

Work in Progress – ‘Lab-on-a-chip’ MicroManufacturing with a Nanotechnology Component for a First-Year Engineering Program

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Abstract - Engineering students with interests in microelectromechanical systems (MEMS) and nanotechnology typically can only gain exposure to this new field in late undergraduate curricula, research offerings, or graduate school. Early exposure to this field is not typically an option in engineering programs. Perhaps the first of its kind, this ‘Lab-on-a-chip’ Micromanufacturing Lab with a Nanotechnology component is piloted and offered to regular first-year engineering students as an alternate lab section in the standard Fundamentals of Engineering course (ENG 183) for Winter and Spring 2004 at Ohio State University. Students participate in a hands-on design and fabrication of a working Lab-on-a-chip to detect the presence of a biological antibody through fluorescent antigen-antibody binding. They construct a simple photosensor to detect emission from the bound antigen. Coincident with the hands-on activity are Nanotechnology modules and lab tours that expose the students to the challenges in manufacturing at the nanoscale for similar devices.

Index Terms - First-year engineering, Laboratory Project, Micromanufacturing, Nanotechnology..

BACKGROUND

First-year engineering students at Ohio State University are required to take a 2-quarter sequence entitled Fundamentals of Engineering. Each 3-credit course is comprised of basic skills and a lab component. The lab component of the first course is focused on reverse engineering while the second course includes a quarter-long design-build project. This work in progress describes our efforts to develop a design-build project centered around a lab-on-a-chip device. The work was funded through the National Science Foundation Nanotechnology in Undergraduate Education (NUE) program.

PROJECT DESCRIPTION

In recent years, the concept of integrating biochemical analysis with microelectromechanical systems (MEMS) has spawned the new field of BioMEMS. Such devices are also called ‘lab-on-a-chip’ and combine a number of biological functions (such as enzymatic reactions, antigen-antibody conjugation, and DNA/gene probing) with proper microfluidic components (such as sample dilution, pumping, mixing, metering, incubation, separation), and detection in micron-sized channels and reservoirs into a miniaturized device. The integration and automation involved can improve the reproducibility of the results and eliminate labor, time, and sample preparation errors that occur in the intermediate stages of an analytical procedure.

The basis for our project is the fluorescence detection of a biological antibody via binding of a fluorescent antigen in a microfluidics device. Provided with design constraints and given one lab period to explore the workings of a prototype device, students must design the layout for a microfluidic lab-on-a-chip within a two-inch circle using CADKEY. The student files are used by the instructional team to produce a photomask for photolithographic production of a mold on a silicon wafer. The students then produce a polydimethylsiloxane (PDMS) casting from the silicon wafer mold and a flat PDMS lid covers the molded base to produce enclosed channels. A lower size limit of about 80 μm is imposed as a design constraint to ensure accurate printing of the photomask and reproduction using photolithography. Students test the flow of water through their chip to explore pumping and capillary valving at the micron level and perform a final test with the actual antigen and antibody. During the lab periods that the molds are being fabricated, basic electronics are discussed along with photometric detection methods. Students build a simple photodetector from a small gift box, LED, and CdS photocell. They calibrate their sensor

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with reflection from black and white surfaces and investigate the emission from fluorescent paint.

NANOTECHNOLOGY COMPONENT

Nanotechnology in any real sense of the word involves manipulating molecules. The equipment necessary to do research and fabrication at the nanoscale is typically on the order of hundreds of thousands of dollars. It is infeasible for freshman engineers to perform experiments using equipment requiring several hours of advanced training.

We have taken a different approach to incorporating nanotechnology into the freshman experience. Our primary goal is to teach the students about size scales. This is often done in engineering courses but many students do not grasp orders of magnitude well. One of the first exercises we carry out is to estimate the size of a single dot produced by a 600 dpi laser printer and we use this in the context of producing their photomask to explain that even 1200 dpi is not sufficient to produce smooth, continuous features for microdevices (much less nano). In order to tie the hands-on activities to nanotechnology we used three components: First, the biological analysis being carried out in the lab-on-a-chip is true antibody-antigen binding or single molecules interacting with one another. Students are shown this behavior schematically in lab presentations then see the emission from these bound molecules in the final chip test. Second, we asked several researchers from around campus to produce five-paged documents in their area of expertise along with discussion questions. These "Nanotechnology Modules" cover a wide range of nanotechnology topics such as Top/Down, Bottom/Up Strategies for Nanomanufacturing, Nanoscale sensors for chemical sensing, Molecular Self-Assembly, Polymer Processing at the Nanoscale, Nanofluidics, and Nanotechnology for Drug Delivery. Students are asked to read the modules and answer selected discussion questions in their lab memos. Third, we arranged with nine laboratories across campus to host two groups of four students (on separate days) and demonstrate a piece of equipment associated with nanotechnology research. Laboratories included two clean room facilities where students saw the equipment used to prepare their silicon wafer molds, photonics, nanoindenter, magnetic suspension nanomanipulator, atomic force microscopy, and a micro/nanofabrication lab for polymer bioMEMs devices. Since each lab group only saw one of these, the final class laboratory period is devoted to oral presentations where each group gives an 8 minute talk on the

lab they visited thus exposing the remainder of the class to the lab they experienced.

STUDENT PERFORMANCE & ATTITUDES

Generally the students were eager to learn about the lab-on-a-chip technology and nanotechnology. In the very first lab memo they were asked to describe what they knew about nanotechnology to establish a baseline. Some students reported knowing little to nothing about nanotechnology. Others made mention of some more well-known medical applications. Still others suggested usefulness in military applications on the battlefield such as biological agent detection in the case of biological warfare. It is important to note that some of these students may have overheard these ideas from conversations by the instructional team or gained this insight when the students themselves asked questions regarding the course and the lab project.

Students were able to perform the lab activities easily and with minimal assistance from the instructional staff. Some of the nanotechnology modules were a little above level for freshmen and were edited between the first and second pilot. By the end of the course, students were actively engaged in asking questions about polymers, nanotechnology, biotechnology, and the relation between these fields and their intended major.

In the second pilot, on-line surveys were carried out to gauge student attitudes towards research as a career or undergraduate research as an elective during their college career. Students generally had little knowledge (or were mistaken) about the nature of graduate research and careers in research.

By the end of the course, students could discuss the particular application for their lab-on-a-chip with a high degree of confidence and could explain some of the equipment used in nanotechnology research.

Further analysis of student attitudes and knowledge about engineering applications of nanotechnology is currently underway.

ACKNOWLEDGMENT

This project was supported financially by the National Science Foundation (EEC-0304469) and the First Year Engineering Program in the College of Engineering at The Ohio State University.