UNIVERSITÀ DI PAVIA

Anno Accademico 2021/2022

QUANTUM NANOSTRUCTURES	
Enrollment year	2020/2021
Academic year	2021/2022
Regulations	DM270
Academic discipline	FIS/03 (MATERIAL PHYSICS)
Department	DEPARTMENT OF PHYSICS
Course	
Curriculum	Fisica delle tecnologie quantistiche
Year of study	2°
Period	2nd semester (01/03/2022 - 15/06/2022)
ECTS	6
Lesson hours	48 lesson hours
Language	Italian or English upon students' request (English friendly course)
Activity type	ORAL TEST
Teacher	GERACE DARIO (titolare) - 3 ECTS GERACE DARIO (titolare) - 3 ECTS
Prerequisites	This course deals with interdisciplinary topics at the interface between condensed matter physics and theoretical physics, with a focus on quantum mechanics aspects. The background knowledge of basic notions of electromagnetism, optics, quantum physics, and solid-state physics, at the level of Physics bachelor, may help grasping some of the main topics taught. The course is mainly devoted to Master students in Physical Sciences, and it can eventually be attended by PhD students as well. This course may be complemented with attendace of the courses 'Solid State Physics I' and 'Magnetism and Superconductivity' in the first semester.
Learning outcomes	The course aims at delivering basic conceptual knowledge about the physics of nanostructured systems for the quantum confinement of electrons and holes in solids, which are crucially relevant to the current development of a number of quantum technologies. Specific attention

	will be devoted to optical and transport properties in either semiconductor or superconductor low dimensional systems, obtained by exploiting modern epitaxial growth and nanofabrication techniques. Moreover, the course aims at giving a broad overview about the recent applications of nanostructured devices in modern quantum technologies, such as sources of quantum states of light, single-electron transistors, and the definition of qubits. The targeted objectives can be summarized as follows: 1 – learning the main semiconductor and superconductor materials growth and nanofabrication technologies; acquiring basic theoretical knowledge of the effects of reduced dimensionality on optical and transport properties; understanding the main theoretical and experimental tools characterizing the physics of these quantum nanostructures; 2 – applications of the concepts acquired, e.g. to the problem solving on targeted questions in the physics of quantum nanostructures; comparing the different nanostructures based on their qualitative optical and transport behaviors; 3 – being able to read, learn and communicate the results of recent scientific papers. At the end of the course, a ‘suggested reading’ session is devoted to students’ presentations about one or more recent research papers, chosen among a few proposed and dealing with the recent developments in the physics of nanostructures.
Course contents	The course deals with the physics and the applications of nanostructured solid state systems to modern quantum technologies; in particular, the course will focus on either semiconductor or superconductor materials in which quantum confinement in one, two, or three dimensions for electrons (and/or holes) allows to obtain low-dimensional physical systems. The following subjects will be treated: - Semiconductor nanostructures: an introduction to semiconductor physics basic concepts, heterostructures and band discontinuities, envelope function method. - Two-dimensional systems: quantum wells, two-dimensional electron gas. Optical properties: Absorption and emission, interband and intersubband transitions in quantum wells, semiconductor laser; confined excitons and polaritons, quantum polaritonics. Transport properties: Effects of electric and magnetic fields; Quantum Hall effect, integer and fractional. - One- and zero-dimensional systems: quantum wires and quantum dots, electronic levels, transport and optical properties, correlation effects. Definition of qubits in semiconductor quantum dots, and applications to quantum technologies. Photonic confinement, cavity QED and Jaynes Cummings model, single-photon sources. - Superconductor nanostructures: introduction to superconductor materials basic concepts, theory of superconducting circuits, superconducting qubits with Josephson junctions, circuit quantum

	electrodynamics, overview of applications of superconductor nanostructures to quantum technologies, with focus on quantum gates.
Teaching methods	Lectures are given through PowerPoint presentations and blackboard explanations. The PowerPoint slides will facilitate the comprehension of the main concepts thanks to the projection of exemplifying pictures, high-resolution images, plots of theoretical and experimental data, while blackboard demonstrations and derivations will be needed to pause on topics that require more attention from the student. Theoretical aspects will be mainly treated through blackboard lectures. While no dedicated exercise classes will be given, a few examples on how to deal with problems and exercises will be presented during the regular lectures. Occasionally, the regular course lectures could be complemented by seminars or invited lectures given by distinguished and highly qualified professors and researchers.
Reccomended or required readings	-L.C. Andreani, Lecture notes (1998/1999). -J.H. Davies, The Physics of Low-dimensional Semiconductors: An Introduction (Cambridge University Press, 1998). -M.H. Devoret, Quantum fluctuations in electrical circuits, in Les Houches Session LXIII, Quantum Fluctuations (edited by S Reynaud, E Giacobino & J Zinn-Justin, 1995). -S.M. Girvin, Superconducting Qubits and Circuits: Articial Atoms Coupled to Microwave Photons, Lectures delivered at Ecole d'Eté Les Houches (Oxford University Press, 2011).
Assessment methods	The students acquisition of knowledge objectives will be verified through and oral examination. The oral colloquium will be focused on at least three of the topics treated during the course, and the student will be allowed to begin discussing one at his own choice. Then, the examining board will continue with specific and targeted questions, with an overall duration of the exam being between 45 and 60 minutes, usually. The final mark will be the result of the evaluations of the answers to the single topics. In evaluating the students' knowledge and understanding, it is recommended to focus on physical aspects (qualitative trends, figures, methods for measuring various physical properties) rather than on a detailed study of mathematical derivations.
Further information	
Sustainable development goals - Agenda 2030	$lbl_legenda_sviluppo_sostenibile