



### COURSE UNIT (MODULE) DESCRIPTION

| Course unit (module) title            | Code |
|---------------------------------------|------|
| Materials Characterization Techniques |      |

| Lecturer(s)                                          | Department(s) where the course unit (module) is delivered |
|------------------------------------------------------|-----------------------------------------------------------|
| Coordinator: Prof. Gintautas Tamulaitis<br>Other(s): | Faculty of Physics                                        |

| Study cycle | Type of the course unit (module) |
|-------------|----------------------------------|
| First       | Compulsory                       |

| Mode of delivery | Period when the course unit (module) is delivered | Language(s) of instruction |
|------------------|---------------------------------------------------|----------------------------|
| Auditorium       | 6 (Spring) semester                               | English or Lithuanian      |

| Requirements for students         |                                           |
|-----------------------------------|-------------------------------------------|
| Prerequisites:<br>General Physics | Additional requirements (if any):<br>None |

| Course (module) volume in credits | Total student's workload | Contact hours | Self-study hours |
|-----------------------------------|--------------------------|---------------|------------------|
| 5                                 | 128                      | 64            | 64               |

| Purpose of the course unit (module): programme competences to be developed                                                                                                                                                                                                                                                                                                                                                                                                                 |                                                                                                                           |                                                                                                                          |
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| The course is aimed at the development of the basic knowledge, which is necessary to comprehend the principles of the currently most important techniques for materials characterization, the understanding of the advantages and limitations of the techniques, the competencies of assessment and proper use of the results obtained using these techniques, and the experimental skills in applying the general measuring approaches in specific materials characterization techniques. |                                                                                                                           |                                                                                                                          |
| Learning outcomes of the course unit (module)                                                                                                                                                                                                                                                                                                                                                                                                                                              | Teaching and learning methods                                                                                             | Assessment methods                                                                                                       |
| Dedicated basic knowledge to understand the principles of the main techniques currently in use for structural, electrical and optical measurements (1.1)                                                                                                                                                                                                                                                                                                                                   | Lectures supported by application of the basic knowledge in seminars and laboratory works                                 | Predominantly in mid-term and final exam assessments, partly in assessment of the work in seminars.                      |
| Understanding of general approaches used in physical measurements and their applications in specific measurement techniques (1.2)                                                                                                                                                                                                                                                                                                                                                          | Lectures supported by detailed examples in seminars and hands-on experience in laboratory works                           | Predominantly in mid-term and final exam assessments, partly in assessment of the work in seminars and laboratory works. |
| Understanding of capabilities, advantages and limitations of a wide scope of materials characterization techniques (1.3)                                                                                                                                                                                                                                                                                                                                                                   | Lectures for basics, seminars for detailed presentation of specific techniques, hands-on experience with a few techniques | Predominantly in mid-term and final exam, partly in assessment of the work in seminars and laboratory works.             |
| Skills in selection of measurement techniques, estimation of their applicability limits, data analysis and interpretation (1.3)                                                                                                                                                                                                                                                                                                                                                            | Laboratory works, seminars and self-study work based on the materials presented in lectures                               | Assessment of seminar activities, laboratory works and individual tasks.                                                 |
| Skills of working as a part of teams exploiting big experimental facilities (4.2)                                                                                                                                                                                                                                                                                                                                                                                                          | Laboratory works, interactive observation of big                                                                          | Assessment of achievements in performing laboratory works                                                                |

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|  | measurement facilities in action, data processing and analysis as a part of self-study work | supported by self-study work. |
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| Content: breakdown of the topics                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Contact hours |           |          |           |                 |                           | Self-study work: time and assignments |                  |                                                                                                                                                                                                                                                                                 |
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|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Lectures      | Tutorials | Seminars | Exercises | Laboratory work | Internship/work placement | Contact hours                         | Self-study hours | Assignments                                                                                                                                                                                                                                                                     |
| 1. Direct and indirect measurements. Measurement errors and mistakes. Contacts and contactless techniques.                                                                                                                                                                                                                                                                                                                                                                                                                         | 1             |           |          |           |                 |                           | 1                                     | 4                |                                                                                                                                                                                                                                                                                 |
| 2. Measurements of electrical parameters: I-V curves; linear four point probe, van der Pauw, Hall effect techniques, capacitance and inductance measurements.                                                                                                                                                                                                                                                                                                                                                                      | 3             |           | 1        |           | 3               |                           | 7                                     | 5                | Preparation for laboratory works for all students, preparation for seminar presentation for 3 of them (supposing hereon the total number of 24 students, while the hours indicated are in average and substantially increase individually in the week of seminar presentation). |
| 3. Measurements of optical transmittance and absorption coefficient. Optical spectrometers. Determination of optical parameters of transparent and opaque materials. Measurement peculiarities in infrared and deep UV regions. Optical modulation spectroscopy.                                                                                                                                                                                                                                                                   | 4             |           |          |           | 3               |                           | 7                                     | 5                | Preparation for laboratory works for all students, preparation for seminar presentation for 3 of them                                                                                                                                                                           |
| 4. Techniques for surface morphology measurements: profilometers, techniques for geometrical parameters of thin films, atomic force microscopy.                                                                                                                                                                                                                                                                                                                                                                                    | 2             |           | 1        |           | 3               |                           | 6                                     | 5                | Preparation for laboratory works completion of the first individual task for all students, preparation for seminar presentation for 4 of them.                                                                                                                                  |
| 5. Luminescence spectroscopy. Photoluminescence, X-ray luminesce, and cathodoluminescence. Light dispersion and detection equipment. Time-resolved photoluminescence spectroscopy (streak camera, up-conversion, time-correlated photon counting technique, measurements in microsecond domain). Spatially-resolved luminescence spectroscopy (micro-luminescence, confocal microscopy, scanning near-field optical microscopy). Characterization of stimulated light emission: variable stripe length and Hakki-Paoli techniques. | 5             |           |          |           | 3               |                           | 8                                     | 5                | Preparation for laboratory works for all students, preparation for seminar presentation for 7 of them.                                                                                                                                                                          |
| 6. Luminescence efficiency; injection efficiency, internal quantum efficiency, and light extraction efficiency. Measurements with integrating sphere. Ray tracing calculations.                                                                                                                                                                                                                                                                                                                                                    | 2             |           | 1        |           | 3               |                           | 6                                     | 5                | Preparation for laboratory works for all students, preparation for seminar presentation for 4 of them.                                                                                                                                                                          |
| 7. Photocurrent spectroscopy. Photo-induced                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 2             |           | 1        |           |                 |                           | 3                                     | 5                | Preparation for seminar                                                                                                                                                                                                                                                         |

|                                                                                                                                                                              |           |  |          |  |           |  |              |                                                                                                                                                     |
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| transient spectroscopy and deep-level transient spectroscopy.                                                                                                                |           |  |          |  |           |  |              | presentation for 4 students.                                                                                                                        |
| 8. Techniques based on nonlinear optical phenomena. Pump and probe experiments. Generation of white light continuum. Four-wave mixing. Light-induced transient gratings.     | 2         |  | 1        |  | 3         |  | 6 5          | Preparation for laboratory works for all students, preparation for seminar presentation for 3 of them.                                              |
| 9. Elastic and inelastic light scattering. Rayleigh, Mie, and Tyndall scattering. Brillouin and Raman scattering. Raman scattering techniques for material characterization. | 2         |  | 1        |  |           |  | 3 5          | Preparation for seminar presentation for 3 students.                                                                                                |
| 10. Photoelectron spectroscopy. Angle-resolved photoelectron spectroscopy, X-ray photoemission spectroscopy.                                                                 | 2         |  | 1        |  |           |  | 3 5          | Preparation for seminar presentation for 3 students.                                                                                                |
| 11. Mass spectrometry. Secondary ion mass spectrometry.                                                                                                                      | 1         |  | 1        |  | 2         |  | 4 5          | Preparation for laboratory works for all students, preparation for seminar presentation for 5 of them.                                              |
| 12. X-ray crystallography. X-ray diffraction. Types of experimental techniques, data analysis. X-ray sources for diffractometric measurements.                               | 4         |  |          |  | 2         |  | 6 5          | Preparation for laboratory works and completion of the second individual task for all students, preparation for seminar presentation for 6 of them. |
| 13. Scanning electron microscopy. Transmission electron microscopy.                                                                                                          | 2         |  |          |  | 2         |  | 4 5          | Preparation for laboratory works for all students, preparation for seminar presentation for 3 of them, completion of the third individual task      |
| <b>Total</b>                                                                                                                                                                 | <b>32</b> |  | <b>8</b> |  | <b>24</b> |  | <b>64 64</b> |                                                                                                                                                     |

| Assessment strategy | Weight ,% | Deadline                                                | Assessment criteria                                                                                                                                                                                                                                                                                             |
|---------------------|-----------|---------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Laboratory works    | 20        | Throughout entire semester                              | 4 hands-on laboratory works and 4 laboratory works via interactive visits of large measurement facilities with subsequent individual data analysis. Completion of all 8 tasks required. Key assessment criteria: ability to properly plan and perform measurements; skills in data analysis and interpretation. |
| Seminar activities  | 30        | Throughout entire semester                              | Two presentations (25%-weight each); key assessment criteria: knowledge of the subject presented, good planning, clear and substantiated presentation, suggestibility; participation in discussions (50%-weight each).                                                                                          |
| Self-study          | 10        | Throughout entire semester                              | Solution of three specific tasks assigned individually. (The self-study is also indirectly assessed in seminars and laboratory works).                                                                                                                                                                          |
| Mid-term exam       | 20        | 8 <sup>th</sup> or 9 <sup>th</sup> week of the semester | Answers to five equal-weight open questions in write. Key assessment criteria: understanding of the general approaches, fundamentals of the measurement techniques, and ability to discuss their capacities and applicability.                                                                                  |
| Final exam          | 20        | Session time                                            | Answers to two equal-weight open questions in write and their oral discussion. Key assessment criteria: understanding of the general approaches, fundamentals of the measurement techniques, and ability to discuss their capacities and applicability.                                                         |

| Author | Year of | Title | Issue of a periodical | Publishing place and house or web link |
|--------|---------|-------|-----------------------|----------------------------------------|
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|                                               | publication      |                                                                                                | or volume of a publication               |                                                             |
|-----------------------------------------------|------------------|------------------------------------------------------------------------------------------------|------------------------------------------|-------------------------------------------------------------|
| <b>Compulsory reading</b>                     |                  |                                                                                                |                                          |                                                             |
| G. Tamulaitis                                 | Updated annually | Materials accessible via Moodle system                                                         |                                          | <a href="http://vma.esec.vu.lt/">http://vma.esec.vu.lt/</a> |
| Yang Leng                                     | 2013             | Materials Characterization: Introduction to Microscopic and Spectroscopic Methods, 2nd edition |                                          | Wiley-VCH                                                   |
| D. K. Schroder                                | 2015             | Semiconductor Material and Device Characterization; 3rd Edition                                |                                          | Wiley-Interscience IEEE Press                               |
| <b>Optional reading</b>                       |                  |                                                                                                |                                          |                                                             |
| A. Patane, N. Balkan, eds.                    | 2012             | Semiconductor Research. Experimental Techniques.                                               | Springer Series in Materials Science 150 | Springer                                                    |
| R. P. Campos, A. C. Cuevas, R. E. Muñoz, Eds. | 2015             | Materials Characterization                                                                     |                                          | Springer                                                    |