QCE 2026 Tutorial: Superconducting Qubit Devices and Their Large-Scale Integration and Relationship to the Semiconductor Industry

Materials:

Introduction to Quantum Computing

Quantum Computing Architecture Hardware for Engineers

Review of Superconducting Qubit Devices and Their Large-Scale Integration

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Time (mins)	Section	Descriptions	Learning Outcomes
30	I. Overview of Quantum Computing: Basics & Hardware **Lecture/ Beginner**	Review the basics of quantum computing (superposition, entanglement, and interference); Introduce DiVincenzo's criteria and how superconducting qubit QC fulfills the criteria.	1. Able to describe the basic quantum computer operations: Initialization, Readout, 1-Qubit, and 2-Qubit Manipulations 2. Understand that DiVincenzo's criteria as the necessary but not sufficient criteria to build a useful quantum computer 3. Have a general idea of how a superconducting quantum computer fulfills DiVincenzo's criteria.
30	II. Superconducting basics and Josephson junction **Lecture/ Beginner /Intermediate**	Discuss the superconducting behavior of various materials. Discuss the fabrication and operating principle of the Josephson junction.	1. Understand how temperature, magnetic field, current density, and film thickness affect the superconducting behavior. 2. Understand the concepts of the phase parameter, Josephson inductance/energy, and capacitive energy. 3. Appreciate how the Josephson junction is manufactured using integrated circuit techniques and its relationship to semiconductor fabrications.
30	III. Superconducting Qubits **Lecture + demo/ Beginner /Intermediate**	Discuss various types of superconducting qubits and demonstrate the trade-off between anharmonicity and charge-noise immunity (Python code will be provided). Discuss the effect of the two-level system (TSL) defects.	1. Understand the trade-off between various types of superconducting qubits and their constraint. 2. Appreciate the importance of transmon qubits and why they are charge-insensitive. 3. Able to adjust E_C and E_J in the Python code to appreciate the trade-off between anharmonicity and charge-insensitivity. 4. Able to read the graph 5. Understand the effect of TSL and how it is related to the qubit fabrication
30	IV. Implementation of 1-qubit and 2-qubit gates **Lecture + demo/ Intermediate / Advanced**	Discuss general one-qubit gates; Discuss two-qubit gate implementations; Demonstrate √iSWAP gate using QuTip	1. Understand the virtual-Z gate and rotating frame concept 2. Understand the decomposition of an arbitrary gate into 3 rotations 3. Understand that there are various types of two-qubit gate implementation strategies (tunable coupler, all-microwave-drive, etc.) 4. Appreciate how qubit swaps in the QuTip simulation; understand the importance of frequency and timing precision.
30	V. Controlling electronics and Readout **Lecture and demo/ Beginner**	Discuss the path and evolution of the classical control signal from room-temperature to the qubit and back to classical signal processing. Demonstrate the layout of a transmon qubit using QiskitMetal with a readout resonator and CPW.	1. Understand the importance of precise classical control signals 2. Understand the trade-off between fast readout and qubit coherence time 3. Understand the role of a quantum-limited amplifier and a Purcell filter in the readout process 4. Identify components on a qubit chip
30	VI. Electronic Design Automation (EDA) and Large-Scale Integration **Lecture and demo/ Beginner /intermediate**	Discuss the role of EDA in superconducting qubit design and examples of possible large-scale integration to achieve hundreds of logical qubits and millions of physical qubits	1. Understand the roles of various EDA tools in superconducting qubit quantum computing design 2. Understand the limitations of current EDA tools 3. Appreciate the possibilities and limitations of some examples of large-scale integrations 4. Appreciate how semiconductor 3D integration technologies, such as flip-chip bonding, interposer, and through-silicon-via (TSV), will enable large-scale integration.