DOCTORAL STUDIES COURSE UNIT DESCRIPTION

Name of subject	Scientific Field	Center	Center/Institute/ Department
Ultrafast Semiconductor Devices (7,5 ECTS credits)	Materials Engineering T 008	Center for Physical Sciences and Technology	Optoelectronics
Student's workload	Number of credits ECTS	Student's workload	Number of credits ECTS
Lectures		Consultations – 8 hours	
Individual study – 120 hours	7,5	Seminars – 2 hours	

Course annotation
Fundamentals of charge transport in ultrafast semiconductor devices. Hot electron effects in strong electric fields: negative differential conductivity, impact ionization, drift velocity overshoot. Hot optical electrons: characteristic time scales and the main effects. The role of contact phenomena in ultrafast devices. **Photonic devices.** Ultrafast semiconductor lasers. Dynamics of laser diodes. Photoresistors, p-i-n , and avalanche photodiodes. Saturable absorbers for ultrafast mode-locked lasers. Ultrafast light modulators. Optical switches. **Devices using quantum phenomena**. Resonant tunnelling diodes and resonant tunnelling transistors. Single electron transistors. Quantum dot and quantum well laser diodes. Quantum cascade lasers. **Terahertz frequency range electronics**. Optoelectronic methods of THz generation and detection. Emission of terahertz radiation from femtosecond laser-illuminated semiconductor surfaces. Passive components of terahertz electronics systems: filters, lenses, modulators, absorbing and non-reflecting structures. Applications of terahertz radiation in materials research, spectroscopy of chemical and biological materials, and imaging.
List of literature
1. G.Ghione. Semiconductor devices for high-speed optoelectronics, Cambridge University Press, Cambridge, 2009, 463 p. 2. S. Prasad, H. Schumacher, A. Gopinath. High-speed electronics and optoelectronics: devices and circuits, Cambridge University Press, 2009, 430 p. 3. D. Mittleman. Sensing with terahertz radiation, Springer, Berlin, 2003, 337 p. 4. S. M. Sze. High-speed semiconductor devices, John Wiley and Sons, New York, 1990, 630 p.
Subject submission and evaluation
Doctoral students prepare individually, it is planned to provide at least three consultations for each of them. During the last consultation, the day before the exam, the doctoral student is notified of the main questions of the exam. Before the examination, the doctoral student must make a presentation in the seminar on a topic discussed in advance with the lecturers.

Consulting teachers	Scientific degree	Pedagogical name	Main scientific works published in a scientific field in last 5 year period
Arūnas Krotkus, (arunas.krotkus @ftmc.lt)	Habil. Dr.	Prof.	1. Malevich, VL; Ziaziulia, PA; Norkus, R; Pacebutas, V; Nevinskas, I; Krotkus, A, "Terahertz Pulse Emission from Semiconductor Heterostructures Caused by

			Ballistic Photocurrents", SENSORS 21, Article Number 4067 (2021). 2. Devenson, J; Norkus, R; Juskenas, R; Krotkus, A, "Terahertz emission from ultrathin bismuth layers", OPTICS LETTERS 46 (15), pp.3681-3684 (2021). 3. C.S. Ponseca, A. Arlauskas, H.Yu, F. Wang, I. Nevinskas, V. Vaicaitis, A. Krotkus, O. Inganas, F. Gao, "Pulsed Terahertz Emission from Solution-Processed Lead Iodide Perovskite Films", ACS Photonics, 6, 1175-1181 (2019). 4. Adomavicius, R; Nevinskas, I; Treu, J; Xu, X; Koblmuller, G; Krotkus, A, "Pulsed THz emission from wurtzite phase catalyst-free InAs nanowires", JOURNAL OF PHYSICS D-APPLIED PHYSICS 53, 19LT01 (2020). 5. Pacebutas, V; Karpus, V; Geizutis, A; Kamarauskas, M; Selskis, A; Krotkus, A, "Reduction of optical transition energy in composite GaInAsBi quantum wells", INFRARED PHYSICS & TECHNOLOGY 121, Article Number 104002.4 (2022).
Ramūnas Adomavičius, (ramunas.adomavicius@ftmc.lt)	Dr.		1. I. Beleckaitė, J. Treu, S. Morkoetter, R. Doblinger, X. Xu, J.J. Finley, G. Koblmüller, R. Adomavičius, A. Krotkus, "Enhanced THz emission efficiency of composition-tunable InGaAs nanowire arrays", Applied Physics Letters 110(20), 201106 [5 p.] (2017). 2. I. Beleckaitė, L. Burakauskas, R. Adomavičius, "Double-pump-pulse terahertz emission method as a novel tool to investigate ultrafast processes in semiconductors", Infrared, Millimeter, and Terahertz Waves, IEEE, 28 October 2018. (DOI: 10.1109/IRMMW-THZ.2018.8509977). 3. I. Beleckaitė, L. Burakauskas, R. Adomavičius, "Study of surface electric field and photocarrier dynamics in InAs by means of a modified double-pump-pulse terahertz emission method", Lithuanian Journal of Physics, 58, 116-125 (2018). 4. I. Beleckaitė, R. Adomavičius, "Determination of the terahertz pulse emitting dipole orientation by terahertz emission measurements", Journal of Applied Physics, 125, 225706 [8 p.] (2019). 5. R. Adomavičius, I. Nevinskas, J. Treu, X. Xu, G. Koblmuller, A. Krotkus, "Pulsed THz emission from wurtzite phase catalyst-free

			InAs nanowires", Journal of Physics D: Applied Physics 53, 19LT01 (2020).
Irmantas Kašalynas, (irmantas.kasalynas@ftmc.lt	Dr.		1. L. Minkevičius, S. Indrišiūnas, R. Šniaukas, B. Voisiat, V. Janonis, V. Tamošiūnas, I. Kašalynas, G. Račiukaitis, and G. Valušis "Terahertz multilevel phase Fresnel lenses fabricated by laser patterning of silicon", Optics Letters,Vol. 42, Issue 10, pp. 1875-1878 (2017). 2. A. Urbanowicz, J. Jorudas, I. Kašalynas, "Terahertz time-domain spectroscopy of two-dimensional plasmons in AlGaN/GaN heterostructures". Applied Physics Letters, 117 (5), 051105, (2020) (https://doi.org/10.1063/5.0014977). 3. V. Janonis, R. M. Balagula, I. Grigelionis, P. Prystawko, I. Kašalynas, "Spatial coherence of hybrid surface plasmon-phonon-polaritons in shallow n-GaN surface-relief gratings", Optics Express 29, pp. 13839-13851 (2021). 4. D. Pashnev, V. V. Korotyeyev, J. Jorudas, A. Urbanowicz, P. Prystawko, V. Janonis, I. Kašalynas, "Investigation of electron effective mass in AlGaN/GaN heterostructures by THz spectroscopy of drude conductivity", IEEE Transactions on Electron Devices 69, pp. 1-5 (2022). 5. R. M. Balagula, L. Subačius, J. Jorudas, P. Prystawko, M. Grabowski, M. Leszczyński, I. Kašalynas, "Space-charge domains in n-type GaN epilayers under pulsed electric field", Appl. Phys. Lett. 121, 102101 (2022).
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			