UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

SYLLABUS DEL CORSO

Tecnologie Quantistiche Applicate

2122-1-F1701Q149

Aims

Quantum Technologies exploit the ability to control quantum phenomena in matter to create sensors with otherwise unreachable sensitivities and computing systems capable of solving otherwise inaccessible problems. This is the second quantum revolution that is underway in recent years and at the base of which there are quantum devices - qubits - realized by exploiting different platforms. In this course the student will acquire the key skills necessary to understand the mechanisms by which qubits can be used as elements of a computer or as sensors. In particular, we will focus on superconducting qubits, which are now the core of the most advanced quantum computers, and the technologies related to their use.

Contents

- qubits practical implementations
- operate with qubits
- qubits as sensors
- superconducting qubits
    - design, fabrication and characterization
    - usage and related technologies
    - application examples
- other type of qubits and examples of their application

Detailed program

- Quantum systems for quantum technologies: qubits.
- Qubits as quantum computer elements and as quantum sensors
- Quantum sensing principles

- quantum sensing protocols (Ramsey and Rabi measurements)
- quantum sensing sensitivity
- Quantum systems for realizing qubits: neutral atoms, trapped ions, spins, superconducting circuits, photons....
- Superconducting qubits
  - Josephson junctions and SQUIDS. RF cavities.

  - circuit QED
  - Design, materials and fabrication

  - superconducting qubit properties and use: coherence time, control and readout, entanglement, squeezing…
  - Supporting technologies: microwave electronics, superconducting electronics, and low temperature techniques

  - superconducting qubit applications
    - QND photon counting and axion searches
    - superconducting quantum computer
    - quantum simulations
- Semiconductor qubits
  - basic principles
  - superconducting vs. semiconductor qubits
- Quantum photonics
  - basic principles
  - single photon detection: CCD, SiPM, APD, SPSND (superconducting nanowire, TES, KIDs).

  - single photon sources (deterministic and non-deterministic). Photon source characterization
  - quantum photonic examples
    - Bell inequality tests
    - quantum imaging

    - enhanced quantum interferometry and LIGO

Prerequisites

A course in Quantum Mechanics at the bachelor's degree level in physics (the basic concepts required will be recalled)

Teaching form

Lessons (6 credits)

Textbook and teaching resource

The course slides will be available through the elearning web page.
One text providing the basic concepts might be:

- “Quantum measurement “, Vladimir B. Braginsky, Farid Ya Khalili, Kip S. Thorne, Cambridge University Press, 1992

More specific textbooks will be suggested during the course.
Furthermore, review articles will be referenced during the course according to the topics covered in class. A preliminary list includes:

- “Quantum sensing”, C. L. Degen, F. Reinhard, and P. Cappellaro. Rev. Mod. Phys. 89, 035002; https://doi.org/10.1103/RevModPhys.89.035002
- “A quantum engineer's guide to superconducting qubits”, P. Krantz, M. Kjaergaard, F. Yan, T. P. Orlando, S. Gustavsson, and W. D. Oliver. Applied Physics Reviews 6, 021318 (2019); https://doi.org/10.1063/1.5089550
- “Introduction to Experimental Quantum Measurement with Superconducting Qubits”, Mahdi Naghiloo, PhD 2019, Murch Lab, Washington University in St. Louis; arXiv:1904.09291

Semester

1st semester

Assessment method

Oral.
Exam grade 18-30/30
No intermediate test is planned.

Office hours

On appointment by email