The Johns Hopkins University/Army Research Laboratory Microelectronics Research Collaborative Program

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The Johns Hopkins University and the Army Research Laboratory began a collaborative effort in 1995 to conduct research and development in electrochemistry, piezoelectronics, manufacturing science, microelectromechanics, and display technology. This article presents an overview of the various projects in these five technical areas as well as the educational benefits of the collaboration.
(Keywords: Collaboration, Education, Microelectronics, Research and development.)

INTRODUCTION

In September 1995, The Johns Hopkins University and the Physical Sciences Division of the Army Research Laboratory (ARL) began a multidisciplinary program that involves elements of collaborative research, development, and education. The educational component consists of the development of doctoral/postdoctoral programs and special educational opportunities for ARL employees as well as the creation of other associations like the Faculty Visiting Lecturer Program. In contrast to the usual contract or grant, this is a true collaborative program in which investigators from Hopkins and ARL work on projects jointly and use each other's facilities. The agreement covers a 4-year period, which may be extended for an additional 2 years to broaden the partnership between Hopkins and ARL.

Research and development are being conducted in five areas: electrochemistry and energy science, piezoelectronics, manufacturing science, microelectromechanics, and high-resolution display technology. Fourteen projects were approved for fiscal year 1996. The effort involves investigators from APL, the Homewood campus, and the Johns Hopkins Medical Institutions. The Program Management Committee from Hopkins consists of J. Wagner (Program Manager), R. Benson (Executive Director), R. Westgate (Education Coordinator), and T. Poehler (Vice Provost for Research). ARL's Program Manager during 1995–96 was M. Dutta.

TECHNICAL PROJECTS

The objectives and approaches used for the 14 projects within the 5 technical areas are summarized in the following sections. (Investigators are indicated in parentheses; an asterisk identifies an APL staff member.)

Electrochemistry and Energy Science

Development of Membranes for Methanol Fuel Cells

The long-term objective of this project is to develop new membranes for use as solid polymer electrolytes in methanol fuel cells. Membranes currently in use allow methanol to diffuse across them, resulting in oxidation at the cathode and a "chemical short circuit." To design the next-generation membrane material, the transport behavior of existing membranes must be fully understood from a molecular perspective. Experiments are being conducted using Fourier transform infrared spectroscopy and attenuated total reflectance spectroscopy to investigate the diffusion of methanol across selected membranes. (JHU: T. Barbari and P. Searson; ARL: S. Gilman)

Synthesis and Processing of Carbon Electrodes for Charge Storage Applications

Alternative fabrication techniques are being explored to develop improved carbon electrodes for lithium ion batteries and electrochemical capacitors. Current systems use carbon particles dispersed in an organic binder such as polyvinylidene fluoride. The initial Hopkins approach uses an inorganic binder (silica) in a sol-gel process to produce a silica/carbon composite. (JHU: P. Searson and T. Barbari; ARL: R. Jow and M. Salomon)

Electrochemical Studies on Catalysts for the Oxidation of Methanol in Methanol–Oxygen Fuel Cells

One major factor limiting the performance of the methanol–oxygen fuel cell (Fig. 1) is poisoning of the catalyst by the adsorbed intermediates (CO_{ads} and CHO_{ads}), which causes a reduction in the steady-state current density by at least a factor of 10^4. Indirect methods for treating this problem are impractical. It is therefore crucial to identify the adsorbed intermediates and develop methods to destabilize them. The catalytic activity of a number of metal alloys and metal oxides is being investigated using several electrochemical techniques (e.g., *in situ* scanning tunneling microscopy) to understand the mechanism and kinetics of methanol oxidation. (JHU: R. Srinivasan* and P. Gopalan*; ARL: S. Gilman and R. Jow)

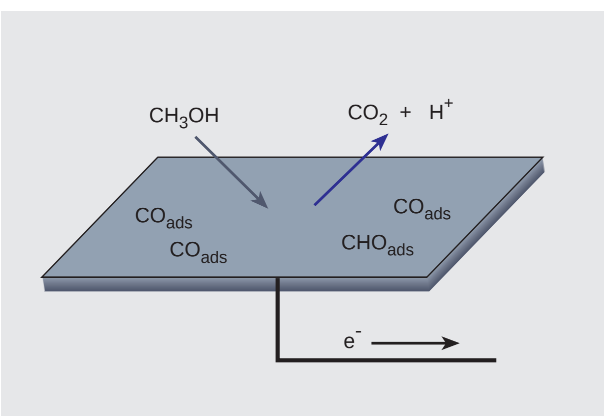


Figure 1. Schematic of a catalytic surface in a methanol–oxygen fuel cell.

Piezoelectronics

The primary goal in this area of collaboration is to develop more stable oscillators. A secondary objective is to exploit the oscillator instabilities for sensor applications.

Quartz Microsensor Array

The objective of this project is to develop uncooled infrared imagers based on an array of low-noise, highly temperature-sensitive quartz crystal microresonators (Fig. 2). This is feasible because of the exceedingly low noise level associated with quartz crystal resonators and the achievement of proper thermal isolation. Using photolithographic methods, the microresonators are deposited on thin-film supports and coated with specialized infrared-absorbing films. When the resonators are illuminated with light in the spectral range of absorption, the temperature of the individual pixels increases and the signal is read out as a change in frequency relative to an unilluminated reference resonator. (JHU: W. Bryden,* J. Suter,* G. Bao, and A. Andreau; ARL: J. Vig, R. Filler, and Y. Kim)

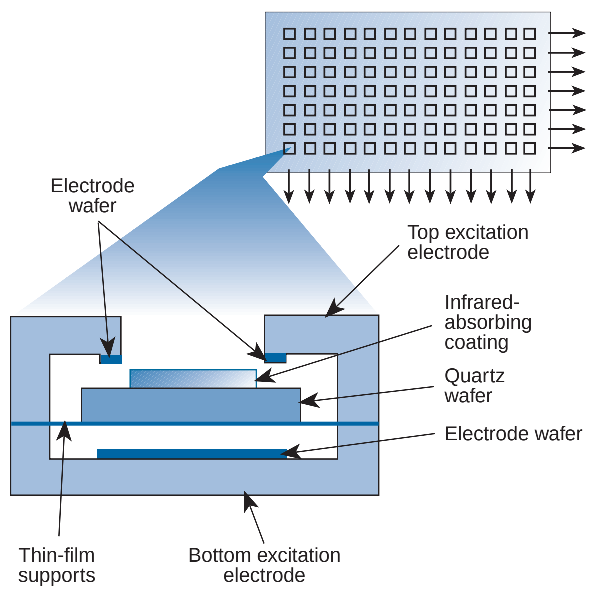


Figure 2. Infrared imager based on a quartz microresonator array.

Piezoelectric Crystal Growth

The trend in electronic systems toward high frequencies has led to the need for thermally compensated piezoelectric materials having better performance than quartz. Materials such as lithium tetraborate ($Li_2B_4O_7$), lithium niobate ($LiNbO_3$), lithium tantalite ($LiTaO_3$), and langasite ($La_3Ga_5SiO_{14}$) all offer improved performance provided that high-quality crystals can be grown. This project applies the static directional cooling method to grow crystals with a minimum of defects. (JHU: D. Nagle and J. Spicer; ARL: J. Kosinski)

Design and Fabrication of Levitated Resonators

A new concept to improve the frequency stability of quartz resonators is the focus of this project. Stability is achieved by levitating the quartz plate electrostatically, thereby eliminating the need for mounting structures. A prototype (Fig. 3) has been designed and assembled for test and evaluation using an optical position-measuring system to determine the displacement of the quartz plate. Issues to be investigated include energy trapping, thermal transfer, and the quality factor. (JHU: J. Suter,* J. Norton,* G. Bao, and W. Bryden*; ARL: J. Vig)

Manufacturing Science

Neuromimetic Microelectronic Systems for Sensory Information Processing

This collaborative effort focuses on the development of pulse-coupled neural devices that will help solve the problem of real-time automatic target recognition. A neuromimetic approach is being used to adapt neural information processing systems to silicon microelectronics. Hardware and algorithms are being co-developed to demonstrate the concepts. A prototype silicon retina (Fig. 4) is being used to test pulse-coupled neural network concepts. (JHU: A. Andreau, G. Cauwenberghs, F. Pineda,* and K. Strohbehn*; ARL: M. Tompsett)

Determination of Selected Physical Properties of Various Piezoelectric Materials

The broad goal of this project is to characterize the key physical properties of piezoelectric materials at the boule and wafer level to support the manufacturing science of single-crystal materials. Material properties of interest include elastic constants, thermal expansion, piezoelectric and dielectric constants, temperature dependence, and homogeneity. The initial focus is on the measurement of the elastic constants. (JHU: J. Winter and R. Green; ARL: J. Kosinski, A. Ballato, and J. Vig)

Microelectromechanics

Magnetic Resonance Force Microscopy

Magnetic resonance force microscopy is a new technique capable of detecting very small magnetic moments with submicrometer spatial resolution. With the use of a magnetic resonance force microscope (Fig. 5), it may also be possible to detect the magnetic moment of single proton and electron spins. Such a device has been designed and fabricated for electronic and biological applications, such as investigations of defects in electronic materials and studies of individual cells. It uses a radio frequency (RF) coil to excite magnetic resonance in a sample. A miniature cantilever measures the magnetic force induced in the sample nuclei by a gradient magnetic field. The RF field flips the spin of the sample nuclei back and forth, which in turn causes the cantilever to vibrate. The vibrational motion is detected by a fiber-optic interferometer. (JHU: R. Fainchtein*; ARL: D. Smith)

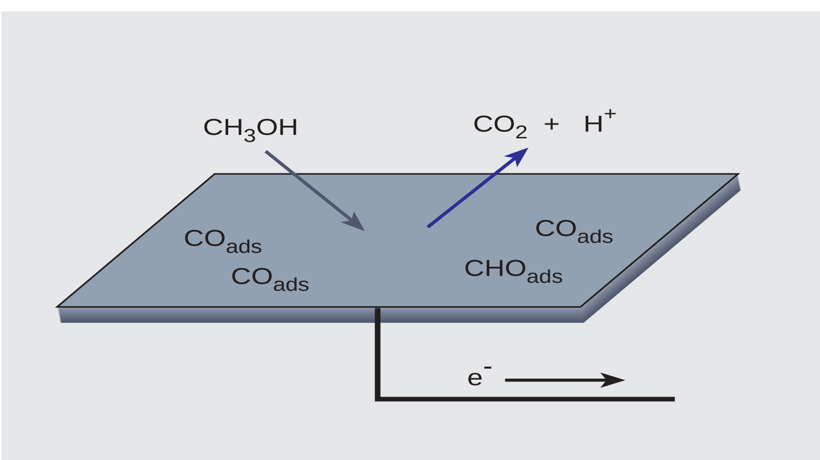


Figure 3. Levitated quartz resonator apparatus.

Mechanical Properties of Materials Used in Microelectromechanical Systems (MEMS) and Microdevices

Mechanical properties of the various materials used in MEMS are important in the design and fabrication of microdevices. Since the samples are rather thin and small, special testing techniques

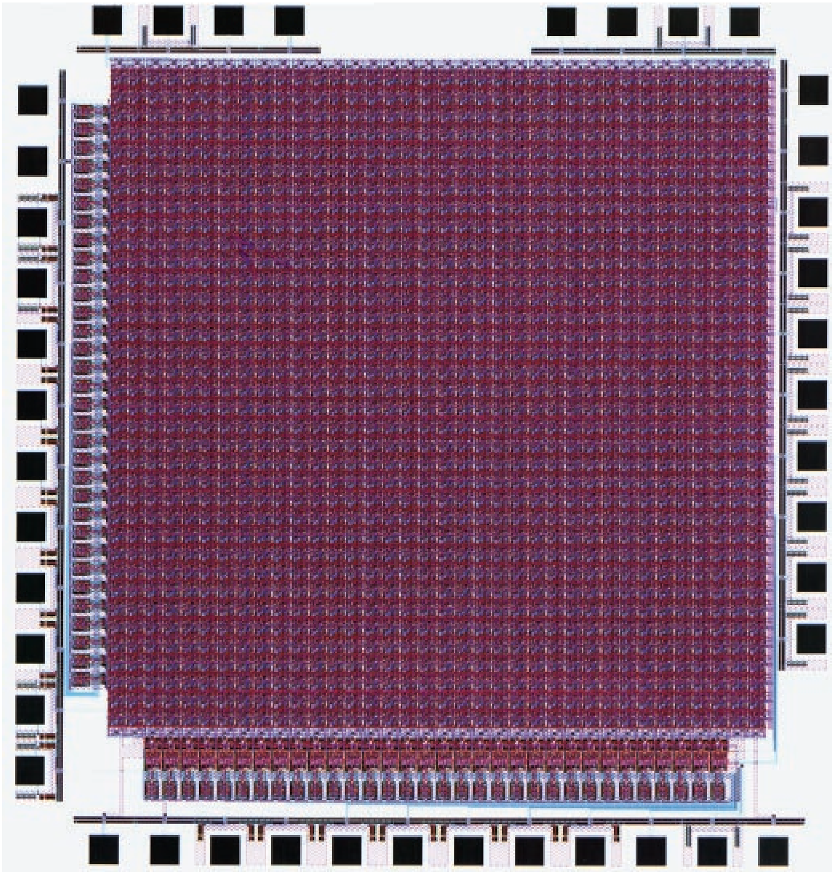


Figure 4. Prototype 32 × 32 pixel silicon retina (2.7 × 2.8 mm).

are needed. The objectives of this project are to develop such techniques and measure the mechanical properties of various materials to determine the effects of processing and environment. Previous approaches using indirect techniques had problems associated with specimen preparation and handling, the elimination of friction in the loading mechanism, and the validity of the indirect strain measurement. The Hopkins approach solves these problems using a uniaxial tensile test for a direct measurement of strain on the specimen (Fig. 6). Initial results have exhibited good accuracy and excellent reproducibility, thereby validating the approach. (JHU: W. Sharpe and R. Edwards*; ARL: R. Zeto)

Microfabricated Chemical Analysis Systems for Chemical and Biological Warfare Agent Detection

The overall objective of this project is to integrate biochemical and microbiological analysis techniques with MEMS technology to develop versatile sensor systems for the detection of chemical and biological warfare agents. The specific objective of the first year was to design and fabricate microstructures that will be used to develop a miniature displacement immunoassay system. The initial demonstration of the proof of concept was the detection of aflatoxin. Different designs have been evaluated for the micromechanical reactors with the antibody immobilized on a support medium. The final design is shown in Fig. 7. The sensor was incorporated into a flow system, and the dissociation kinetics were investigated. Fluorescence detection schemes are being

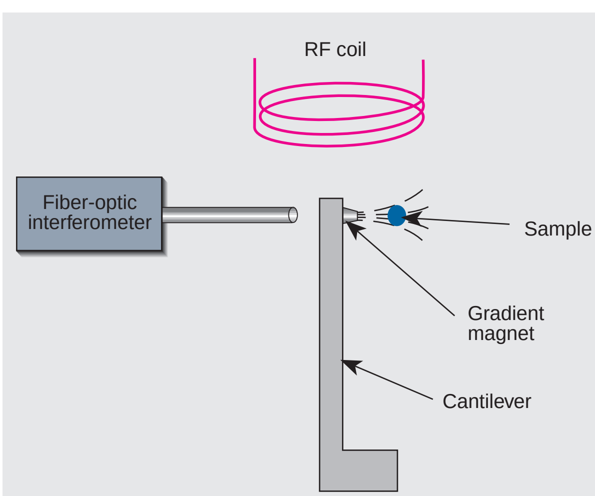


Figure 5. Schematic of a magnetic resonance force microscope.

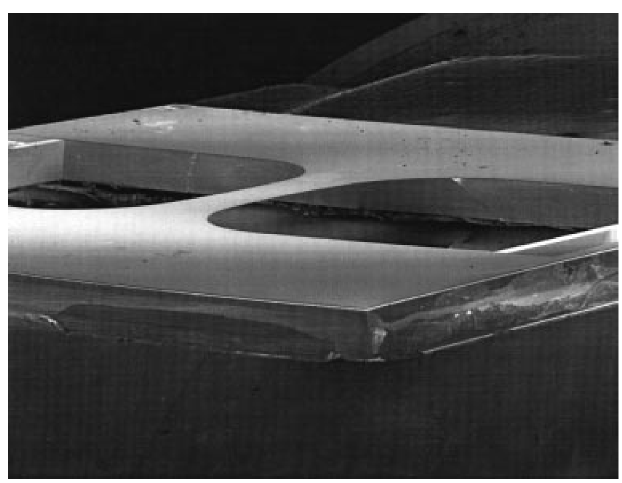


Figure 6. Scanning electron microscope photograph of a tensile test specimen.

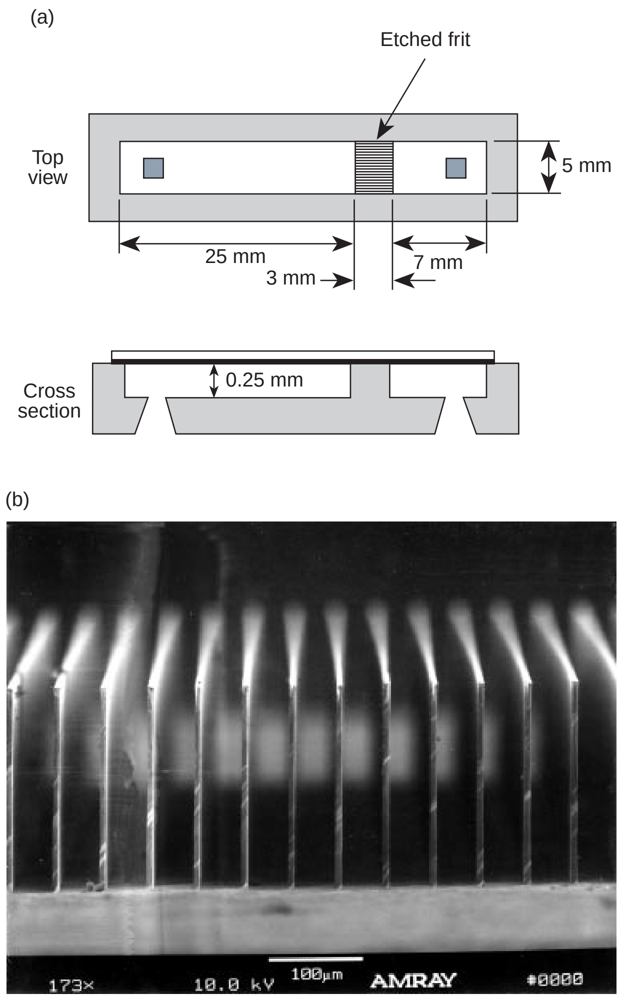


Figure 7. Microreactor design: (a) schematic and (b) cross-sectional view of etched frit as observed in a scanning electron microscope.

developed. (JHU: N. Sheppard, J. Groopman, and R. Benson*; ARL: R. Zeto and T. Wong)

High-Resolution Display Technology

The primary objective in this area is the development of high-luminous-efficiency phosphors for various display technologies. The research focuses on organic electroluminescent materials and inorganics for low-voltage cathodoluminescence.

Field Emitter Display Applications

The synthesis and deposition of low-voltage, efficient phosphors for field emitter display applications is an important area of research. This project combines the synthesis of phosphor particles with novel electrophoretic deposition techniques to provide molecular control of the bandgap, dopant concentration, and surface properties. Since the detailed mechanisms of electrophoretic deposition of phosphors are not known, initial experiments have been conducted using commercially available phosphor particles to understand the deposition mechanism and the role of particle size. (JHU: G. Meyer and P. Searson; ARL: D. Morton)

Synthesis and Deposition of Electroluminescent Polymers for Display Applications

This project involves the development of conducting polymer light-emitting diodes (LEDs) for large-area displays that operate at low drive voltages. The polymers being investigated—polyphenylene vinylene and copolymers of fluorinated thiophenes—are deposited using dip and spin-coating methods. Key issues being addressed are carrier injection and transport, which depend on both the polymer and electrode materials. (JHU: T. Poehler; ARL: D. Morton and M. Wraback)

High-Resolution Display Technology: Molecular-/Polymer-Based Electroluminescent Devices

This project focuses on the development of high-efficiency polymer LEDs that initially involve poly(*p*-pyridine), which is stable to 270°C and is oxidation-resistant. Thin films can be deposited from solution, and the bandgap (or emitting wavelength) can be tailored by changing the heteroatom. A possible configuration for a polymer LED is shown schematically in Fig. 8. (JHU: R. Potember,* K. Bowen, and J. Sadowsky*; ARL: D. Morton)

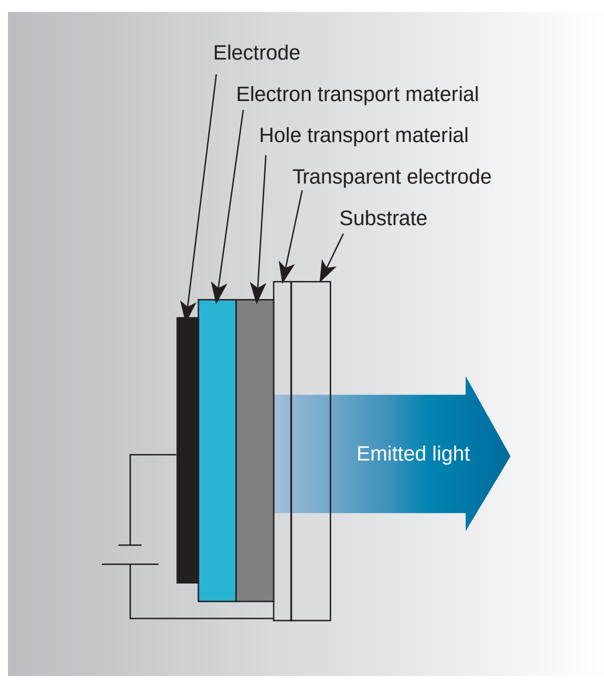


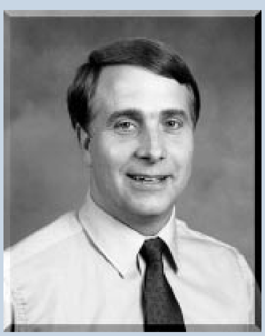
Figure 8. Configuration of an organic light-emitting diode.

EDUCATIONAL COMPONENT

Graduate students and postdoctoral candidates are involved in all 14 projects discussed here with the goal of developing strong doctoral and postdoctoral programs in these technology areas. Researchers from Hopkins have also conducted a MEMS Technology Seminar at Fort Monmouth for ARL employees that dealt with manufacturing processes and selected applications. The seminar covered several specific topics: fabrication technologies, mechanical properties, testing of microstructures, coating/deposition of special materials on microstructures, transduction methods, packaging, special power supplies, micro- and nanometer probe and manipulation, chemical and biological analytical techniques: principles and miniaturization issues, medical applications, and optical applications. (Hard-copy handouts of the material covered in the seminars are available from the authors.)

THE AUTHORS

RICHARD C. BENSON was educated at Michigan State University (B.S. in physical chemistry, 1966) and the University of Illinois (Ph.D. in physical chemistry, 1972). Since joining APL in 1972, he has been a member of the Milton S. Eisenhower Research and Technology Development Center and is assistant supervisor of the Sensor Science Group. He is currently involved in research and development on miniature sensors, counterfeit deterrence features for U.S. currency, the properties of materials used in microelectronics and spacecraft, and the application of optical techniques to surface science. Dr. Benson has also conducted research in Raman scattering, optical switching, laser-induced chemistry, chemical lasers, energy transfer, chemiluminescence, fluorescence, and microwave spectroscopy. He is a member of the IEEE, American Physical Society, American Vacuum Society, and Materials Research Society. His e-mail address is Richard.Benson@jhuapl.edu.



JAMES W. WAGNER received a bachelor's degree in electrical engineering in 1975 from the University of Delaware and a master's degree in clinical engineering in 1978 from the JHU School of Medicine. In 1984, he completed a doctoral degree at Hopkins in materials science and engineering; he now serves as professor and chair of that same department. He holds a joint appointment with the Department of Biomedical Engineering and is the Advanced Sensors Thrust Area Coordinator for the Hopkins Center for Nondestructive Evaluation. In addition, he is the Program Manager of the Materials Center of Excellence (a collaborative program with ARL) and Technical Program Director of the Microelectronics Research Collaborative Program. He serves also on the National Materials Advisory Board. Since joining JHU in 1984, Dr. Wagner's research has focused on coherent optical and microwave methods involving the principles of holography, optical interferometry, and fiber optics. His e-mail address is jwagner@jhu.edu.