DOCTORAL STUDIES COURSE UNIT DESCRIPTION

Name of subject	Scientific Field	Faculty	Center/Institute/ Department
Laser Technology (7,5 ECTS credits)	Materials Engineering T 008	Faculty of physics	VU LTC FTMC LTS
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
Modern industrial lasers. Fiber and thin-disc continuous ytterbium lasers. High power diode lasers for IR and UV areas. Industrial nanosecond, picosecond and femtosecond pulse high repetition rate lasers. **Properties of laser beams and their characterization**. Beam quality parameter M^2. Principles of selecting parameter M^2 for industrial lasers. Methods of measuring of beams parameters. **Measurement of energetic and temporal parameters of laser radiation**. Energy and power measurement methods and tools. Duration measurement methods and tools. Measurement methods for kilowatt average power beams. **Laser radiation focusing devices**. Focusing with lenses. Single and compound lens focusing. Construction of welding and cutting heads. Laser beam scanning devices. Transport of laser radiation using optical fibers. Devices for determining the optimal focusing distance. **Interaction of laser radiation with matter**. Absorption and reflection of metals, semiconductors and dielectrics and their dependence on wavelength, temperature and surface properties. Physical basis of laser processing of absorbent materials. **Heat transfer during laser processing.** One-dimensional heat transfer. Analytical and numerical methods used in the study of laser material processing. Heat transfer in case of processing with ultrashort pulses: a two-temperature model. **Laser surface treatment**. Surface remelting. Surface alloying. Surface texturing and roughening. Laser cleaning. Laser marking. **Laser cutting**. Various cutting methods: steaming, melting and blowing, scraping, controlled splitting. Oxygen activated laser cutting. **Laser welding**. Physical principles of conduction and deep welding methods. Remote welding and its areas of application. **Laser drilling**. Principles of small and large hole drilling. Dependence of drilling quality on the duration of laser pulses. Drilling with single and repeated pulses. Drilling with ultra-short pulses. **Laser prototyping**. Areas of use. Main methods: stereolithography, selective laser bonding, production of laminated objects, direct laser casting. Multiphoton polymerization with ultrashort pulses. Method comparisons. **Laser micromachining and ablation**. Principles and areas of application of laser micromachining. Ablation of metals and plastics with nanosecond pulses. Ablation and micromachining characteristics using ultrashort laser pulses. Generation of nanoparticles by ablation of materials in liquids.

Laser assisted material processing. Basic principles. Laser assisted turning, milling and shaping. Laser-assisted photochemical etching.
Volumetric labeling of transparent materials. Principles of processing transparent media. Areas of use. Bulk processing of transparent media with femtosecond pulses. Refractive index modification of media. Birefringent modifications in fused quartz and their applications. Labeling transparent media with femtosecond pulses.
Automation of laser processing processes. Principles of automation. Monitoring of parameters of the laser beam, work table and workpiece. Power and temperature control. Robots in laser material processing.
Safety when working with laser devices. Equipment design principles when working with 3rd and 4th hazard class lasers.

List of literature

1. W. M. Steen, J. Mazumder, Laser Material Processing, 4 Ed., Springer, London, 2010.
2. E. Kannatey-Asibu, Jr., Principles of Laser Material Processing, John Wiley & Sons, Hoboken, New Jersey, 2009.
3. J.C. Ion Laser Processing of Engineering Materials, Elsevier Butterworth Heinemann, Amsterdam, 2005 (ISBN 0-7506-6079-1).
4. D. Bauerle Laser Processing and Chemistry, 3rd Edition, Springer 2000 788 p. (ISBN: 3-540-66891-8).
5. M.Fox, Optical Properties of Solids, 2nd ed., Oxford University Press, New York, 2010.-416 p.
6. M. von Allimen, A. Blatter, Laser-Beam Interactions with Materials: Physical principles and Applications, 2nd updated ed. Springer Series in Materials Sciences, Springer-Verlag Berlin 1995.
7. S. Nolte, F. Schrempel, F. Dausinger, Ultrashort Pulse Laser Technology, Springer, 2016, 358 p. (iSBN: 978-3-319-17658-1).
8. R. Osellame, G. Cerullo, R. Ramponi (Eds.), Femtosecond Laser Micromachining, Springer, 2012, 483 p. (ISBN: 978-3-642-23365-2).
9. R.D. Schaeffer, Fundamentals of laser micromachining, CRC Press, 2012, 238 p. (ISBN: 978-1-4398-6084-7).

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 3 given questions. It must be done in 1.5 hours. Usually, a list of 10-15 generalized questions is prepared, according to the topics specified in the syllabus, from which the 3 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 3 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. T. Tičkūnas, M. Perrenoud, S. Butkus, R. Gadonas, S. Rekstyte, M. Malinauskas, D. Paipulas, Y. Bellouard, V. Sirutkaitis, Combination of additive and subtractive laser 3D microprocessing in hybrid glass/polymer microsystems for chemical sensing applications, Opt. Express 25(21), 26280-26288 (2017). 2. S. Butkus, M. Rickus, R. Sirutkaitis, D. Paipulas, V. Sirutkaitis, Fabrication of High Aspect Ratio Channels in Fused Silica Using Femtosecond Pulses and Chemical Etching at Different Conditions, JLMN -Journal of Laser Micro Nanoengineering 14: 19-24, (2019). 3. J. Skruibis, O. Balachninaite, S. Butkus, V. Vaicaitis, V. Sirutkaitis, Multiple-pulse Laser-induced breakdown spectroscopy for monitoring the femtosecond laser micromachining process of glass, Optics and Laser Technology, 111, 295–302 (2019). 4. S. Butkus, E. Gaižauskas, L. Macernyte, V. Jukna, D. Paipulas and V. Sirutkaitis, Femtosecond Beam Transformation Effects in Water, Enabling Increased Throughput Micromachining in Transparent Materials, Appl. Sci. 2019, 9, 2405 (21 p.) (2019); doi:10.3390/app9122405 (www.mdpi.com/journal/applsci). 5. S. Butkus, V. Jukna, D. Paipulas, M. Barkauskas and V. Sirutkaitis, Micromachining of invar foils with GHz, MHz and kHz femtosecond burst modes, Micromachines 11, 733 (2020) doi:10.3390/mi11080733.
Gediminas Račiukaitis, (g.raciukaitis@ftmc.lt)	Dr.		1. A. Žemaitis, P. Gečys, M. Barkauskas, G. Račiukaitis, M. Gedvilas, Highly-efficient laser ablation of copper by bursts of ultrashort tuneable (fs-ps) pulses, Scientific Reports, 9, 12280 (2019)

			2. V. Tomkus,,V. Girdauskas, J. Dudutis, P. Gečys, V. Stankevič, G. Račiukaitis, Impact of the wall roughness on the quality of micrometric nozzles manufactured from fused silica by different laser processing techniques, Applied Surface Science, 483, 205-211 (2019) 3. V. Stankevič, A. Čermák, S. Mikalauskas, P. Kožmín, S. Indrišiūnas, G. Račiukaitis, Processing of ultra-hard materials with picosecond pulses: From research work to industrial applications, Journal of Laser Applications. 30, 032201 (2018) 4. S. Indrišiūnas, B. Voisiat, M. Gedvilas, G. Račiukaitis, New Opportunities for Custom-Shape Patterning Using Polarisation Control in Confocal Laser Beam Interference Setup, Journal of Laser Applications, 29(1), 011501 (2017) 5. P. Gečys, E. Markauskas, S. Nishiwaki, S. Buecheler, R. De Loor, A. Burn, V. Romano, and G. Račiukaitis, CIGS thin-film solar module processing: case of high-speed laser scribing, Scientific Reports. 7, 40502 (2017)
Domas Paipulas (domas.paipulas@ff.vu.lt)	Dr.	Doc.	1. S. Butkus, V. Jukna, D. Paipulas, M. Barkauskas and V. Sirutkaitis, Micromachining of invar foils with GHz, MHz and kHz femtosecond burst modes, Micromachines 11, 733 (2020) doi:10.3390/mi11080733 2. T. Tičkūnas, D. Paipulas, V. Purlys, 4Pi multiphoton polymerization, Appl. Phys. Lett., 116, 031101 (2020). 3. S.Rekštytė, D. Paipulas, V.Mizeikis, Passive fluidic micro-sensor with all-optical readout realized using a direct laser writing technique, Opt.Lett. 44 (18), 4602-4605 (2019). 4. T. Tičkūnas, M. Perrenoud, S. Butkus, R. Gadonas, S. Rekstyte, M. Malinauskas, D. Paipulas, Y. Bellouard, V. Sirutkaitis, Combination of additive and subtractive laser 3D microprocessing in hybrid glass/polymer microsystems for chemical sensing applications, Opt. Express 25(21), 26280-26288 (2017). 5. S. Rekštytė, D. Paipulas, M.Malinauskas, V. Mizeikis, Microactuation and sensing using reversible deformations of laser-written polymeric structures, Nanotechnology. 28(12), 124001-12 (2017).

Vygandas Jarutis (vygandas.jarutis@ff.vu.lt)	Dr.	Doc.	1. V. Jarutis, K. Jurkus, V. Smilgevičius „Temperature tuned doubly resonant OPO: Peculiarities“ Optics Communications 382, 405-409 (2017). 2. J. Vengelis, V. Jarutis, V. Sirutkaitis, "Estimation of photonic crystal fiber dispersion by means of supercontinuum generation", Optics Letters, Vol. 42, No. 9, 1844-1847, May 1 2017. 3. 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). 4. Julius Vengelis, Vygandas Jarutis, Marius Franckevičius, Vidmantas Gulbinas, and Valdas Sirutkaitis, Investigation of supercontinuum generated in the cladding of highly nonlinear photonic crystal fiber, Journal of the Optical Society of America B, 36 (2), A79-A85, (2019). 5. I. Pipinytė, J. Vengelis, V. Jarutis, M. Vengris, R. Grigonis, V. Sirutkaitis, Investigation of continuum generation in the non-zero dispersion-shifted fiber pumped by femtosecond nanojoule pulses in 1450-1800 nm spectral range, Results in Physics 17, 103064 (2020).
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			