DOCTORAL STUDIES COURSE UNIT DESCRIPTION

Name of subject	Scientific Field	Faculty	Center/Institute/ Department
Modern optics and spectroscopy (10 ECTS credits)	Physics N 002	Faculty of Physics	Laser Research Center, Institute of Chemical Physics
Student's workload	Hours	Student's workload	Hours
Lectures	24	Consultations	12
Individual study	214	Seminars	

Course annotation

1. Solid state lasers (R. Butkus)
Structure and properties of solid state laser materials. Optical properties of rare earth ions in materials of solid state lasers. Transition metal ions in solid state laser materials. Non-radiative transitions in laser materials. Slab and fiber lasers. Diode pumping of solid state lasers. Kerr lens modelocking. Lasers in the infrared. The Extreme Light Infrastructure.

2. Optical parametric amplifiers (A. Dubietis)
Short introduction to nonlinear three-wave interactions in birefringent media. Basic nonlinear optical crystals. Parametric fluorescence and superfluorescence. Principles of optical parametric amplification. Parametric gain. Phase matching and wavelength tuning range. Short pulse optical parametric amplification. Group velocity mismatch. Amplification bandwidth. Practical setups for optical parametric amplifiers. Supercontinuum as a seed signal. Self-focusing and self-phase modulation. Supercontinuum generation: nonlinear media and practical schems. Principles of noncollinear optical parametric amplification. Ultrafast optical parametric amplifiers. Optical parametric chirped pulse amplification (OPCPA): current state of the art.

3. Propagation of pulsed radiation (G. Valiulis)
Wave amplitude and phase temporal as well as spatial modulation. Light pulse profiles (Gaussian, Secant, Rectangular, Hyper-Secant). Transform-limited and phase modulated pulses. Light pulse propagation equation in dispersive medium, various dispersion approximations. Normal and anomalous group velocity dispersion. Light pulses dispersive broadening and compression. The spatial (angular) spectrum. Parabolic diffraction equation. Bessel beams. Pulsed beam diffraction. Angular dispersion of the optical wave-packet. Tilted pulses. Non-diffractive pulsed beams (X waves) in linear dispersive medium. Three-wave parametric interaction equations. Parametric amplification in monochromatic pump field. Parametric amplification bandwidth. Nonlinear dispersion. Chirp (phase modulation) reversal. Pulse narrowing caused by pump envelope under the group-velocity matching conditions. Saturation regime. Modal amplification regime.

4. Interaction of matter with spatio-temporally confined light (M. Malinauskas)
Spatially selective light-matter interaction. Spatio-temporal confinement of light. Linear and non-linear interaction, stochastic and deterministic processes, avalanche ionization and multi-photon absorption. Optical power, dose and intensity, light polarization. Pulse duration, repetition rate and number of pulses. Irreversible photomodification via polymerization, crosslinking, reduction, self-organization, trapping. Photoinitiation and chemical quenching,

plasma formation at tight beam focusing. Laser raster microscopy and its implementations towards nanoscopy via STED inspired techniques. Direct laser writing 3D lithography. Extreme UV and multicolor lithography. Optical projection printing. Laser induced forward transfer (LIFT). Laser inscription in transparent solids. Light based 4D printing and 5D memory. Optical micro-manipulation. Integrated lab-on-chip and lab-in-fiber microsystems.

5. Time-resolved spectroscopy (M. Vengris)

Principles of light absorption and emission in atoms, molecules, solids and nanostructures. Quantum mechanical description of time-dependent systems. Techniques for time-resolved fluorescence spectroscopy. Global and target analysis of time-resolved spectroscopic data. Time-resolved absorption spectroscopy (pump-probe). Pump-probe spectroscopy in soft X-ray, extreme UV, mid-IR wavelength ranges. Multi-pulse transient absorption spectroscopy. Time-resolved Raman spectroscopy. Coherent electronic and vibrational spectroscopies: transient gratings, 3 pulse photon echo. Two-dimensional electronic and vibrational spectroscopies.

6. Vibrational Spectroscopy

Brief introduction to theory of vibrational energy levels of diatomic molecules. Infrared absorption and Raman scattering. Normal vibrations of polyatomic molecules. Molecular symmetry in vibrational spectroscopy. Methods of calculation of wavenumbers and intensities of vibrational spectral bands. Enhancement of Raman signals – Resonance Raman scattering and SERS. ATR-FTIR spectroscopy, Nonlinear vibrational spectroscopy. Vibrational spectra and chemical imaging. Raman and infrared microscopies. Modern applications of vibrational spectroscopy.

List of literature

Part 1

1. W. Koechner, *Solid State Laser Engineering* 6th, rev. and updated ed., Springer-Verlag, New York, 2006, 750 p.
2. E. Gaižauskas, V. Sirutkaitis, *Kietojo kūno lazeriai*, VU leidykla, Vilnius, 2008, 290 p.
3. D. Charalambidis et al., *The Extreme Light Infrastructure—Attosecond Light Pulse Source (ELI-ALPS) Project*, In book: Progress in Ultrafast Intense Laser Science XIII, Springer Series in Chemical Physics, January 2017, DOI: 10.1007/978-3-319-64840-8_10
4. Z.Chang et al., Intense infrared laser for strong-field science, Adv. Opt. Photonics, 14, 652-782 (2022).

Part 2

1. G. Cerullo, S. De Silvestri, Ultrafast optical parametric amplifiers, Review of Scientific Instruments 74, 1-18 (2003).
2. C. Manzoni and G. Cerullo, Design criteria for ultrafast optical parametric amplifiers, J. Opt. 18, 103501 (2016).
3. A. Dubietis, Netiesinė optika, Vilniaus universiteto leidykla, 2011, 178 p.
4. A. Dubietis, A. Couairon, Ultrafast Supercontinuum Generation in Transparent Solid State Media, Springer Nature, Cham, Switzerland; ISBN 978-3-030-14994-9, 2019, 125 p. https://link.springer.com/book/10.1007/978-3-030-14995-6

Part 3

1. A. P. Stabinis, G. Valiulis, Ultratrumpųjų impulsų netiesinė optika, Leidykla TEV, 2008, 242 p.
2. S.A.Akhmanov, V.A.Vysloukh, A.S.Chirkin, “Optics of Femtosecond Laser Pulses”, American Institute of Physics, New York, 1992, 366 p.

3. G. Cerullo, S. De Silvestri, Ultrafast optical parametric amplifiers, Review of Scientific Instruments 74, 1-18 (2003).
4. Localized Waves, edited by H. E. Hernandez-Figueroa, M. Zamboni-Rached, and E. Recami Wiley, New York, 2008, 369p.
5. A.Stabinis, G. Valiulis and E. A. Ibragimov, Effective sum frequency pulse compression in nonlinear crystals, Opt. Comm., 86, 301 (1991).
6. G. Valiulis, A. Dubietis, R. Danielius, D. Caironi, A. Visconti, and P. Di Trapani, Temporal solitons in □(2) materials with tilted pulses, J. Opt. Soc. Am. B, 16, 722 (1999).

Part 4
1. K. Sugioka and Y. Cheng, Ultrafast lasers—reliable tools for advanced materials processing, Light: Sci. Appl. 3, e149 (2014).
2. D. Tan, K.N. Sharafudeen, Y. Yue, J. Qiu, Femtosecond laser induced phenomena in transparent solid materials: Fundamentals and applications, Prog. Mater. Sci. 76, 154–228 (2016).
3. M. Malinauskas, A. Žukauskas, S. Hasegawa, Y. Hayasaki, V. Mizeikis, R. uividas, and S. Juodkazis, Ultrafast laser processing of materials: from science to industry, Light: Sci. Appl. 5, e16133, (2016).
4. L. Jonusauskas, S. Juodkazis, and M. Malinauskas, Optical 3D printing: bridging the gaps in the meso-scale, J. Opt. 20, 053001, (2018).

Part 5
1. H. van Amerongen, L.Valkūnas, R.van Grondelle. Photosynthetic excitons. World Scientific Publishers, 2. Singapore, 2000, 590p.
2. M.Vengris. Introduction to time-resolved spectroscopy. (lecture notes) web.vu.lt/ff/m.vengris/images/TR_spectroscopy02.pdf – retrieved 2017.09.15
3. A.Tokmakoff. Time-dependent quantum mechanics and spectroscopy. (lecture notes) https://tdqms.uchicago.edu/ - retrieved 2017.09.15
4. F.Fuller and J.Ogilvie. Annu. Rev. Phys. Chem. 2015.66:667-690.
Part 6
1. M. Diem, Modern Vibrational Spectroscopy and Micro-Spectroscopy, New York: John Wiley and Sons, 2015, 411 p.
2. R. Salzer, H.W. Siesler, Infrared and Raman Spectroscopic Imaging, Wiley-VCH Verlag GmbH & Co., 2009, 510 p.
3. V. Šablinskas, J. Čeponkus, Modernioji molekulių virpesinė spektrometrija, 2014, 241 p. http://www.bfsk.ff.vu.lt/Modernioji_molekuliu_virpesine_spektrometrija.pdf
4. J. M. Hollas, Modern spectroscopy. J. Willey & sons, 2004, 452 p.

Consulting teachers	Scientific degree	Pedagogical name	Main scientific works published in a scientific field in last 5 year period
Rytis Butkus	Dr.	Doc.	1. K. Lengyel, É. Tichy-Rács, K. Timpmann, S. Vielhauer, I. Romet, L. Kovács, G. Corradi, R. Butkus, M. Vengris, R. Grigonis, V. Sirutkaitis, I. Sildos, V. Kiisk, L. Puust and V. Nagirnyi, Cooperative luminescence of Yb3+ ion pairs in Li6Y(BO3)3:Yb single crystals. Journal of Luminescence, 2021. 230: p. 117732. 2. V. Tamulienė, R. Butkus, A. Stabinis, Bandwidth analysis of optical parametric

			amplifier pumped by broadband pulses, JOSA B. 37, 1413–1418 (2020). 3. A. Maecinkevičiūtė, K. Michailovas, R. Butkus, Generation and parametric amplification of broadband chirped pulses in the near-infrared, Opt. Commun. 415, 70–73 (2018). 4. V. Vaičaitis, R. Butkus, O. Balachninaitė, U. Morgner, I. Babushkin, Diffraction-enhanced femtosecond white-light filaments in air, Appl. Phys. B-Lasers Opt. 124, 221 (2018). 5. V. Pašiškevičius, V. Smilgevičius, R. Butkus, R. Coetzee, F. Laurell, Spatial and temporal coherence in optical parametric devices pumped with multimode beams, Lith. J. Phys. 58, 62–75 (2018).
Audrius Dubietis	habil. Dr. (HP)	Prof.	1. S. Vezzoli, V. Bruno, C. DeVault, T. Roger, V. M. Shalaev, A. Boltasseva, M. Ferrera, M. Clerici, A. Dubietis, D. Faccio, Optical time reversal from time-dependent Epsilon-Near-Zero media, Physical Review Letters 120, 043902 (2018). 2. A. Halder, V. Jukna, M. Koivurova, A. Dubietis, J. Turunen, Coherence of bulk-generated supercontinuum, Photonics Research 7, 1345-1353 (2019). 3. R. Šuminas, G. Tamošauskas, G. Valiulis, V. Jukna, A. Couairon, A. Dubietis, Multi-octave spanning nonlinear interactions induced by femtosecond filamentation in polycrystalline ZnSe, Applied Physics Letters 110, 241106 (2017). 4. R. Šuminas, G. Tamošauskas, A. Dubietis, Filamentation-free self-compression of mid-infrared pulses in birefringent crystals with second-order cascading-enhanced self-focusing nonlinearity, Optics Letters 43, 235-238 (2018). 5. G. Tamošauskas, G. Beresnevičius, D. Gadonas, A. Dubietis, Transmittance and phase matching of BBO crystal in the 3-5 μm range and its application for characterization of mid-infrared laser pulses, Optical Materials Express 8, 1410-1418 (2018).
Gintaras Valiulis	habil. Dr. (HP)	Prof.	1. G. Valiulis, K. Kalantojus, P. DiTrapani, Y.-D. Wang, O. Jedrkiewicz, Simultaneous stationarity and localization of linear wave

			packets: The importance of dimensionality and broad spectral support, Physical Review A 89, 053809 (2014). 2. R. Šuminas, G. Tamošauskas, G. Valiulis, A. Dubietis, Spatiotemporal light bullets and supercontinuum generation in β-BBO crystal with competing quadratic and cubic nonlinearities, Optics Letters 41, 2097 (2016). 3. R. Šuminas, G. Tamošauskas, G. Valiulis, V. Jukna, A. Couairon, A. Dubietis, Multi-octave spanning nonlinear interactions induced by femtosecond filamentation in polycrystalline ZnSe, Appl. Phys. Lett. 110, 241106 (2017). 4. A. Dubietis, D. Faccio, G. Valiulis, Chapter 8: Rogue X waves; Non-Diffracting Waves, H. E. Hernandez-Figueroa, M. Zamboni-Rached, E. Recami, eds., Wiley-WCH, ISBN 978-3-527-41195-5, 2014, pp. 211-230.
Mangirdas Malinauskas	Dr.	Prof.	1. M. Malinauskas, A. Žukauskas, S. Hasegawa, Y. Hayasaki, V. Mizeikis, R. uividas, and S. Juodkazis, Ultrafast laser processing of materials: from science to industry, Light: Sci. Appl. 5, e16133, (2016). 2. A. Zukauskas, I. Matulaitiene, D. Paipulas, G. Niaura, M. Malinauskas, and R. Gadonas, Tuning the refractive index in 3D direct laser writing lithography: towards GRIN microoptics, Laser Photon. Rev. 9, 706-712 (2015). 3. S. Rekstyte, T. Jonavicius, D. Gailevicius, M. Malinauskas, V. Mizeikis, E.G. Gamaly, and S. Juodkazis, Nanoscale Precision of 3D Polymerization via Polarization Control, Adv. Opt. Mater. 4, 1209-1214 (2016). 4. D. Gailevicius, V. Padolskyte, L. Mikoliunaite, S. Sakirzanovas, S. Juodkazis, and M. Malinauskas, Additive-Manufacturing of 3D Glass-Ceramics down to Nanoscale Resolution, Nanoscale Horiz. 4, 647-651 (2019). 5. L. Jonusauskas, D. Gailevicius, S. Rekstyte, T. Baldacchini, S. Juodkazis, M. Malinauskas, Mesoscale Laser3D Printing, Opt. Express 27, 15205-15221 (2019).

Mikas Vengris	Dr.	Prof.	1. Llansola-Portoles, M. J.; Redeckas, K.; Streckaite, S.; Ilioaia, C.; Pascal, A. A.; Telfer, A.; Vengris, M.; Valkunas, L.; Robert, B. Lycopene crystalloids exhibit singlet exciton fission in tomatoes. Physical Chemistry Chemical Physics 20, 8640 (2018). 2. Pan, J.; Gelzinis, A.; Chorosajev, V.; Vengris, M.; Senlik, S. S.; Shen, J. R.; Valkunas, L.; Abramavicius, D.; Ogilvie, J. P. Ultrafast energy transfer within the photosystem II core complex. Physical Chemistry Chemical Physics 19, 15356 (2017). 3. Redeckas, K.; Voiciuk, V.; Vengris, M. Investigation of the S-1/ICT equilibrium in fucoxanthin by ultrafast pump-dump-probe and femtosecond stimulated Raman scattering spectroscopy. Photosynthesis Research 128, 169 (2016) . 4. Redeckas, K.; Voiciuk, V.; Zigmantas, D.; Hiller, R. G.; Vengris, M. Unveiling the excited state energy transfer pathways in peridinin-chlorophyll a-protein by ultrafast multi-pulse transient absorption spectroscopy. Biochimica Et Biophysica Acta-Bioenergetics 1858, 297 (2017). 5. Vengris, M.; Garejev, N.; Tamosauskas, G.; Cepenas, A.; Rimkus, L.; Varanavicius, A.; Jukna, V.; Dubietis, A. Supercontinuum generation by co-filamentation of two color femtosecond laser pulses. Scientific Reports 9, 9011 (2019).
Valdas Šablinskas	Dr. (HP)	Prof.	1. J. Ceponkus, M. Jonusas, C. P. Cotter, M. Pucetaite, V. Aleksa, G. A. Guirgis and V. Sablinskas, Structural studies of 1,1-dimethyl-2-oxy-1-silacyclohexane by means of matrix isolation infrared absorption spectroscopy, The Journal of Physical Chemistry A, 119 (11), 2721–2726 (2015). 2. M. Pucetaite, S. Tamosaityte, R. Galli, V. Sablinskas, G. Steiner, Microstructure of urinary stones as studied by means of multimodal nonlinear optical imaging, J. Raman Spectrosc., (online Early View, DOI: 10.1002/jrs.4985) (2016). 3. G. Steiner, G. Preusse, C. Zimmerer, M. Krautwald-Junghanns, V. Sablinskas, H.

			Fuhrmann, E. Koch, T. Bartels, Label free molecular sexing of monomorphic birds using infrared spectroscopic imaging, Talanta 150, 155–161 (2016). 4. M. Pucetaite, M. Velicka, J. Pilipavicius, A. Beganskiene, J. Ceponkus, V. Sablinskas, Uric acid detection by means of SERS spectroscopy on dried Ag colloidal drops. Journal of Raman Spectrocopy, 47(6), 681-686 (2016). 5. V. Šablinskas, M. Velička, M. Pučetaitė, V. Urbonienė, J. Čeponkus, R. Bandzevičiūtė, F. Jankevičius, T. Sakharova, O. Bibikova, G. Steiner, In situ detection of cancerous kidney tissue by means of fiber ATR-FTIR spectroscopy, SPIE digital library, art. no. 1049713 (2018).
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Committee Chairman prof. S. Juršėnas			