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BOARD #149: Nanoimprint lithography – a nanotechnology demonstration lab for STEM undergraduate instruction

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Nanoimprint lithography – a nanotechnology demonstration lab for STEM undergraduate instruction

Abstract

The CHIPS and Science Act introduced in 2022 aims to enhance all aspects of semiconductor industry, including related efforts in STEM education and work force training. We present our project in support of this broad goal. The project aims to introduce to and instruct students on an alternate method of micro/nano fabrication – nanoimprint lithography (NIL). The topic is part of the Introduction to Nanotechnology course that is offered at Virginia Military Institute, a public senior military college. The nanotechnology course is offered by the author in the Department of Physics and Astronomy; it is a three credit hours technical elective, with a significant portion dedicated to theory of semiconductors and micro/nano fabrication and characterization. In addition to the instruction on theoretical concepts, the course includes several related demos and activities, which allow students to get hands on experience in the thin films lab. The NIL module includes introduction of NIL fabrication technique; safety and lab rules; instruction on the NIL desktop equipment; selection of a template; making the sample; characterization of samples by optical microscopy and scanning electron microscopy; lab report; literature search exercise; classroom presentation. In addition, students learn about career opportunities related to nanoimprint lithography and semiconductor industry. The course activities are well aligned with the ABET general criteria for engineering that include requirements for both basic science and broad education components, instruction on modern equipment, and development of leadership, and written and oral communication skills.

Introduction

The CHIPS and Science Act of 2022 [1] has provided funding specific for the development and in support of domestic semiconductor and telecommunication industries, for microelectronics research, fabrication building facilities, education, and training of workforce [2].

In support of this initiative, we are refocusing portion of the nanotechnology course and developing a new lab related to the nanofabrication technique of nanoimprint lithography. The goal is to provide students with basic information on the technique, to generate interest for the field, and to prepare them for potential graduate school or careers in the field. The school has been supportive of this project through internal funding for acquisition of new equipment and supplies and for developing educational material. This paper describes an example of potential educational material for engineering students and demonstrates how the module aligns with some of the ABET criteria.

The course “Introduction to Nanotechnology” is one of the technical electives offered in the Department of Physics and Astronomy at Virginia Military Institute. The three-credit hours course has been offered for over a decade every other year and more recently it has been offered on a yearly basis. It is a junior level course with general physics as prerequisites. The course is also suitable as technical elective course for other STEM majors, including all engineering majors (mechanical, civil and environmental, and electrical and computer engineering) and has been well populated by these majors since its offering. The catalog description specifies that this is “A course designed to introduce the student to the multidisciplinary and rapidly developing field of nanotechnology. Topics include nanomaterials, micro/nanofabrication, microscopy, nanoelectronics, biological nanotechnology, nanoterrorism, social and ethical implications, etc.” A detailed list of topics covered during the course includes introduction to semiconductors, micro/nanofabrication (including alternative methods of nanofabrication such as microcontact printing, nanoimprint lithography, self-assembly), scanning probe microscopies (scanning electron microscopy (SEM) and atomic force microscopy (AFM)), nanomaterials (fullerenes, carbon nanotubes, graphene, quantum dots, nanoparticles), optical tweezers, magnetic storage, magnetoresistive materials, optoelectronic nanostructures, biomimetics, photonic bandgaps, MEMS/NEMS. [3]

In addition to lectures there are several lab activities for this course that take place in the department’s thin films lab [4]. Students get hands on experience in spin coating film fabrication, photolithography, optical and scanning probe microscopy characterizations, and assembling models of allotrope forms of carbon, to mention a few. Occasionally, as schedule permits, there are lab visits to either nearby research and university labs, such as department of physics or NanoEarth labs at Virginia Tech. Assignments include solving mathematical problems, literature search on various topics, and a final report on a topic of their choice with a class presentation.

Learning in this course is evaluated through various means: homework, in class tests and final exam, lab reports, essays, literature searches, final paper, class presentation, discussions, and a questionnaire.

During the semester, students also learn about opportunities for independent studies, internships, and about graduate school and career choices related to nanotechnology. The author has advised and mentored students during summer undergraduate experience in nanotechnology and nanoscience.

Nanoimprint Lithography Module

Within the micro/nanofabrication lecture, students learn about the nanoimprint lithography technique [5-7]. The development of this NIL module is still a work in progress. The module includes a) lecture on NIL fabrication technique; safety and lab rules; instruction on the NIL desktop equipment; selection of a template; making the sample; characterization of samples by optical microscopy and scanning electron microscopy); lab report; literature search exercise; classroom presentation. In addition, students learn about career options and opportunities related to semiconductor industry in general, and to nanoimprint lithography process in particular.

a) For the lecture part of the NIL module, students are first introduced to lithography and embossing/debossing terms. The imprint technique is widely used in various disciplines and students have the opportunity to see its applications from construction, or arts, and culinary techniques to more sophisticated high precision fields.

Embossing using hard molds has been used commercially for decades and more recently, on the submicrometer scale, it has been used in the production of CDs, DVDs, and diffraction gratings.[8] Nanoimprint lithography represents an alternate nanofabrication technique, along with microcontact printing, and scanning probe lithography. Nanoimprint lithography has had a rapid development, becoming an established field; there are now dedicated journals and conferences just for this topic alone [9]. In the NIL process, a master stamp is pressed into a softened resist polymer layer. After the pattern is transferred the polymer is cured, either by cooling down below transition temperature or by UV curing [8].

There are several NIL techniques classified based on the material processing methods (thermal, UV, laser assisted); based on pressing methods (solid parallel-plate press, air cushion press, electrostatic force press, and roller nanoimprint); on the imprinting area, or based on material dispensing methods (spinning or precision dropping) [5, 7].

Among the numerous applications of NIL technique, students learn about the ones related to mass production of integrated circuits, integrated optics, fluidic devices, magnetic data storage, medical and biological applications, and nanoimprinting of biomimetic nanostructures [10-12].

NIL presents several advantages over the traditional micro/nanofabrication methods: no diffraction limit, it is a 3D patterning method, single step of direct imprinting of a material (compared to a multistep process of lithography and etching), high resolution (below 5 nm), large area, high throughput, low cost, efficient method.

Drawbacks of the NIL technique include alignment on multiple metal layers, mold fabrication and cost (it requires e-beam lithography), mold damage during pattern transfer, cost associated with implementing a new process and its specific materials.

b) Safety and lab rules

For the lab portion of the module students are first instructed on the lab rules and safety related to the equipment, such as protection from UV radiation, handling resins and chemicals, the fume hood, using safety goggles, gloves, and lab coats. They are also reminded to follow instructions and rules specified in the equipment manual. They are given instructions on how to keep a laboratory notebook and how to record the information.

c) Instruction on the NIL equipment

We have recently acquired a nanoimprint lithography desktop roll-to-plate (R2P) device. The desktop NIL R2P unit from Stensborg [13] is an easy to operate equipment. The template is placed on the drum while the sample foil is laying flat on the plate. The translational motion of the plate is coordinated with the rotational motion of the drum so that the pattern is transferred onto the foil and at the same time is UV cured by the optical engine. Five to ten minutes of the lab are dedicated to learning how to operate the machine, what are the optimal settings and to trial runs. Students are instructed on how to mount the mold on the drum, how to align it with the substrate, which resin to select, how to coat and load the foil on the plate, what are the optimal settings for speed of the moving substrate, for applied force, height of the film, thickness of the template, light intensity, etc.

d) Selection of template and making the sample

Currently there are only two options for the transparent templates. One such template, or mold, is shown in **Figure 1** (left). We plan to have additional ones made in the near future. The templates are approximately 2” x 2” and can be used multiple times. Once the teams chose the template, they proceed to make their own sample, under the supervision of the lab instructor. The resin is spread on the substrate using a film applicator. The samples are made on polyester flexible substrate using a resin of medium viscosity and UV curable at 395 nm. **Figure 1** (right) illustrates a sample made by students. For the lab part of the module students work in teams. This is a beneficial experience for developing problem-solving skills, for deepening understanding through discussions, and for strengthening communication skills. In addition, students do not have the pressure of doing entire lab on his/her own given the fixed time designated for the lab.

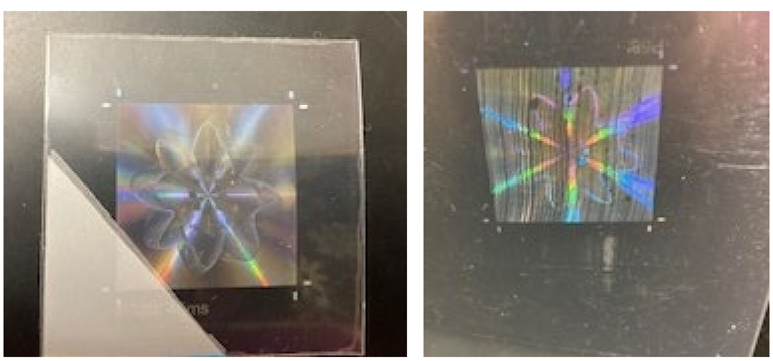

Figure 1. Example of template (left) used to fabricate by NIL process the sample (right).

e) Characterization of samples is being done by eye inspection and by optical and scanning electron microscopy. This step allows for practice with these techniques that were learned in the earlier photolithography lab module. The students visualize relevant features on the sample, surface roughness, measure critical dimensions, detect presence of any defects, scratches, and make an informed decision regarding the overall quality of their sample. Both, fabrication and characterization of the samples are lab activities done during the class.

f) A lab report is expected to be generated once all the fabrication and characterization has been finalized. We are in the process of developing a lab template with guiding rubrics that are filled-in by students.

g) Literature search for the NIL application is an exercise for students to include the NIL technique, materials, feature size, and the specific application. Below is an example of the assignment.

> *Find a recent article about an application of the nanoimprint lithography (NIL) technique. List:*
>
> a. *type of NIL technique used*
> b. *what materials are used*
> c. *resolution/measured properties*
> d. *specific application*
>
> *Hand in a maximum one-page typed summary and a copy of the article. You are expected to present your finding to the class.*

h) Classroom presentation and discussion includes the results in the lab portion of the NIL module and the literature search for the NIL application. Students share their findings with the rest of the class. This type of activity enhances both writing and oral technical communication.

The course activities are well aligned with the ABET general criteria for engineering that include requirements for both basic science and broad education components, instruction on modern equipment, and development of leadership, and written and oral communication skills.

The nanotechnology course has generated interest among students for the field of nanoscience and nanotechnology. Among the topics selected for their final project they have chosen nanotechnology in cosmetics, jewelry, nanoparticles in automotive oil, nanotechnology in concrete, nanoparticles in medicine and many more.

Benefits and ABET criteria

The school is a four-year college [14] and therefore we address only the ABET general criteria relevant to the baccalaureate level programs.

Activity	Resources	ABET Criterion	Benefits
Lecture and class discussions	Power Point Handouts Bibliography	C1. Students C5. Curriculum	Advising on career matters C5.a. technical elective C5.c. broad education

Lab Rules	Handouts, Instruction in lab		Reinforces lab standards and safety rules
Instruction on the NIL equipment	In lab demo Handout based on the manual	C7. Facilities C8. Institutional support	Modern equipment, accessible Guidance regarding the use of tools, equipment, laboratories Adequate resources
Selection of template and making sample	In lab	C3.1 Student Outcomes C3.5 Student Outcomes C3.6 Student Outcomes	Ability to solve problems by applying principles of engineering, science, and math Function effectively on a team Conduct experiment, analyze and interpret data, draw conclusions
Characterization of the samples	In lab optical microscope, SEM	C3.1 Student Outcomes C3.5 Student Outcomes C3.6 Student Outcomes	Ability to solve problems by applying principles of engineering, science, and math Function effectively on a team Conduct experiment, analyze and interpret data, draw conclusions
Lab report	Instructions Lab write-up	C3.3 Student Outcomes C3.5 Student Outcomes C3.6 Student Outcomes	Communicate effectively Function effectively on a team Conduct experiment, analyze and interpret data, draw conclusions
Literature search	Assignment NIL applications	C3.7 Student Outcomes	Acquire and apply new knowledge
Classroom presentation	Class discussions and student presentations	C3.3 Student Outcomes C3.7 Student Outcomes	Communicate effectively Acquire and apply new knowledge

Comments from students

Students acknowledge the benefits of the course as expressed in the following remarks:

“One learning goal this class gave me was broadening my learning scope from just mathematics to more specific and hands on fields like nanotechnology.”

“Nanotechnology could help me with my capstone as I could decide to do something based on nano engineering at a broad level.”

“I like to understand how technology works and can now understand what goes behind the process of making sophisticated technology such as computer storage.”

“I would like to learn more about the usage and how quantum dots work to be more commonly applicable to everyday devices.”

Future Work

While the nanotechnology course has been offered for a while, this is the first time the nanoimprinter has been used as a demo in the course. The author plans to continue including the demo in the course and to finalize the written template for this activity.

Once finalized, the study and NIL module will be forwarded to engineering departments for review and adaptation to the educational requirements of engineering departments. The module will continue to be offered in the physics department with plans for development as a capstone or independent study in connection with research in the thin films lab.

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