

DOCTORAL STUDIES COURSE UNIT DESCRIPTION

Name of subject	Scientific Field	Faculty	Center/Institute/ Department
Materials and Technologies for Functional Electronics and Photonics (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	1	Consultations	0.25
Individual study	6.25	Seminars	

Course annotation

Solid electrolyte ceramics and their technologies: crystal structures of solid electrolytes, technology of solid electrolyte ceramics, ion dynamics in solid electrolytes, applications of solid electrolyte ceramics (Dr. Tomas Šalkus).

Surface analysis methods: electron detection, ion detection, photon detection, advanced microscopy techniques (Prof. Roland Tamošiūnas).

Laser technologies for processing electronics and photonics materials: laser microprocessing, laser ablation, laser modification of materials, laser-assisted processing of materials (Dr. Gediminas Račiukaitis).

Advanced laser 3D micro-/nano-processing: volumetric modification of dielectrics via ultrafast pulses, direct laser writing of three dimensional micro- and nano-additive manufacturing, its applications (Prof. Mangirdas Malinauskas).

Disordered organic and inorganic materials: formation of disordered materials, morphology of amorphous materials, chalcogenide glasses, organic polymers, tetrahedral amorphous materials (a-ge, a-si), electron states, features of light absorption, charge carrier transport, recombination of charge carriers, application of disordered materials (Prof. Kęstutis Arlauskas).

Nanometric derivatives, technologies and their applications: epitaxial semiconductor technologies, quantum confined semiconductor derivatives, nanotechnologies and their applications (Dr. Vaidas Pačebutas).

1. SOLID ELECTROLYTE CERAMICS AND THEIR TECHNOLOGIES

1.1. CRYSTAL STRUCTURES OF SOLID ELECTROLYTES

- Crystal structures of Ag^+ solid electrolytes;
- Crystal structures of V_O^{**} and H^+ solid electrolytes;
- Crystal structures of Li^+ and Na^+ solid electrolytes.

1.2. TECHNOLOGY OF SOLID ELECTROLYTE CERAMICS

- Ceramic powder synthesis;
- Processed taking place during ceramics sintering;
- The influence of ceramics sintering on their microstructure, dilatometric measurements.

1.3. ION DYNAMICS IN SOLID ELECTROLYTES

- Basics of impedance spectroscopy;
- Impedance spectrum of solid electrolyte ceramics;
- Relaxation and resonant dispersion of ionic conductivity in solid electrolyte.

1.4. APPLICATIONS OF SOLID ELECTROLYTE CERAMICS

- All-solid- state battery;
- Fuel cell;

- Gas sensors; - Ionistors.
List of literature
1. Tetsuichi Kudo and Kazuo Fueki “Solid State Ionics”, Kadansha, 1990. 2. M.B. Salamon “Physics of Superionic Conductors”, Springer-Verlag Berlin Heidelberg, New York, 1979. 3. A.F. Orliukas, “Superjoniniai laidininkai”, Vilnius, VUL, 2004. 4. J.Ross Macdonald, Impedance Spectroscopy, 1987.
2. SURFACE ANALYSIS METHODS 2.1. ELECTRON DETECTION - Photoelectron spectroscopy (XPS, UPS); - Auger-electron spectroscopy (AES); - Electron energy loss spectroscopy (EELS); - Low-energy electron diffraction (LEED); - Other electron-detection techniques. 2.2 ION DETECTION - Secondary ion mass spectroscopy (SIMS); - Secondary neutral mass spectroscopy (SNMS); - Rutherford back-scattering spectroscopy (RBS); - Low-energy ion scattering (LEIS); - Other ion-detection techniques. 2.3. PHOTON DETECTION - Energy-dispersive X-ray spectroscopy (EDX); - X-ray diffraction (XRD); - Reflection absorption IR spectroscopy (RAIRS); - Raman scattering; - Ellipsometry; - Other photon-detection techniques. 2.4. ADVANCED MICROSCOPY TECHNIQUES - Atomic force microscopy (AFM); - Scanning tunneling microscopy (STM); - Electron microscopies (TEM, SEM+FIB); - Near field optical microscopy (SNOM); - Other microscopies.
List of literature
1. G.Friedbacher, H.Bubert. Surface and Thin Film Analysis. Wiley, 2011. 2. J.C.Vickerman, I.S.Glimore. Surface Analysis – The Principal Techniques. Wiley, 2009. 3. B.Voigtländers. Atomic force microscopy. 2nd Ed. Springer, 2019. 4. A.Ul-Hamid. A Beginners’ Guide to Scanning Electron Microscopy. Springer, 2018. 5. P.W.Hawkes, J.C.H.Spence. Science of Microscopy. Springer, 2006.
3. LASER TECHNOLOGIES FOR PROCESSING ELECTRONICS AND PHOTONICS MATERIALS 3.1 LASER MICROPROCESSING - laser micromachining methods, - lasers used for micromachining, - basic micromachining processes (welding, cutting, marking, alloying). 3.2. LASER ABLATION - specifics of ablation using pulses of various durations (fs- μs), - metal ablation and microstructure formation, - plastic ablation and microstructure formation,

- ablation of dielectrics using single-photon and multi-photon absorption, - ablation in liquid, - formation of ripples, - surface cleaning.
3.3 LASER MODIFICATION OF MATERIALS - annealing, - crystallization, - alloying,
3.4 LASER-ASSISTED PROCESSING OF MATERIALS - laser-assisted chemical etching, - pulsed laser deposition.
List of literature
1. D.Bäuerle, Laser Processing and Chemistry, 3rd Edition, Springer 2000 788 p.. (ISBN: 3-540-66891-8). 2. S. Nolte, F. Schrepel, F. Dausinger, Ultrashort Pulse Laser Technology, Springer, 2016, 358 p. (ISBN: 978-3-319-17658-1). 3. R. Osellame, G. Cerullo, R. Ramponi (Eds.), Femtosecond Laser Micromachining, Springer, 2012, 483 p. (ISBN: 978-3-642-23365-2) 4. H. Misawa. S. Juodkasis, 3D Laser microfabrication. Principles and Application, Wiley-VCH Verlag, 2006. 5. O. Balachninaite, A. Bargelis, A. Dementjev, R. Jonušas, G. Račiukaitis, V. Sirutkaitis, Lazerinė technologija, Vilnius, VUL, 2008.
4. ADVANCED LASER 3D MICRO-/NANO-PROCESSING
4.1 VOLUMETRIC MODIFICATION OF DIELECTRICS VIA ULTRAFAST PULSES - Optical power, dose, intensity, light polarization; - Spatio-temporal localised light-matter interaction: feature size and spatial resolution; - Linear and non-linear interaction, stochastic and deterministic phenomena, avalanche ionization and multi-photon absorption, thermal accumulation; - Photopolymerization mechanisms and cross-linkable materials; - Photomodification of transparent materials.
4.2 DIRECT LASER WRITING OF THREE DIMENSIONAL MICRO- AND NANO-ADDITIVE MANUFACTURING, ITS APPLICATIONS - Direct laser writing 3D lithography; - Direct laser writing in solid transparent dielectrics; - Laser induced forward transfer (LIFT); - Applications of 3D microstructures: micromechanical systems, microfluidic chips, micro-optical components, photonic crystals, metamaterials.
List of literature
1. T. Baldacchini (Ed.), <i>Three-Dimensional Microfabrication Using Two-Photon Polymerization</i> (2nd Edition), Elsevier, (2020), 766 p. (eISBN: 9780128178287). 2. M. Malinauskas, A. Zukauskas, S. Hasegawa, Y. Hayasaki, V. Mizeikis, R. Buividas, and S. Juodkasis, Ultrafast laser processing of materials: from science to industry, <i>Light: Sci. Appl.</i> 5, e16133 (2016); 10.1038/lsa.2016.133, Nature Publishing Group. 3. E. Skliutas et al., Photopolymerization mechanisms at spatio-temporally ultra-confined light, <i>Nanophotonics</i> 10 (4), 1211-1242 (2021); 10.1515/nanoph-2020-0551.
5. DISORDERED ORGANIC AND INORGANIC MATERIALS
5.1. FORMATION OF DISORDERED MATERIALS - definition of disorder; - glazing;

- the formation of glasses from liquid and gaseous phases 5.2. MORPHOLOGY OF AMORPHOUS MATERIALS - geometry and chemistry of close network; - characterization methods of structures; - accidental or continuous close arrangement. 5.2.1. CHALCOGENIDE GLASSES, ORGANIC POLYMERS - 1D, 2D net structures, compositional looseness; - “8 – n” rule and "ideal glass"; - topological defects and variable valency; - models of the structure of organic glasses. 5.2.2. TETRAHEDRAL AMORPHOUS MATERIALS (a-Ge, a-Si) - amorphone and continuous random network (CRN) models; - “dangling” bonds; - Doping. 5.3 ELECTRON STATES - density of electron states; - local states. 5.4. FEATURES OF LIGHT ABSORPTION 5.5. CHARGE CARRIER TRANSPORT - zonal, diffuse hopping, polaron models; - percolation. 5.6. RECOMBINATION OF CHARGE CARRIERS 5.7. APPLICATION OF DISORDERED MATERIALS - Solar cells; - light emitting diodes (LED); - field effect transistors (FET); - sensors; - copying and printing devices.
List of literature
1. Morigaki K., Physics of Amorphous Semiconductors. Imperial College Press and World Scientific Publishing Co. Pte. Ltd. 1999, 415 p. 2. Zallen R., The Physics of Amorphous Solids. WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim, 2004, 300 p. 3. Madan, A., Shaw, M.P., The physics and applications of amorphous semiconductors. Academic Press Complimentary Copy Coordinator, Marketing Dept., San Diego, CA, 1988, 488 p. 4. Mott N. F., Davis E. A., Electronic Processes in Non-Crystalline Materials. Clarendon Press, Oxford, 1979, 710 p. 5. Popescu M.A., Non-Crystalline Chalcogenides. Kluwer Academic Publishers, Dordrecht – Boston – London, 2000, 377 p. 6. C N R Rao, A K Cheetham and A Thirumurugan, Hybrid inorganic–organic materials: a new family in condensed matter physics. J. Phys.: Condens. Matter 20 (2008) 083202. 7. C. Brabec, U. Scherf, V. Dyakonov, Organic Photovoltaics: Materials, Device Physics, and Manufacturing Technologies, Wiley-VCH, 2008, 597 p.
Subject submission and evaluation
6. NANOMETRIC DERIVATIVES, TECHNOLOGIES AND THEIR APPLICATIONS 6.1. EPITAXIAL SEMICONDUCTOR TECHNOLOGIES - Liquid-phase epitaxy; - Vapor-phase epitaxy, metalorganic chemical vapor deposition; - Molecular beam epitaxy.

6.2. QUANTUM CONFINED SEMICONDUCTOR DERIVATIVES

- Quantum dots and their applications;
- Quantum wells and their applications in optoelectronics;
- Semiconductor quantum wires.

6.3. NANOTECHNOLOGIES AND THEIR APPLICATIONS

- Nanocrystal fabrication technologies and applications;
- Nanowire fabrication technologies and applications;
- Carbon nanotechnologies (graphene, nanotubes, fullerenes).

1. Stephen A. Campbell, The science and engineering of microelectronic fabrication, second edition, New York -Oxford, Oxford University Press, 2001.
2. John H. Davies, The Physics of Low-Dimensional Semiconductors, An Introduction, Cambridge University Press, 1998.
3. Paras N. Prasad, Nanophotonics, Wiley-Interscience, 2004.
4. H-G. Rubahn, Nanophysik und Nanotechnologie, Teubner-Verlag, 2002.

1. The FEFMNT course for PhD students is taught by 6 lecturers, each with 4 or 8 academic hours, according to a set schedule in the spring semester.
2. Doctoral students choose a topic for their paper from a list provided. The title of the topic and the content of the paper must not overlap with the content of the dissertation. But it is recommended that the topic of the paper should be knowledge-enhancing. For example: a PhD student working in the field of laser machining chooses a topic on surface characterisation techniques.
3. PhD students prepare a paper and a PPT presentation on their chosen topic, which they present concisely (10 minutes) and answer the questions of the jury during the examination.
4. The topic of the paper is chosen during the course reading, but no later than the last lecture. The paper and the presentation shall be submitted for review by the board at least 5 working days before the examination. The list of topics and the choices made are marked in the Teams FEFMNT course channel.
5. Doctoral students wishing to take the examination must register at the Dean's Office at a date and time agreed in advance with the committee.
6. The assessment of the exam consists of: the paper, its presentation, answers to the questions, 4 written questions. All components contribute equally. I.e. the sum is divided by 7 and this equals the examination grade.
7. The exam questions are individually selected so that they do not overlap with the topic of the paper.
8. Commissioners who are unable to attend the examination shall submit written evaluations of the papers and presentations before the examination.

Consulting teachers	Scientific degree	Pedagogical name	Main scientific works published in a scientific field in last 5 year period
T. Šalkus (tomas.salkus@ff.vu.lt)	Dr.	Doc.	1. M. Mosialek, R.P. Socha, B. Bozek, D. Wilgocka-Slezak, E. Bielanska, A. Kežionis, T. Šalkus, E. Kazakevičius, A.F. Orliukas, M. Dziubaniuk, J. Wyrwa, J. Wojewoda-Budka, M. Faryna, B. Lis, M. Dudek, R. Lach, Changes in properties of scandia-stabilised ceria-doped zirconia ceramics caused by silver migration in the electric field, Electrochimica Acta 338, 135866 (2020). 2. V. Kavaliukė, T. Šalkus, S. Balčiūnas, J. Banys, A.I. Pogodin, O.P. Kokhan, I.P.

			Studeniyak, Electrical properties of $(\text{Cu}_{1-x}\text{Ag}_x)_7\text{GeS}_5\text{I}$ crystals investigated by impedance spectroscopy, <i>Solid State Ionics</i> 363, 115593 (2021). 3. A.V. Shlyakhtina, N.V. Lyskov, T. Šalkus, A. Kežionis, M.V. Patrakeev, I.A. Leonidov, L.G. Shcherbakova, S.A. Chernyak, K.I. Shefer, E.M. Sadovskaya, N.F. Ereemeev, V.A. Sadykov, Conductivity and oxygen diffusion in bixbyites and fluorites $\text{Ln}_{6-x}\text{MoO}_{12}$ ($\text{Ln} = \text{Er}, \text{Tm}; x = 0, 0.5$), <i>International Journal of Hydrogen Energy</i> 46, 16965 (2021). 4. S. Daugėla, T. Šalkus, A. Kežionis, A. Dindune, D. Valdniece, T.K. Pietrzak, A. Žalga, A.F. Orliukas, Temperature-dependent structural changes of $\text{Na}_2\text{Mn}_3(\text{P}_2\text{O}_7)_2$ phase in $\text{NaLiMnP}_2\text{O}_7$ mixed phase compound, <i>Integrated Ferroelectrics</i> 220, 100–109 (2021). 5. D. Tediashvili, G. Gečė, J. Pilipavičius, S. Daugėla, T. Šalkus, J. Juodkazytė, L. Vilčiauskas, Synthesis, characterization, and degradation study of Mn-based phosphate frameworks $(\text{Na}_3\text{MnTi}(\text{PO}_4)_3, \text{Na}_3\text{MnPO}_4\text{CO}_3, \text{Na}_4\text{Mn}_3(\text{PO}_4)_2\text{P}_2\text{O}_7)$ as aqueous Na-ion battery positive electrodes, <i>Electrochimica Acta</i> 417, 140294 (2022).
R. Tomašiūnas (rolandas.tomasunas@ff.vu.lt)	Dr.	Prof.	1. I. Reklaitis, F.Nippert, R.Kudžma, T.Malinauskas, S.Karpov, I.Pietzonka, H.J.Lugauer, M.Strassburg, P.Vitta, R.Tomašiūnas, A.Hoffmann. Differential carrier lifetime in InGaN-based light-emitting diodes obtained by small-signal frequency-domain measurements. <i>J. Appl. Phys.</i> 121, 035701 (2017). 2. V.Svrcek, M.Kolenda, A.Kadys, I.Reklaitis, D.Dobrovolskas, T.Malinauskas, M.Lozech, D.Mariotti, M.Strassburg, R.Tomasiunas. Significant carrier extraction enhancement at the interface of an InN/p-GaN heterojunction under reverse bias voltage. <i>Nanomaterials</i> 8, 1039 (2018). 3. I.Reklaitis, L.Krencius, T.Malinauskas, S.Yu.Karpov, H.J.Lugauer, I.Pietzonka, M.Strassburg, P.Vitta, R.Tomašiūnas. Time of carrier escape and recombination coefficients in InGaN quantum-well active regions of blue,

			cyan, and green light-emitting diodes. Semicond. Sci. Technol. 34, 015007 (2019). 4. P.Ščajev, D.Litvinas, G.Kreiza, S.Stanionytė, T.Malinauskas, R.Tomašiūnas, S.Juršėnas. Highly efficient nanocrystalline Cs_xMA_{1-x}PbBr₃ perovskite layers for white light generation. Nanotechnology 30, 345702 (2019). 5. J.Mickevičius, M.Andrulevicius, O.Ligor, A.Kadys, R.Tomašiūnas, G.Tamulaitis, E.-M.Pavelescu. Type-II band alignment of low-boron-content B_{0.95}GaN/GaN heterostructures. J. Phys. D: Appl. Phys. 52, 325105 (2019).
G. Račiukaitis (gediminas.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. K. Ratautas, A. Jagminienė, I. Stankevičienė, E. Norkus, G. Račiukaitis, Laser-assisted selective copper deposition on commercial PA6 by catalytic electroless plating – process and activation mechanism, Applied Surface Science 470, 405-410, (2019). 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)
M. Malinauskas (mangirdas.malinauskas@ff.vu.lt)	Dr.	Prof.	1. L. Jonusauskas, D. Gailevicius, S. Rekštyte, T. Baldacchini, S. Juodkakis, M. Malinauskas, Mesoscale Laser 3D Printing, Opt. Express 27 (11), 15205-15221 (2019); https://doi.org/10.1364/OE.27.015205, OSA. 2. D. Gailevicius, V. Padolskyte, L. Mikoliunaite, S. Sakirzanovas, S. Juodkakis,

			and M. Malinauskas, Additive-Manufacturing of 3D Glass-Ceramics down to Nanoscale Resolution, <i>Nanoscale Horiz.</i> 4, 647-651 (2019); 10.1039/C8NH00293B, RSC. 3. M. Malinauskas, A. Zukauskas, S. Hasegawa, Y. Hayasaki, V. Mizeikis, R. Buividas, and S. Juodkasis, Ultrafast laser processing of materials: from science to industry, <i>Light: Sci. Appl.</i> 5, e16133 (2016); 4. S. Rekstyte, T. Jonavicius, D. Gailevicius, M. Malinauskas, V. Mizeikis, E.G. Gamaly, and S. Juodkasis, Nanoscale Precision of 3D Polymerization via Polarization Control, <i>Adv. Opt. Mater.</i> 4(8), 1209-1214 (2016); 10.1002/adom.201600155, Wiley-VCH Verlag GmbH & Co. 10.1038/lsa.2016.133, Nature Publishing Group. 5. L. Jonusauskas, S. Juodkasis, and M. Malinauskas, Optical 3D printing: bridging the gaps in the meso-scale, <i>J. Opt.: invited review</i> 20, 053001, (2018); 10.1088/2040-8986/aab3fe, IOP
K. Genevičius (kristijonas.genevicius@ff.vu.lt)	Dr.		1. E. Kamarauskas, A. Jegorove, R.J. Cepas, S. Daskeviciute-Geguziene, K. Genevicius, M. Franckevicius, M. Talaikis, R. Dobuzinskas, F. Scheler, K. Sveinbjornsson, V. Jankauskas, V. Getautis, Cross-linkable fluorene-based hole transporting materials for perovskite solar cells, <i>Chem. Phys.</i> 579 (2024) 112183. https://doi.org/10.1016/j.chemphys.2024.112183. 2. Jegorove, M. Daskeviciene, K. Kantminiene, V. Jankauskas, R.J. Cepas, A. Gruodis, V. Getautis, K. Genevicius, New fluorene-based bipolar charge transporting materials, <i>RSC Adv.</i> 14 (2024) 2975–2982. https://doi.org/10.1039/d3ra07583d. 3. T. Serevicius, R. Skaisgiris, J. Dodonova, I. Fiodorova, K. Genevicius, S. Tumkevicius, K. Kazlauskas, S. Jursenas, Temporal Dynamics of Solid-State Thermally Activated Delayed Fluorescence: Disorder or Ultraslow Solvation?, <i>J. Phys. Chem. Lett.</i> 13 (2022) 1839–1844. https://doi.org/10.1021/acs.jpcllett.1c03810.

			4. N. Klipfel, J. Xia, P. Culik, S. Orlandi, M. Cavazzini, N. Shibayama, H. Kanda, C. Igci, W. Li, Y.-B. Cheng, V. Jankauskas, K. Genevicius, A.M. Asiri, C. Momblona, K. Rakstys, G. Pozzi, M.K. Nazeeruddin, Zn(II) and Cu(II) tetrakis(diarylamine)phthalocyanines as hole-transporting materials for perovskite solar cells, <i>Mater. Today Energy</i> 29 (2022). https://doi.org/10.1016/j.mtener.2022.101110 5. S. Daskeviciute-Geguziene, A. Magomedov, M. Daskeviciene, K. Genevicius, N. Nekrasas, V. Jankauskas, K. Kantminiene, M.D. McGehee, V. Getautis, Cross-linkable carbazole-based hole transporting materials for perovskite solar cells, <i>Chem. Commun.</i> 58 (2022) 7495–7498. https://doi.org/10.1039/d2cc02612k.
V. Pačebutas (vaidas.pacebutas@ftmc.lt)	Dr.		1. I. P. Marko, S. R. Jin, K. Hild, Z. Batool, Z. L. Bushell, P. Ludewig, W. Stolz, K. Volz, R. Butkutė, V. Pačebutas, A. Geižutis, A. Krotkus and S. J. Sweeney, “Properties of hybrid MOVPE/MBE grown GaAsBi/GaAs based near-infrared emitting quantum well lasers”, <i>Semicond. Sci. Technol.</i> 30 094008 (2015). 2. V. Pačebutas, R. Butkute, B. Čechavičius, S. Stanionytė, E. Pozingytė, M. Skapas, A. Selskis, A. Geižutis, A. Krotkus, “Bismides: 2D structures and quantum dots”, <i>Journal of Physics D - Applied Physics</i> Vol. 50, No. 36, 364002 (2017). 3. V. Pačebutas, S. Stanionytė, A. Arlauskas, R. Norkus, R. Butkutė, A. Geižutis, B. Čechavičius, A. Krotkus, „Terahertz excitation spectra of GaAsBi alloys“, <i>Journal of Physics D - Applied Physics</i> Vol. 51, No. 47, 474001 (2018). 4. T. Paulauskas, V. Pačebutas, R. Butkutė, B. Čechavičius, A. Naujokaitis, M. Kamarauskas, M. Skapas, J. Devenson., M. Čaplovičová, V. Vretenár, X. Li, M. Kociak and A. Krotkus, „Atomic-Resolution EDX, HAADF, and EELS Study of GaAs_{1-x}Bi_x Alloys“, <i>Nanoscale Research Letters</i> (2020) 15:121. 5. V. Pačebutas, V. Karpus, A. Geižutis, M. Kamarauskas, A. Selskis, A. Krotkus,

			„Reduction of optical transition energy in composite GaInAsBi quantum wells“, Infrared Physics & Technology 121 (2022) 104002.
Certified by the Doctoral Committee of Material Engineering (T 008) on 14/03/2025, protocol No. (7.17 E) 15600-KT-99			
Committee Chairman dr. Arūnas Kadys			