AC 2011-1943: MICROFLUIDICS @ THE BEACH: INTRODUCTION OF MICROFLUIDICS TECHNOLOGY TO THE CHEMICAL ENGINEERING CURRICULUM AT CSULB

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Microfluidics @ the Beach: Introduction of Microfluidics Technology to the Chemical Engineering Curriculum at CSULB

Introduction

Microfluidics technology involves the study of the behavior of fluids at microscale, fluid manipulations, and the design of the devices that can effectively perform such manipulations. It has been widely applied to the miniaturization of analytical methods and chemical and biological processes because of its many advantages, such as significant reduction in analysis time, much lower sample and reagent consumption (in the nanoliter range or less), and enhanced system performance and functionality by integrating different components onto microfluidic devices[1-2]. These applications are usually called micro total analysis systems (μTAS) or lab on a chip (LOC) [3-4]. Since its debut in the 90s[5-7], microfluidics technology has made significant progress and gradually moved from pure research projects to commercialized products, such as Agilent Technologies' 2100 Bioanalyzer for biomolecule analysis[8], Caliper Life Sciences' LabChip systems for biomolecule analysis and drug discovery[9], and Fluidigm Corporation's BioMark system for real-time PCR[10].

We notice that from the microfluidics technology industry (especially in California) there is a need for chemical engineers with related skills, such as microfluidic chip design, microfabrication, optical imaging, and programming languages for instrument control and data analysis. However, our current curriculum does not provide our students training for these skills. To address this, we initiated a course development project for two new elective courses, *Introduction to Microfabrication and Microfluidics Technology* and *Microfluidics Technology and Its Applications*, along with corresponding hands-on lab sessions in Fall 2010. In this project, both undergraduate and graduate students were involved in the design of the lab sessions. They helped to convert the experiments in our ongoing research projects into the ones suitable for teaching by actually performing them and revising the protocol to fit our class needs.

In this paper, we present the progress of our project and discuss the course contents and research experiments revised for student labs.

Facilities and Course Contents

California State University, Long Beach (CSULB) is predominantly an undergraduate institution, so the author, Dr. Roger C. Lo, has been seeking to include microfluidics technology in the chemical engineering curriculum at the senior and first-year graduate level since his initial appointment in Fall 2009. Currently in the College of Engineering, there are several courses covering some topics of microfluidics technology offered in the Department of Electrical Engineering (EE 435 Microelectronics, EE 436/536 Microfabrication and Nanotechnology, and EE 437 Multidisciplinary Nano-Science and Engineering). However, these courses focus on the device fabrication, material characterization, and the standard photolithographic techniques used in the microelectronics industry. In addition, these courses did not come with lab sessions, because CSULB had neither a fabrication facility nor faculty members with microfluidics-specific expertise. To initiate his research program and this course development project, the author has established a Class 10,000 cleanroom capable of fabricating poly(dimethylsiloxane)

(PDMS) microfluidic chips using soft lithographic techniques[11] and the Analytical Instrumentation Laboratory capable of fluorescence microscopy and image processing for microfluidics applications through the collaboration with another ChE faculty, Professor Sergio Mendez. The cleanroom and laboratory are fully functional since Summer 2010, and we have presented some preliminary results from these facilities at the 2010 AIChE Annual Meeting[12].

In the first course, the fundamentals of microfabrication techniques, chip design and microfluidics will be introduced in both class lectures and related readings. In the lab sessions, students will actually go to our research laboratory to design and fabricate microfluidic chips using soft lithography and perform simple experiments on fluid flows in the microchannel. The topics covered are summarized below.

Table 1. Course Contents of *Introduction to Microfabrication and Microfluidics Technology*

Format	**Topic**
Lecture	Introduction to microelectronics industry and semiconductor processing technology
Lecture	Photolithographic process for pattern transfer
Lab	Mask layout and design using AutoCAD
Lecture	Micromachining processes
Lecture	Soft lithography
Lab	PDMS microchip fabrication
Lecture	Introduction to microfluidics technology
Lecture	Microfluidic component fabrication and integration
Lecture	Chip-to-world connection: Interface between microfluidic devices and the macroscopic world
Lab	On-chip micromixing
Lecture	Final report and project presentation

The objective of this course is to familiarize our senior and first-year graduate students with common microfabrication techniques and basics of microfluidics technology and to prepare them for the sequential course, *Microfluidics Technology and Its Applications*. The expected course outcomes are as follows:

- To understand the basic chemistry, materials, and processes of photolithographic pattern transfer, micromachining, and soft lithographic casting
- To understand the basic concepts of microfluidics, on-chip component fabrication, and chip-to-world interfacing
- To get familiar with the common CAD tool for mask layout and design, actual microfabrication process, and manipulation of fluids on the microfluidic chip through hands-on lab sessions
- To get familiar with report writing and oral presentation for communication of technical information

In the second course, the fundamentals of fluidics and transport phenomena and applications of microfluidics technology, e.g., in chemistry, engineering, and biotechnology, are introduced through class lectures and journal paper readings. In the lab sessions, students will perform experiments on their microfluidic chips, such as DNA electrophoresis, mixing, organic synthesis, and fuel cell reactions, to get familiar with fluid manipulations, proper calibration of detectors, and data analysis. They will also learn how to use programming languages, e.g., MATLAB, and software packages, e.g., ImageJ, to process numerical and image data.

Table 2. Course Contents of *Microfluidics Technology and Its Applications*.

Format	**Topic**
Lecture	Introduction to microfluidics technology and lab-on-a-chip systems
Lecture	Fluidics and transport phenomena in microchannels
Lecture	Electrokinetics in microchannels
Lab	Pressure-driven flow, electroosmotic flow, diffusion, and mixing
Lecture	Surface science and engineering in microchannels
Lecture	Sample preparation, separation, and detection on microfluidic chips
Lecture	Data acquisition and processing for lab-on a chip systems
Lab	Data extraction and processing using MATLAB and ImageJ
Lecture	Applications of microfluidic technology in chemistry, engineering, and biotechnology
Lab	Microchip gel electrophoresis and organic synthesis
Lecture	Final report and project presentation

The objective of this course is to provide our students with theoretical backgrounds on transport phenomena and Electrokinetics involved in microfluidics technology and to familiarize them with the design, construction, and operation of lab-on-a-chip systems for desired applications. The expected course outcomes are summarized below:

- To understand the basic principles of flows and electrokinetics at microscale
- To understand the fundamentals of surface sciences and engineering in microchannels
- To obtain working knowledge to get involved in the area of microfluidics technology, including the theories, actual chip design and fabrication, lab-on-a-chip operations, sample preparation and detection, and data acquisition and processing
- To get familiar with report writing and oral presentation for communication of technical information

The lecture and lab materials are being developed using several sources:

- Textbooks: *Fundamental of Microfabrication* (Marc Madou, CRC Press, 2nd edition) and *Fundamentals and Applications of Microfluidics* (Nam-Trung Nguyen and Steve Wereley, Artech House)
- Articles in relevant journals, e.g., Chemical Engineering Education, Journal of MEMS, Analytical Chemistry, Microfluidics and Nanofluidics, Electrophoresis, PNAS, and Lab on a Chip
- Some research results published by the author[12-15]

In these courses, students will work in teams composed of both graduate and undergraduate team members for their term projects. They will choose topics for which they will design and fabricate microfluidic chips to monitor or manipulate some flow conditions or reactions. The author will try to match the chosen topics with the research interests of the graduate students. This team combination will provide our undergraduate students a quick view in graduate studies in our department. For each term project, the team has to perform literature survey on the topic they choose and discuss their design concepts with the author early in the semester. After finalization of the chosen topic, the team members will start to work on the project and prepare a written report and present their work orally at the end of the semester.

Experiment for Student Labs

As we mentioned earlier, the experiments for student labs will be adapted from the author's ongoing research project. We are currently developing a microfluidics-based system for high-throughput chemical and biological assays using UV area imaging detection. The coauthors, Thuyoanh Truong and William Ferguson, are undergraduate and graduate students, respectively, who joined the author's research group in 2010 to work on this instrument development project. After initial training by the author, they have been designing and making PDMS and photocurable glue chips for our research applications. They have revised the author's original protocols to fit the equipment and facility at CSULB and are now rewriting them as a cleanroom lab manual for other students. The figures of a sample mask design and a fabricated chip are shown below (Figure 1).

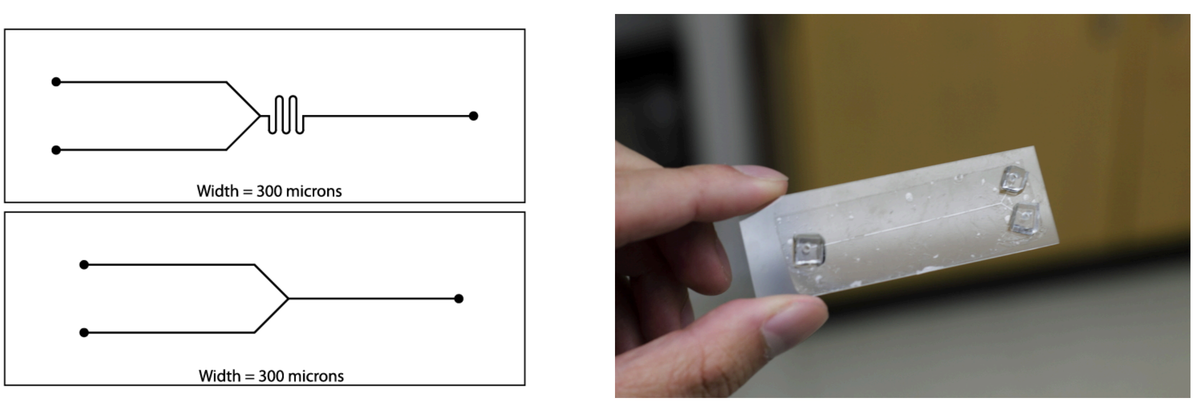

Figure 1. Some chip designs for microreactions and a PDMS thin chip for UV absorbance-based detection (Photo by Chao-Chieh Chiang)

The newly developed cleanroom lab manual will be given to the two new students, one graduate and one undergraduate, who are joining the author's research group this spring as their reference for microchip fabrication. They will be asked to follow the instructions on the manual to make their chips without prior training from the author or the coauthors. We will monitor their progress and ask them how clear the instructions are to follow and revise any unclear parts, so that every student who has basic lab training can follow the manual to make their own chips. Other lab manuals for experiments of micromixing, microchip electrophoresis, and microreactions will be developed in the same manner.

Course Assessment

In addition to the homework assignments and exams for student performance, these two new courses will be evaluated by anonymous questionnaires at the end of the semester. These course outcome assessment survey forms will use a five-point Likert scale with 5 being *Strongly Agree* and 1 be *Strongly disagree*. The criteria of each expected course outcome will be included, and students can rate how successfully they reach the goal as described by the criteria. The results from these surveys will be compared to students' performance in the homework assignments and exams to identify the course materials that we need to revise for better learning outcomes.

We are currently developing a new rubric for oral presentation evaluation based on ABET's guidelines. We will invite our students, ChE faculty, and the members of our departmental advisory council (from both academia and industry) to participate in the student presentation sessions. They will use the rubric to critique the oral presentations to evaluate the effectiveness of our students' technical communication skills. The evaluators will also be asked to provide comments on the strength and weakness of each individual presentation. We believe that these feedbacks will help us effectively identify the weakness in our students' presentation skills because they are being evaluated from the viewpoints of students, faculty, and external academic/industrial professionals, respectively. These feedbacks will be compiled and sent to the students for their reference to improve oral presentation skills.

Conclusion

We present in this paper our efforts and current progress to introduce microfluidics technology to the chemical engineering curriculum at CSULB. These two new elective courses are intended to expose our senior and first-year graduate students at CSULB to this exciting field of study and to provide them with working knowledge to get involved in this area. Once we complete the course development, they will be first offered to students in our department for two years as a pilot program and will later be offered to all science and engineering majors at CSULB after revising the course contents according the feedbacks from our students, faculty, and members of our departmental advisory council. Through this course development project, our students will obtain not only the working knowledge of microfluidics technology, but also the communication skills required for effective technical information exchange. We hope that in the future these two courses may excite more students to pursue advanced studies and careers in this area of growing importance.

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