

# Advancing Quantum Computing through Room-Temperature Superconductivity: Prospects and Challenges

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July 2025

## Abstract

Superconducting qubits are a leading platform for quantum computing, enabling scalable quantum processors but requiring operation at near-absolute-zero temperatures. The discovery of room-temperature superconductors could revolutionize this field by eliminating the need for complex cryogenic systems, potentially making quantum computers more accessible and cost-effective. This paper reviews the current state of superconducting quantum computing, explores recent developments in room-temperature superconductivity, and assesses their potential application to quantum computing systems. We propose a comprehensive research methodology for OA Quantum Labs to investigate these technologies, including material synthesis, device fabrication, and quantum testing. While room-temperature superconductivity holds immense promise, significant challenges remain in achieving quantum coherence at higher temperatures and validating controversial claims.

## 1 Introduction

Quantum computing leverages the principles of quantum mechanics to perform computations beyond the capabilities of classical computers, with applications in cryptography, materials science, and artificial intelligence. Superconducting qubits, used by industry leaders like IBM and Google, are among the most advanced quantum computing platforms due to their scalability and compatibility with microfabrication techniques. However, these qubits require operation at temperatures near 15 millikelvin, necessitating costly and complex cryogenic systems. The prospect of room-temperature superconductivity—materials that conduct electricity without resistance at ambient temperatures—offers a transformative opportunity to simplify quantum computing hardware. This paper, authored by Danny Wall, CTO of OA Quantum Labs, examines the role of superconductivity in quantum computing, reviews the latest research on room-temperature superconductors, and outlines a research strategy to explore their application in quantum systems.

## 2 Superconductivity in Quantum Computing

Superconducting qubits are electronic circuits that exhibit quantum behavior when cooled to extremely low temperatures, typically using dilution refrigerators. These circuits, made

from materials like niobium, aluminum, or tantalum, incorporate Josephson junctions to create nonlinear inductors, enabling distinct energy levels that represent quantum states [3]. The transmon qubit, a widely used design, mitigates charge noise, achieving coherence times exceeding 0.3 milliseconds in recent implementations [4].

Recent advancements have significantly enhanced superconducting quantum computing. Google’s Willow chip, a 105-qubit processor, achieved “below-threshold” quantum error correction, reducing logical error rates to 0.143% per cycle for a distance-7 surface code, exponentially decreasing errors as qubit counts increase [1]. IBM’s roadmap targets a fault-tolerant quantum computer, Starling, by 2029, capable of executing 100 million quantum gates on 200 logical qubits using advanced error correction techniques like bi-variate bicycle codes [2]. These developments highlight the maturity of superconducting qubits but underscore the challenge of operating at cryogenic temperatures.

Table 1: Recent Advancements in Superconducting Quantum Computing

Organization	Advance	Reference
Google Quantum AI	Willow chip: 105 qubits, below-threshold error correction ( $\Lambda = 2.14 \pm 0.02$ )	[1]
IBM	Roadmap to Starling: 200 logical qubits, 100M gates by 2029	[2]
Various	Tantalum-based transmon qubits with coherence times $> 0.3$ ms	[4]

### 3 Room-Temperature Superconductivity: Current Research

The quest for room-temperature superconductivity, defined as zero electrical resistance at or near 293 K (20°C) and ambient pressure, is a long-standing goal in condensed matter physics. Superconductors typically operate at low temperatures, with high-temperature superconductors like cuprates functioning at around 100–150 K under ambient pressure [7]. Recent theoretical and experimental developments suggest that room-temperature superconductivity is physically possible.

A 2025 study published in the *Journal of Physics: Condensed Matter* analyzed fundamental physical constants (Planck constant, electron charge, electron mass) and concluded that the critical temperature ( $T_c$ ) for superconductors could reach 100–1000 K, encompassing room temperature [6]. This finding, led by researchers at Queen Mary University of London, provides a theoretical foundation for continued exploration. Experimentally, a team at SLAC and Stanford stabilized superconductivity in nickelates at room pressure using thin-film growth techniques, achieving  $T_c$  values from 26 K to 42 K, though still far from room temperature [7]. Another study reported weak superconducting signals in copper-substituted lead apatite (CSLA), with diamagnetic behavior below 250 K, but failed to observe a complete Meissner effect, casting doubt on its viability [8]. Past claims, such as LK-99 in 2023, were retracted due to replication failures, highlighting the need for rigorous validation [9].

Table 2: Promising Materials for Room-Temperature Superconductivity

Material	Advantages	Limitations	Status
Nickelates	Stable at room pressure, Tc up to 42 K	Far below room temperature	Experimental [7]
CSLA	Potential room-temperature signals	Weak signals, no Meissner effect	Preliminary, unverified [8]
Cuprates	High Tc ( 150 K)	Requires high pressure or low temperature	Mature, limited scalability [7]

## 4 Application to Quantum Computing Systems

Room-temperature superconductors could revolutionize quantum computing by eliminating the need for dilution refrigerators, which are costly and limit system scalability. Current superconducting qubits rely on materials with low defect densities and specific properties to form Josephson junctions, which create nonlinear energy levels essential for quantum states [3]. A room-temperature superconductor with similar properties could enable quantum processors to operate in standard environments, reducing infrastructure costs and enabling broader adoption.

However, achieving quantum coherence at room temperature is not guaranteed by superconductivity alone. Superconducting qubits are sensitive to multiple decoherence sources, including material defects, electromagnetic interference, and two-level system losses [5]. Even with zero electrical resistance, thermal fluctuations at 293 K could disrupt quantum states unless mitigated by advanced shielding or design modifications. Moreover, the suitability of candidate materials like nickelates or CSLA for Josephson junction fabrication remains untested, as their superconducting mechanisms differ from traditional materials like niobium [7]. Thus, while room-temperature superconductors offer significant potential, their integration into quantum computing requires overcoming substantial engineering challenges.

## 5 Research Methodology for OA Quantum Labs

OA Quantum Labs, leveraging its expertise in quantum technologies, proposes a multi-phase research program to explore room-temperature superconductors for quantum computing applications.

### 5.1 Material Synthesis and Characterization

- **Objective**: Synthesize and verify the superconducting properties of candidate materials like nickelates and CSLA. - **Methods**: Use thin-film growth techniques (e.g., molecular beam epitaxy) to fabricate samples, followed by measurements of critical temperature, critical magnetic field, and Meissner effect using techniques like X-ray scattering and magnetometry [7]. - **Equipment**: Access to cleanroom facilities, magnetometers, and spectroscopy tools.

## 5.2 Device Fabrication

- **Objective**: Fabricate quantum devices, such as Josephson junctions or transmon qubits, using room-temperature superconductors.
- **Methods**: Adapt lithographic techniques to accommodate new materials, ensuring compatibility with existing micro-fabrication processes [3]. Test small-scale devices (e.g., single qubits) to assess feasibility.
- **Challenges**: Ensure material purity and low defect density to minimize decoherence.

## 5.3 Quantum Property Testing

- **Objective**: Evaluate the quantum coherence and gate fidelities of fabricated devices.
- **Methods**: Measure T1 (relaxation) and T2 (coherence) times using microwave spectroscopy, comparing performance to niobium- or tantalum-based qubits [4]. Assess error rates in single- and two-qubit gates.
- **Metrics**: Target coherence times > 0.1 ms and gate fidelities > 99%.

## 5.4 Optimization and Iteration

- **Objective**: Improve material and device performance through iterative experimentation.
- **Methods**: Use machine learning to optimize material synthesis parameters and device designs, similar to approaches in superconducting qubit optimization [10]. Explore doping strategies to enhance Tc and coherence properties [7].

## 5.5 Collaboration and Validation

- **Objective**: Ensure reproducibility and credibility of findings.
- **Methods**: Partner with institutions like SLAC, Stanford, or IBM for peer validation. Publish results in peer-reviewed journals like Nature or Physical Review Letters to contribute to the scientific community.

# 6 Conclusion

Superconducting qubits have driven significant progress in quantum computing, with advancements like Google's Willow chip and IBM's Starling roadmap paving the way for fault-tolerant systems. Room-temperature superconductivity, if realized, could transform this field by eliminating cryogenic requirements, but challenges in maintaining quantum coherence and fabricating suitable devices remain. OA Quantum Labs is well-positioned to lead this research, leveraging its expertise to explore promising materials like nickelates and CSLA. Through a rigorous methodology of synthesis, fabrication, testing, and collaboration, we aim to advance the development of scalable, practical quantum computers.

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