EECS 398. **Introduction to Quantum Information Technologies** Winter 2024

- *Prepare yourself for the 2nd Quantum Revolution*

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Venue: DOW 1206,
Time: T, Th 2:30-4:30pm

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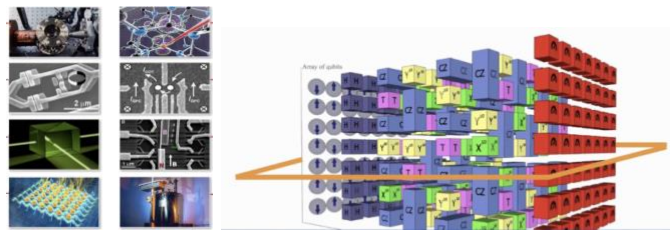

Description: The development of quantum mechanics in the first half of the twentieth century has transformed our understanding of the physical world and brought about unprecedented advance in modern technology. Since the 1980's the introduction of quantum mechanics into information processing has led to new paradigms in communications, sensing, and computation. The progress made in this 2nd quantum wave has fueled the rapidly growing business (currently >$1B, star-ups >$1.7B); e.g. Alibaba, Amazon, IBM, Google, and Microsoft have already launched commercial quantum-computing cloud services. A new wave of quantum-based sensing, communications, artificial intelligence and many more are coming. As a result, *there will be a huge market for QISE skilled engineers in both quantum hardware and algorithms in the coming years*.

This course will provide the students with the foundation knowledge to understand the development of this rapidly evolving field, leading to the discussion of new technologies. We will address how the mysterious quantum phenomena are brought to real world realizations that will further advance our knowledge. After introducing the founding principles of quantum science and quantum information, the second half of the semester will focus on photonic realization because of its appeal in delivering near-term quantum technologies that would create far-reaching societal impacts. By the end of the course, the students will grasp a fundamental understanding for quantum information and be able to bridge quantum physical phenomena and new technologies for communication, sensing, and computing.

No prior knowledge of quantum mechanics, optics, classical computing or information is assumed. It's helpful if students get familiar with basic optics, e.g. at the level of Intro Optics course (EECS 334). We welcome students from various backgrounds and disciplines, such as ECE, CSE, MSE, ME, and Physics, etc. During first year offering, we had the majority of students from CSE.

Grading: ~6 homework sets, two exams, and a final project presentation.

Tentative course outlines

1. Introduction to the Quantum revolution happened over 100 years ago
2. Overview of quantum information science and engineering (QISE)
3. Foundation of QISE–quantum bits (qubits), superposition, measurement, experiment realization using photon polarization states
4. qubits represented by electron spins, quantum gates & Block sphere
5. Multipartite quantum states, tensor products
6. Fundamental postulates of quantum mechanics
7. Quantum operations in comparison to classical gates, single-qubit gates, two-qubit gates
8. Quantum computing in a nutshell–Deutsch and Grover algorithms
9. Entanglement introduction and 2022 Nobel prize in physics
10. Bell states, GHZ state, Bell's theorem, CHSH inequality and experimental validations
11. System Hamiltonian and quantum states evolution, Harmonic oscillator model
12. Physical qubit realizations–2 level systems, cold neutral atoms
13. Physical qubit realizations: ion traps, superconducting qubits
14. Continuous-variable (CV) quantum states, vacuum state, coherent state, squeezed state, number state
15. Generation of entangled photons via spontaneous parametric down-conversion (SPDC), theoretical description for SPDC
16. Entanglement distribution, Bell measurement, quantum teleportation with qubits
17. Quantum superdense coding, entanglement-assisted communication
18. Quantum cryptography, single-photon-based BB84 protocol, entanglement-based B92 protocol
19. Security of quantum key distribution (QKD) with practical devices, photon-number splitting attack, decoy-state QKD
20. Squeezed light and quantum metrology beyond the shot-noise limit, the LIGO example
21. Quantum receiver structures–incoherent, coherent, Kenney, and Dolinar receivers
22. Quantum information technologies with continuous variables–CV quantum teleportation, CV superdense coding, CV-QKD
23. Outlook for quantum information technologies