

Chapter 6


Semiconductor Technologies for Quantum Computing Hardware

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ABSTRACT

The integration of semiconductor technologies with quantum computing hardware holds immense promise in revolutionizing computation paradigms. This abstract delves into the pivotal role semiconductor materials play in advancing quantum computing hardware, focusing on their fabrication, implementation, and scalability. Silicon quantum dots emerge as frontrunners in this landscape, offering a robust platform for qubit realization. Through lithography, ion implantation, and etching processes, semiconductor-based qubits demonstrate remarkable potential for scalability and manufacturability. This abstract navigates through the fundamentals of quantum computing, elucidating the principles of qubits and quantum gates. It explores the historical evolution of semiconductor technologies in quantum computing hardware, highlighting silicon as a promising substrate for quantum dot-based architectures. Challenges such as coherence times and error rates are scrutinized alongside potential solutions.

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1. INTRODUCTION

The integration of AI, quantum computing, and semiconductor technology holds immense potential for revolutionizing computing capabilities. Quantum computing, particularly through semiconductor-based approaches like CMOS technologies, offers the promise of implementing large qubit arrays on a single chip, enabling ultra-high-performance computing crucial for AI applications (Verberk et al., 2022). Furthermore, advancements in quantum technology are driving the development of quantum chips utilizing superconducting materials and silicon-based spin qubits, aligning with semiconductor manufacturing expertise and paving the way for more powerful quantum computing devices (Nikandish et al., 2021). Additionally, the application of 3D integration technologies to quantum computing devices, compatible with advanced CMOS fabrication processes, addresses scalability challenges of various qubit types and enhances the overall integration and packaging aspects crucial for rapid advancements in the field (Zhao et al., 2021). Moreover, the utilization of quantum computing for technology computer-aided design (TCAD) in semiconductor devices presents a new avenue for solving quantum confinement problems with high accuracy and efficiency, showcasing the potential of quantum algorithms in semiconductor simulations (Yang and Guo, 2023). Semiconductor technologies play a crucial role in advancing quantum computing hardware due to their compatibility with traditional integrated circuit processes and the ability to create large arrays of qubits on a single chip (Jia et al., 2022). Silicon-based materials offer promising prospects for quantum computing, with silicon spin qubits demonstrating ultralong coherence times in the milliseconds range (Fogarty, 2022). Moreover, the integration of silicon metal-oxide-semiconductor technology in quantum information processing architectures presents scalable solutions for fault-tolerant quantum computation, utilizing global control methods to simplify processor complexity and address device variations. By leveraging the advancements in semiconductor and superconductor technologies, researchers aim to control and detect quantum states efficiently, paving the way for the development of powerful quantum computing devices (Vladimirescu, 2023).

Semiconductor technologies play a crucial role in advancing quantum computing hardware, particularly in the development of CMOS-based quantum computers (Nikandish et al., 2020). Semiconductor-based quantum computing is promising because it can be used to implement large arrays of qubits with their control and readout circuitry on a single chip. These technologies have enabled the realization of qubit initialization, control, and readout with high fidelity, and the demonstration of a programmable two-qubit quantum processor (Zhang et al., 2018). The qubit initialization, control, and readout can be realized with relatively high fidelity. Furthermore, the integration of semiconductor technologies into quantum systems, particularly in quantum photonics, presents both opportunities and challenges (Uusimaa and Nechay, 2022). Laser diodes can be used for excitation for quantum systems and quantum control of molecules. The potential of semiconductor nanowires as a materials platform for quantum computing has also been explored, with promising results in the manipulation of single spins in quantum dots and the study of Majorana fermions (Frolov, 2013). A semiconductor nanowires grown from the bottom-up as a materials platform for a quantum computer.

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