DOCTORAL STUDIES COURSE UNIT DESCRIPTION

Name of subject	Scientific Field	Faculty	Center/Institute/ Department
Optical Materials (7,5 ECTS credits)	Materials Engineering T 008	Faculty of physics	VU LTC
Student's workload	Number of credits ECTS	Student's workload	Number of credits ECTS
Lectures		Consultations	Up to 1
Individual study	7,5 without any consultations; 6,5 in case of full amount of consultations	Seminars	

Course annotation
Introduction. Classification of optical phenomena; Complex refractive index and dielectric constants. Special properties of materials in solid state. **Optical materials.** Lorentz and Drude models. Crystalline dielectrics and semiconductors: oxides, halides and halogenides. Metals. Metallic colors. Optical glasses. Mixed glasses and dielectrics (metallic and semiconductor nanoparticles). Doping of transparent solids with rare metal ions. Plastic optics and molecular materials. **Synthesis, shaping and polishing of optical materials.** Glassmaking technology. Growth of optical crystals (Verneuil, Czochralski, Bridgeman, Stepanov, Float zone methods, growth from a water-based solutions of salts); Mechanical processing of optical crystals and glasses: cutting, grinding and polishing using free- and fixed abrasives. Equipment: abrasives and related materials. Diamond turning method. Beilby layer, subsurface damage and roughness. Methods of joining optical parts. Production aspheric surfaces and free-forms. Volume Bragg Gratings. Introduction to optimization of production process using design of experiments: variable types, response function model, full and fractional factorial designs, screening and optimization strategies, blocking. **Methods of controlling the shape and roughness of optical surfaces.** Controlled parameters. Methods of controlling the shape and roughness of spherical and flat optical surfaces. Focal length measurement methods. Control of angular dimensions. **Methods of characterization of optical materials.** Photoacoustic absorption spectroscopy, refractive index measurement with refractometers and ellipsometers, infrared absorption and Raman scattering measurements, homogeneity measurements. **Optical coatings**. *Classical deposition technologies to form optical layers.* Physical Vapor Deposition (PVD) Methods (thermal-resistive evaporation; electron beam evaporation; glancing angle deposition (GLAD): anisotropic and porous coatings; ion assisted evaporation), Sputtering methods (magnetron sputtering (DC, RF); ion beam sputtering (IBS)), Chemical Vapor Deposition (CVD), Atomic Layer Coating (ALD), Deposition from liquids and sol-gel coatings. *The most popular coating designs and their spectral response.* Specification of required spectral properties, optical coating design optimization methods. Optical thickness units and classical optical coating structures. Antireflection AR coatings (1V, 2V); filters: broadband, "cut-off", narrowband; high-reflectivity mirrors (metallic, dielectric); beam splitters: for

intensity, spectral dividers (dichroic filters), polarizers; dispersive coatings (chipped mirrors); types and properties of sculptural coatings. *Special topics in optical coatings.* Clean room environment; control methods of growing layer thickness during the deposition process; vacuum pumps (types: advantages and shortcomings); cleaning and transportation of optical substrates; methods of mixing materials during evaporation (optical properties and models of mixtures); deposition of extremely large optical elements: planetary dome, shading methods; the most popular coating materials and working gases. **Actively controlled optical elements.** Electro-optical modulators and switches. Galvanic scanners. Liquid crystal electro-optical elements. Micromechanical spatial and temporal light modulators (MOEMS). Acousto-optical modulators and scanners. Adaptive optical elements. **Standardized characterization methods for of optical elements.** Losses of absorption, scattering and reflection, transmission; estimation of surface shape deviations: waviness and roughness; scratch and dig method for cosmetic surface quality assessment; characterization of optical resistance and damage threshold; **Fiber optical elements.** Materials that are used to make optical fibers and fiber manufacturing methods. Photonic crystal fibers. Fiber optic cables and bundles. Characterization of fiber parameters.
List of literature
1. M.Fox, Optical Properties of Solids, 2nd ed., Oxford University Press, New York, 2010.- 416 p. 2. J.H.Simmons, K.S.Potter, Optical materials, Academic Press, San Diego, London 2000, 391 p. 3. Optical Interference Coatings. Eds. N.Kaiser, H.K.Pulker. Springer, 2002. - 500 p. 4. R.C.Poweel, Physics of Solid-State Laser Materials. AIP Press, 1998. - 423 p. 5. The Properties of Optical Glass, Eds. H.Bach, N.Neuroth, Springer-Verlag, Berlin, 1998.- 414 p. 6. F. Mitschke, Fiber Optics, 2nd ed., Springer, Heidelberg, 2016, 349 p. 7. Optical Shop Testing, 3rd ed., Ed. D.Malacara. J.Wiley&.Sons, Inc., 2007 - 883 p. 8. S. Kasap, P. Capper (eds.) - Springer Handbook of Electronic and Photonic Materials, New York, NY, Springer, 2007, 1572 p. 9. R. Zallen, The Physics of Amorphous Solids, Wiley, 1998, 318 p.
Subject submission and evaluation
There are no lectures on the subject. Doctoral students have to learn by themselves from the specified textbooks. A part of this course is given to Laser Technology program master's students in the 2nd semester in Lithuanian, so sometimes PhD students from other universities or other programs choose to listen to part of those lectures together with current master's students of faculty of Physics. The subject portfolio includes consultations, the topics of which are offered by doctoral students who have chosen the course. The exam consists of two parts. The first is the preparation of a paper, which reviews a certain topic of the subject of laser technologies, which is important for PhD student's work in preparing the dissertation. The scope of the report is >40,000 printing marks. Attempts are made to select the topic of the report in such a way that its material is useful for the overview of the dissertation and the work carried in it. The topic of the report is first proposed by the doctoral student together with his scientific supervisor and then agreed with the consulting professors. After coordination on report topic, the doctoral student prepares the report and forwards it to the consulting professors, who are included in the examination committee. Then the time is set for the presentation of the report and doctoral student gives ~ 20 minutes long presentation. The presentation is delivered to at least 3 members of the examination committee. After the

presentation, the questions of the commission members are answered. The report and its presentation with answers to questions can be evaluated with a maximum of 5 points. The second part of the exam consists of written answers to 6 given questions. It must be done in 2 hours. Usually, a list of generalized questions is prepared, according to the topics specified in the syllabus, from which the 6 questions are selected. After the doctoral students had written their answers, they are scanned and sent to all members of the examination board. Written answers to the 6 given questions can be evaluated with a maximum of 5 points. The assessment of each member of the examination board, both for the report and its presentation, as well as for the answers to the given questions, are averaged and a final summary assessment is recorded based on this, the maximum value of which is 10 points.			
Consulting teachers	Scientific degree	Pedagogical name	Main scientific works published in a scientific field in last 5 year period
Valdas Sirutkaitis (valdas.sirutkaitis@ff.vu.lt)	Habil. Dr.	Prof.	1. L. Gallais, D.-B. Douti, M. Commandré, G. Batavičiūtė, E. Pupka, M. Ščiuka, L. Smalakys, V. Sirutkaitis, and A.Melninkaitis, Wavelength dependence of femtosecond laser-induced damage threshold of optical materials, Journal of Applied Physics 117, 223103 (2015); doi: 10.1063/1.4922353. 2. J. Vengelis, A. Tumas, I. Pipinytė, M. Kuliešaitė, V. Tamulienė, V. Jarutis, R. Grigonis, V. Sirutkaitis, Characteristics of optical parametric oscillator synchronously pumped by Yb:KGW laser and based on periodically poled potassium titanyl phosphate crystal, Optics Communications 410, 774-781, (2018). 3. J. Vengelis, V. Jarutis, V. Sirutkaitis, Measurement of the phase refractive index of a photonic crystal fiber mode, Optics Letters, 43, 2571-2574, (2018). 4. K. Ivanauskienė, I. Stasevičius, M. Vengris, V. Sirutkaitis, Pulse-to-pulse instabilities in synchronously pumped femtosecond optical parametric oscillator, Journal of the Optical Society of America B, 36(1), 131-139, (2019). 5. J. Vengelis, G. Sinkevičius, J. Banys, L. Masiulis, R. Grigonis, J. Domarkas, V. Sirutkaitis, Investigation of piezoelectric ringing effects in Pockels cells based on beta barium borate crystals, Applied Optics 58 (33), 9240-9250 (2019).
Rytis Butkus (rytis.butkus@ff.vu.lt)	Dr.	Doc.	1. V. Vaicaitis, R. Butkus, O. Balachninaite, U. Morgner, I. Babushkin, Diffraction-enhanced femtosecond white-light filaments in air, Appl. Phys. B, 124, 221 (2018). 2. A. Marcinkevičiūtė, K. Michailovas, R. Butkus, Generation and parametric amplification of broadband chirped pulses in

			the near-infrared, Opt. Commun. 415, 70-73 (2018). 3. V. Vaicaitis, M. Kretschmar, R. Butkus, R. Grigonis, U. Morgner, I. Babushkin, Spectral broadening and conical emission of near-infrared femtosecond laser pulses in air, JOSA B, 51, 045402 (2018). 4. V. Pasiskevicius, V. Smilgevicius, R. Butkus, R. Coetzee, F. Laurell, Spatial and temporal coherence in optical parametric devices pumped with multimode beams, Lith. J. of Phys. 58, 62-75 (2018). 5. V. Tamuliene, V. Smilgevicius, D. Kudarauskas, R. Butkus, A. Stabinis, A. Piskarskas, Optical parametric amplification by incoherent conical pump beam, Lith. J. of Phys. 57, 19-28 (2017).
Tomas Tolenis (tomas.tolenis@ ftmc.lt)	Dr.		1. T. Tolenis, L. Grinevičiūtė, R. Buzelis, L. Smalakys, E. Pupka, S. Melnikas, A. Selskis, R. Drazdys, A. Melninkaitis, Sculptured anti-reflection coatings for high power lasers, Opt. Mat. Express, Vol. 7, Issue 4, 2017. 2. T. Tolenis, L. Grinevičiūtė, L. Smalakys, M. Ščiuka, R. Drazdys, L. Mažulė, R. Buzelis ir A. Melninkaitis, Next generation highly resistant mirrors featuring all-silica layers, Sci. Rep., 7, Article No. 10898, 2017. 3. S. Melnikas, T. Tolenis, L. Smalakys, G. Batavičiūtė, A. Melninkaitis, S. Kičas, Enhancement of laser-induced damage threshold in chirped mirrors by electric field reallocation, Opt. Express, 25 (22), pp. 26537-26545, 2017. 4. A. Paulauskas, S. Tumėnas, A. Selksis, T. Tolenis, A. Valavičius, Z. Balevičius, Hybrid Tamm-surface plasmon polaritons mode for detection of mercury adsorption on 1D photonic crystal/gold nanostructures by total internal reflection ellipsometry, Optics Express, 26(23), 2018. 5. L. Grinevičiūtė, C. Babayigit, D. Gailevičius, E. Bor, M. Turduev, V. Purlys, T. Tolenis, H. Kurt, K. Staliunas, Angular filtering by Bragg photonic microstructures fabricated by physical vapour deposition, Appl. Surf. Sc., Vol. 481, p.p. 353-359, 2019.
Andrius Melninkaitis (andrius.melnin kaitis@ff.vu.lt)	Dr.	Doc.	1. Balys Momgaudis, Viaceslav Kudriasov, Mikas Vengris, and Andrius Melninkaitis, "Quantitative assessment of nonlinearly absorbed energy in fused silica via time-

			resolved digital holography," Opt. Express 27, 7699-7711 (2019). 2. Linas Smalakys, Balys Momgaudis, Robertas Grigutis, Simonas Kičas, and Andrius Melninkaitis, „Contrasted fatigue behavior of laser-induced damage mechanisms in single layer ZrO2 optical coating“ Optics Express Vol. 27, Issue 18, pp. 26088-26101, (2019). https://doi.org/10.1364/OE.27.026088 3. Balys Momgaudis, Stephane Guizard, Allan Bilde, and Andrius Melninkaitis, "Nonlinear refractive index measurements using time-resolved digital holography," Opt. Lett. 43, 304-307 (2018). 4. Tolenis, T., Grinevičiūtė, L., Smalakys, L., Ščiuka M., Drazdys R., Mažulė L., Buzelis R., Melninkaitis A., Next generation highly resistant mirrors featuring all-silica layers. Sci Rep 7, 10898 (2017) doi:10.1038/s41598-017-11275-0. 5. Tomas Tolenis, Lina Grinevičiūtė, Rytis Buzelis, Linas Smalakys, Egidijus Pupka, Simas Melnikas, Algirdas Selskis, Ramutis Drazdys, and Andrius Melninkaitis, "Sculptured anti-reflection coatings for high power lasers," Opt. Mater. Express 7, 1249-1258 (2017).
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			