A Multidisciplinary Curriculum Based on Team-Work and Industrial Partnership

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Abstract: Under the umbrella of the NSF Center for Industrial Sensors and Measurement (CISM), development of novel materials and micro-fabrication techniques for sensors and sensor systems for hostile environments are being actively pursued at The Ohio State University (OSU). CISM's organizational structure provides a framework for interaction among scientists, engineers, students and business leaders. Exploiting the collaborative environment of CISM combined with research advances in sensors, an innovative team-work and industry-oriented curriculum development is underway. The curriculum is designed around the multidisciplinary approach of CISM and focuses on an interactive approach emphasizing problem solving, team-work, communication, and industrial experience. As part of this curriculum, a 5 credit hour honors course was taught in the Winter Quarter of 2000. In this course students were exposed to: (i) lectures covering basic scientific and technological principles of a wide range of sensor materials, (ii) writing of a term paper and making an in-class presentation, (iii) computer simulation and modeling of sensor arrays, and (iv) laboratory project demonstrating the fabrication and testing of sensor probes. The course was team-taught by faculty members from a wide range of disciplines in engineering and physical sciences. Also, guest lecturers were brought in to cover topics where their expertise is well known. Term paper preparation involved targeting a specific industry sector, identifying a sensor need and developing a report based on the literature (including patent literature). Laboratory project involved group effort leading to the fabrication of a sensor probe starting from raw materials to probe design, packaging and testing.

Keywords: multidisciplinary curriculum, sensor course, honors course, minor degree.

[1] Introduction

In cutting-edge research, there is a growing trend for multifaceted partnerships involving academia, government, national laboratories and industries. Such partnerships in education are slowly emerging. With changing societal needs and demands, the way we educate and train the future generation of engineers is evolving. We need to integrate the latest research developments into the student curriculum more readily and train students in a collaborative environment with involvement from industries. This will help students appreciate the impact of their education on society and will also help develop skills useful for their future careers. Indeed, multifaceted partnerships provide unique opportunities for enriching the educational experience of students that is yet to be exploited.

At the NSF Center for Industrial Sensors and Measurement (CISM), development of novel materials and micro-fabrication approaches for sensors and sensor systems for hostile environments are being actively pursued at The Ohio State University (OSU).[1-4] Research teams include students and faculty from the Departments of Chemistry, Physics, Materials Science and Engineering, Electrical Engineering, Industrial Engineering, Chemical Engineering and Mechanical Engineering. CISM's organizational structure provides a framework for interaction among scientists, engineers, students and business leaders. Students from various disciplines closely interact with each other, as well as with scientists and engineers from industries and national laboratories. Taking advantage of the infrastructure and the multifaceted partnership of CISM combined with research advances in new sensor materials and their micro-machining, we have started to develop an innovative curriculum.[5-7]

The curriculum is designed around the multidisciplinary approach of CISM and focuses on an interactive approach emphasizing problem solving, group projects, communication and industrial experience. A series of courses in sensor materials and Bio-MEMS including instructional laboratories are being designed from a multidisciplinary approach and are team-taught by faculty members from a wide range of disciplines as well as experts from industries. These courses are targeted for senior undergraduate and starting graduate students. Students taking this sequence along with additional courses in instrumentation and measurements from participating departments, and appropriate Business and Law courses will have the option to receive a minor or certificate degree in "Sensors and Measurements". Emphasis in Business and Law courses will be on such issues as product design and liability, problems created by new technologies, protection of intellectual property, technology transfer and the relationship to the Internet.

In previous publications, details of the curriculum including results of the offering of some of the courses has been reported.[5-7] Course descriptions including lecture notes can be viewed at internet sites: http://www.biomems.net, http://m04.cism.ohio-state.edu/nsf.crcd and http://www.er6.eng.ohio-state.edu/mse. This paper will describe the offering of a 5-credit hour honors course for the first time during the Winter Quarter of 2000.

2. Honors Course in Sensor Materials

In its first offering the course was taken by 6 students. Undergraduate enrollment was very limited, because it is difficult to fit in a new course on a short notice into their pre-determined curriculum. Future offerings will need to be advertised well in advance to a wider pool of students. This course is intended to be a condensed version of the three-course sequence being developed under the NSF-CRCD program.[5-7] In this course, students were exposed to: (i) lectures covering basic scientific and technological principles, (ii) writing of a term paper and making an in-class presentation, (iii) computer simulation and modeling of sensor arrays, and (iv) laboratory experiments demonstrating the fabrication and testing of sensor probes.

2.1 In-Class Lectures

Lectures were given by faculty members from a wide range of disciplines in engineering and physical sciences. Also, guest lecturers were brought in to cover topics where their expertise is well known. Students were given a closed-book written test based on the lecture materials. Questions were set by a multidisciplinary team of faculty who also graded students' answers to their questions. A list of lecture topics is shown below; lecture notes can be viewed at: http://www.er6.eng.ohio-state.edu/mse.

Introduction
- Technological needs and justifications

Synthesis and Fabrication
- Conventional ceramic synthesis
- Chemical synthesis and nano-phase materials
- Materials issues in thick and thin films
- **Micro-machining**
- Bio-MEMS

Surfaces, Interfaces and Catalysis
- Structure and composition
- Defects and properties
- Adsorption, desorption and catalysis

Characterization of Sensors
- Microstructure-sensing property relations
- Surface and interface characterization
- Electrical and sensing properties

Theory and Modeling
- Sensing mechanisms
- Microstructure-property relationship
- Sensor arrays and artificial intelligence

2.2. Term Paper

Term paper preparation involved targeting a specific industry sector, identifying a sensor need and developing a report based on the literature (including patent literature). Examples of term paper topics are shown in Table I. Papers were limited to 15 pages with major emphasis on the status of current technology leading to identification of outstanding challenges and future trends in the chosen topic. Each paper was graded giving significant weight to the depth and level of critical discussion. Each student made a presentation followed by questions from the audience. The quality of the presentation was judged by multiple faculty members and the peer group of students in the class. The term papers have been archived in the CISM library and can be accessed as reference materials.

Table I: Examples of term papers written for the honors course in "Sensor Materials"

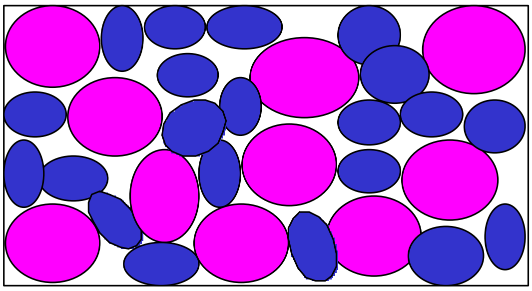
Paper Number	*Term Paper Title*
1.	Micromachined pressure sensors
2.	Potentiometric zirconia oxygen sensors: a review
3.	Computational methods applied to ZrO_2-based gas sensors
4.	Enzyme-based electrochemical biosensors: a review
5.	Thin film oxygen sensors
6.	Challenges in Non-silicon MEMS

2.3 Computer Simulation and Modeling

Recognizing the growing importance of computational science & engineering (CSE) in modern technological advancements, modeling and simulation forms a key module of the curriculum. In this course, examples were drawn from the work of CISM in modeling of TiO_2-based gas sensors. Based on successful simulations of the response of n-type anatase to a reducing gas like CO,[8,9] we recently developed a model for the sensing response of composites of n and p-type TiO_2 (anatase and rutile, respectively). This example provided an excellent introduction for the students to the problem of computer design and optimization of a material system, involving the phenomena of surface chemical reactions, electrical conduction through a granular material, and the use of neural networks to analyze the response of a sensor array. We briefly describe the p-n composite modeling aspects here.

A schematic illustration of a composite of rutile and anatase grains of TiO_2 is shown in Fig. 1. Microstructural studies using TEM had revealed large anisotropic rutile grains embedded in smaller anatase particles. While the n-type anatase responds with a decrease in resistance upon exposure to a reducing gas such as CO, the resistance of the p-type rutile increases. Thus mixtures of the two phases can have a response anywhere in between that of the pure n and p phases. Indeed, precisely this flexibility allows the optimization of a sensor composition to produce selectivity to a particular gas and insensitivity to other reducing gases. Figure 1b shows the surface contact fraction, which is proportional to the conductivity, through an anatase/rutile mixture as the rutile fraction increases. These properties are used by the students to design arrays of sensors that can be sensitive to a variety of gases.

(a) **(b)**



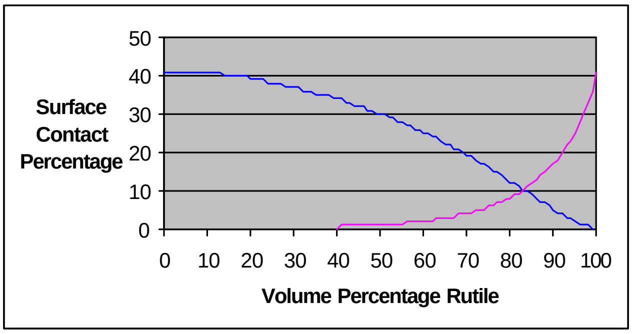


Fig. 1. (a) A composite composed of large grains of rutile and small grains of anatase TiO_2; (b) calculated surface contact (and conductivity) of n-n anatase chains and p-p rutile chains as a function of rutile fraction.

2.4 Laboratory Project

The main objective of the laboratory project was to train students so that they would be able to fabricate a sensor probe starting from raw materials to probe design, packaging and testing. The recipe for the laboratory project comes directly out of graduate research in CISM. The class was divided into three groups each consisting of two students. Each group worked on one of the following laboratory projects.

- Fabrication and characterization of a solid reference oxygen sensor
- Fabrication and characterization of a thick-film CO sensor
- Fabrication and characterization of artificial muscle actuator valves on a TEM gold grid

Each group was given a laboratory handout with technical details and a CISM student was assigned as a project coordinator. Each coordinator is a graduate student working on the topic as part of their M.S./Ph.D. thesis research. The project coordinator explained some of the experimental details and demonstrated operation of equipment and facility. Students worked in the laboratory for two hours every week over several weeks to complete the project. They completed the project in 7 weeks with the submission of a written report. Figure 2 shows an example of a probe designed for the oxygen sensor with solid reference electrode.

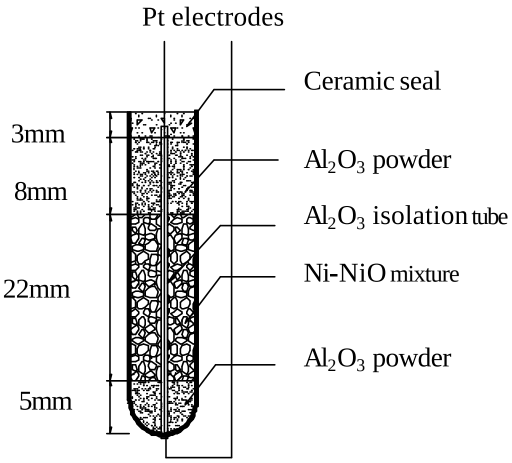


Fig. 2. A schematic and a photograph of a solid reference oxygen sensor probe.

3. Assessment and dissemination

Students completed a questionnaire, designed by the OSU Honors House. Students liked how the laboratory project was organized. They also liked the term paper assignment along with in-class presentation. However, they clearly pointed out that the topics covered in the lectures were too wide and needed to be narrowed down. These comments will be taken into account in the future offerings. Also, a web-based course evaluation will be developed in the future to provide feedback and evaluation of the approaches and materials used in the course.

The results of the sensor curriculum development effort, in general, are being disseminated through two mechanisms. The first is the presentation and publication of papers describing the curriculum together with descriptions of sample capstone design projects and the participation of industrial sponsors in these projects. Papers are being presented at the Frontiers in Education Conference, and at other professional society meetings and symposia. For example, CISM faculty have presented the curriculum plans at: (1) the International Conference on Engineering Education (ICEE-98 and ICEE-99)[5,6] and (2) Education Symposia of professional societies such as the American Ceramic Society (ACerS), The Minerals, Metals and Materials Society (TMS) and the American Society for Engineering Education (ASEE).[7] The second means will be the establishment of an Internet site for computer-aided instruction and distance learning. This will further enhance our current effort of posting lecture materials on the internet: http://www.biomems.net, http://m04.cism.ohio-state.edu/nsf.crcd and http://www.er6.eng.ohio-state.edu/mse. Future plans also include use of video and multimedia instruction as well as the existing OSU distance learning system that connects classrooms to off-site participants.

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Acknowledgements

This program was supported by grants from the National Science Foundation (EEC-9872531 and EEC-9523358) and OSU Honors House. Y. Wang would also like to acknowledge support under NSF CAREER award, DMR-9703044.