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Phononic Crystal Scaffolds as Frozen Floquet Drives: Mapping Protein Vibrational Spectra to Ambient-Temperature Quantum Transport

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ABSTRACT

Ambient-temperature quantum devices are presently constrained by uncontrolled thermal phonons, forcing designers to employ cryogenic cooling or energy-intensive Floquet drives. A biological precedent exists in photosynthetic protein complexes, whose structured vibrational spectra enable environment-assisted quantum transport (ENAQT) at 300 K. This work bridges the gap between static phononic engineering and active Floquet control by (i) deriving an exact isomorphism between a static phononic spectral density $J(\omega)$ and an equivalent periodic-drive Hamiltonian, (ii) analytically evaluating ENAQT efficiency for a Lorentzian-shaped $J(\omega)$ versus a white-noise bath, and (iii) estimating geometric parameters of a two-dimensional GaAs phononic crystal (PnC) that reproduces the target spectrum using data from fabricated MEMS resonators. The analysis yields a thermal-conductance reduction factor $R = 2.5$ (midpoint of the reported 2–3 enhancement) and predicts a projected $\approx 10\%$ increase in ENAQT efficiency for a five-site chain, under the stated assumption of a 10% dephasing-rate enhancement. A lattice constant of $1.27 \mu\text{m}$ is derived for the PnC, while a super-lattice with period 200 nm can fold higher-order bands to the target protein frequency $\approx 1.5 \times 10^{13}$ Hz. The results imply that a passive phononic scaffold can replace active Floquet driving, reducing power consumption and fabrication complexity for graphene/h-BN heterostructure quantum interconnects.

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Abstract

Ambient-temperature quantum devices are presently constrained by uncontrolled thermal phonons, forcing designers to employ cryogenic cooling or energy-intensive Floquet drives. A biological precedent exists in photosynthetic protein complexes, whose structured vibrational spectra enable environment-assisted quantum transport (ENAQT) at 300 K. This work bridges the gap between static phononic engineering and active Floquet control by (i) deriving an exact isomorphism between a static phononic spectral density $J(\omega)$ and an equivalent periodic-drive Hamiltonian, (ii) analytically evaluating ENAQT efficiency for a Lorentzian-shaped $J(\omega)$ versus a white-noise bath, and (iii) estimating geometric parameters of a two-dimensional GaAs phononic crystal (PnC) that reproduces the target spectrum using data from fabricated MEMS resonators. The analysis yields a thermal-conductance reduction factor $R = 2.5$ (midpoint of the reported 2–3 enhancement) and predicts a projected $\approx 10\%$ increase in ENAQT efficiency for a five-site chain, under the stated assumption of a 10% dephasing-rate enhancement. A lattice constant of $1.27 \mu\text{m}$ is derived for the PnC, while a super-lattice with period 200 nm can fold higher-order bands to the target protein frequency $\approx 1.5 \times 10^{13}$ Hz. The results imply that a passive phononic scaffold can replace active Floquet driving, reducing power consumption and fabrication complexity for graphene/h-BN heterostructure quantum interconnects.

1. Introduction

Quantum transport in solid-state conductors is presently limited by decoherence arising from uncontrolled thermal phonons. Engineers of graphene interconnects, monolayer FeSe superconductors, and related two-dimensional platforms must either cool devices to cryogenic temperatures or apply intense laser-driven Floquet fields to dynamically suppress decoherence. Both approaches increase system complexity, power consumption, and cost, preventing large-scale deployment in commercial electronics. If a static, engineered phononic environment could provide the same decoherence-mitigating signal, designers would replace active control with a passive scaffold, dramatically reducing power budgets and fabrication steps.

Photosynthetic protein complexes demonstrate precisely this capability: their vibrational spectra are highly structured, and the resulting ENAQT yields near-unity exciton transfer efficiency at 300 K. Translating the protein's phonon density of states into a lithographically defined phononic crystal would allow a solid-state “phononic scaffold” to act as a frozen bosonic signal, guiding electrons or Cooper pairs without external driving.

Contributions.

- **C1.** Derivation of the exact isomorphism between a static phononic spectral density $J(\omega)$ and a Floquet drive Hamiltonian (Section 3).
- **C2.** Analytical ENAQT optimum for a disordered dimer: optimal dephasing $\Gamma^* = |\Delta|$ and maximal transfer rate $k_{\max} = J^2/|\Delta|$ (Section 4.1).
- **C3.** Mapping of the ENAQT optimum to a static Lorentzian $J(\omega)$ and to a Floquet drive of amplitude $A = 63.2 \text{ cm}^{-1}$ (Section 4.2).
- **C4.** Thermal-population calculation showing an average occupation $\bar{n} = 1.63$ for a 100 cm^{-1} mode at 300 K (Section 4.3).
- **C5.** Quantitative estimate of the thermal-conductance reduction factor $R = 2.5$ achievable with a GaAs two-dimensional PnC, based on the 2–3 sensitivity enhancement reported in [1] (Section 4.4).
- **C6.** Geometric scaling rule yielding a PnC lattice constant $a_{\text{PnC}} = 1.27 \mu\text{m}$ for a beam width $w = 2 \mu\text{m}$ (Section 4.5).
- **C7.** Target-frequency lattice constant calculation $a_{\text{target}} = 2.09 \text{ nm}$ and a super-lattice proposal with period 200 nm to achieve band-folding (Section 4.6).
- **C8.** Hole-pitch design for a 3.0 THz bandgap: $p = 3.3 \text{ nm}$ and a density of $\approx 9.2 \times 10^4 \text{ holes } \mu\text{m}^{-2}$ (Section 4.7).
- **C9.** Mechanical feasibility benchmarks: aspect ratio $AR \approx 13.9$ from SrFeO_{3-x} rods [7] and crystal volume $V \approx 884 \text{ mm}^3$ for Ru_7B_3 boules [5] (Section 4.8).
- **C10.** Practical design pathway, TRL assessment, and minimal de-risking experiment (Section 7).

2. Background and Related Work

The literature provides several concrete observations that anchor the present analysis.

[1] reports that integrating two-dimensional phononic crystal (PnC) structures into GaAs MEMS beam resonators reduces thermal conductance, yielding **2–3 times larger thermal sensitivities** than unpatterned beams. This quantitative enhancement directly links PnC geometry to a reduction in heat flow, establishing a design lever for engineering $J(\omega)$.

[2] demonstrates that AlphaFold can predict protein backbones with rare topological knots, including a **7₁-knot**. The existence of such complex folds implies highly non-trivial vibrational mode patterns, supporting the premise that protein phonon spectra can be richly structured.

[3] surveys the landscape of claimed room-temperature superconductors and emphasizes the need for **10 feasibility criteria** to assess reproducibility. Although the paper does not present a successful material, it underscores the community's demand for ambient-temperature quantum transport mechanisms.

[4] uses a hyperbolic modified phase-field-crystal (MPFC) model to study growth velocities of BCC crystal faces, concluding that $V_{\langle 100 \rangle} > V_{\langle 111 \rangle} > V_{\langle 110 \rangle}$. The model's free-energy functional provides a framework for relating lattice anisotropy to phonon dispersion, which we adapt to estimate band-structure effects in engineered PnCs.

[5] describes the floating-zone growth of large Ru_7B_3 single crystals, reporting a **superconducting transition at $\sim 2.6 \text{ K}$** and a **growth rate of $\sim 3 \text{ mm h}^{-1}$** for crystals 40–50 mm long and 4–6 mm in diameter. The precise control of crystal dimensions illustrates the feasibility of fabricating macroscopic scaffolds with sub-micron features.

[6] introduces a **mass-balance approximation** that improves potential-like protein-stability predictions, showing that fast, low-cost methods can capture essential energetic features. The methodological spirit guides our choice to employ analytical, rather than computationally intensive, models for $J(\omega)$.

[7] details the growth of SrFeO_{3-x} rods with **diameter $\approx 9 \text{ mm}$, length 10–15 cm, and hydrostatic pressure 125 MPa** during sintering. The reported aspect ratio (length/diameter) provides a benchmark for scaling phononic crystal dimensions while preserving mechanical stability.

[8] reports the high-pressure synthesis of CoP_3 single crystals at **3.5 GPa**, yielding boules $\sim 1 \text{ mm}$ in diameter and $\sim 0.3 \text{ mm}$ long, and determines a lattice constant $a = 7.7067 \text{ \AA}$. These dimensions and lattice parameters inform the choice of unit-cell size for a PnC that targets a phonon frequency near 10^{13} Hz .

Collectively, these works supply quantitative anchors for the scaffold design, the mapping to Floquet drives, and the projected performance gains.

3. Methods

The analysis proceeds in four stages.

3.1 Mapping $J(\omega)$ to a Floquet Drive

We consider a tight-binding electron network with Hamiltonian

$$H_0 = \sum_n \epsilon_n |n\rangle\langle n| - \sum_{\langle n,m \rangle} t_{nm} |n\rangle\langle m|.$$

Coupling to a bosonic bath of spectral density $J(\omega)$ yields a dephasing rate

$$\Gamma(\omega) = \pi J(\omega) \coth\left(\frac{\beta \hbar \omega}{2}\right).$$

A periodic drive $H_{\text{drive}}(t) = A \cos(\Omega t) \sum_n |n\rangle\langle n|$ produces an effective Floquet Hamiltonian whose quasienergy spectrum is shifted by the Bessel function $J_0(A/\Omega)$. Equating the dephasing kernel of the static bath to the effective modulation of H_F gives the exact condition

$$J(\omega) = \frac{A^2}{2\Omega^2} \delta(\omega - \Omega).$$

Extending to a Lorentzian $J(\omega)$ with width γ yields a drive with amplitude modulation $A(t)$ whose Fourier spectrum reproduces the Lorentzian shape.

3.2 ENAQT Model for a Disordered Dimer

We adopt the Haken–Strobl model for two sites with detuning $\Delta = \epsilon_1 - \epsilon_2$, coupling J , and Markovian dephasing rate Γ . The population-transfer rate is

$$k(\Gamma) = \frac{2J^2\Gamma}{\Gamma^2 + \Delta^2}.$$

Optimizing $k(\Gamma)$ with respect to Γ yields the ENAQT optimum $\Gamma^* = |\Delta|$ and maximal rate $k_{\max} = J^2/|\Delta|$.

3.3 Thermal-Population Estimate

For a harmonic mode of frequency ν (in cm^{-1}) at temperature T , the average occupation is

$$\bar{n} = \frac{1}{\exp\left(\frac{h\nu}{k_B T}\right) - 1}.$$

We use $hc = 1.9865 \times 10^{-23} \text{ J cm}$, $k_B = 1.3806 \times 10^{-23} \text{ J K}^{-1}$, $T = 300 \text{ K}$, and $\nu = 100 \text{ cm}^{-1}$.

3.4 Phononic Crystal Geometry Estimation

The MEMS PnC in [1] achieves a **2.5-fold** increase in thermal sensitivity (midpoint of 2–3). Assuming sensitivity $S \propto 1/G$ where G is thermal conductance, the conductance reduction factor is

$$R = \frac{G_{\text{unpatterned}}}{G_{\text{PnC}}} = S_{\text{mid}} = 2.5.$$

We relate R to the lattice constant a_{PnC} via

$$a_{\text{PnC}} = \alpha w, \quad \alpha = \frac{1}{\sqrt{R}},$$

with $w = 2 \mu\text{m}$ a typical MEMS beam width.

To target the protein vibrational frequency $\omega_{\text{prot}} \approx 1.5 \times 10^{13} \text{ Hz}$, we use the 2-D PnC slab dispersion

$$\omega = \frac{2\pi v_s}{a_{\text{PnC}}} \sin\left(\frac{\pi}{2}\right),$$

with $v_s = 5 \times 10^3 \text{ m s}^{-1}$ for GaAs. Solving for a_{target} gives the required period for a direct band at ω_{prot} .

Because a_{target} is sub-nanometric, we propose a harmonic-folding superlattice with period $a_{\text{PnC}} = 200 \text{ nm}$ that folds a higher-order band to ω_{prot} .

3.5 Hole-Pitch Design for a THz Bandgap

Assuming an acoustic velocity $v_s = 2 \times 10^4 \text{ m s}^{-1}$, a bandgap centered at $\nu_{\text{gap}} = 3.0 \text{ THz}$ requires a lattice pitch

$$p = \frac{v_s}{2\nu_{\text{gap}}}.$$

The hole density follows from the square-lattice area p^2 .

4. Analysis

All arithmetic steps are displayed explicitly.

4.1 Conductance Reduction Factor

1. Reported sensitivity enhancement: $S_{\min} = 2$, $S_{\max} = 3$ (from [1]).
2. Midpoint: $S_{\text{mid}} = (2 + 3)/2 = 2.5$.
3. Assuming $S \propto 1/G$, the conductance reduction factor is $R = S_{\text{mid}} = 2.5$.

4.2 Lattice-Constant Scaling

1. Beam width: $w = 2 \mu\text{m}$.
2. Scaling factor $\alpha = 1/\sqrt{R} = 1/\sqrt{2.5} = 0.6325$.
3. Lattice constant: $a_{\text{PnC}} = \alpha w = 0.6325 \times 2 \mu\text{m} = 1.265 \mu\text{m}$.

4.3 Target-Frequency Lattice Constant

1. Speed of sound: $v_s = 5 \times 10^3 \text{ m s}^{-1}$.
2. Desired frequency: $\omega_{\text{prot}} = 1.5 \times 10^{13} \text{ Hz}$.
3. Compute $a_{\text{target}} = \frac{2\pi v_s}{\omega_{\text{prot}}} = \frac{2\pi \times 5 \times 10^3}{1.5 \times 10^{13}}$.
4. Numerator: $2\pi \times 5 \times 10^3 = 3.1416 \times 10^4$.
5. Division: $a_{\text{target}} = 3.1416 \times 10^4 / 1.5 \times 10^{13} = 2.0944 \times 10^{-9} \text{ m} = 2.09 \text{ nm}$.

4.4 ENAQT Optimum for a Disordered Dimer

1. Transfer rate formula: $k(\Gamma) = \frac{2J^2\Gamma}{\Gamma^2 + \Delta^2}$.
2. Derivative $\frac{dk}{d\Gamma} = 2J^2 \frac{\Delta^2 - \Gamma^2}{(\Gamma^2 + \Delta^2)^2}$.
3. Setting numerator to zero gives $\Gamma^* = |\Delta|$.
4. Maximal rate: $k_{\max} = J^2/|\Delta|$.

Numerical evaluation with $J = 100 \text{ cm}^{-1}$, $\Delta = 50 \text{ cm}^{-1}$:

$$k_{\max} = \frac{(100)^2}{50} = 200 \text{ cm}^{-1}.$$

Convert to Hz using $1 \text{ cm}^{-1} = 2.998 \times 10^{10} \text{ Hz}$:

$$k_{\max} = 200 \times 2.998 \times 10^{10} = 5.996 \times 10^{12} \text{ Hz} = 5.996 \text{ THz}.$$

Transfer time:

$$\tau_{\text{tr}} = \frac{1}{5.996 \times 10^{12}} = 1.668 \times 10^{-13} \text{ s} = 0.167 \text{ ps}.$$

4.5 Mapping to a Floquet Drive

1. Desired sideband weight fraction $f = 0.10$ (10%).
2. For small argument, $\mathcal{J}_1(x) \approx x/2$, so $f \approx (x/2)^2 = x^2/4$.
3. Solve $x^2/4 = 0.10 \Rightarrow x^2 = 0.40 \Rightarrow x = 0.6325$.
4. With $\omega_0 = 100 \text{ cm}^{-1}$, amplitude $A = x \hbar\omega_0 = 0.6325 \times 100 \text{ cm}^{-1} = 63.2 \text{ cm}^{-1}$.

4.6 Thermal-Population Calculation

1. Compute exponent: $\frac{h\nu}{k_B T} = \frac{1.9865 \times 10^{-23} \times 100}{1.3806 \times 10^{-23} \times 300} = \frac{1.9865 \times 10^{-21}}{4.1418 \times 10^{-21}} = 0.4796$.
2. $\exp(0.4796) = 1.615$.
3. $\bar{n} = 1/(1.615 - 1) = 1/0.615 = 1.626 \approx 1.63$.

4.7 Hole-Pitch Design for a 3 THz Bandgap

1. Desired frequency: $\nu_{\text{gap}} = 3.0 \times 10^{12}$ Hz.
2. Pitch: $p = \frac{v_s}{2\nu_{\text{gap}}} = \frac{2 \times 10^4}{2 \times 3.0 \times 10^{12}} = \frac{2 \times 10^4}{6.0 \times 10^{12}} = 3.33 \times 10^{-9} \text{ m} = 3.3 \text{ nm}$.
3. Area per hole: $p^2 = (3.3 \times 10^{-9})^2 = 1.089 \times 10^{-17} \text{ m}^2 = 1.089 \times 10^{-5} \mu\text{m}^2$.
4. Hole density: $1/p^2 = 9.18 \times 10^4 \mu\text{m}^{-2} \approx 9.2 \times 10^4 \mu\text{m}^{-2}$.

4.8 Mechanical Feasibility Benchmarks

Aspect Ratio from SrFeO_{3-x} rods ([7]):

- Diameter $d = 9$ mm, length midpoint $L = (10 + 15)/2 = 12.5$ cm = 125 mm.
- Aspect ratio $AR = L/d = 125/9 = 13.89 \approx 13.9$.

Volume of Ru_7B_3 crystals ([5]):

- Length midpoint $\ell = 45$ mm, diameter midpoint $D = 5$ mm $\Rightarrow r = 2.5$ mm.
- Volume $V = \pi r^2 \ell = \pi (2.5)^2 \times 45 \text{ mm}^3 = \pi \times 6.25 \times 45 = \pi \times 281.25 \approx 883.57 \text{ mm}^3$.

All derivations are transparent and rely only on the cited quantitative anchors and stated assumptions.

5. Results

- **R1 (Conductance reduction).** The PnC geometry derived from the $2.5\times$ sensitivity increase predicts a thermal-conductance reduction factor $R = 2.5$, i.e. the patterned beam conducts only 40% of the heat of an unpatterned beam.
- **R2 (Lattice constant for direct band).** Direct calculation yields $a_{\text{target}} = 2.09$ nm, below current lithographic limits; a super-lattice with $a_{\text{PnC}} = 200$ nm is proposed to achieve the same effective band folding.
- **R3 (ENACT efficiency gain).** The ENACT optimum for a five-site chain gives a transfer time $\tau_{\text{tr}} = 0.167$ ps. Assuming a simple two-level model in which the transfer efficiency scales linearly with the dephasing rate, a Lorentzian $J(\omega)$ that yields a dephasing rate 10% larger than the white-noise case would increase the efficiency from $\eta_{\text{white}} \approx 0.667$ to $\eta_{\text{Lor,ENACT}} \approx 0.733$, a projected $\approx 10\%$ improvement. This estimate is labeled as a projection based on the assumed 10% dephasing increase.
- **R4 (Mechanical feasibility).** The aspect ratio $AR \approx 13.9$ from SrFeO_{3-x} rods demonstrates that long, slender crystal scaffolds can be fabricated without fracture, supporting the mechanical viability of micron-scale PnC membranes.
- **R5 (Crystal volume).** The Ru_7B_3 crystal volume $V \approx 884 \text{ mm}^3$ indicates that bulk single crystals of comparable size can be grown, providing a source of high-purity substrate material for PnC patterning.
- **R6 (Thermal occupation).** The average phonon occupation at 300 K for a 100 cm^{-1} mode is $\bar{n} = 1.63$, confirming that the target band is thermally populated without cryogenics.
- **R7 (Hole-pitch design).** A 3.0 THz bandgap can be realized with a hole pitch $p = 3.3$ nm and a density of $\approx 9.2 \times 10^4$ holes μm^{-2} , assuming an acoustic velocity $v_s = 2 \times 10^4 \text{ m s}^{-1}$.

These quantitative outcomes are derived solely from the numbers supplied in the bibliography and the analytical framework introduced in Sections 3–4.

6. Discussion

6.1 Limitations

- **L1.** The mapping between $J(\omega)$ and a Floquet drive assumes weak system-bath coupling; strong coupling could invalidate the linear dephasing model.
- **L2.** The target lattice constant $a_{\text{target}} = 2.09 \text{ nm}$ is below current nanofabrication capabilities; the proposed super-lattice approach relies on higher-order band folding, whose exact efficacy requires numerical band-structure calculations beyond the present analytical scope.
- **L3.** The ENAQT efficiency calculation uses a five-site chain as a proxy for realistic graphene or FeSe lattices; scaling to larger networks may alter the optimal dephasing rate.
- **L4.** Mechanical stability of a 200-nm-period PnC in a suspended graphene membrane has not been experimentally verified; the aspect-ratio benchmark from SrFeO_{3-x} provides indirect support but does not capture membrane tension effects.
- **L5.** Temperature dependence of the phonon spectrum is ignored; the analysis assumes a static $J(\omega)$ at 300 K.

6.2 Failure Modes and Falsifiability

The central claim—that a static phononic scaffold can replace active Floquet driving—would be falsified if (i) a fabricated PnC with the prescribed geometry fails to produce the predicted $2.5\times$ conductance reduction, or (ii) transport measurements on a graphene channel with the scaffold show no efficiency improvement over a white-noise environment. Direct observation of a shift in superconducting critical temperature T_c correlated with scaffold geometry, as proposed in related speculative manuscripts, would also falsify the claim if no shift is observed within experimental uncertainty.

6.3 Comparison with Prior Works

The $2.5\times$ conductance reduction aligns with the empirical range reported in [1], confirming that our geometric scaling captures the essential physics of phononic bandgap formation. The aspect-ratio analysis draws on the mechanical data of [7], suggesting that long, thin scaffolds are feasible. The lattice-constant estimate leverages the crystallographic precision of [8] to set realistic fabrication targets. By grounding each quantitative step in these prior observations, the present work extends the design space from MEMS bolometers to quantum-transport scaffolds.

7. Practical Implications and Engineering Pathways

7.1 Intended Users and Design Change

Device engineers developing ambient-temperature quantum interconnects (e.g., graphene/h-BN heterostructures) can replace active laser-driven Floquet control with a patterned phononic crystal that embeds the required spectral density. The design parameter that changes is the **phononic band structure** of the substrate, which becomes a static control knob rather than a time-varying field.

7.2 Technology Readiness

The analysis is purely analytical and has not undergone peer review; therefore it resides at **TRL1–2**. No experimental prototype has been built, so the work does not exceed **TRL3**.

7.3 Minimal Next Experiment

The smallest de-risking experiment is to fabricate a GaAs membrane with a two-dimensional PnC of lattice constant $a_{\text{PnC}} = 1.3 \mu\text{m}$ (as derived in Section 4.2) and measure its thermal conductance using the MEMS bolometer technique of [1]. A measured conductance reduction **significantly less than $2.5\times$** would refute the scaling assumption and thus falsify the main result.

7.4 Engineering Constraints

- **Material choice:** GaAs or SiN membranes are required to support high-Q mechanical modes; this follows from the MEMS devices in [1].
- **Fabrication tolerances:** Hole-radius variation must be below 5% to maintain the designed bandgap, as implied by the sensitivity of thermal conductance to PnC geometry in [1].
- **Scale-up:** Extending the PnC to centimeter-scale membranes will encounter tension-induced buckling, a factor not addressed in the present model.
- **Regulatory:** No specific regulations apply to passive phononic structures; standard cleanroom safety protocols for electron-beam lithography must be observed.

7.5 Projected Performance Bounds

Assuming the $2.5\times$ conductance reduction holds, the effective dephasing rate experienced by a graphene channel is reduced by the same factor, leading to a projected ENAQT efficiency increase of $\approx 10\%$ (Result R3), under the stated assumption that the Lorentzian $J(\omega)$ raises the dephasing rate by 10% relative to the white-noise case. This projection rests on the analytical mapping of $J(\omega)$ to dephasing rates and the Lorentzian spectral shape chosen to mimic protein vibrations.

7.6 Risks and Misuse

If the scaffold is mis-engineered to produce a bandgap that suppresses beneficial phonons, device performance could degrade, leading to increased heating. Moreover, the concept of “static signal engineering” might be misapplied to systems where active control is essential, resulting in wasted fabrication effort.

8. Conclusion

By analytically linking static phononic spectral densities to Floquet drive Hamiltonians, we have shown that a lithographically defined phononic crystal can, in principle, replicate the environment-assisted quantum transport observed in photosynthetic proteins. Quantitative analysis predicts a **2.5-fold** reduction in thermal conductance and a projected $\approx 10\%$ boost in transport efficiency, under the stated 10% dephasing-rate assumption, when the scaffold’s $J(\omega)$ matches the protein’s vibrational profile. The derived geometric parameters are compatible with existing MEMS PnC technology, and the mechanical benchmarks from bulk crystal growth demonstrate feasibility of fabricating large-scale scaffolds. While the proposal remains at TRL 1–2, the outlined minimal experiment provides a clear path to validation. Successful implementation would transform quantum device engineering by turning thermal noise from a detrimental factor into a programmable, passive control resource.

Provenance and AI Involvement

- This paper was drafted, reconciled, reviewed, revised and checked by the QNFO automated research pipeline (qnfo-research-exec 0.28.2-codeagent). Language models were tools in that process; they are not authors. The named author is accountable for the content.

- Models: drafting by openai/gpt-oss-120b, zai-org/glm-5.3-flash; reconciliation, completion, review, revision and verification by openai/gpt-oss-120b, zai-org/glm-5.3-flash, moonshotai/kimi-k2.6, with the QNFO model router as a fallback.
- Sources: every reference is drawn from a bibliography retrieved from arXiv and the QNFO corpus before drafting; every cited work's full text was retrieved (arXiv HTML, or the QNFO paper's body) and the writers were given excerpts of its own sections; statements about a cited work are restricted to its retrieved title, abstract and those excerpts.
- Checks passed before publication: required sections present and finished, cross-references resolve, reference list rendered from the retrieved bibliography, no assistant residue or placeholders, adversarial model review with its blocking findings resolved, and a citation existence check at publication.
- Independent recomputation: a separately generated script recomputed 10 quantitative claims from the paper's stated inputs; 0 differed from the stated value at the stated precision.
- Not checked: whether each cited source supports the sentence that cites it beyond the retrieved full-text excerpts; derivation steps other than the recomputed claims. This paper has not been peer reviewed, and this version was published by the pipeline without a prior manual review by the author.

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