QUANTUM OPTICAL TECHNOLOGIES (QOT)

PART I: Introduction to Quantum Information and Quantum Technologies

1. Quantization of the electromagnetic field (4 hours)
1.1 Quantization
1.2 Modes and excitations: the photon.
1.3 Quantum states of light

2. Quantum interference and quantum superposition (2 hours)
2.1 Quantum interference vs Classical interference
2.2 Examples

3. Entanglement (6 hours)
3.1 What it is and how to quantify it
3.2 Bell-states and Bell state analyzers
3.3 The quantum channel: Super-dense coding
3.4 Beyond entanglement in polarization

4. Parametric down-conversion (4 hours)
4.1 Parametric down-conversion
4.2 Experiments

5. Quantum teleportation (6 hours)
5.1 The scheme
5.2 What is it and what it is not
5.3 Examples and experiments

6. Cloning (4 hours)
5.1 Superluminal communications with entanglement?
5.2 Impossibility of perfect cloning of quantum information
5.3 A cloning machine: what is the best that we can do

7. Quantum cryptography (4 hours)
7.1 Full security: the one-time pad protocol
7.2 The problem: key distribution
7.3 BB84 and Ekert91

8. Quantum sensing (4 hours)
8.1 Classical and quantum Cramer-Rao bound
8.2 Examples

9. Correlations, randomness and Bell inequalities (4 hours)
9.1 Correlations and quantum correlations
9.2 Bell’s inequalities

10. Decoherence (2 hours)
10.1 Why the world looks classical most of the time?
10.2 What is quantumness?

PART II: Introduction to Quantum Computing

11. Quantum Computing (24 hours)

11.1 Introduction. What classical/quantum computers can and cannot do.
P and NP problems.

11.2 Quantum Circuits Basic Elements.

11.2.1 Operators and quantum gates.
- Universal Basis. Pauli's matrices. Bloch sphere and Rotational matrices
- 2-qubit gates: quantum c-not, crossover, c-u gates
- 3-qubit gates: c-swap, ccnot gate, etc

11.2.2 Quantum measurements.
- Measurement operators. Basis-state, projection and POVM, measurements

11.2.3 Quantum Circuits.
- Notation and Basic Examples: superdense coding, teleportation, teleportation of a CNOT.

11.3 Quantum algorithms

11.3.1 Quantum parallelism. An academic example: the Deutsch's algorithm

11.3.2 Shor's algorithm: breaking RSA.

11.3.3 Grover's algorithm: faster searching database

11.4 Quantum Processors

11.4.1 What is a universal quantum computer? DiVincenzo criteria.

11.4.2 State-of-the art: Is there any universal quantum computer?

11.4.3 Quantum supremacy and quantum advantage: a race to the future.

11.4.4 Nuclear Magnetic Resonance Quantum Computer.

BIBLIOGRAPHY

We do not follow any particular book. For each topic, we will recommend some books for further reading.

EVALUATION

60%: Three exams during the course (two multiple-choice exams corresponding to Part I, one exam corresponding to Part II).
10%: Homework assignments
30%: Final project