The Faculty of Engineering and Science
The Study Board for Mathematics, Physics and Nanotechnology

Curriculum for the Master's program in Nanomaterials and Nanophysics

Aalborg University
September 2016

Campus Aalborg

Preface

Pursuant to Act 261 of March 18, 2015 on Universities (the University Act) with subsequent changes, the following curriculum for the Master's program in Nanomaterials and Nanophysics is stipulated. The program also follows the Joint programme regulations and the Examination Policies and Procedures for the Faculty of Engineering and Science.

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Chapter 1: Legal Basis of the Curriculum, etc.

1.1 Basis in ministerial orders

The Master's program in in Nanomaterials and Nanophysics is organised in accordance with the Ministry of Science, Technology and Innovation's Ministerial Order no. 1520 of December 16, 2013 on Bachelor's and Master's Programs at Universities (the Ministerial Order of the Study Programs) and Ministerial Order no. 670 of June 19, 2014 on University Examinations (the Examination Order) with subsequent changes. Further reference is made to Ministerial Order no. 258 of March 18, 2015 (the Admission Order) and Ministerial Order no. 114 of February 3, 2015 (the Grading Scale Order) with subsequent changes.

1.2 Faculty affiliation

The Master's program falls under the Faculty of Engineering and Science, Aalborg University.

1.3 Board of Studies affiliation

The Master's program falls under the Board of Studies for Mathematics, Physics, and Nanotechnology under the School of Science and Engineering.

1.4 External Evaluation

The Master's program is associated with the external evaluator corps for Physics and Astronomy.

Chapter 2: Admission, Degree Designation, Program Duration and Competence Profile

2.1 Admission

Applicants with a legal claim to admission (retskrav):
Applicants with one of the following degrees are entitled to admission:

- Bachelor of Science in Nanotechnology, Aalborg University
- Bachelor of Engineering in Nanotechnology, Aalborg University

Applicants without legal claim to admission:
Students with another Bachelor degree may, upon application to the Board of Studies, be admitted following a specific academic assessment if the applicant is considered as having comparable educational prerequisites. The University can stipulate requirements concerning conducting additional exams prior to the start of study.

2.2 Degree designation in Danish and English

The Master's program in in Nanomaterials and Nanophysics entitles the graduate to the designation civilingeniør, cand.polyt. (candidatus/candidate polytechnices) i nanomaterialer og nanofysik. The English designation is: Master of Science (MSc) in Engineering (Nanomaterials and Nanophysics).

2.3 The program's specification in ECTS credits

The Master's program is a 2-year, research-based, full-time study program. The program is set to 120 ECTS credits.

2.4 Competence profile on the diploma

The following competence profile will appear on the diploma:

> A graduate of the Master's program has competencies acquired through an educational program that has taken place in a research environment.
>
> The graduate of the Master's program can perform highly qualified functions on the labor market on the basis of the educational program. Moreover, the graduate has prerequisites for research (a Ph.D. program). Compared to the Bachelor's degree, the graduate of the Master's program has developed her/his academic knowledge and independence, so that the graduate can independently apply scientific theory and method in both an academic and occupational/professional context.

2.5 Competence profile of the program:

Students graduating with a degree in Nanomaterials and Nanophysics have acquired the following knowledge, skills and competencies:

Knowledge	• within selected areas have knowledge that is based on the highest international research level, for instance in fields like solid state physics, optics, semiconductor physics, surfaces and interfaces, properties of materials and components on the nanoscale, polymer and composite materials and nanoelectronics • on a scientific level be able to understand and reflect over theory, methods and experiments within the mentioned areas
Skills	• can use basic scientific methods and tools within the field of physics and materials science • can be able to select appropriate theories, methods and tools to solve practical problems • can communicate research-based knowledge and discuss professional scientific problems both with peers and non specialists
Competencies	• can manage work and development situations that are complex, unpredictable and require new solutions • can independently initiate and implement discipline-specific and interdisciplinary cooperation and assume professional responsibility • can independently take responsibility for own professional development and specialization

Chapter 3: Content and Organisation of the Program

The program is structured in modules and organised as a problem-based study. A module is a program element or a group of program elements, which aims to give students a set of professional skills within a fixed time frame specified in ECTS credits, and concluding with one or more examinations within specific exam periods that are defined in the curriculum.

The program is based on a combination of academic, problem-oriented and interdisciplinary approaches and organised based on the following work and evaluation methods that combine skills and reflection:

- lectures
- classroom instruction
- project work
- workshops
- exercises (individually and in groups)
- teacher feedback
- reflection
- portfolio work

All modules are assessed through individual grading according to the 7-point scale or Pass/Fail. All modules are assessed by external examination (external grading) or internal examination (internal grading or by assessment by the supervisor only).

Overview of the Master's program in Nanomaterials and Nanophysics:

Semester	Code	Module	ECTS	Assessment	Exam
1	NFM1-1	Characterisation and Synthesis	15	7-point scale	Internal
	NFM1-2	Materials Chemistry	5	7-point scale	Internal
	NFM1-3	Synthesis and Characterisation	5	Pass/Fail	Internal
	NFM1-4	Semiconductor Physics	5	7-point scale	Internal
2	NFM2-1	Functional Nanostructures	15	7-point scale	External
	NFM2-2	Nanostructures and –materials	5	Pass/Fail	Internal
	NFM2-3	Nano-optics	5	7-point scale	Internal
	NFM2-4	Surface Science	5	7-point scale	Internal
3**	NFM3-1	Advanced Applications of Nanotechnology	15	7-point scale	Internal
	NFM3-2	Nanoelectronics	5	Pass/Fail	Internal
	NFM3-3	Optoelectronics*	5	Pass/Fail	Internal
	NFM3-4	Solid Mechanics with Microstructure*	5	Pass/Fail	Internal
4	NFM4-1	Master's Thesis	30	7-point scale	External

*Optoelectronics and Solid Mechanics with Microstructure can be exchanged by other elective modules such as the modules offered by the school or university.

**cf. Joint programme regulations 2.3, students are also given the choice of composing an individual planned semester, including extending the master's thesis to up to 60 ECTS if the thesis includes experimental work. The student can also go abroad, take modules at another Danish university, or complete the project in collaboration with or at a company. All these options require an application and approval by the board of studies. The approval should happen before the semester starts.

3.0 Course in Problem Based Learning and Student Responsibilities at Aalborg University

Title:
Problem Based Learning and Student Responsibilities at Aalborg University

Prerequisites:
None, but the course is compulsory for students not acquainted to the Aalborg PBL model

Objective:
Students who complete the module should:
Knowledge:

- Have knowledge about the organization at Aalborg university and where to get help in different matters
- Have knowledge about how to communicate both in your project groups but also when attending courses
- Have comprehension for how a semester is structured and about the different examination forms we use at Aalborg University
- Have comprehension for how project work and laboratory work is carried out at Aalborg University including safety issues in the laboratory
- Have comprehension for issues concerning plagiarism and the consequence when doing plagiarism
- Have knowledge about the software which are used in the study
- Have knowledge about the IT systems used and how to get started
- Have knowledge about the students counselor and what they can do

Skills:

- Be able to use problem based learning and perform group work when doing projects and courses at Aalborg University
- Be able to use Moodle i. e. for finding lecture plans, time schedules etc.

Competences

- Be able to apply the concepts, theories and methods for problem based learning and group work
- Be able to account for the considerations involved in the process of formulating project reports in practice.

Type of instruction:
Lectures, discussions and group work. The course will take place on Wednesday afternoons.
Form of examination:
Internal assessment during the course/class participation according to the rules in the Examination Policies and Procedures, Addendum to the Framework Provision of Faculty of Engineering and Science, Aalborg University. In this case the assessment is primarily based on the oral performance during the course, this means that the student has to be active during the course time and participate in discussions. The course is an integrated part of the project for those not acquainted to the Aalborg

PBL model, and is a precondition for participation in the project examination. In this way there will be no diploma for the course and it will not be visible on the academic transcripts.

Evaluation criteria:
Passed/not passed as stated in the Framework Provisions

3.1. Description of modules for 1st semester, NFM1

3.1.1. Project module on 1st semester, NFM1

Title: Characterisation and Synthesis/Karakterisering og syntese.

Objectives: This project module will give the student experience with advanced methods for synthesis and characterisation of nanostructures and nanomaterials.

Students who pass this module develop:

Knowledge on

- Methods for creation of nanostructures
- Methods for characterisation of nanostructures

Skills in

- Optical spectroscopy on nanostructures
- Nanolithography
- Advanced microscopy (e.g. SEM, AFM)

Competencies

- Application of advanced methods for creation of small structures based on lithography and/or self-organising systems
- Application of various techniques for studying the fundamental properties of nanostructures like, e.g., size, shape, and electronic properties

Exam format: Individual oral evaluation based on project report.

Evaluation criteria: Are stated in the Joint programme regulations.

3.1.2. Course modules on 1st semester, NFM1

NFM1-2: Course module Materials Chemistry/Materialekemi.

Prerequisites: The module builds on knowledge in the area of Inorganic Chemistry and Physical Chemistry.

Aim: The purposes of the course are to introduce both fundamental chemical principles of materials and nanomaterials, and main methods for developing, optimising, post-treating and characterising materials regarding different physical and chemical performances. The focus will be placed on the relation between chemical composition, structure and properties. The two courses will introduce the current status of materials and nanomaterials technologies.

Learning outcomes: After the course the students should be able to:

Knowledge

- Understand the fundamental principles of materials chemistry
- Understand different application areas of materials and to optimize the production process of materials

Skills

- Prepare, characterize and modify materials to reach the target properties by using the materials chemistry knowledge and laboratory facilities
- Design, synthesize, and produce nanostructured materials with given properties.
- Characterize conventional materials and nano-materials

Content: Materials chemistry focuses on the fundamental principles and applications of both conventional and advanced inorganic materials. The course is divided into the following two parts.

1. General inorganic materials chemistry:
   - Glass chemistry
   - Ceramic chemistry
   - Metal chemistry
   - Cement chemistry
   - Characterisation of inorganic materials

2. Nanomaterials chemistry
   - Thin films
   - Nano-crystals and –particles
   - Carbon nanotubes and other inorganic nanotubes
   - Mesoporous materials
   - Nano wires
   - Production of polymer nanomaterials
   - Nano-structured polymer

Exam format: Individual oral evaluation.

Evaluation criteria: Are stated in the Joint programme regulations.

NFM1-3: Course module Synthesis and Characterisation/Syntese og karakterisering.

Prerequisites: The module builds on knowledge in the area of Electronic structures of solids and Nanofabrication.

Aim: Students completing the module will obtain:

Knowledge within the following areas:

- Optical characterisation techniques
- Ellipsometry
- Photo luminescense
- Electron microscopy
- Electron beam writing
- Thin film deposition
- Reactive ion etching
- Fucused ion beam lithography
- Atomic force microscopy

Skills that enables them to:

- Apply basic experimental techniques for geometrical characterisation of nanostructures
- Synthesise and characterise thin film
- Produce surface structures using particle beam lithography

Competencies:

- Be able to design fabrication processes for nano-scale components
- Be able to produce simple components
- Be able to analyse results and compare to basic limitations

Type of instruction: Lectures combined with theoretical and practical exercises.

Exam format: Individual continuous evaluation based on exercises given through the course.

Evaluation criteria: Are stated in the Joint programme regulations.

NFM1-4: Course module Semiconductor Physics/Halvlederfysik.

Prerequisites: The module builds on knowledge obtained by the module solid state physics II or similar.

Objective: To provide an understanding of the principles behind semiconductors and their applications as well as explain the operation of important electronic and optoelectronic semiconductor components such as transistors.

Knowledge: is obtained within the following subjects:

- Electrons in periodic structures and the band structures of semiconductors
- Crystal structure and characteristic properties of semiconductors including: Silicon and III-V compounds
- Acceptor and donor impurities
- Dynamics and statistics of charge carriers
- P-N diodes and metal-oxide-semiconductor structures

Skills: The student obtains an understanding of the properties of semiconductors and the operation of important semiconductor components .

Competencies: Knowledge of different semiconductors. Understanding of the principles behind semiconductor electronics.

Type of instruction: Lectures with exercises.

Exam format: Individual written or oral evaluation.

Evaluation criteria: Are stated in the Joint programme regulations.

3.2. Description of modules for 2nd semester, NFM2

3.2.1. Project module on 2nd semester, NFM2

Title: Functional Nanostructures/Funktionelle nanostrukturer.

Prerequisites: The module builds on knowledge obtained from project on NFM1.

Objectives: This project module will give the student experience with advanced methods for creation of functional nanostructures. In addition, possible applications of the created nanostructures will be investigated.

Students who pass this module develop:

Knowledge on:

- Methods for creation of functional nanostructures
- Applications of functional nanostructures

Skills in:

- Characterisation of functional nanostructures
- Theoretical description of the properties of functional nanostructures

Competencies:

- Through application of micro- and macroscopic modelling the student will be able to describe the properties and functionality of nanostructures.
- Applications of the properties of the designed nanostructures for adding special functions to macroscopic components

Exam format: Individual oral evaluation based on project report.

Evaluation criteria: Are stated in the Joint programme regulations.

3.2.2. Course modules on 2nd semester, NFM2

NFM2-2: Course module Nanostructures and –materials/Nanostrukturer og –materialer.

Prerequisites: The module builds on knowledge in the area of Quantum Mechanics, Statistical Mechanics, and electronic Structures of Solids.

Aim: Students completing the module will obtain:

Knowledge within the following areas:

- Timedependent perturbation theory
- Electrical properties of metals
- Electrical properties of semiconductors
- PN junctions and tunnel diodes
- Metal-semiconductor junctions
- Optical properties of semiconductors
- Excitons
- Semiconductor light emitting diodes and lasers
- Photonic bandgap structures
- Optical properties of nanospheres

Skills that enables them to:

- Apply basic theoretical models analyse the properties of nanostructure
- Apply effects of electron confinements in the design of electronic and optical components

Competencies:

- Be able to understand basic principles behind active electronic and optical components
- Be able to design simple components

Type of instruction: Lectures combined with theoretical exercises.

Exam format: Individual oral evaluation.

Evaluation criteria: Are stated in the Joint programme regulations.

NFM2-3: Course module Nano-optics/Nanooptik.

Prerequisites: The module builds on knowledge in the area of Electromagnetism, Optics and spectroscopy

Aim: The student must obtain knowledge about nano optical components, emission and propagation of light in nanoscale environments, and the related theory and theoretical methods. Students completing the module will obtain

Knowledge: Knowledge within the following areas

- Planar nano-optical components
- Optical waveguides
- Photonic crystals
- Metallic nanostructures
- Surface Plasmon Polaritons
- Resonators
- Optical antennas
- Light-emission and optical interaction in nanoscale environments
- Near-field-probe microscopy
- Theoretical methods in nano-optics, e.g. the multiple multipole method, spectral methods and propagator methods
- Computerbased solution of nano optical problems

Skills: Skills for solving problems in the above mentioned areas including solving problems numerically on a computer.

Competencies: Competencies that will develop and strengthen knowledge and understanding of the theories and methods of nano -optics within other fields. Based on given information the student must be able to discuss and argument using concepts from the field of nano-optics.

Type of instruction: Lectures combined with theoretical exercises and computer modeling exercises

Examination form: Individual written or oral evaluation.

Evaluation criteria: Are stated in the Joint programme regulations.

NFM2-4: Course module Surface Science/Overfladefysik.

Prerequisites: The module builds on knowledge obtained by the modules Solid State Physics I + II and Quantum Mechanics or similar

Objectives: Students, who follow this module, will acquire insight into principles and methods from solid state physics and chemistry, as well as physics of atoms and molecules on surfaces, interfaces and thin films on the nanoscale. Growth of nanostructures and thin films, as well as chemical reactions, takes place at solid state surfaces. Thus it is important to understand the fundamental physics of surfaces, as well as related applications. After following this module the student should be able to:

• Explain the presented topics, theories and methods
• Use the presented theories and methods on simple systems and phenomena

Knowledge: should be acquired within the following topics:

- Morphology and structure of (crystalline) surfaces and interfaces.
- Growth phenomena in 1, 2 and 3 dimensions, epitaxy, diffusion, segregation and creation of alloys.
- Electronic structure of surfaces (electronic surface states) in metals and semiconductors.
- Gas-surface interactions, including adsorption, desorption, and reactions between adsorbents on surfaces (catalysis).
- Spectroscopic and diffractive methods for characterising the electronic and geometric structure of surfaces and interfaces.
- Application of and the theory behind scanning probe techniques (STM and AFM).

Skills: The student will become skilled in solving problems within the topics listed above and will acquire competencies in the application of theories and methods in the field of surface science.

Competencies: that are acquired develop and strengthen the knowledge and understanding of theory and methods in surface science, as well as their applications. Based on the skills acquired in this module the student should be able to reflect on and discuss topics from surface science.

Type of instruction: Lectures supported by problem solving classes.

Exam format: Individual oral or written evaluation.

Evaluation criteria: Are stated in the Joint programme regulations.

3.3. Description of modules for 3rd semester, NFM3

3.3.1. Project module on 3rd semester, NFM3

Title: Advanced Applications of Nanotechnology/Avancerede anvendelser af nanoteknologi.

Prerequisites: The module builds on knowledge obtained from the project on NFM2.

Objectives: This project module will give the student experience with independently applying nanotechnology within a chosen technological area.

Students who pass this module develop:

Knowledge on:

- Applications of nanotechnology for solving technological problems.

Skills in:

- Applied aspects of nanotechnology.

Competencies:

- Given a problematic technological issue the student can use different tools from nanotechnology to find solutions to the actual problem.

Exam format: Individual oral evaluation based on project report.

Evaluation criteria: Are stated in the Joint programme regulations.

3.3.2 Course modules on 3rd semester, NFM3

NFM3-2: Course module Nanoelectronics/Nanoelektronik.

Prerequisites: The module builds on knowledge in the area of Semiconductor physics.

Objective: To provide knowledge of foundations and operation of low-dimensional semiconductor and nanoelectronic components based on low-dimensional structures.

Knowledge: is obtained within the following subjects:

- Electronic properties of quantum wells and quantum wires
- Methods of simulating their properties
- Application of 2-and 1-dimensional nanostructures as metal-oxide-semiconductor transistors

Skills: The student obtains an understanding of terms and methods for simulation of low-dimensional structures and is able to account for the operation of important nanoelectronic components.

Competencies: Knowledge of low-dimensional semiconductors. Understanding of the principles behind nanoelectronic components.

Type of instruction: Lectures with exercises.

Exam format: Individual continuous evaluation based on active participation.

Evaluation criteria: Are stated in the Joint programme regulations.

NFM3-3: Course module Optoelectronics/Optoelektronik.

Prerequisites: The module builds on knowledge in the area of Optics and spectroscopy.

Aim: The student must obtain knowledge about electro-optic components such as electro-optic modulators, displays, light-emitting diodes, lasers, photodetectors, optical fibers, and how these components can be assembled into a communication system.

Students completing the module will obtain:

Knowledge: Knowledge within the following areas:

- Electro-optic modulator
- Displays, light-emitting diodes, luminescence
- Lasers: semiconductor -, gas – and dye lasers
- Lasers: population inversion and pump threshold
- Lasers: mode-locking and Q-switching
- Photodetectors based on temperature changes, photo emission, and photoconductivity
- Optical fibers
- Optical communication systems
- Noise

Skills: Skills for solving problems within the above mentioned areas.

Competencies: Competencies that will develop and strengthen knowledge and understanding of the theories and methods of optoelectronics within other fields. Based on given information the student must be able to discuss and argument using concepts from the field of optoelectronics.

Type of instruction: Lectures combined with theoretical exercises.

Examination format: Individual oral or written evaluation.

Evaluation criteria: Are stated in the Joint programme regulations.

NFM3-4: Course module Solid Mechanics with Microstructure/Materialemekanik.

Aim: Students who complete the module are expected to:

Knowledge:

- Have gained understanding of basic mechanical properties of engineering materials and modelling procedures used to quantify these properties, as well as the ways in which these properties characterise material response

Skills:

- Be able to understand basic continuum mechanics theories and apply them to simple structural components
- Be able to substantiate different observable deformation modes by underlying physical mechanisms
- Be able to document knowledge related to the application of selected analytical/numerical methods for materials characterisation

Competences:

- Have gained awareness of various responses exhibited by solid engineering materials when subjected to mechanical loadings and an explanation of the physical mechanisms associated with design-limiting behaviour of engineering materials
- Have gained an understanding of predictive analytical and computational frameworks that provide quantitative skills to manage materials-limiting problems in engineering design

Type of instruction: The form(s) of teaching will be determined and described in connection with planning the semester. The description will account for the form(s) of teaching and may be accompanied by an elaboration of the roles of the participants (see chapter 3).The course/project theme is performed in either English or Danish dependent on the participants' language skills.

Exam format: Individual oral or written evaluation.

Evaluation criteria: Are stated in the Joint programme regulations.

3.4. Description of modules for 4th semester, NFM4

3.4.1 Project module on 4th semester, NFM4

Title: Master's Thesis/Kandidatspeciale.

Prerequisites: The module builds on knowledge from the project on NFM3 (3rd semester).

Objectives: The Master's thesis should be approved by the Board of Studies. It will be done as problem based project work, where the student will develop:

Knowledge on:

- Either specialist information on one or a few chosen elements of the relevant topic.
- Or broader insight in the topic with regards to theory, methodology, key elements and their mutual contextual relations.
- Or competencies that, in a relevant way, support and expand the actual competence profile of the student.

Skills in:

- Applying nanotechnology.

Competencies:

- Identifying, formulating and analysing actual problems using independent, systematic and critical thinking.
- Relating a problem to the scientific area in question and justify the choices made with regards to the problem definition in a relevant way.
- Independently making and justifying the choice of scientific theoretical and/or experimental methods.
- The ability to independently apply critical thinking to evaluate both the chosen theory and methodology, as well as to evaluate the analysis, results and conclusions of the project both during and at the end of the project.
- Presenting relevant academic and professional aspects of the project work in a clear and systematic way.

Exam format: Individual oral evaluation based on project report.

Evaluation criteria: Are stated in the Joint programme regulations.

Chapter 4: Entry into Force, Interim Provisions and Revision

The curriculum is approved by the Dean of the Faculty of Engineering and Science and enters into force as of 1st of September 2016.

Students who wish to complete their studies under the previous curriculum from 2013 must conclude their education by the summer examination period 2017 at the latest, since examinations under the previous curriculum are not offered after this time.

Chapter 5: Other Provisions

5.1 Rules concerning written work, including the Master's thesis

In the assessment of all written work, regardless of the language it is written in, weight is also given to the student's spelling and formulation ability, in addition to the academic content. Orthographic and grammatical correctness as well as stylistic proficiency are taken as a basis for the evaluation of language performance. Language performance must always be included as an independent dimension of the total evaluation. However, no examination can be assessed as 'Pass' on the basis of language performance alone; similarly, an examination normally cannot be assessed as 'Fail' on the basis of poor language performance alone.
The Board of Studies can grant exemption from this in special cases (e.g., dyslexia or a native language other than Danish).

The Master's thesis must include an English summary.[1] If the project is written in English, the summary must be in Danish.[2] The summary must be at least 1 page and not more than 2 pages. The summary is included in the evaluation of the project as a whole.

5.2 Rules concerning credit transfer (merit), including the possibility for choice of modules that are part of another program at a university in Denmark or abroad

In the individual case, the Board of Studies can approve successfully completed (passed) program elements from other Master's programs in lieu of program elements in this program (credit transfer). The Board of Studies can also approve successfully completed (passed) program elements from another Danish program or a program outside of Denmark at the same level in lieu of program elements within this curriculum. Decisions on credit transfer are made by the Board of Studies based on an academic assessment. See the Joint programme regulations for the rules on credit transfer.

5.3 Rules for examinations

The rules for examinations are stated in the Examination Policies and Procedures published by the Faculty of Engineering and Science on their website.

[1] Or another foreign language (upon approval from the Board of Studies.
[2] The Board of Studies can grant exemption from this.

5.4 Exemption

In exceptional circumstances, the Board of Studies study can grant exemption from those parts of the curriculum that are not stipulated by law or ministerial order. Exemption regarding an examination applies to the immediate examination.

5.5 Completion of the Master's program

The Master's program must be completed no later than four years after it was begun.

5.6 Rules and Requirements concerning the Reading of Texts in Foreign Languages and a Statement of the Foreign Language Knowledge

It is assumed that the student is able to read academic texts in English and uses reference works, etc., in other European languages.

5.7 Additional information

The current version of the curriculum is published on the Board of Studies' website, including more detailed information about the program, including exams.