EPFL

Superconducting electronics: A materials perspective

MSE-438

Moll Philip

Cursus	Sem.	Type
Materials Science and Engineering	MA2, MA4	Opt.

Language of teaching	English
Credits	3
Session	Summer
Semester	Spring
Exam	Written
Workload	90h
Weeks	14
Hours	**4 weekly**
Courses	2 weekly
TP	2 weekly
Number of positions	

Summary

Introduction to superconducting electronic applications and their material requirements, including the fundamental phenomenology of superconductors. Key applications and their material requirements: a) magnets; b) quantum metrology; c) quantum computation.

Content

The goal is to provide an elementary introduction into superconducting technology, angled at engineers, materials scientists and microtechnologists, and physicists. The course will not treat the physics of superconductivity but rely on its phenomenological description.

The students should understand the peculiar properties of superconductors, and why they are unique and sometimes irreplacable elements in electronics. The focus will be on the peculiar properties of zero resistance, critical currents and fields, and phase coherence.

- Phenomenological theory of superconductivity required to model/predict the behavior of superconductors.
- Exercises for simple calculations.

1) Superconducting magnets & Power cables
- Technological applications: Magnetic Resonance Imaging, Superconducting motors and energy conversion, Research magnets
- Concepts of critical currents and critical magnetic field
- Abrikosov Vortices, type1 vs type 2 superconductors. Superconductivity under high field conditions.
- Pinning forces and pinning force analysis. Technological cable testing methods. Force scaling diagrams.
- Materials design aspects: Pinning design - dirt is good. Leading technologies of inclusion design, self-precipitate formation, ion-irradiation, nano-particle inclusions,...
- Superconducting filaments. Multi-core wires and in-line reactions to achieve desired values of pinning.

2) Quantum interference devices
- Technological applications: SQUID sensors, voltage standards, ultra-precise current sources/measurements
- Concept of phases and phase dynamics within the superconducting condensate
- Discussion of the Josephson effect and the Josephson relations
- The SQUID, first DC then AC.
- Sensing of the vector potential and not the magnetic field
- Materials design aspects: perfomance and utility requirements for applications, LTS/HTS SQUID. Noise aspects of thin film superconductivity and phase noise/phase slips. Key design: cleanliness. Film annealing, buffer layers, substrate matching, purity, importance of magnetic defects.

3) Quantum computation
- Technological applications: quantum information technology, quantum sensing
- Concepts of coherence and wave dynamics (beyond the steady state)
- Elements of qbit design (2-level systems, harmonic oscillators, non-linear element through Josephson junctions)

- Cooper box in detail, possibly also transmons time permitting
- Essentials of superconductor design subjected to GHz EM fields
- Materials design aspects: coherence is key. Pair-breaking through ac-fields, phase noise through substrate coupling, quality factors of qbits. Deposition strategy for grain-boundary control.

+ Practical work: Students in teams (depending on student numbers) will self-explore a HTS SQUID. A robust demonstrator SQUID for education purposes ("Mr. SQUID") based on cuptrate-HTS. The students will:

a) Cool it down with LN2 and observe the zero-resistance transition in a resistance measurement.
b) Explore the I-V characteristics of a dc-SQUID, including the Josephson characteristics, the critical currents, etc.
c) Observe flux oscillations by moving a permanent magnet around the dewar.
d) Realize the extreme sensitivity of this technology by monitoring the voltage changes as the team moves around in the room due to their small but finite susceptibility and the earth field.

Keywords

Superconductivity, quantum information technology, superconducting engineering and materials design, SQUID, high-field magnets

Learning Prerequisites

Recommended courses

- Fundamentals of solid-state materials MSE-423

Important concepts to start the course

The students should be familiar with elementary electrodynamics, differential equations and quantum mechanical description of electrons in metals (band structure)

Learning Outcomes

By the end of the course, the student must be able to:

- Use superconductors in circuits
- Define material requirements for an application
- Distinguish different types of superconductors
- Contrast metals and superconductors

Transversal skills

- Collect data.
- Plan and carry out activities in a way which makes optimal use of available time and other resources.
- Use a work methodology appropriate to the task.

Teaching methods

We will have lectures and exercise classes, followed by guided experiments with a superconducting quantum interference device.

Expected student activities

Perform experiments on SQUID and write a report. Attend the lecture once a week.

Assessment methods

Written report of experiment and written exam