DOCTORAL STUDIES COURSE UNIT DESCRIPTION

| Name of subject | Scientific Field | Center | Department |
|---|---|---|---|
| **Quantum Semiconductor Structures**<br>(8 ECTS credits) | Physics N 002 | Center for Physical Sciences and Technology | Optoelectronics Department |
| Student’s workload | Hours | Student’s workload | Hours |
| Lectures | 30 | Consultations | |
| Individual study | 160 | Seminars | 10 |

Course annotation

The course aims at presenting basics of a physics of low-dimensional systems and a survey of latest achievements in a field of 2DE, 1DE and 0DE physics.

Detailed studies of the electron energy spectrum in quantum low-dimensional structures and solution of corresponding assigned problems presents introductory skills in a theoretical analysis of quantum nanostructures. The studies of kinetic, optical, electric, and magnetic phenomena in the two- and one-dimensional electron systems prepare students for a self-contained scientific work in contemporary laboratories of condensed matter physics.

The course examines problems of two-, one-, and zero-dimensional electron physics and surveys contemporary achieviements in physics, technology, and engineering of quantum semiconductor nanostructures, namely, quantum wells, heterojunctions, superlattices, quantum wires and dots, nonograins, and quantum point contacts. The course is comprised of the following main topics: quantum wells, resonant tunneling, inversion layers and heterojunctions, Wigner crystalization, quantum Hall effect, quantization of the ballistic conductance, quantum dots, Coulomb blockade, and 2DE kinetics.

List of lectures:

1. Introduction – Size quantization. Infinitely deep potential well. Overview of size quantization effects. Finite quantum well.
2. Quantum wells. Band offsets. Discontinuity of the effective mass. In-plane mass. Envelope function approximation. Kane model. Luttinger Hamiltonian. 2D holes.
3. Ultrathin QWs. Electrons above QWs, virtual levels. Band structure engineering.
4. Two-dimensional electrons. Density of states. 2DE gas. Boltzmann ir Fermi 2DEs. Screening. Dielectric function. Wigner crystal.
5. Coulomb impurities. Excitons. Biexcitons ir trions.
6. Optical transitions of 2D electrons. Transition probability. Absorption coefficient. Interband transitions. Excitonic absorption. Intersubband transitions. Quantum cascade laser.
7. Heterojunctions. MOS structure. Low-2DE-concentration limit. Triangular well. Inversion layer. Fang–Howard wave function.
8. Heterojunctions. Image potential. 2DEs at a surface of liquid He. GaAs-AlGaAs heterojunctions. Modulation doping. Potential balance. □-doping. The sawtooth superlattice.
9. 2DEs in electric and magnetic fields. Stark effect. Field induced ionization. Landau levels. Hall effect. Quantum Hall effect. Crossed ***E*** ir ***B*** fields. Problem of Hall plateaus. Fractional quantum Hall effect.
10. Resonant tunnelling. Transfer matrix technique. Double barrier. Photon-assisted tunnelling.

11. Superlattices. Energy spectrum: Transfer matrix and TBA techniques. Double QW.
12. Superlattices. Bloch oscillations. The Stark ladder. Experimental observations of the Stark ladder and Bloch oscillations. *n-i-p-i* crystals. Photoeffect. Screening of the potential profile.
13. Kinetics. Scattering of 2DEs by ionized impurities. 2DE-phonon interaction. Scattering by acoustic phonons. 2DE mobility. PO scattering.
14. Quantum wires. Fabrication by the direct etching. Growth in situ. 1D electrons. Density of states. Parabolic and cylindrical quantum wires. Quantization of ballistic conductance. Ballistic resistors. Quantum point contacts. Carbon nanotubes.
15. Quantum dots. Fabrication techniques. Stranski–Krastanow dots. Parabolic QDots. FIR spectroscopy. Coulomb blocade. Single-electron transistor.

List of literature


1. C. Weisbuch and B. Vinter, *Quantum Semiconductor Structures* (Academic Press, 1991)
2. G. Bastard, *Wave Mechanics Applied to Semiconductor Heterostructures* (Les Ulis, 1988)
3. J. H. Davies, *The Physics of Low-Dimensional Semiconductors* (Cambridge University Press, 1998)
4. M. J. Kelly, *Low-Dimensional Semiconductors* (Oxford University Press, 1995)
5. P. Harrison, *Quantum Wells, Wires and Dots* (Wiley, 2005)
6. V. Karpus, *Dvimačiai elektronai* (Ciklonas, 2004).


| Consulting teachers | Scientific degree | Pedagogical Name | Main scientific works published in a scientific field in last 5 year period |
|---|---|---|---|
| Vytautas Karpus | Dr. | | 1. V. Karpus, S. Tumėnas, A. Eikevičius, H. Arwin, Interband optical transitions of Zn, *Phys. Status Solidi B* 253(3), 419–428 (2016).<br>2. R. Butkutė, G. Niaura, E. Pozingytė, B. Čechavičius, A. Selskis, M. Skapas, V. Karpus, A. Krotkus, Bismuth quantum dots in annealed GaAsBi/AlAs quantum wells, *Nanoscale Res. Lett*. 12, 436 (2017).<br>3. V. Karpus, R. Norkus, R. Butkutė, S. Stanionytė, B. Čechavičius, A. Krotkus, THz-excitation spectroscopy technique for band-offset determination, *Optics Express* 26, 33807–33817 (2018).<br>4. V. Pačebutas, R. Norkus, V. Karpus, A. Geižutis, V. Strazdienė, S. Stanionytė, A. Krotkus, Band-offsets of GaInAsBi-InP heterojunctions, *Infrared Physics and Technology* 109, 103400 (2020).<br>5. T. Paulauskas, B. Čechavičius, V. Karpus, L. Jočionis, S. Tumėnas, J. Devenson, V. Pačebutas, S. Stanionytė, V. Strazdienė, A. Geižutis, M. Čaplovičová, V. Vretenár, M. Walls, A. Krotkus, Polarization dependent photoluminescence and optical anisotropy in CuPtB-ordered dilute $GaAs_{1-x}Bi_x$ alloys, *J. Appl. Phys*. 128, 195106 (2020). |

Certified during Doctoral Committee session 02/02/2022, protocol No. (7.17 E) 15600-KT-32

Committee Chairman prof. S. Juršėnas