DOCTORAL STUDIES COURSE UNIT DESCRIPTION

Name of subject	Scientific Field	Center	Department
Technology of Semiconductors and their Structures (7,5 ECTS credits)	Materials Engineering T 008	Center for Physical Sciences and Technology	Physical Technologies Optoelectronics
Student's workload	Number of credits ECTS	Student's workload	Number of credits ECTS
Lectures		Consultations	
Individual study	7,5	Seminars	

Course annotation

Objectives and expected skills

Task of the study: to gain knowledge about the properties of semiconductor structures, fundamental mechanisms and technological methods for intentional development of layered hybrid structures creating the basis for practical devices such as radiation sources, detectors, physical and chemical exposure sensors, energy sources (solar cells) and integrated autonomous systems, converting optical, electrical, magnetic and mechanical effects into an electronic signal. Skills to be improved: to select and understand the essence of the information found in various sources, to use the information in solving the scientific problems, as well as for improvement of the professional competence and knowledge in performing the scientific research and development of innovative products and technological processes.

Content of the subject and main themes

1. Structure and related properties of semiconductor materials. Transfer phenomena:

- models for formation of semiconductor crystals and layers, growth methods;
- structure, electronic and photonic properties, charge transfer phenomena.

2. Multilayer and multicomponent structures. Band engineering:

- quantum structures: wells, supercells, stripes, dots;
- intentional changes in the electronic structure ("band-gap-engineering"); A2B6 and A3B5 compounds and solid solutions; energies of the electronic states under the quantum limitations; the density state functions in quantum structures.
- tunnelling phenomena, discontinuity of the bands; quantum transport (influence of magnetic field on the 2D electrons, Shubnikov–de Haas experiments, quantum Hall effect).
- heterojunctions and related properties.

3. Optical properties of quantum structures:

- excitons and shallow impurities in the quantum structures;
- absorption, optical emission, interband transfer;
- Bloch oscillations; quantum limitations related to the Stark effect.

4. Thin film technologies and applications:

- mechanisms and models explaining thin film growth: epitaxy, stressed layers, dependence on the substrate-layer contact, layer adhesion, nanoclusters – nucleation during growth, polycrystalline layers, formation of intergranular boundaries, methods for characterization of the properties in the layers;
- formation of metal-semiconductor contacts in the planar structures, measurement of the characteristics, specific aspects of the electrical properties;
- methods for formation of thin-layer planar field-effect transistors, possibilities to reduce the dimensions, fundamental and technological limitations; insulating and passivating coatings
- optoelectronic devices and their properties;

- deposition methods and growth technologies for thin films: PVD, CVD (PECVD), MOCVD, MBE, ALD;
- lithography methods (photolithography, laser, e-beam, x-ray), related processes; formation of the functional structures by etching (wet chemical etching, dry etching based on reactive ions plasma);
- principles of the technology for the CMOS and integrated systems; clean rooms, general principles for functioning.

5. Methods for investigation of materials and nanostructures:

- structural characterisation: x-ray structural analysis;
- analysis of chemical composition:XPS, .RBS, ESCA, SIMS, Auger spectroscopy.
- methods of microscopy: optical microscopy, SNOM, SEM, TEM, methods of scanning probe microscopy;
- cathodo- and photo-luminescence measurements, Raman spectroscopy, FTIR spectroscopy, ellipsometry.

6. New materials and technologies:

- nanostructured materials and structures, hybrid structures and formation technologies including the bottom-up growth principles, self-arrangement;
- methods for producing of the two-dimensional materials of the atomic thickness (graphene, transition metals dichalcogenides (TMD), etc.), technologies for large-area production, intentional modification of the properties, applications for device development;
- printing and writing methods for formation of the elements and systems on the flexible substrates, hybrid system integration methods; wearable electronics; electronic systems on a transparent and flexible substrate.

7. Semiconductor based structures applied in systems converting external influence into output signals:

-detection of mechanical features: pressure, force, acceleration, stream, principles of functioning and mechanisms originating the response;
- laser based distance measurement, basis of functioning and applied solutions;
- methods for detection and identification of surrounding chemical composition, sensors and functioning principles, resistive gas sensors, ion sensitive field effect transistors, photo-spectrometers;
- IR, vis and UV light emitting sources (emitters) and detectors;
- thin film photovoltaic elements, multi-junction solar cells.

List of literature

1. Solid State Properties. From Bulk to Nano. Mildred Dresselhaus, Gene Dresselhaus, Stephen B. Cronin, Antonio Gomes Souza Filho (eds.), 2018, Graduate Texts in Physics, Springer-Verlag GmbH Germany. ISBN 978-3-662-55920-8, ISBN 978-3-662-55922-2 (eBook). https://doi.org/10.1007/978-3-662-55922-2 .
2. Semiconductor Materials. An Introduction to Basic Principles. B. G. Yacobi (ed.). 2004 Kluwer Academic Publishers, New York, Boston, Dordrecht, London, Moscow. eBook ISBN: 0-306-47942-7; Print ISBN: 0-306-47361-5. Kluwer Online at: http://kluweronline.com and Kluwer's eBookstore at: http://ebooks.kluweronline.com.
3. Characterization of Semiconductor Heterostructures and Nanostructures. (2nd Edition). C. Lamberti and G. Agostini (Eds.), 2013, Elsevier B.V., ISBN 978-0-444-59551-5, http://dx.doi.org/10.1016/B978-0-444-59551-5.00001-7.
4. Thin film growth. Physics, materials science and applications. Zexian Cao (ed.). 2011, Woodhead Publishing Limited, ISBN 978-1-84569-736-5 (print), ISBN 978-0-85709-329-5 (online).
5. Modern Semiconductor Devices for Integrated Circuits. Chenming Calvin Hu, 2010. https://people.eecs.berkeley.edu/~hu/Book-Chapters-and-Lecture-Slides-download.html.

6. Bo Liu, Kun Zhou. Recent progress on graphene-analogous 2D nanomaterials: Properties, modeling and applications. Progress in Materials Science, vol. 100 (2019) pp. 99–169. doi.org/10.1016/j.pmatsci.2018.09.004.

Subject submission and evaluation

Teaching approaches

Primary method for the subject study is learning.

Consultations with the responsible supervisors are available on individual basis for specific themes.

Final exams

The final test of the knowledge of the subject is based on a report on a pre-defined topic. The report have to cover the main aspects of the scientific and technological problems that are the basis of the doctoral studies and the dissertation theme. The size of the report is less than 30 pages (A4 sheet, Times New Roman 12pt, line spacing - 1). The discussions about the work problems must be related to at least 2-3 themes from the list of the subject topics and have to be disclosed in details.

Assessment method

The exam includes three parts with individual scoring. First, the report have to be submitted to the commission 2-3 weeks before the exam date. Second, an oral presentation based on the slides have to be given during the exam session. The presentation must not exceeding 30 minutes. The third part of the exam is based on the discussions after the oral presentation. The discussion is the process of the questions of the commission members and the answers of the student on the aspects of the topic of the report and the presentation.

The date of the exam is determined by agreeing between the members of the comission and the student. The scoring sum include the report up to 3 points, report up to 3, answers to questions and discussions up to 4 points (total up to 10 points).

Consulting teachers	Scientific degree	Pedagogical name	Main scientific works published in a scientific field in last 5 year period
Arūnas Šetkus (arunas.setkus@ftmc.lt)	Habil. Dr.	Prof.	1. T Daugalas, V Bukauskas, A Lukša, V Nargelienė and A Šetkus. Intentionally created localized bridges for electron transport through graphene monolayer between two metals. Nanotechnology, vol. 23 (2022) pp. 375402-1 – 12. doi: 10.1088/1361-6528/ac7578. 2. R. Juškėnas, S. Balakauskas, Z. Mockus, S. Kanapeckaitė, P. Kalinauskas, G. Stalnionis, A. Naujokaitis, A. Selskis, A. Šetkus, G. Niaura. Impact of sulfurization procedure parameters on photoelectrochemical, compositional and structural features of kesterite. Materials Science and Engineering B, vol. 274 (2021) pp. 115483-1 – 7. doi: 10.1016/j.mseb.2021.115483. 3. M. Rudzikas, A. Šetkus, M. Stange, J. Ulbikas, A. Ulyashin. Simple interface based colorization of Si based solar cells and panels with ITO/SiNx:H double layer antireflective coatings. Solar Energy, vol. 207 (2020) pp.

			218 – 227. doi: 10.1016/j.solener.2020.06.091. 4. M. Kamarauskas, V. Agafonov, T. Daugalas, S. Balakauskas, A. Mironas, R. Nedzinskas, G. Niaura, M. Treideris and A. Šetkus. Photovoltaic effect-driven IR response of heterojunctions obtained by direct CVD synthesis of MoS2 nanolayers on crystalline silicon. Nanotechnology, vol. 31 (2020) pp. 425603-1 – 12; doi: 10.1088/1361-6528/ab98c0. 5. A..Sakavičius, G. Astromskas, V. Bukauskas, M. Kamarauskas, A. Lukša, V. Nargelienė, G. Niaura, I. Ignatjev, M. Treideris, A. Šetkus, Long distance distortions in the graphene near the edge of planar metal contacts, Thin Solid Films, vol. 698 (2020) pp. 137850-1–10, doi.org/10.1016/j.tsf.2020.137850 6. M. Kamarauskas, M. Treideris, V. Agafonov, A. Mironas, V. Strazdienė, A. Rėza, A. Šetkus. Black silicon quality control by conditions of nickel assisted etching of crystalline silicon surfaces in photovoltaic devices. Lit. J. Physics, vol. 60 (N.1) (2020) pp. 57 – 66. doi.org/10.3952/physics.v60i1.4164. 7. V. Agafonov, et.al.. Single variable defined technology control of the optical properties in MoS2 films with controlled number of 2D-layers. Nanotechnology, vol. 31 (2020) pp. 025602-1 – 12. doi: 10.1088/1361-6528/ab4753. 8. T. Kaplas, V. Jakstas, A. Biciunas, A. Luksa, A. Setkus, G. Niaura. I. Kasalynas. Effect of High-Temperature Annealing on Graphene with Nickel Contacts. Condens. Matter. Vol. 4 (2019) p. 0021-1 – 7; [doi:10.3390/condmat4010021]. 9. M. Treideris, et.al.. Minimization of Optical Reflectance by Copper Assisted Etching of Crystalline Silicon Surface. Phys. Stat. Solidi A, Vol. 215 (2018) pp. 1700600-1 – 9 [doi: 10.1002/pssa.201700600]. 10. A. Sakavičius, et.al. Annealing time effect on metal graphene contact properties. ECS journal of solid state science and technology. Vol. 7, iss. 5 (2018), p. 77-81. [DOI: 10.1149/2.0201805jss].

Renata Butkutė (renata.butkute @ftmc.lt)	Dr.	Doc.	1. S Pūkienė, et al., Enhancement of photoluminescence of GaAsBi quantum wells by parabolic design of AlGaAs barriers, Nanotechnology, Vol. 30, 455001 (11pp) (2019) https://doi.org/10.1088/1361-6528/ab36f3. 2. V. Karpus, et al., THz-excitation spectroscopy technique for band-offset determination, Optics Express, Vol. 26, No. 26, 33807 (2018); https://doi.org/10.1364/OE.26.033807. 3. V. Pačebutas, et al., Bismides: 2D structures and quantum dots, Journal of Physics D: Applied Physics 50 (36), 364002 (2017). 4. R. Butkutė, et al., Bismuth quantum dots and strong infrared photoluminescence in migration-enhanced epitaxy grown GaAsBi-based structures, Opt. Quant. Electron., Volume 47, Issue 4, pp 873–882 (2015), DOI 10.1007/s11082-014-0019-8.. 5. I.P. Marko, et al, Properties of hybrid MOVPE/MBE grown GaAsBi/GaAs based near-infrared emitting quantum well lasers, Semicond. Sci. Technol., Vol. 30, 094008 (10pp) (2015); doi:10.1088/0268-1242/30/9/094008
Certified by the Doctoral Committee of Material Engineering (T 008) on 09/02/2023, protocol No. (7.17 E) 15600-KT-39			
Committee Chairman prof. habil. dr. Valdas Sirutkaitis			