DOCTORAL STUDIES COURSE UNIT DESCRIPTION

Name of subject	Scientific Field	Center	Department
Modern Applied Optics (7,5 ECTS credits)	Materials Engineering T 008	Center for Physical Sciences and Technology	Laser Technologies
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
Fiber properties. Materials used and production methods. Optical losses. Chromatic dispersion. Dual refractive index. ***Types of fibers.*** Multimode and single-mode fibers, step and gradient index fibers, polarization maintaining fibers, fibers with modified dispersion characteristics. Fibers for high power amplifiers (large mode area and double cladding fibers, micro-structured optical fibers, photonics crystal fibers, chirally coupled core fibers). Fibers doped with rare earth ions. ***Modes in step index fibers.*** Characteristic equation, linearly polarized (LP) modes, normalized frequency, single-mode fiber condition, multimode fibers. Hybrid modes. Nonlinear propagation of pulse in fibers. The Schrödinger equation describing the pulse propagation in the fiber, the effective mode diameter. Numerical methods for solving the Schrödinger equation (split-step Fourier method, finite difference method). ***Dispersion of group velocities in fibers.*** Broadening of pulses in fibers due to dispersion. Third-order dispersion. Dispersion management. ***Self phase modulation and cross-phase modulation in fibers.*** Spectrum broadening due to self phase modulation and cross phase modulation, non-linear phase shift, pulse shape and initial chirp effects on self phase modulation. Effect of group velocity dispersion on self phase modulation, flat top pulse formation. Light propagation in birefringent fibers and cross phase modulation. ***Stimulated Brillouin and Raman scattering in fibers.*** The origin of phenomena. Brillouin and Raman amplification spectra, thresholds, coupled amplitude equations. Brillouin and Raman fiber lasers and amplifiers. ***Parametric phenomena in fibers.*** Four waves mixing, coupled amplitude equations. Phase matching and ways to achieve it (phase matching in multi-mode, single-mode, birefringent fibers, etc. methods). Parametric gain, gain bandwidth. Parametric fiber oscillators and amplifiers. ***Beam propagation method (BPM)***. FFT and FD beam propagation methods. Wide-angle BPM and Pade approximants. Bidirectional BPM. Scalar and full-vectorial 3D BPM. PML and TBC boundary conditions for beam propagation methods. Imaginary distance BPM and waveguide mode solving. Application of BPM for modeling of propagation of surface plasmons. ***Finite-difference time-domain beam propagation method (FDTD).*** Scalar and full-vectorial time-domain beam propagation method. Algorithm of FDTD and Yee cells mesh. Time-domain Pade approximants for modeling of propagation of short pulses. Evaluation of dispersion and nonlinearities in FDTD method. Application of FDTD in near field and nano optics.

Near field optics. Nonradiating and nonpropagating optical fields. Models for near field optics (FDTD, volume integral equations, BPM). Nano-collectors and nano-emitters. Theory of scanning near field optical microscopy (SNOM). Role of surface plasmons in near field optics. Near field tomography and inverse scattering problem.

Integrated waveguide optics. Application of BPM and FDTD for modeling of integrated optics. Silicon on isolator integrated optics. Modes in ridge waveguides. Y-splitters, Mach-Zehnder interferometers, grating couplers and mode filters. Modulators and detectors, integration with optical fibers and lasers.

Micro-ring resonators. Modes in bended dielectric waveguides. Analytical models for micro-ring resonators. Micro-ring resonators based filters, sensors and modulators.

Ellipsometry. Polarized light. Complex plane. Poincare sphere. Mueller matrix ellipsometry. Spectroscopic ellipsometers and their ellisometric configurations. Applications of ellipsometry. New elipsometric schemes.

Surface spectroscopy. Structural features of the surfaces. Electronic structure of the surfaces. Energy levels of the surfaces. Surface enhanced effects. Strong and weak coupling between different optical surface excitations. Plasmonic resonances (surface plasmon polaritons, localized plasmons, Fano resonances, Tamm plasmon polaritons) Bloch surface waves, Tamm optical states. Application of plasmonic resonances for the optical gas-bio-sensing and integrated optical circal.

Infrared vibrational spectroscopy and applications. Dielectric permittivity in electron-phonon systems. IR vibrational and rotational spectra. Reflection, transmission and attenuated total internal reflection spectroscopy. Fourier spectroscopy. Polarization modulation techniques. Enhanced IR reflection methods of thin molecular films.

Photoacoustic spectroscopy. Photoacoustic effect. Photoacoustic gas spectroscopy. Resonance and non-resonance photoacoustic cuvettes. Detection limit of photoacoustic spectroscopy. FTIR photoacoustic spectroscopy.

Resonant light-matter interaction. Scattering, absorption and stimulated emission. Depletion of the absorption lines. Coherent phenomena in absorption. Optical mutations, free induction relaxation, optical echo.

Laser methods of analytical spectroscopy. Advantages of laser spectroscopy. Transmission-reflection methods. Absorption measurements methods. Fluorescence and Raman scattering methods. Absorption, differential absorption, scattering, fluorescence methods. Nonlinear analytical laser spectroscopy methods. Elimination of Doppler depletion.

Kinetic laser spectroscopy. Relaxation processes in homogeneous and non-homogeneous systems. Pulse fluorescence spectroscopy. Electrical and optical time domain gates. Pump-probe method. Vibrational IR spectroscopy. Dynamic grating method. Photonic echo. Three dimensional coherent spectroscopy. Coherent reaction control.

List of literature

1. G. Agrawal, Nonlinear Fiber Optics, Third Edition, 3rd edition (Academic Press, 2001).
2. Bahaa E. A. Saleh, Malvin Carl Teich, Fundamentals of Photonics, (Editor(s): J. W. Goodman) (John Wiley & Sons, Inc., 1991). Chapter 8.
3. M. Born, E. Wolf. Principles of Optics, T (expanded ed). - Cambridge U. Press, 2002. -952 p.
4. L.Novotny, B.Hecht, Principles of Nano-Optics, Cambridge Unv. Press, 2006, 539p. (ISBN 0-521-83224-1)
5. International Trends in Applied Optics, A.H.Guenther Ed.. - SPIE Press, 2002. - 697 p. (ISBN: 0-8194-4510-X).
6. Nanoplasmonics, eds. S.Kawata and H.Masuhara, Elsevier, 2006, 316 p. (ISBN 0-444-52249-2).
7. Peter Hannaford. Femtosecond laser spectroscopy, Springer, 2005.

8. G. Lifante, Integrated Photonics: Fundamentals, John Wiley & Sons, 2003, 194p. (ISBN 0-470-84868-5)
9. R.Petruškevičius, Artimo lauko ir plačiakampė optika, ,TEV, Vilnius, 2008, 117ps. (ISBN 978-9955-879-33-6).
10. L. Chrostowski, M. Hochberg, Silicon Photonics Design, Cambridge University Press, 2015, 439p.. (ISBN 978-1-107-08545-9)
11. V. Van, Optical Microring Resonators: Theory, Techniques, and Applications, CRC Press, 2017, 288p. (ISBN 978-1-4665-5124-4)
12. Arwin, H. TIRE and SPR-Enhanced SE for Adsorption. In Ellipsometry of Functional Organic Surfaces and Films, Hinrichs K., Eichhorn K.-J., Eds.; Springer-Verlag: Berlin Heidelberg, Germany, 2014; Chapter 12, pp. 249–264.
13. Raether, H. Surface Plasmons on Smoof and Rough Surfaces and on Gratings, Springer-Verlag, Berlin, 1988.
14. Barnes, W. L. Surface plasmon–polariton length scales: a route to sub-wavelength optics. J. Opt. A Pure Appl. Opt. 2006, 8, S87–S93.
15. Yeh, P.; Yariv, A.; Hong, C.-S. Electromagnetic propagation in periodic stratified media I General theory. J. Opt. Soc. Am. 1977, 67, 423–438.
16. Surface Polaritons. Ed. V.M.Agranovich and D.L.Mills. North-Holland, 1982. (ISBN: 978-0444861658)

Additional readings

1. A.Mendez and T. F. Morse, Specialty Optical Fibers Handbook, 1 edition (Academic Press, 2007).
2. F. Mitschke, Fiber Optics: Physics and Technology (Springer, 2010).
3. D. Hewak (Editor), Properties, Processing and Applications of Glass and Rare Earth-Doped Glasses for Optical Fibres (INSPEC, 1998).
4. M. N. Zervas, "High power ytterbium-doped fiber lasers — fundamentals and applications," Int. J. Mod. Phys. B 28, 1442009 (2014).
5. R. Paschotta, "Double-clad Fibers," Encycl. Laser Phys. Technol., http://www.rp-photonics.com/double_clad_fibers.html
6. K. P. Hansen, C. B. Olausson, J. Broeng, D. Noordegraaf, M. D. Maack, T. T. Alkeskjold, M. Laurila, T. Nikolajsen, P. M. Skovgaard, M. H. Sørensen, and others, "Airclad fiber laser technology," Opt. Eng. 50, 111609–111609 (2011).
7. X. Ma, C.-H. Liu, G. Chang, and A. Galvanauskas, "Angular-momentum coupled optical waves in chirally-coupled-core fibers," Opt. Express 19, 26515–26528 (2011).
8. X. Ma, C. Zhu, I.-N. Hu, A. Kaplan, and A. Galvanauskas, "Single-mode chirally-coupled-core fibers with larger than 50μm diameter cores," Opt. Express 22, 9206 (2014).
9. Handbook of optical systems, Ed. H. Gross, Vol. 1, H. Gross, Fundamentals of technical optics, Wiley-VCH, 2005. - 826 p; Handbook of optical systems, Ed. H. Gross, Vol. 2, W.Singer, M.Totzeck, H.Gross, Physical image formation, Wiley-VCH, 2005. - 690 p. (ISBN: 3-527-40378-7).
10. Handbook of Optics. Vol. I - IV. M.Bass (Editor in Chief). McGraw-Hill, Inc. -1995 -2001. ~ 5000 p.; The optics encyclopedia. Basic foundations and practical applications, Vol. 1-5 (Wiley VCH, 2004); Encyclopedia of modern optics, 1-5 Vol., Ed. R.D. Guenther (Elsevier, Academic Press, 2005).
11. Optical Imaging and Microscopy: Techniques and Advanced Systems. Eds. P.Torok and F-J.Kao. - Springer, 2002. - 395 p
12. S.Sinzinger, JJahns. Microoptics. Wiley-VCH, 2003. -433 p.
13. Photonic crystals: Advances in Design, Fabrication, and characterization. Eds. K.Busch et al. Wiley-VCH, 2004. -480 p

<table>
<tr><td colspan="4">14. A.Taflove, S.C.Hagness, Computational Electrodynamics: The Finite-Difference Time-Domain Method, Artech House, 2000, 852p. (ISBN 1-58053-076-1)
15. M.Ohtsu, K.Kobayashi, Optical Near Fields, Springer, 2004, 205p. (ISBN 3-540-40483-X).
16. Nanophotonics, eds. H.Rigneault, J.-M.Lourtioz, C.Delalande, A.Levenson, ISTE Ltd, 2005, 324p. (ISBN 1-905209-28-2).
17. J.Yamaychi, Propagating Beam Analysis of Optical Waveguides, Research Studies Press Ltd, 2003, 279p. (ISBN 0-86380-256-6).
18. K.Okamoto, Fundamentals of Optical Waveguides, Elsevier, 2006, 561p. (ISBN 0-12-525096-7).
19. J. M. Hollas. Modern spectroscopy. Chichester: John Wiley & Sons, 1992. 407 p. (ISBN: 978-0-470-04785-9)
20. Springer Handbook of Lasers and Optics, Ed. F. Trager, (Springer, 2007). - 1332 p. (ISBN: 978-0-387-95579-7)
21. S.Mukamel. Principles of nonlinear optical spectroscopy, Oxford University Press, New York, 1995.</td></tr>
<tr><td>Consulting teachers</td><td>Scientific degree</td><td>Pedagogical name</td><td>Main scientific works published in a scientific field in last 5 year period</td></tr>
<tr><td>Kęstutis Regelskis (kestutis.regelskis@ftmc.lt)</td><td>Dr.</td><td></td><td>1. G. Liaugminas, J.Želudevičius, and K. Regelskis, "Fiber source of femtosecond pulses at 910–940 nm based on a Mamyshev pulse oscillator and wavelength conversion in a photonic crystal fiber," J. Opt. Soc. Am. B 38, 2920-2925 (2021).
2. J. Želudevičius, G.Dubosas, and K.Regelskis, "Investigation of multipass Yb-doped fiber amplifiers," Appl. Opt. 60, 10332-10342 (2021).
3. J. Želudevičius, R.Rutkauskas, and K.Regelskis, "Coherent beam combining of pulsed fiber amplifiers by noncolinear sum-frequency generation," Optics Letters 44, 1813-1816 (2019).
4. J. Želudevičius, M. Mickus, and K. Regelskis, "Investigation of different configurations and operation regimes of fiber pulse generators based on nonlinear spectral re-shaping," Opt. Express 26, 27247–27264 (2018).
5. J.Želudevičius, K.Regelskis, and G.Račiukaitis, "Experimental demonstration of pulse multiplexing and beam combining of four fiber lasers by noncollinear frequency conversion in an LBO crystal," Optics Letters 42, 175–178 (2017).</td></tr>
<tr><td>Raimondas Petruškevičius (raimondas.petruskevicius @ftmc.lt)</td><td>Dr.</td><td></td><td>1. K. Vaškevičius, M. Gabalis, D. Urbonas, A. Balčytis, R. Petruškevičius, S. Juodkazis, "Enhanced sensitivity and measurement range SOI microring resonator with integrated one dimensional photonic crystal", JOSA B, 34 (4), 750-755 (2017).</td></tr>
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Zigmas Balevičius (zigmas.balevicius@ftmc.lt)	Dr.	Doc.	1. J. Anulytė, E. Bužavaitė-Vertelienė, V. Vertelis, E. Stankevičius, V. Vilkevičius, Z. Balevičius, "Influence of a gold nano-bumps surface lattice array on the propagation length of strongly coupled Tamm and surface plasmon polaritons," J. Mater. Chem. C, 2022,10, 13234-13241. (Q1) (IF=8.067). 2. I. Plikusienė, E. Bužavaite-Vertelienė, V. Mačiulis, A. Valavičius, A. Ramanavičienė, Z. Balevičius, "Application of Tamm Plasmon Polaritons and Cavity Modes for Biosensing in the Combined Spectroscopic Ellipsometry and Quartz Crystal Microbalance Method," Biosensors 2021, 11, 501. (Q1, IF=5.743) . 3. E. Stankevičius, K. Vilkevičius, M. Gedvilas, E. Bužavaitė-Vertelienė, A. Selskis, Z. Balevičius, "Direct Laser Writing for the Formation of Large-Scale Gold Microbumps Arrays Generating Hybrid Lattice Plasmon Polaritons in VIS-NIR Range," Advanced Optical Materials (2021) DOI: 10.1002/adom.202100027. (Q1) (IF=10.050). 4. E. Buzavaite-Verteliene, V. Vertelis, Z. Balevicius, "The experimental evidence of a strong coupling regime in the hybrid Tamm plasmon-surface plasmon polariton mode," Nanophotonics, 10 (5) (2021) 1565-1571.

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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			