

**SEMICONDUCTING PROPERTIES OF QUASICRYSTALS WITH UNIQUE SYMMETRY AND THEIR APPLICATIONS IN PHOTONIC DEVICES***Navbahor Qurbanbayeva Sheramat qizi**Berdaq Karakalpak State University,**Faculty of Physics, Department of Physics*

**Abstract:** Quasicrystals, distinguished by their non-periodic but ordered atomic structures and unique rotational symmetries, have attracted increasing attention in the field of advanced materials. Unlike conventional crystals, quasicrystals exhibit forbidden symmetries—such as fivefold or tenfold rotation—that result in novel electronic and optical behaviors. This paper explores the semiconducting characteristics of quasicrystalline materials and evaluates their potential use in photonic devices. By investigating the electronic band structures and optical properties arising from quasiperiodicity, we demonstrate how these materials can be engineered for enhanced light-matter interactions, photon localization, and spectral filtering. The integration of quasicrystalline semiconductors into photonic circuits, sensors, and solar cells reveals promising pathways for next-generation optoelectronic technologies.

**Keywords:** Quasicrystals, semiconducting materials, photonic devices, aperiodic symmetry, band structure, light localization, optical filters, photon confinement, advanced materials, non-periodic lattices

The discovery of quasicrystals in the early 1980s challenged the long-standing paradigm that crystals must possess periodic atomic arrangements. Characterized by their aperiodic yet highly ordered structures, quasicrystals exhibit symmetries that are forbidden in traditional crystallography, including fivefold, eightfold, and tenfold rotational axes. This unusual symmetry gives rise to novel electronic, mechanical, and optical properties that are not observed in conventional periodic lattices.

In recent years, attention has shifted toward the semiconducting and optoelectronic applications of quasicrystals, particularly their ability to manipulate electromagnetic waves at the nanoscale. The quasiperiodicity in atomic arrangement leads to complex band structures, which in turn affect charge transport, energy gap behavior, and light-matter interaction. Moreover, the photonic analogs of quasicrystals—known as photonic quasicrystals—exhibit properties such as omnidirectional photonic bandgaps, enhanced light localization, and defect-tolerant waveguiding.

This paper aims to explore the semiconducting behavior of quasicrystals with unique symmetries and assess their relevance in the design of innovative photonic devices. We discuss both theoretical and experimental findings regarding their electronic structure, optical conductivity, and fabrication challenges. Particular focus is placed on the role of symmetry in controlling electronic states and guiding photons through quasiperiodic lattices. Applications

including photonic filters, light-trapping layers in solar cells, and highly selective optical sensors are highlighted as areas where quasicrystals offer distinct performance advantages.

This study combines theoretical modeling, materials analysis, and literature-based comparative evaluation to explore the semiconducting behavior of quasicrystals and their use in photonic applications.

### 1. Theoretical Modeling

We used **density functional theory (DFT)** and **tight-binding simulations** to analyze the electronic band structures of quasicrystalline approximants—structures that mimic quasicrystals with periodic boundaries. Symmetries considered included icosahedral, decagonal, and dodecagonal configurations.

### 2. Optical Property Simulation

The optical response—such as dielectric functions, refractive indices, and absorption spectra—was simulated using **finite-difference time-domain (FDTD)** methods. These simulations focused on photonic bandgap formation, light localization, and defect mode behavior.

### 3. Material Review and Fabrication Techniques

A comparative analysis was conducted across experimentally studied quasicrystalline materials such as **Al–Cu–Fe**, **Al–Pd–Mn**, and **Zn–Mg–Y** alloys. Fabrication methods reviewed include **molecular beam epitaxy (MBE)**, **pulsed laser deposition (PLD)**, and **nanoimprinting lithography** for photonic quasicrystal arrays.

### 4. Photonic Device Prototypes

Case studies from existing literature were used to evaluate photonic devices incorporating quasicrystalline lattices, such as **broadband filters**, **LEDs**, **solar absorbers**, and **biosensors**.

## Results

### Band Structure Characteristics

Quasicrystals exhibited pseudogaps and energy-localized states, arising from their aperiodic order. Simulations revealed that these materials have **suppressed electronic conductivity in certain directions** but exhibit **anisotropic semiconducting behavior**, useful for directional charge transport.

### Photonic Bandgap Behavior

Photonic quasicrystal structures with 10-fold and 12-fold symmetries displayed **complete photonic bandgaps** over broad angular ranges. Unlike periodic photonic crystals, these bandgaps were less sensitive to defects and maintained **omnidirectional reflectivity**.

### Enhanced Light-Matter Interaction

Quasicrystalline arrangements were shown to support **slow-light modes** and **strong field localization**, enabling improved absorption in thin photovoltaic films and enhanced sensitivity in optical biosensors.

### Fabrication Feasibility

Successful fabrication of decagonal and Penrose-tiling photonic structures at micro- and nanoscale resolution was demonstrated, with reproducibility and optical performance comparable to periodic analogs.

The results validate the potential of quasicrystals as semiconducting and photonic materials with distinct advantages over conventional crystalline systems. Their quasiperiodic symmetry gives rise to **unique electronic density of states** and **non-Bravais lattice behavior**, which enable the formation of **tunable bandgaps** and **defect-immune light pathways**.

This opens up opportunities in:

- **Photonic integrated circuits:** where light can be routed with minimal scattering losses.
- **Optoelectronic sensors:** that benefit from high-Q localized modes.
- **Solar energy:** where quasicrystals can improve light trapping without periodicity constraints.

However, challenges remain in material synthesis, especially in achieving **uniform long-range quasiperiodicity** at industrial scale. Moreover, **charge carrier mobility** in metallic quasicrystals remains lower than in conventional semiconductors, though this can be mitigated by alloying or hybrid structures.

Quasicrystals with unique symmetries offer a promising new platform for semiconducting and photonic device engineering. Their distinctive aperiodic order enables novel quantum and optical phenomena—such as omnidirectional photonic bandgaps, field localization, and anisotropic conductivity—which are not achievable with conventional periodic materials.

As fabrication methods evolve and computational modeling becomes more sophisticated, quasicrystal-based materials are expected to play an increasingly important role in **next-generation photonic devices**, including **filters, waveguides, solar cells, and bio-integrated sensors**.

Future work should explore hybrid architectures combining quasicrystals with 2D materials, and the use of machine learning to optimize lattice design for specific optoelectronic applications.

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