UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

COURSE SYLLABUS

Advanced Solid State Physics

2324-1-FSM01Q021

Aims

The aims of this advanced course in Solid State Physics are to provide the conceptual tools and the notions that are particularly useful to the students undertaking a path in materials for digital technologies (ICT) and quantum technologies (QT). However, this course is also useful to those ones interested in materials for energy efficiency, such as the ones entering superconductive cables, LEDs and power-electronics devices.

Contents

Beyond the infinite and periodic solid: surfaces and shallow defects by substitutionals in semiconductors, within the single-electron scheme.
Beyond the non-interacting electrons: many-electron theories, electronic screening, effects of a magnetic field, ferromagnetism, and superconductivity.

Detailed program

Beyond the infinite periodic crystal: surfaces and shallow defects

- What is a surface or an interface, 2-D Bravais lattices
- The LEED technique
- Surface microscopies
- Charge density at metal surfaces
- Surface states from nearly free electrons
- Tight binding surface states
- Photoemission spectroscopy

- Surface states in metals
- The hybrid-orbital approach
- Semiconductor surfaces “as cut”
- The intriguing Si (111) reconstructions
- Dimer pairs at the (100) and (110) reconstructions
- Charge transfer at polar surfaces
- Surface energy, surface stress
- The equilibrium morphologies
- Surface vibrations
- Inelastic He scattering and realistic dispersions
- Shallow impurities: energy levels and envelope function
- Band alignement at metal/semiconductor junctions and heterojunctions

The many-electron problem and the effects of electronic screening

- From the many-electron system to the mean-field equation: Hartree equation
- The Hartree-Fock equations and meaning of the exchange energy contribution
- The interacting gas of free electrons
- Foundations of the density functional theory: the Hohenberg and Kohn theorem and the Kohn-Sham equation
- Ground-state properties and elementary excitations
- Cellular methods, the muffin tin potential, and the augmented plane waves
- Orthogonalization of valence states to core states: orthogonalized plane waves and pseudopotentials
- Electronic screening in the Thomas-Fermi model
- Electronic screening in the perturbative, Lindhard model
- Bonding and crystal structure in simple metals and other solids

Magnetic properties of solids

- Stoner model for band ferromagnetism in metallic solids
- Effect of temperature in the Stoner model, Curie temperature
- Ferromagnetism in insulating solids and the Heisenberg hamiltonian
- Antiferromagnetism and anisotropic magnetic susceptivity
- Excited magnetic states: spin waves and magnons
- Neutron scattering, role of magnons at low temperature
- ferromagnetic domains

Superconductivity

- Introduction to superconductivity: Onnes experiment and Meissner-Ochsenfeld effect
- The London and London equations: penetration of currents and magnetic fields
- The thermodynamics of the superconducting phase: free-energy, entropy and heat capacity
- Cooper pairs and instability of the Fermi sea
- Ground state in the Bardeen-Cooper-Schrieffer (BCS) theory
- Existence of the gap, its nature, and definition of the excited states in the BCS theory
- The supercorrent as steady state, critical values of current and magnetic field and Meissner effect in the BCS theory
- Experimental measurements of the gap, its temperature dependence and isotopic effect
- High-Tc superconductors

Prerequisites

Theory of infinite and periodic solids in the single-electron scheme (basic course in Solid State Physics). Quantum mechanics.

Teaching form

Lessons, practice lessons, and discussions with the students.

Textbook and teaching resource

MAIN TEXTBOOKS:

H. LUTH, Solid Surfaces.., Sixth Edition, Springer Verlag, 2015;
A. ZANGWILL, Physics at Surfaces, Cambridge 1990;
H. IBACH AND H. LUTH, Solids State Physics, Fourth Edition, Springer Verlag 2009.

ADDITIONAL TEXTS (all the material which is strictly necessary to the exam is uploaded as pdf presentations of the lessons in the e-learning platform)

N.W ASHCROFT AND N.D. MERMIN, Solid State Physics, Saunders College Publishing
F. BASSANI E U. GRASSANO, Fisica dello Stato Solido, Casa Editrice Boringhieri
G. GROSSO AND G. PASTORI PARRAVICINI, Solid state Physics, Academic Press
A.P. SUTTON, Electronic Structure of Materials, Oxford University Press
J.R. HOOK and H.E. Hall, Solid State Physics, John Wiley & Sons
S. BLUNDELL, Magnetism in Condensed Matter, Oxford University Press.

Semester

Second semester in the first year of the Master Degree

Assessment method

Oral examination with three open questions, referring to different parts of the program. The mark is produced by an average of the three answers.

Office hours

By e-mail appointment with the teacher and/or with the colleagues of the examination commmettee.

Sustainable Development Goals

AFFORDABLE AND CLEAN ENERGY | INDUSTRY, INNOVATION AND INFRASTRUCTURE