Nanotechnology curriculum

V1 (pre-pilot)

Experts in Nanotechnology Exploitation project

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Curriculum v1.0 a.k.a. pre-pilot curriculum

For the Nanotechnology pilot at the University of Twente we made a curriculum (curriculum v1.0).

Module		Hours
1	Introduction to nanotechnology	5.0
	This module provide a general introduction of the field of nanotechnology. It will introduce the nanometre as a length scale, but also demonstrate the interdisciplinary nature of the field. The history of the emergence of nanotechnology will be discussed. Application areas in which nanotechnology will have its impact will be discussed, including the type of products that are already in the marketplace today. In the last part of the module different societal aspects that arise with the introduction of nanotechnology will be discussed, including the potential risks.	
Basics:		
2	Nanomaterials	10.0
	This module is one of the core modules of the course. First, a short introduction into atoms and molecules will be given. This is essential knowledge in the upcoming items in this module. Next, the module will introduce a variety of usable materials and nanomaterials to the participant. The materials discussed are macroscopic materials which can be shaped on nanometre level: polymers, silicon/semiconductors. The other class of materials discussed are the nanomaterials. These are made with the building blocks of nanotechnology: atoms and molecules. Examples of these nanomaterials are: carbon-based structures (nanotubes/fullerenes/graphene), biomolecules, nanoparticles (metal, semiconductor, polymeric), nanocomposites (combination of nanoparticles with biomolecules in pharmaceutical applications), and nanocoatings (antimicrobial, omniphobic, etc.). Of all these materials, the properties, applications, and fabrication methods will be discussed. Some of these briefly because a more comprehensive module about these topics will follow.	
3	Processes & fabrication	10.0
	This module focusses on the processes and fabrication steps in which the nanomaterials are formed or the materials are being shaped to useful nanostructures. The structure of this module contains three main components, the two distinct approaches in the development of nanostructures and/or nanomaterials: top-down processing and bottom-up fabrication. The third component is the synthesis/fabrication of nanoparticles. In top-down processing, we will discuss the concepts of photolithography, etching techniques (wet etching and plasma etching), deposition techniques (sputtering, ALD, MBE, and different CVD techniques like PECVD, LPCVD, and MOCVD) and imprint techniques (hot embossing). These techniques will be coupled to examples in wide range of applications. Examples of these applications are MEMS-based nanotechnology, nanosieves, and nanostructured omniphobic surfaces. For bottom-up fabrication we will first give a general introduction into nanochemistry, with a focus on the techniques of self-assembly, monolayer formation, and soft lithography/rapid prototyping. Application examples in this component are self-assembled protein cages for drug delivery, functionalized surfaces, and polydimethylsiloxane-based (PDMS-based) devices.	

	The third component, nanoparticles is a category on its own. These particles can be made with both top-down processing techniques (Equal Channel Angular Pressing (ECAP) and size reducing techniques like milling) as well as bottom-up fabrication techniques (self-assembly). The variety of materials of which these nanoparticles are made is wide and covers materials like gold and other metals and oxides. A special group of nanoparticles are the quantum dots, which are made as a hybrid system. These techniques and materials will be discussed and compared. Also, applications in the semiconductor industry, and biomedical/pharmaceutical world and coatings world will be discussed.	
4	Characterization	10.0
	This module discusses different characterization techniques for nanostructure. We will focus on the explanation and identification of the physical and instrumental principles of the techniques, including molecular and continuum (macroscopic) scale characterization of organic and inorganic materials and their application to specific questions. By the end of this course the students are able to estimate specific nanostructure materials and molecular properties from given examples and problems. Techniques that are discussed are: - Optical tools (microscopy, nanoscopy) - Scanning probe techniques (STM, AFM) - Electron microscopies (SEM, TEM) - Spectroscopy techniques (fluorescence) - X-ray techniques (XPS, XRD)	
Applications:		
5	Medical applications	7.5
	This is the first module completely focused on a group of applications of nanotechnology. This group are the medical applications. Within this group, we will discuss devices with a particular nanosensing application for the early diagnostics of diseases (the lab-on-a-chip systems) and the field of nanomedicine. The first two topics are device orientated, which means that the whole process from designing to fabrication to characterization will be discussed again, but briefly. But now, also the real-life application will be discussed. The main question we are going to answer here is “how is nanotechnology used in an everyday scenario”. The third topic has a more biological and pharmaceutical nature. Again, the process of designing to characterization will be discussed briefly (but now of course completely focusses on bottom-up fabrication) and the working of these nanomedicines in the body will be discusses more comprehensive.	
6	nanobio applications	7.5
	The second applications-orientated module is focusing on nanobiological applications. Main applications are the bio-inspired nanostructured surfaces with superhydrophobic and/or antibacterial properties, and devices which are used for research on artificial organs (the organ-on-a-chip systems). The same structure as in module 5 is followed, meaning the whole process from designing to characterization combined with the application of the structures.	
7	Energy	7.5
	This module describes the use of nanotechnology in the exciting, dynamic and fast-developing field of nano-energy, which joins nanoscience and nanotechnology with energy science. We cover the science and engineering of nanomaterials and	

	nanodevices used in all forms of (renewable) energy harvesting, energy conversion, storage of (renewable) energy, and utilization. In the harvesting part the following techniques are discussed: - Organic and inorganic solar cells - Blue energy - MEMS-based energy harvesting Energy conversion: - Dye-sensitized solar cells - Photocatalysis - Water conversion - Proton exchange membranes And in the storage part: - Fuel cells - Batteries - Polymeric supercapacitors Utilization: - Comparison between different solar cells - Status quo of fuel cells The same structure as in the last two application-based modules will be used, meaning that both the development and the application will be discussed.	
8	Nano-electronics & nano-optics	7.5
	Not available in this version.	
Hands-on:		
9	Case study	7.5
	Not available in this version.	
	Total:	**72.5**

Because of these widespread fields of technology and application we were not able to finalize module 8 and 9 on paper before the pilot. However, this was not of importance, since a selection was made for the pilot training. This selection was used in the pilot to test the concept and structure of the curriculum and consisted mainly of nanotechnology modules, but it also had some societal and innovation management modules in it. This was the result of the company survey. The companies showed more interest in an application directed workshop than a fundamentally orientated workshop. With the chosen modules, the coherence of the project activities are also demonstrated. The now-following list gives all the modules and topics, with a short motivation why it was put in the curriculum.

Basics

The first module is the basics module. This module is basic knowledge for all later following application modules. The basics is divided into three topics. Each topic is listed with the responsible lecturer during the workshop:

- Top-down fabrication: Principles, Techniques and Examples – dr. Alexey Kovalgin (SC)

    - This module contains the common top-down fabrication steps as film deposition techniques (chemical vapour deposition, atomic layer deposition, etc.), photolithography, etching (wet etching and dry etching), and ion implantation.
- Molecular Nanofabrication: functional nanostructures by integrated lithography-assembly processes – prof. Jurriaan Huskens (MnF)
    - This module is dived into three important bottom-up processes: monolayer formation, nanoimprint lithography, and the combination of both in microcontact printing.
- Nano-characterization: Chemical identification and imaging at the molecular and atomic scale – dr. Peter Schön (MTP/Saxion)
    - This modules first showed some conventional nano-characterization techniques like atomic force microscopy and Raman and Infrared spectroscopy, but quickly continued with combination of AFM with IR spectroscopy and AFM with scanning near-field optical microscopy.

Applications (academic lectures)

After the basics, the applications are discussed. The choice has fallen on two key research themes within the MESA+ Institute for Nanotechnology: unconventional electronics and early diagnostics of diseases. The other two themes were too fundamental and therefore excluded in the curriculum. Both discussed themes were divided into a fundamentals part and an application part. The first contained the basic knowledge, which is needed to understand the applications in the second lecture.

Unconventional electronics

This module discussed items like Moore's law, beyond Moore (more Moore or more than Moore), XUV lithography, and how unconventional electronics can become conventional. As example of unconventional electronics, a chaotic system of nanoparticles that was able to be used as a logic system was taken.

- Fundamentals – prof. Wilfred van der Wiel (NE)
- Applications of nanotechnology in integrated circuits – prof. Jurriaan Schmitz (SC)

Early diagnostics of diseases

The lab-on-a-chip research field is big business now it finally starts to mature. In the fundamentals lecture the participant was lectured about the concept of microfluidics and the important factors in play in this regime. Also a more biological side was discussed, since most of the lab-on-a-chip systems are used in medical applications.

- Fundamentals – prof. Jan Eijkel (BIOS)
- Applications – dr. Loes Segerink (BIOS)

Applications (industrial lectures)

In order to complete the application lectures given by academics, we also incorporated three lectures by industrialists. These lectures showed the best-case-scenarios of how an idea and research can evolve into a (large) company.

- Medspray – Jeroen Wissink
- Solmates – Arjen Janssens
- Micronit Microfluidics – Monica Brivio

Innovation directed lectures

To show the concept of the ENEX project, we also incorporated societal and innovation management directed lectures.

- Applied Nanotechnology – dr. Martin Bennink (NBP/Saxion)
- Translating scientific innovations into products: from ideas to business, risks and opportunities – dr. David Fernandez Rivas (MCS/BμBclean)
- Fuzzy front-end and Technology Roadmapping – Koos Slagter MSc (Saxion)
- Technology Venturing: triangulation of value creation – Matthijs Hammer MSc (TU Delft/Saxion)
- Societal aspects of nanotechnology – dr. Haico te Kulve (STƏPS)

Lab tours

The program was completed by adding three lab tours. This was done to visualize the discussed topics.

- NanoLab
- BioNanoLab
- SEM characterization lab

Hands-on

The companies who did the industrial lectures also submitted case studies. These were discussed at the end of the pilot and participants were split into groups so they could use the new knowledge to solve this problem.

- Case study

After the pilot

After the pilot, an evaluation questionnaire was held. The results of this were used to improve the curriculum for the e-course. Generally speaking, the pilot was well accepted by the participants, so the curriculum had to be modified only slightly. For this curriculum, please see the curriculum v2 document.