructed by connecting white dots in HRTEM images. Local tile-rearrangements, which can be interpreted as phason flips were observed at temperatures higher than and equal to 1123 K. M. De Boissieu (France) investigated structural quality and phason fluctuations in the IQC (Al–Pd–Re) and IQC (Cd–Yb) phases using high resolution synchroton X-ray diffraction technique. A systematic correlation between diffuse scattering and possible fluctuations of phason was established. From this study, it was indicated that QC is probably stabilized by entropy and not by enthalpy, implying that QC may not be a ground-state phase. N. K. Mukhopadhyay (India) reported the transformation of the deca-

gonal phase in Al–Cu–Co system to a B2 phase, by high energy ball milling. Powders milled for more than 10 h in planetary ball mill contained predominantly B2 phase, with lattice parameter of 0.29 nm. This crystalline phase is found to be quite stable even after 30 h of milling and also during subsequent annealing at 600°C. These experimental evidences led the author to conclude that DQC in Al–Cu–Co is actually less stable than B2 phase at low temperature. X-ray diffraction patterns of various Al–Co–Ni, Al–Co–Cu–(Si), Al–Ni–Fe phases showing the diffuse layers perpendicular to the periodic axis were presented by F. Frey (Germany). These layers were interpreted due to 1D 0.8 nm superstructure. More or less diffuse modulations within the layers were attributed to lateral correlations in columnar clusters. E. Weidner *et al.* (Germany) reported transient ordering states in decagonal $Al_{72}Ni_{12}Co_{16}$ at temperatures up to 1000°C. High resolution X-ray measurements revealed peak splitting consistent with the domain structure of 2D *qp* and 1D *qp* lamellae. It was concluded that disordering in Al–Ni–Co phase is governed by complex transient ordering states.

D. Holland-Moritz (Germany) showed, by systematic *in situ* elastic neutron scattering and energy dispersive diffraction experiments, the presence of short-range icosahedral ordering in deeply under-cooled liquids of alloys forming quasicrystalline and polytetrahedral phases (Al–Cu–Co, Al–Cu–Fe, Al–(Fe, Cu)). K. Sugiyama (Japan) demonstrated that the structure of a W–(Al–Co–Ni) crystalline phase is related to Al–Co–Ni decagonal QCs, by using single crystal X-ray diffraction and high angle annular dark field STEM together with HRTEM.

A. Yamamoto *et al.* (Japan) reported the structural refinement of Al–Pd–Mn QC by using Imaging Plate (IP) Weissenberg camera. A 6D model proposed previously was modified during refinement. The final model included 90 structural parameters and yielded a R factor (R_w = 0.057 and R = 0.057) for 377 independent reflections. The average lattice concepts in the context of structures of QC were discussed by J. Wolny (Poland) and W. Steurer (Switzerland). It was shown that though this idea is useful for understanding many properties and diffraction features, there is no unique way of describing the QC structures. C. Henley *et al.* (USA) studied the structure of $Al_{70}Ni_{21}Co_9$ near the basic Ni phase composition almost from first principles with the help of two inputs: (a) pair potential calibrated by *ab initio* total energy calculations and (b) experimental knowledge of the approximate composition and lattice constants. The structures were represented as decorations of random tiling, which was shown to differ from the cluster model proposed by Yan and Pennycook (*Nature*, 2000, **403**, 266).

Surface and bulk properties

M. Feuerbacher (Germany) presented the role of dislocations (both screw and edge) in the context of deformation of QC at moderate temperatures. It is known that QC exhibits brittleness because dislocations are not able to move. However, at high temperatures it shows ductility due to the mobility of dislocations, which is different from that of other brittle materials. This has been demonstrated in Al–Pd–Mn, Zn–Mg–Dy as well as Al–Ni–Co QCs. Kim and co-workers (Korea) compared tribological behaviour of thermal-sprayed QC coating layers for possible industrial applications of QC materials as low-friction and anti-wear coating.

Y. Yshii (Japan) studied the electronic structure of several cubic crystals, Cd_6M (M = Yb, Ca, Sr, Mg, Y), which are approximant phases of newly discovered Cd-based QCs, by the tight-binding linear muffintin orbitals method. A shallow dip in the DOS appears near the Fermi level and the diameter of the Fermi sphere for Cd-based compounds coincides with the (222100) and (311111) reciprocal lattice vectors, as is the case for the family of QCs with e/a = 2.1. It was emphasized that the Brillouin zone–Fermi surface interaction is not essential in making a dip in the DOS. However, cohesion of the Cd-based compounds is due to hybridization of *d* states of Yb/Ca with a wide *sp* band. In addition to the electronic origin, matching of the atomic size is found to be very crucial for QC formation of Cd-based alloys. It was suggested that the glue atoms, which do not participate in the icosahedral cluster, play an important role in stabilization of the compound.

R. Mcgrath (UK) studied clean surfaces of $Al_{70}Pd_{21}Mn_9$ and $Al_{72}Ni_{11}Co_{19}$ using STM. He showed that Penrose tiling can be reconstructed on the surface and it is consistent with the bulk model of Steinhardt *et al.* (*Nature*, 1998, **396**, 55). The surface was also investigated after adsorption of C_{60} on the surface of the QC. It was found that C_{60} molecules bonded with the Al atoms on the QC structure. P. A. Thiel (USA) discussed atomic arrangement on the surface of bulk QC and correlated friction and epitaxial behaviour of QC phases. J. M. Dubois *et al.* (France) studied wetting and fretting behaviour of QCs and correlated with the density of states at the Fermi energy of QCs. It was observed that such a behaviour is also dependent on oxide layers. The present investigation has challenged the conventional theory of wetting for metal surfaces. R. Bastaz (USA) investigated the surfaces by low energy ion scattering measurement and concluded that the surface layer is rich in Al and the subsurface layer is rich in Pd. It was also reported that the top layer is deficient in Mn. This explains why frequently the pentagonal clusters are observed under STM. D. Naumovic *et al.* (Switzerland) investigated the three-fold surface of Al–Pd–Mn QC phase by two structure-sensitive techniques, i.e. XPD and LEED (X-ray Photoelectron Diffraction and Low Energy Electron Diffraction), and by electronic structure-sensitive technique. After Ar^+ sputtering and annealing at 400°C, a crystalline phase (bcc), characterized by a Fermi edge was observed.

In the concluding session, P. A. Thiel summarized the presentations of the conference and emphasized upon some of the important issues, which need to be resolved in the near future. It is important to mention that all the papers presented in this conference will be published after a peer review in *Journal of Alloys and Compounds* as a special issue. S. Ranganathan, co-chairperson of the next QC conference (ICQ8), invited all the participants to the International Meeting on Quasicrystals to be held in Bangalore from 8 to 13 September 2002.

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