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Editorial

Symmetry and Asymmetry in Quasicrystals or Amorphous Materials

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Abstract: Quasicrystals (QCs) are long-range ordered materials with a symmetry incompatible with translation invariance. Accordingly, QCs exhibit high-quality diffraction patterns containing a collection of discrete Bragg reflections. Notwithstanding this, it is still common to read in the recent literature that these materials occupy an intermediate position between amorphous materials and periodic crystals. This misleading terminology can be understood as probably arising from the use of models and notions borrowed from the amorphous solid's conceptual framework (such us tunneling states, weak interference effects, variable range hopping, or spin glass) in order to explain certain physical properties observed in QCs. On the other hand, the absence of a general, full-fledged theory of quasiperiodic systems certainly makes it difficult to clearly distinguish the features related to short-range order atomic arrangements from those stemming from long-range order correlations.

The Special Issue on "Symmetry and Asymmetry in Quasicrystals or Amorphous Materials" aims to discuss both experimental and fundamental aspects related to the relationship between the underlying structural order and the resulting physical properties of QCs and their related approximant phases [1], focusing on the analogies and differences between these properties and those reported for amorphous materials of similar composition.

It is currently agreed that the presence of non-crystallographic axes is not a necessary condition for a solid to be regarded as a QC, and that the key feature to this end is just to exhibit scale invariance symmetry [2,3]. Indeed, several examples of QCs exhibiting 2-, 3-, and 4-fold symmetry axes along with scale invariance symmetry characterized by irrational scale factors have been reported, being referred to as "cubic QCs" [4]. These findings support the view that QC definition should not include the requirement that they must display a classically forbidden axis of symmetry, as it is stated in the Online Dictionary of Crystallography of the International Union of Crystallography, where one reads: "*Often, quasicrystals have crystallographically 'forbidden' symmetries [...]. However, the presence of such a forbidden symmetry is not required for a quasicrystal*" [5].

The contribution by Jianhang Yue, Yun Feng, Hao Wu, Guorong Zhou, Min Zuo, Jinfeng Leng and Xinying Teng, entitled *The Study of A New Symmetrical Rod Phase in Mg-Zn-Gd Alloys*, nicely fits within this scenario. In this paper, the morphology and properties of Mg-Zn-Gd alloys prepared by a conventional casting method are studied by systematically varying their Mg and Gd content. In this way, a rod phase with atomic composition $Mg_{66}Zn_{30}Gd_4$ is reported to exhibit diffraction spots patterns indicating this phase belongs to a new kind of complex metallic alloy phase whose composition is close to that of $Mg_{60}Zn_{30}Gd_{10}$ QCs. Upon annealing, this rod phase evolved gradually over time from a lamellar eutectic structure, the melting temperature of the rod phase being 453°C. Quite interestingly from the viewpoint of possible applications, microhardness tests showed that its tribological properties are better than those corresponding to QCs of similar composition.

During the last decades we have realized that the electronic structure and vibrational spectrum of many quasiperiodic systems can be understood in terms of resonance effects involving a relatively small

number of atomic clusters of progressively increasing size. In earlier works this scenario was discussed in terms of real-space based renormalization group approaches describing the mathematically simpler, but chemically unrealistic, diagonal (different types of atoms connected by the same type of bond) or off-diagonal (the same type of atom but different types of bonds between them) models. Later on, an increasing number of works have been devoted to the mathematically more complex general case, in which both diagonal and off-diagonal terms are present in the system. In fact, since the properties of chemical bonds linking two different atoms generally depend on their chemical nature, any realistic treatment must explicitly consider that the aperiodic sequence of atoms along the chain naturally induces an aperiodic sequence of bonds in the considered solid. Indeed, a growing number of both experimental measurements and numerical simulation results highlight the important role of chemical bonding in the emergence of some specific physical properties of QCs. This sort of more realistic treatments are discussed in three contribution focusing on appealing representatives of different kinds of aperiodic systems. In the contribution by Vicenta Sánchez and Chumin Wang, entitled *Real Space Theory for Electron and Phonon Transport in Aperiodic Lattices via Renormalization*, the unavoidable presence of structural defects are inherent in both periodic solids and QCs at a finite temperature is addressed by means of a real-space renormalization method, which uses an iterative procedure with a small number of effective sites in each step, and exponentially lessens the degrees of freedom, but keeps their participation in the final results. In this way, different aperiodic atomic arrangements with hierarchical symmetry are investigated, along with their consequences in measurable physical properties, such as electrical and thermal conductivities, in line with previous works of this research group [6,7].

In the contribution by Edmundo Lazo, entitled *Localization Properties of Non-Periodic Electrical Transmission Lines*, the properties of localization of the I(ω) electric current function in non-periodic electrical transmission lines are studied in detail. The electric components have been distributed in several forms: (a) Aperiodic, including self-similar sequences (Fibonacci and Thue–Morse), (b) incommensurate sequences (Aubry–André and Soukoulis–Economou), (c) long-range correlated sequences, and (d) uncorrelated random sequences. The localization properties of the transmission lines were measured by means of typical diagnostic tools of extended use quantum mechanics like normalized localization length, transmission coefficient, or average overlap amplitude, thereby exploiting the analogies between classic electric transmission lines and one-dimensional tight-binding quantum models.

In recent years thrust has been given to understand the spectral properties and the complexity of low dimensional systems, ranging from typical condensed matter systems in the mesoscopic or nano scales of length to biological systems. A common approach in most of these studies has been a kind of unified description involving quantum lattice models to explore diverse physical systems like DNA molecules, graphene nano-ribbons, fractals, hierarchical lattices, QCs or tribological systems. Long range topological order and chemical diversity in one dimensional, or quasi-one dimensional models and hierarchical lattices have shown to result into unusual spectral features like coexistence of extended (conducting) and localized electronic states, or even metal-insulator transitions in quasi-one dimensional ladder networks. The latter has also been successfully utilized to bring out the essential electronic structure and transport properties of DNA with periodic or aperiodic ordering of its constituents. Accordingly, some properties that are understood or claimed as specific properties of the systems considered may turn out to be quite general consequences of the adopted model instead. This subtle point requires a thorough inspection of various quantum lattice models addressing different physical systems.

This issue is fully addressed by Konstantinos Lambropoulos and Constantinos Simserides in the contribution entitled *Tight-Binding Modeling of Nucleic Acid Sequences: Interplay between Various Types of Order or Disorder and Charge Transport.* In their review tight-binding modeling of nucleic acid sequences like DNA and RNA is addressed by considering how various types of order (periodic, quasiperiodic, fractal) or disorder (diagonal, non-diagonal, random, methylation effects) affect charge transport. Several DNA models widely considered in the recent literature (wire, ladder, extended ladder, fishbone

(wire), fishbone ladder) are considered within the framework of renormalization techniques. In doing so, the energy structure of nucleic acid wires, the coupling to the leads, the transmission coefficients and the current–voltage curves are numerically derived and the obtained results are discussed in order to examine the potentiality to utilize the charge transport characteristics of nucleic acids as a tool to probe several diseases.

Certainly, the very notion of photonic crystal can be extended to describe the properties of quasiperiodic photonic structures as well. To this end, one simply considers that the optical properties of the medium are given by a QP refraction index function, instead of a periodic one. The resulting structure can then be properly referred to as a photonic quasicrystal (PQC). Long-range quasiperiodic order, by its own, endows PQCs with certain characteristic properties which are not exhibited by their periodic counterparts. This feature stems from the richer structural complexity of aperiodic sequences, which arises from the presence of quasiperiodic and self-similar order related fingerprints, and naturally leads to the presence of a lot of resonant frequencies due to multiple interference effects throughout the structure. For instance, due to their highly fragmented frequency spectrum, aperiodic multilayers offer more full transmission peaks (alternatively, absorption dips) than periodic ones in a given frequency range for a given system length, and the inflation symmetry gives rise to a denser Fourier spectrum structure in reciprocal space. Thus, aperiodic photonic micro/nanostructures usually support optical multimodes. In the contribution by Hao Jing, Jie He, Ru-Wen Peng, and Mu Wang, entitled *Aperiodic-Order-Induced Multimode Effects and Their Applications in Optoelectronic Devices*, the authors review some developments of aperiodic-order-induced multimode effects and their applications in optoelectronic devices. It is shown that self-similarity or mirror symmetry in aperiodic micro/nanostructures can lead to optical or plasmonic multimodes in a series of one-dimensional/two-dimensional photonic or plasmonic systems. These multimode effects have been employed to achieve optical filters for the wavelength division multiplex, open cavities for light–matter strong coupling, multiband waveguides for trapping "rainbow", high-efficiency plasmonic solar cells, and transmission-enhanced plasmonic arrays. By all indications, these investigations will be beneficial to the development of integrated photonic and plasmonic devices for optical communication, energy harvesting, nanoantennas, and photonic chips.

Conflicts of Interest: The author declares no conflict of interest.

References

1. Maciá-Barber, E. Chemical bonding and physical properties in quasicrystals and their related approximants: Known facts and current perspectives. *Appl. Sci.* **2019**, *9*, 2132. [CrossRef]
2. Janssen, T.; Chapuis, G.; de Boissieu, M. *Aperiodic Crystals. From Modulated phases to Quasicrystals*; Oxford University Press: Oxford, UK, 2007.
3. Maciá-Barber, E. *Quasicrystals: Fundamentals and Applications*; Taylor & Francis, CRC Press: Boca Raton, FL, USA, 2020.
4. Elcoro, L.; Pérez-Mato, J.M. Cubic superspace symmetry and inflation rules in metastable MgAl alloy. *Eur. Phys. J. B* **1999**, *7*, 85–89. [CrossRef]
5. Available online: https://reference.iucr.org/dictionary/Quasicrystal (accessed on 1 August 2020).
6. Sánchez, F.; Sánchez, V.; Wang, C. Renormalization approach to the electronic localization and transport in macroscopic generalized Fibonacci lattices. *J. Non-Cryst. Solids* **2016**, *450*, 194. [CrossRef]
7. Wang, C.; Ramírez, C.; Sánchez, F.; Sánchez, V. Ballistic conduction in macroscopic non-periodic lattices. *Phys. Status Solidi B* **2015**, *252*, 1370–1381. [CrossRef]



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