The NASCENT Center
Nanomanufacturing Systems for Mobile Computing and Mobile Energy Technologies
THE UNIVERSITY OF TEXAS AT AUSTIN
MER 1.206A, Mail Code R8800 • 10100 Burnet Road • Austin, Texas 78758
www.nascent-erc.org

Upper Division Electives in Hands-on Nanotechnologies

1. Introduction & Overview

Thank you for your interest in the online courses in Hands-on Nanotechnologies offered by the NASCENT Nanosystems Engineering Research Center at the University of Texas at Austin.

UT Austin is offering the courses listed below online with portable nanotech labs that are shipped to participating students to enable an experimental component for each course. Participating students will receive 3 credit-hours of UT Austin upper division undergraduate transcripted course credit for each course successfully completed.

Students completing all three courses will receive a **Certificate in Hands-on Nanotechnologies** from the NASCENT Center. Note that while the first two courses do not require any involvement from faculty at the home institutions of participating students, the third course has a significant "capstone" research project which requires oversight from a local faculty member. Students may take the first two courses without taking the third course.

- **Course 1: Nanofabrication and Nanomaterials** (UT Austin Course Code ES 370 L)
  Offered in summer academic terms, beginning summer, 2018.
  Prerequisites: Suggested recommended qualifications listed below.

- **Course 2: Nanodevices** (UT Austin Course Code: ES 370 M)
  Offered in summer academic terms, beginning in summer, 2019.
  Prerequisites: Successful completion of Nanofabrication & Nanomaterials course, and recommended qualifications listed below.

- **Course 3: Nanotech Innovation** (UT Austin Course Code ES 370 N)
  Offered in fall semesters, beginning fall, 2019.
  Prerequisites: Successful completion of Nanofabrication & Nanomaterials, and Nanodevices courses, and recommended qualifications listed below. Please note: this course requires students to complete an involved "capstone" research project, which will require local supervision from a faculty member at your home institution.

If you're interested in pursuing the third course and receiving a certificate, please indicate this preference in the online application questionnaire (also see Section 3 of this document). The NASCENT leadership will then begin a process of working with you and the corresponding faculty member at your home institution.

Courses are taught online. Lectures are recorded and can be viewed at the student's convenience. Multiple online office hours are held weekly with the instructor in real time using Adobe Connect, a video conferencing service.

2. Student Qualification Requirements

There are a limited number of slots open for each course. Students wishing to apply for admission to the first course in the sequence above must meet the qualifications, and must apply on or before April 30, 2018. Students applying earlier will be given preference. Interested students should also meet the following qualifications:

- You should be pursuing an undergraduate degree from a US-based accredited college or university with a major in engineering or natural sciences.

  You should have completed at least their sophomore year of study by the time of taking the first course in the sequence (i.e., registering to take "Nanofabrication & Nanomaterials" during the summer following your sophomore year is OK).

- Finally, you should have a current Grade Point Average (GPA) of at least 3.0 on a 4.0 scale.

If you do not meet these recommended qualifications but still wish to register, please ask a mentor or faculty member to provide a letter of support on your behalf. We suggest that you choose a faculty member who has been your official instructor of record in one or more courses for your academic major. The letter should be sent directly by the faculty member or mentor, and can be sent by e-mail to Dr. Larry Dunn, NASCENT Assistant Director, at Larry.Dunn@austin.utexas.edu (See Section 5 - Questions and Contact Information.)

3. Registration, Program Cost, and Course Dates

The first step in registering is to visit the following UT Austin page and complete a brief questionnaire:

http://links.utexas.edu/cculfhs

The purpose of the questionnaire is to ensure that you meet the minimum recommended qualifications for the Hands-on Nanotechnologies elective courses certificate program.

Once you've completed the questionnaire above, you'll be e-mailed with a link to the official course registration page for the first course in the sequence, "Nanofabrication and Nanomaterials."

Students must typically register to receive a letter grade on their transcript for each course (*e.g.*, A, A-, B+, etc.). Students wishing to register for each course on a "pass/fail" basis must request permission from the course instructor. Decisions on allowing "pass/fail" registration will be made on a case-by-case basis.

The tuition cost for each course is $1900, payable upon registration.

The academic terms during which each of the courses are offered are shown in the table below. The arrows indicate a student's path through the certificate program if starting in the summer of 2018, 2019, or 2020. For example, a student beginning the first course on 6/6/2018 would finish the second course on 8/2/2019, and if continuing on to obtain a certificate would finish the third course on 12/13/2019.

	Course Offered?								
Course Title	**2018 Summer Term (6/6/2018 – 8/2/2018)**	**2018 Fall Semester (8/29/2018 – 12/13/2018)**	**2019 Summer Term (6/6/2019 – 8/2/2019)**	**2019 Fall Semester (8/29/2019 – 12/13/2019)**	**2020 Summer Term (6/6/2020 – 8/2/2020)**	**2020 Fall Semester (8/29/2020 – 12/13/2020)**	**2021 Summer Term (6/6/2021 – 8/2/2021)**	**2021 Fall Semester (8/29/2021 – 12/13/2021)**	**…**
Course 1: "Nanofabrication & Nanomaterials"	Yes		Yes		Yes		Yes		…
Course 2: "Nanodevices"			Yes		Yes		Yes		…
Course 3: "Challenges in Frontier Nanoelectronics"				Yes		Yes		Yes	…

4. Transferring Course Credit to Your Institution

Students completing one or more of the three courses will receive a corresponding number of credit hours of UT Austin upper division undergraduate credit (3 credit hours per course). Course credit is transferrable and courses appear on an official university transcript. The transcript will display a letter grade for each course completed (*e.g.*, A, A-, B+, etc.). For completed courses which were taken on a "pass/fail" basis, the transcript will display "pass" or "fail" for each course completed.

The number of credit hours which you can transfer from UT Austin which will apply toward your degree at your home institution will depend on the rules and policies of your local college or university. Your local registrar's office will typically have policies regarding the transferring of outside university credit. Department chairs or departmental committees will typically make decisions about whether outside credit may be applied toward the completion of a departmental major or minor. You may wish to contact the appropriate faculty or staff at your home institution with any transfer credit questions.

When discussing transfer of UT Austin course credit to your home institution, you may wish to reference the three official course syllabi included at the end of this document (See Section 6 – Course Syllabi).

5. Questions and Contact Information

Interested students may submit questions with the online questionnaire linked to above: http://links.utexas.edu/cculfhs

You may also contact:

Dr. Larry Dunn
Assistant Director, Industry & Innovation Programs
NASCENT Nanosystems Engineering Research Center
University of Texas at Austin
10100 Burnet Road, Building 160
Austin, TX 78758

E-mail: Larry.Dunn@austin.utexas.edu

Thanks for your interest! We look forward to your participation.

6. Course Syllabi

6.1. Syllabus for Course 1 – Nanofabrication & Nanomaterials

Hands-on Nanotechnologies Course #1: Nanofabrication and Nanomaterials Course (ES 377 N1) Outline and Syllabus

---

Teaching Team and Office Hours Information

Primary Instructor: Dr. S.V. Sreenivasan, Endowed Chair in Engineering
Support Additional Instructors: Dr. John Ekerdt, Dr. Ofodike Ezekoye, and Dr. Ovadia (Oved) Abed

---

Objective:	This course is intended for upper level undergraduate students. The course will provide an understanding of the basic tools and materials involved in the fabrication processes needed to create nano-scale structures and functional nanomaterials. Various nano-scale processes for thin film deposition, patterning, pattern transfer, and selective deposition of functional nanomaterials will be discussed. The relevance of these processes to applications in the electronics, and display industries will be discussed. In addition to a fundamental introduction, students will also be given take-home portable nanotech labs. Through the completion of these labs, students will gain hands-on experience in nano-scale fabrication processes and relevant nanometrology techniques needed to characterize these processes.
Textbook:	No required textbook. Students will be referred to books, review articles and publications during the course of this class. The students will have access to the UT-Austin library system.
Student Responsibilities	Students are required to view lecture modules and read assigned materials. Students are expected to complete these modules in a timely manner, and are expected to complete homework including online and hands-on content before their due dates (see next page).
Grading:	Homework including portable nanotech labs (60%), Midterm (20%), Final Exam (20%)
UT Library Access	Students registered in Nanodevices have access to UT Austin Library resources. You can access journal articles, e-books, and other library resources through the UT Austin library website: https://lib.utexas.edu. At this site you can search for the relevant paper and can download an available paper or Ebook through the "Find at UT" link for the relevant article. It will prompt you for your UT EID and password. Alternatively, you can go to https://scholar-google-com.ezproxy.lib.utexas.edu, enter your UT EID and password and use the power of google to search for literature.
Disabled Students:	The University of Texas at Austin can provide upon request appropriate academic adjustments for qualified students with disabilities. For more information, contact the Office of Dean of Students at 471-6259, 471-4241 TDD or the College of Engineering Director of Students with Disabilities at 471-4382.

TOPICS COVERED

MODULES
Module 0: Certificate Program Goals and Course 1 Overview
Module 1: Introduction
Lesson 1.1 Scaling to micro and nano. Unique behavior of materials at nano-scales.
Lesson 1.2 Versatile custom nanofabrication vs. high speed nanofabrication for volume manufacturing
Lesson 1.3 Wafer-scale nano-fabrication vs. roll-to-roll nanofabrication, state-of-the-art and key barriers
Homework 1 ‡: Review of Module 1.
Module 2: Thin Film Deposition
Lesson 2.1 Wet processes – spin coating, slot die and dip coating, gravure coating.
Homework 2 ‡: Wet Processes, Lab on spin coating of sub-100nm films, optical thin film metrology.
Lesson 2.2 Vacuum processes – sputtering, e-beam evaporation, chemical vapor deposition, atomic layer deposition.
Homework 3 ‡: Vacuum processes.
Module 3: Patterning and Pattern Transfer
Lesson 3.1 Introduction to lithography, photolithography
Lesson 3.2 E-beam lithography, nanoimprint lithography
Lesson 3.3 Wet and dry etching techniques, reactive ion etching.
Homework 4 ‡: Photolithography, imprint lithography, etch.
Module 4: Particle and Contamination Control
Lesson 4.1 Aerosols and airborne particles
Lesson 4.2 Clean rooms, clean enclosures for process equipment, filtration techniques.
Lesson 4.3 Material and surface contamination, contamination sources, types of contaminants, metrology and particles characterization.
Homework 5 ‡: High-speed detection/measurement of sub-micron particles.
Module 6: Concluding Remarks and Discussion of Final Exam

6.2. Syllabus for Course 2 – Nanodevices

Hands-on Nanotechnologies Course #2: Nano-Devices (ES 377 – N2)
Course Outline and Syllabus

Instructor Information[1]

Primary Instructor: Dr. Larry Dunn, Assistant Director, NASCENT Center
Support Additional Instructors: Dr. Sanjay Banerjee, Dr. S.V. Sreenivasan, and Dr. Ovadia (Oved) Abed

---

Objective:	This course is intended for upper level undergraduate students. The course will provide an understanding of the operation of a variety of nano-enabled devices. Topics covered will progress from low value per unit area/volume nano-enabled devices which are information sparse (*e.g.,* solar cells, batteries, capacitors) to medium value per unit area/volume nano-enabled devices (*e.g.,* LED lighting and displays) and finally to high value per unit area/volume nano-enabled devices which are information dense (*e.g.,* CMOS imaging arrays, memory, and microprocessors). In addition to a theoretical introduction to various nano-devices, students will be given associated take-home portable nano-labs. Through the completion of these labs, students will gain hands-on experience fabricating and characterizing a variety of working components and devices.
Textbook:	No required book. Students will be referred to optional books, review articles and publications throughout the course.
Office Hours	Weekly office hours will be held on Wednesdays from 5:00 pm – 6:00 pm CDT, and on Thursdays from 6:00 pm – 7:00 pm CDT. These times may be adjusted as needed via communications from the course instructor(s).
Student Responsibilities	Although there is no required textbook for this course, students will be assigned required readings and required video lecture modules. Students are responsible for completing both the readings and viewing of the lecture modules. Students will also be responsible for completing homework assignments, online quizzes, and the final project before their assigned due dates.
Grading:	Homework (including take-home nano-labs): 70%, Midterm exam: 15%, Final exam: 15%.
Prerequisites:	Before enrolling in this course, students must first take the Hands-on Nanotechnology Course #1: "Nanofabrication and Nanomaterials."

[1] Guest lecturers may be invited to present selected topics.

Disabled Students:	The University of Texas at Austin provides upon request appropriate academic adjustments for qualified students with disabilities. For more information, contact the Office of Dean of Students at 471-6259, 471-4241 TDD or the College of Engineering Director of Students with Disabilities at 471-4382.
UT Library Access	Students registered in Nanodevices have access to UT Austin Library resources. You can access journal articles, e-books, and other library resources through the UT Austin library website: https://lib.utexas.edu. At this site you can search for the relevant paper and can download an available paper or Ebook through the "Find at UT" link for the relevant article. It will prompt you for your UT EID and password. Alternatively, you can go to https://scholar-google-com.ezproxy.lib.utexas.edu, enter your UT EID and password and use the power of google to search for literature.

TOPICS COVERED

Module 0: Overview and Background
Lesson 0. Discussion of how this course fits into the Hands-on Nanotechnologies Certificate Program. Introduction to instructors. Discussion of overall course organization and overview of topics to be covered. Discussion of course progression from low value per unit area/volume nano-enabled devices which are information sparse (e.g. solar cells, batteries, capacitors) to high value per unit area/volume nano-enabled devices which are very information dense (e.g. CMOS imaging arrays, memory, and microprocessors).

Module 1: Introduction
Lesson 1.1. Discussion of nano-enabled devices, and components comprising these devices, to be covered in the course. Trends in consumer electronics and how those trends impact roadmaps for CMOS devices, displays, and energy-related devices. Impact of nanotechnology on the trends and roadmaps mentioned above.[2]
Lesson 1.2. Scaling from micro to nano. Nano-enabled photonic, electronic, and magnetic materials. Basic quantum mechanics (e.g., quantized photon emission energies in semiconductors).
Homework 1. Review of Module 0 and Module 1. No Lab component.

[2] Applications to consumer electronics will be emphasized throughout the course.

Module 2: Nanotechnologies for Energy Generation
Lesson 2.1. Societal trends driving interest nanotechnologies for energy – climate change, and renewable energy. Introduction to our current energy generation infrastructure. Nanomaterials for catalysis.
Lesson 2.2. The p-n junction and conventional c-Si photodiode and photovoltaic devices: Theory, fabrication, operation, and large scale implementation.
Assignment of Homework 2.0 (Portable Nanotech Lab): Fabrication and characterization of dye-sensitized solar cell (DSSC) as well as Fabrication and Characterization of an Organic Light Emitting Diode (OLED)
Lesson 2.3. Future concepts in nano-enabled photovoltaics. Quantum Dot solar cells, artificial photosynthesis, organic solar cells, dye-sensitized solar cells, nanowire solar cells.
Lesson 2.4. Light-matter interactions at the nanoscale: antireflective coatings and nanostructured surfaces for PV cells. Plasmonic effects, metamaterials, applications.

Module 3: Nanotechnologies for Energy Storage & Lighting
Lesson 3.1. Overview of societal trends driving interest in energy storage and lighting technologies – renewable energy, electric vehicles, mobile devices, LED lighting, OLED lighting panels, smart lighting. Introduction to our current energy storage and lighting infrastructures.
Lesson 3.2. Discussion Traditional LEDs and Organic Light Emitting Diodes (OLEDs) for lighting. Impact of nanoscale light management structures on LED efficiency..
Lesson 3.3. Operating principles of batteries, capacitors, and fuel cells.
Lesson 3.4. Discussion of state of the art lithium ion batteries and ultracapacitors and their use in electronic devices.
Lesson 3.5. Hydrogen generation and storage. Discussion of nanotechnologies for enabling future improvements in hydrogen generation, hydrogen storage, and fuel cell performance.

Module 4: Nanotechnologies for Displays
Homework #3 (Portable Nanotech Lab). Fabrication and characterization of metal mesh as indium tin oxide (ITO) transparent conductor replacement for flex displays and flex photovoltaics.
Lesson 4.1. Introduction to liquid crystal displays. Discussion of LCD components such as optical films (e.g., Traditional polarizer films, nanoscale wire grid polarizers), transparent conducting films (e.g., Indium Tin Oxide (ITO) and nano-scale metal meshes).
Lesson 4.2. Advanced flat panel displays: plasma displays, 3D displays, Quantum Dot displays, OLED Displays.
Lesson 4.3. Continued discussion of advanced flat panel displays: electronic ink displays, flexible displays, etc. Discussion of flat panel display replacement concepts: microdisplays, holography.
Lesson 4.4. Continued discussion of flat panel display replacement concepts: Augmented Reality/Mixed Reality/Virtual Reality.

Module 5: Nano-enabled transistors, sensors, and memory
Homework 4: Homework on Lessons 5.1 and 5.2. Semiconductor Device Theory and Operation. No Lab Component.
Lesson 5.1. Overview of electron transport in metals, semiconductors, and nanostructures. Fermi statistics; carrier concentrations.
Lesson 5.2. Overview of Silicon device fabrication: semiconductors & crystal structure, crystal growth methods & defects, semiconductor doping, thermal oxide growth, patterning, metal deposition, wet and dry etching.
Homework 5 (Portable Nanotech Lab). Thin Film Transistors - Fabrication, operation, measurement. Measurement of CMOS transistors and comparison of technologies.
Lesson 5.3. Introduction to field-effect transistor (FET) operation and basic FET figures of merit. Thin film Transistors (TFTs) vs. bulk silicon transistors.
Lesson 5.4. Discussion of CCD and CMOS imaging arrays.
Lesson 5.5. Introduction to Solid State Memory Fundamentals: Intro to SRAM, DRAM Flash.
Lesson 5.6. State of the art Flash memory and Solid State Hard Drives.
Lesson 5.7 Moore's Law, industry roadmaps for transistor dimension scaling and manufacturing. Discussion of FinFETs.

6.3. Syllabus for Course 3 – Challenges in Frontier Nanoelectronics

Hands-on Nanotechnologies Course #3: Challenges in Frontier Nanoelectronics (ES 377 N3) Course Outline and Syllabus

---

Teaching Team and Office Hours Information

Primary Instructor: Dr. S.V. Sreenivasan, Endowed Chair in Engineering
Additional Instructors: Dr. Shrawan Singhal

Objective:	This course is intended for upper level undergraduate students and beginning graduate students. The course will discuss strategies to explore grand challenge nanotechnology problems in the areas of electronics, displays and energy. These challenges often require a disciplined innovation framework that involves correctly defining the specifications of the challenge, understanding the technology gaps, and having the relevant interdisciplinary expertise to develop the systems needed to bridge the technology gap. This course will first present an innovation framework, then expose students to multi-scale computational tools that can be used to explore the solution space, and finally apply these techniques to case studies in the area of nanoelectronics.
Textbook:	No required textbook. Students will be referred to books, review articles and publications during the course of this class. The students will have access to the UT-Austin library system.
Student Responsibilities	Students are required to view lecture modules and read assigned materials. Students are expected to complete these modules in a timely manner, and are expected to complete homework including online and hands-on content before their due dates (see next page).
Grading:	Homework including portable nanotech labs (55%), Final Project (45%)
Prerequisites:	Prior to enrolling in this course, students are expected to have completed Nanotech 1 and Nanotech 2. Students also must have a local faculty member at their home academic institution who will mentor them during the capstone research project.
Disabled Students:	The University of Texas at Austin can provide upon request appropriate academic adjustments for qualified students with disabilities. For more information, contact the Office of Dean of Students at 471-6259, 471-4241 TDD or the College of Engineering Director of Students with Disabilities at 471-4382

.

Topics Covered

MODULES
Module 0: Review of Certificate Program Goals and Course 3 Syllabus
Module 1: Introduction
Lesson 1.1 Industry/research roadmaps in electronics and displays
Lesson 1.2 Emerging trends, grand challenge problems, case studies in healthcare
Lesson 1.3 Technology gaps, competitive analysis
Module 2: Innovation Framework
Lesson 2.1 Lean innovation framework, customer discovery, NSF I-Corps program
Lesson 2.2 Finding the correct business model, minimum viable product
Homework 1 ‡: Review of Modules 1 and 2.
Module 3: Computational Approaches to Multi-scale Nanosystems
Lesson 3.1 Statistical methods in nanotechnology, uncertainty quantification
Lesson 3.2 Applications of statistical methods in nanotechnology
Homework 2 ‡: Review of Lesson 3.1 and 3.2.
Lesson 3.3 Model verification & validation, simulation for design & analysis
Lesson 3.4 Machine learning and data analytics
Homework 3 ‡: Model validation, includes lab.
Module 4: Nanotech Innovation Capstone Project
Milestone 4.1 Instructors will assign projects & related literature
Milestone 4.2 Define a hypothesis, submit report per given rubric (1st report)
Milestone 4.3 Discuss projects with teaching team
***(*)** The instructors will do their best to adhere to the dates listed here, but may need to make changes.*
***(‡)** Homework will include qualitative questions, problems or simulations. HW 3 includes a portable lab.*