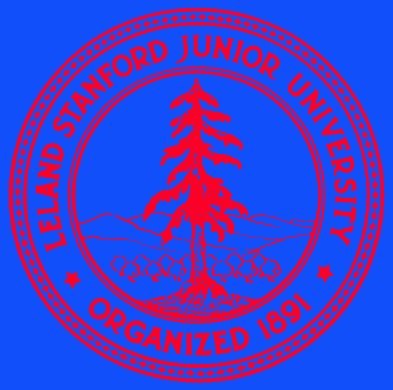
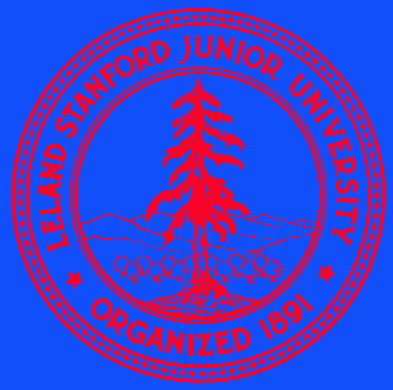
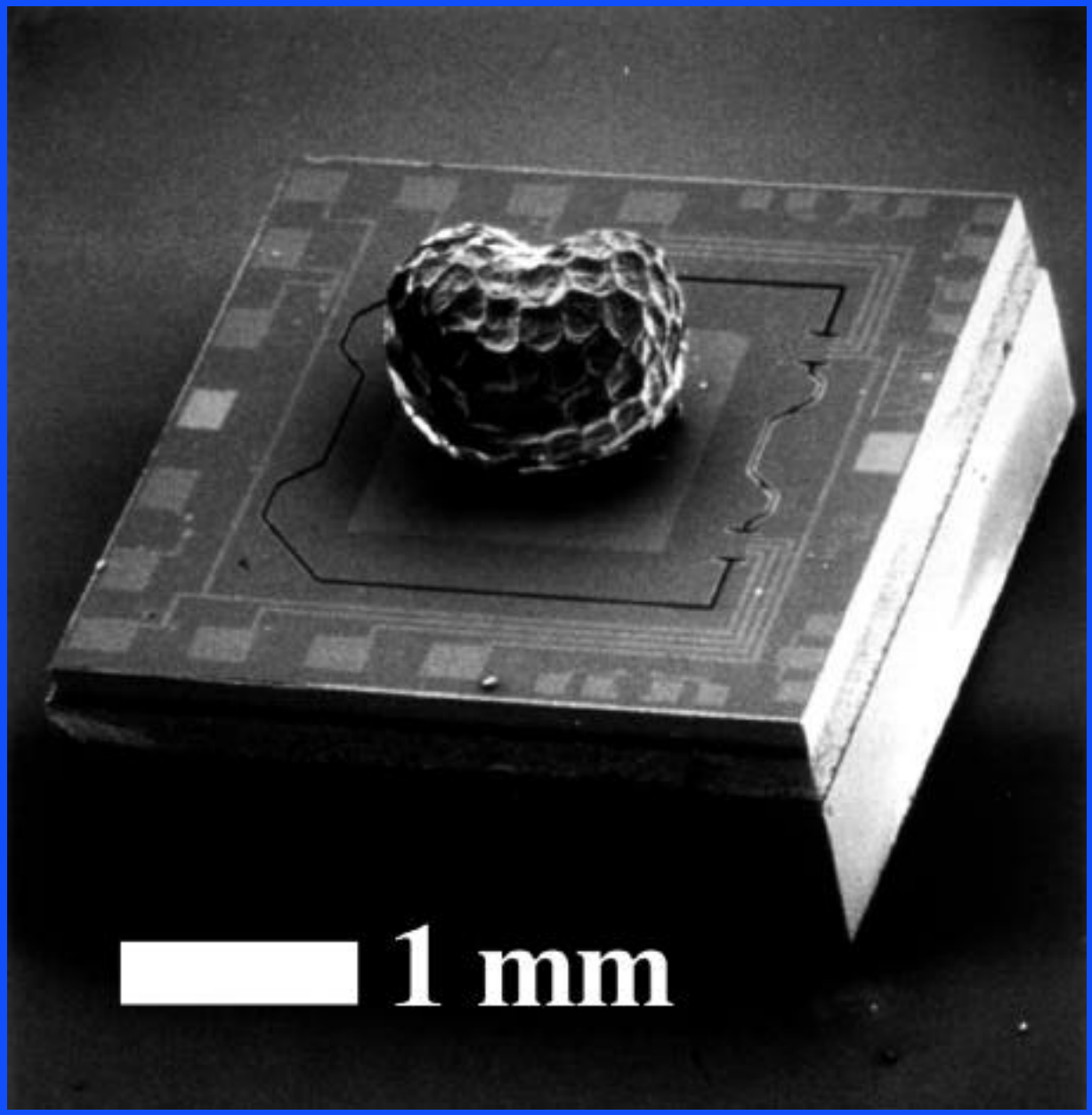
INTRODUCTION

EE312, Prof. Greg Kovacs

Stanford University







Courtesy of Prof. Kurt Petersen, Lucas NovaSensor

MICROMACHINING SENSORS, ACTUATORS AND STRUCTURES: AN *INTERDISCIPLINARY* UNDERTAKING!

“MICROMACHINING”

The term was coined in 1978 by Professor Jim Angell and Steve Terry (now with EG&G IC Sensors).

INTRODUCTION

- **The objective of this material is to provide an overview of the micromachining technologies available at present.**
- **These processes are used to fabricate microstructures that are somewhat more than two-dimensional.**
- **Most of the available micromachining techniques have been adapted from the "mainstream" integrated circuit community.**
- **Important principles include the inter-compatibilities of processes, their compatibility with active circuits, their general availability, and their individual limitations.**
- **A goal for learning this material is to understand how micromachining processes can be combined to create desired structures as well as the relative practicality of a given sequence.**

WHAT CAN ONE MICROMACHINE?

- **Sensors (e.g., pH, light, pressure, force, etc.)**
- **Actuators (e.g., valves, motors, resonators, etc.)**
- **Structures (e.g., precision holes, fluidic channels, lenses, etc.)**

TRANSDUCERS

Transducers convert one form of energy into another.

This term encompasses “sensors” and “actuators.”

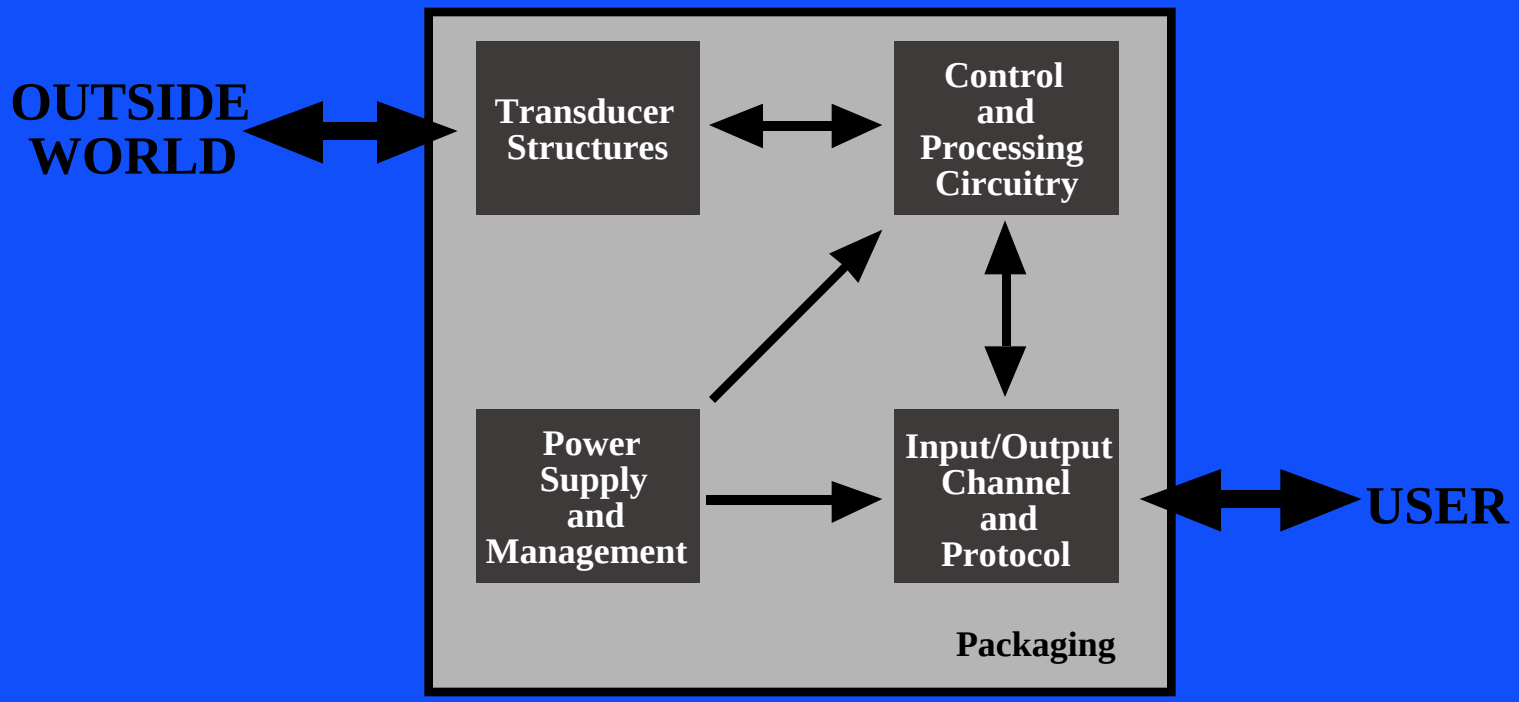
For practical purposes, a transducer is a conduit for information.

Definition from Webster’s Ninth New Collegiate Dictionary:

transduce **\tran(t)s-'d(y)üs, tranz-** ***vt*** **trans•duced; trans•ducing [L *transducere* to lead across, transfer, fr. *trans-* + *ducere* to lead] (1947) 1: to convert (as energy or a messge) into another form...**

transducer **\-d(y)ü-ser** ***n*** **(1924) : a device that is actuated by power from one system and supplies power usually in another form to second system (as a telephone receiver that is actuated by electric power and supplies acoustic power to the surrounding air)**

COMPONENTS OF A TRANSDUCER SYSTEM



MEMS HAS COMPETITION

- **This fact was pointed out by Prof. Kurt Petersen at the Transducers ‘95 conference in Stockholm, Sweden.**
- **His point is that microfabrication techniques should not be automatically used before “conventional” alternatives can be ruled out.**
- **In general, microfabrication is more expensive amd complex than, for example, injection molding.**
- **Another key factor is whether or not R&D costs are truly amortized over product volumes.**

ISSUES TO CONSIDER

Establish commercial or research need in light of “conventional” competition.
Understand the basic physics and operating principles, including scaling laws.
Understand the important issues in designing macroscopic and micromachined versions.
Survey prior work in micromachined versions, as well as “natural” (biological) analogs.
Consider the potential need to integrate on-chip circuitry (now or in the future).
Design a feasible, not overly complex, and reasonably priced fabrication process. If active circuits are, or may be, required, be sure to allow for that by avoiding incompatible steps.
Consider the issues of packaging. Can existing packages be adapted?
Consider realistic testing methods that suit the market (e.g., 100% test or statistical).
Estimate the final cost of the “ready-to-use” or “ready-to-ship” device (does it make sense?).
Consider the possibilities of evolving the design in the future to improve performance, reduce cost, etc. (this may, for example, feed back into the process design).
Make an overall decision as to feasibility prior to embarking on the research effort.

WHAT EE312 IS AND WHAT IT IS NOT...

- **EE312 is an overview course of the new, exciting, and rapidly evolving field of micromachined sensors, actuators, and structures.**
- **It is *NOT* a deep, theoretical treatment of any given type of device.**
- **Micromachining is a set of techniques and is primarily about design, not theory.**
- **The theoretical background that is required is specific to the nature of the device being developed, and it is not possible to cover it for all application domains in EE312.**

STUDENT WORK STRUCTURE

- **Students will be work in groups of two for problem sets and projects.**
- **An effort will be made to combine people with different backgrounds.**
- **Problem sets will involve some research and some design work, but the focus will be on original thought.**
- **Final projects will be done with your partner and should be relevant to the course and creative.**
- **Each team will make a brief presentation at the end of the course, and turn in a brief (< 10 page) final paper.**

COURSE TOPICS

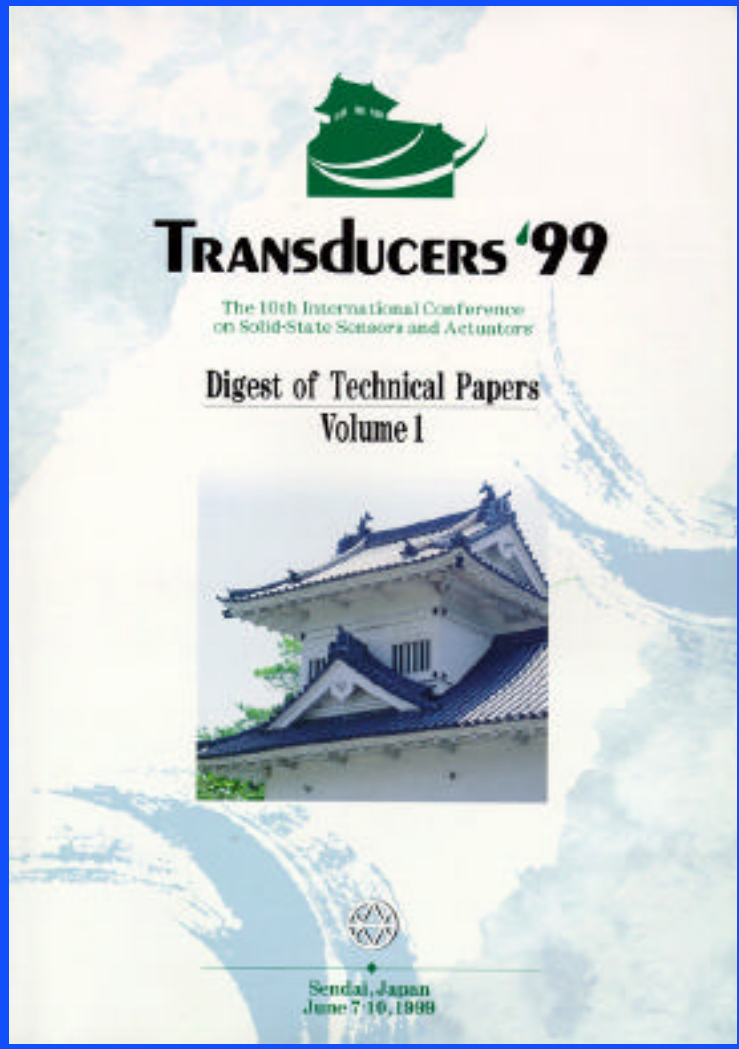
- Introduction
- Micromachining Techniques
- Mechanical
- Optical
- Chemical
- Biological
- Fluidic
- (Thermal)
- (Magnetic and Electromagnetic)

READING MATERIALS

- **This field is, at present, primarily driven by conferences. Thus, the best papers are often in hard-to-find proceedings (Hilton Head, Transducers, MEMS, etc.).**
- **There are a few good books.**
- **There are four major journals: Journal of Microelectromechanical Systems (JMEMS), Journal of Micromechanics and Microengineering, Sensors and Actuators A (Physical) and Sensors and Actuators B (Chemical).**
- **As the field matures, papers on micromachined devices will increasingly appear in the publications of the users' disciplines, rather than journals and conferences dedicated to micromachining for its own sake.**

Conferences

- *Solid-State Sensor and Actuator Workshop*, or *"Hilton Head"* (small, North American only, limited attendance meeting held at Hilton Head, SC, on alternate years, e.g., 1992, 1994, 1996, …).
- *International Conference on Solid-State Sensors and Actuators*, or *"Transducers"* (large, international meeting held in Asia, North America, or Europe on alternate years, e.g., 1991, 1993, 1995, …).
- *Micro Electro Mechanical Systems Workshop*, or *"MEMS"* (moderate sized, international workshop, with a focus on actuators and mechanical devices, held annually).
- *Micro Total Analysis Systems*, or *"μTAS"* (international, focus on micromachined chemical systems, held alternate years in Europe, e.g., 1994 (first), 1996, …).
- *Eurosensors* (European, with broad coverage, held annually).



Proceedings

IEEE

The Ninth Annual International Workshop on
Micro Electro Mechanical Systems

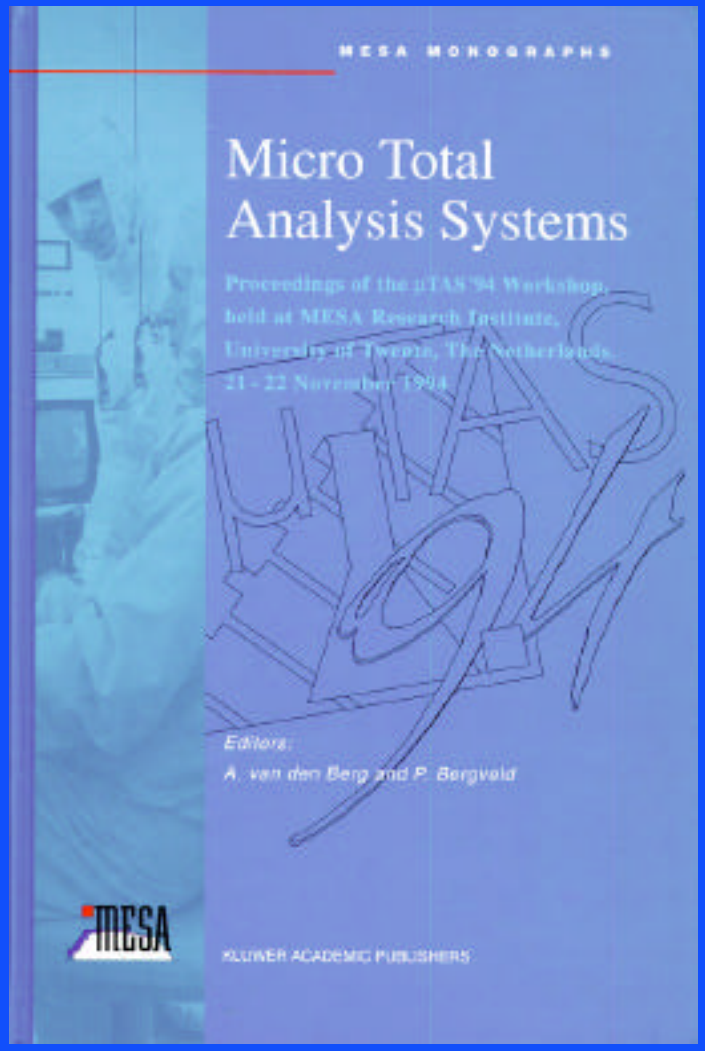
An Investigation of Micro Structures, Sensors, Actuators, Machines and Systems

Sponsored by the
IEEE Robotics and Automation Society

1996

San Diego, California, USA
February 11-15, 1996

IEEE Catalog Number 96CH35856
ISSN 1084-6999



WHERE TO GET PROCEEDINGS

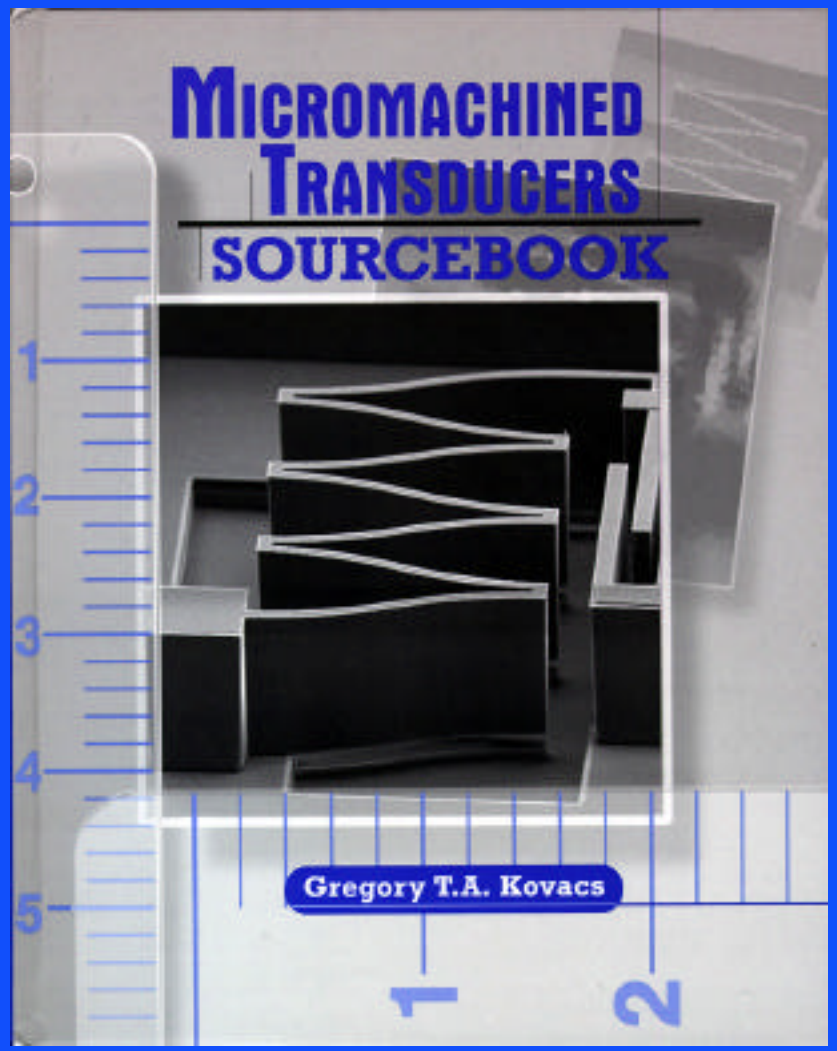
Meeting	Host Organization
Hilton Head	Transducers Research Foundation, Inc., P.O. Box 18195 Cleveland Heights, OH, USA.
Transducers	Variable, depends on host country: 1995 is available from the Royal Swedish Academy of Engineering Sciences, IVA, Box 5073, S-102, 42 Sweden, 1997 is available from the IEEE, at the address given below.
MEMS	IEEE Service Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ, USA.
µTAS	1994 - Kluwer Academic Publishers, P.O. Box 17, 3300 AA Dordrecht, The Netherlands. 1996 - AMI Editorial Office, Münsterplatz 6, Postfach 1955, CH-4001, Base, Switzerland.

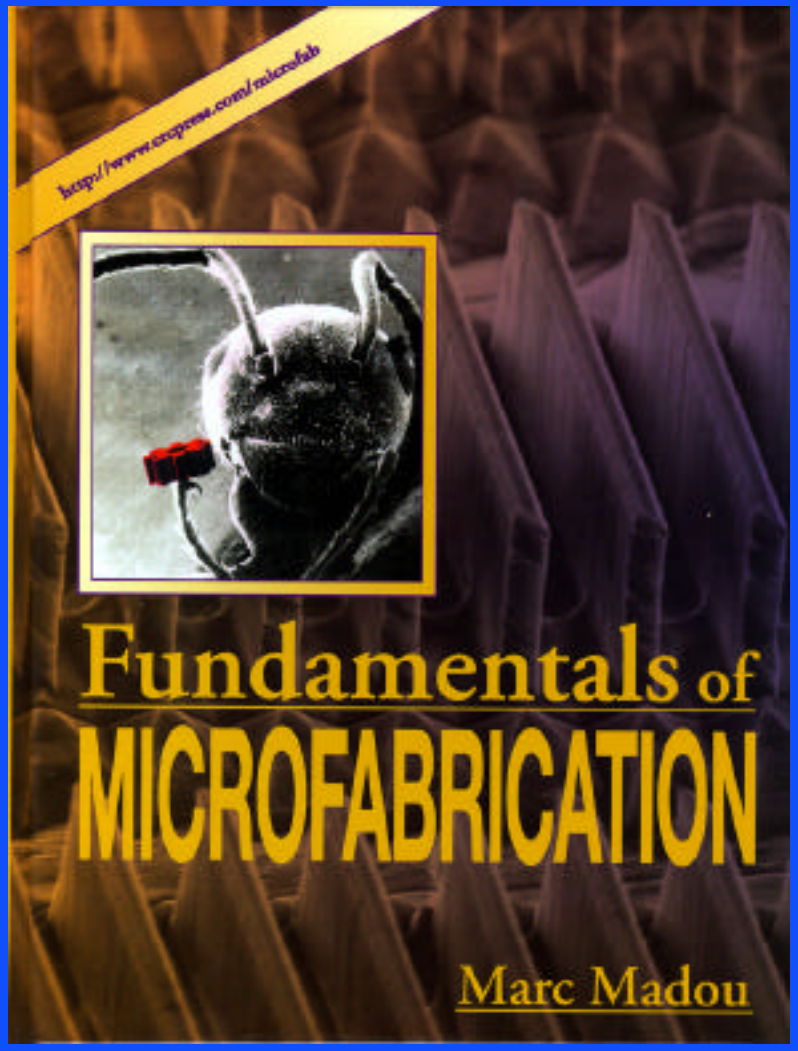
WHY AREN'T THE CONFERENCE PROCEEDINGS ALL IN THE LIBRARY?

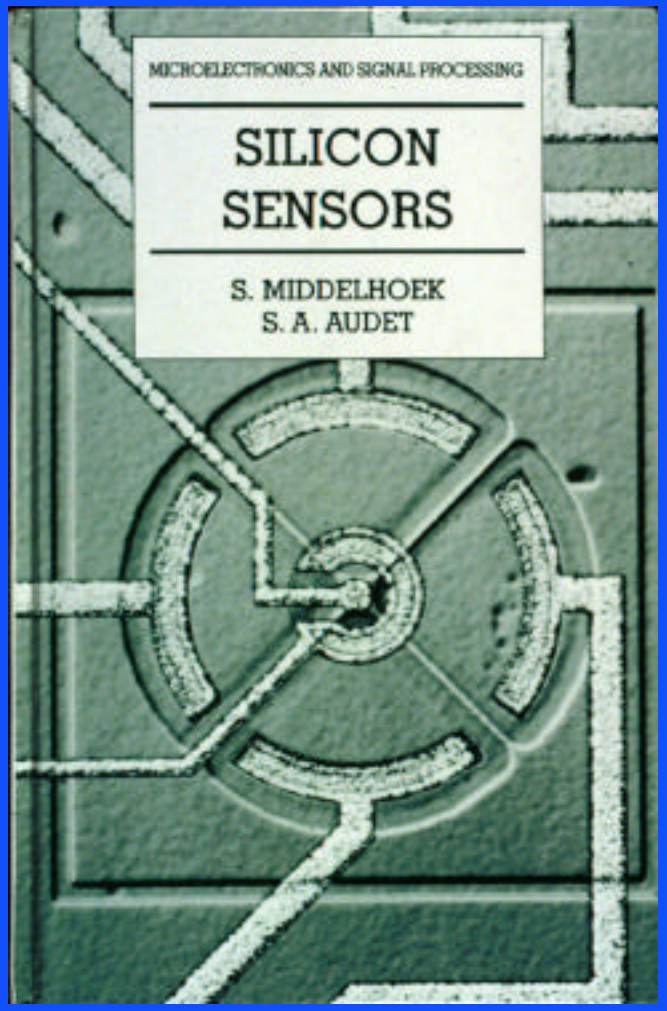
- They are sometimes quite expensive.
- They get trashed easily.
- People tear pages out.
- Alternative: some volumes are available at Kovacs' office for on-site browsing or copying only.
- For heavy users, copies should be obtained from the sponsoring organizations - mention you are a student to see if discounted rates apply.

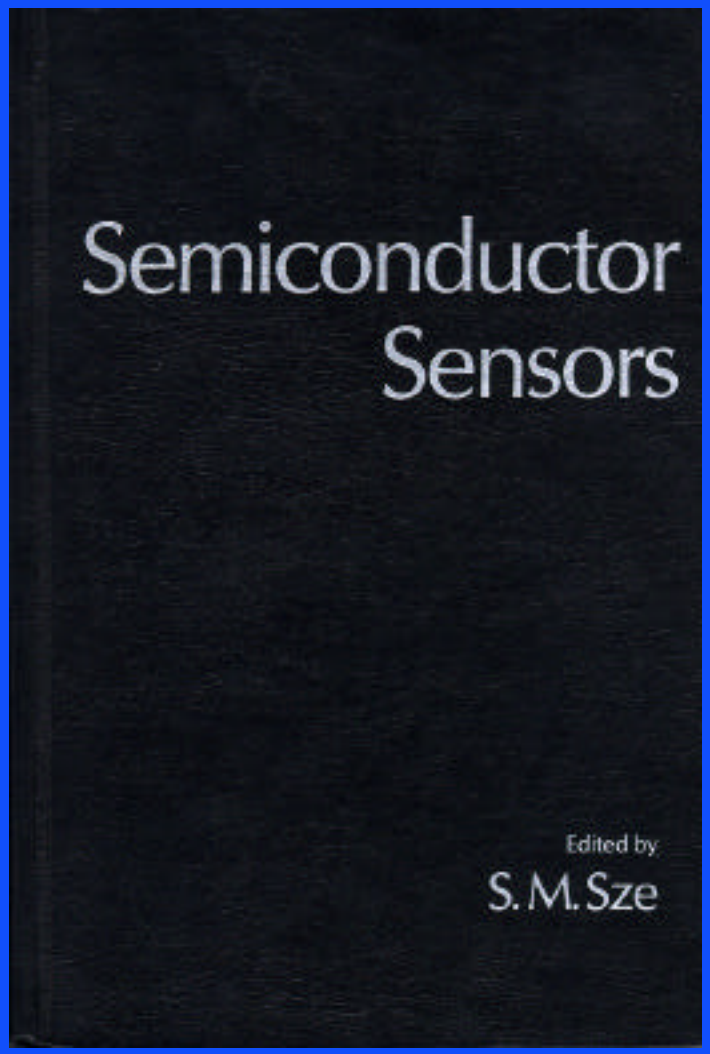
TEXTBOOKS: SOME EXAMPLES

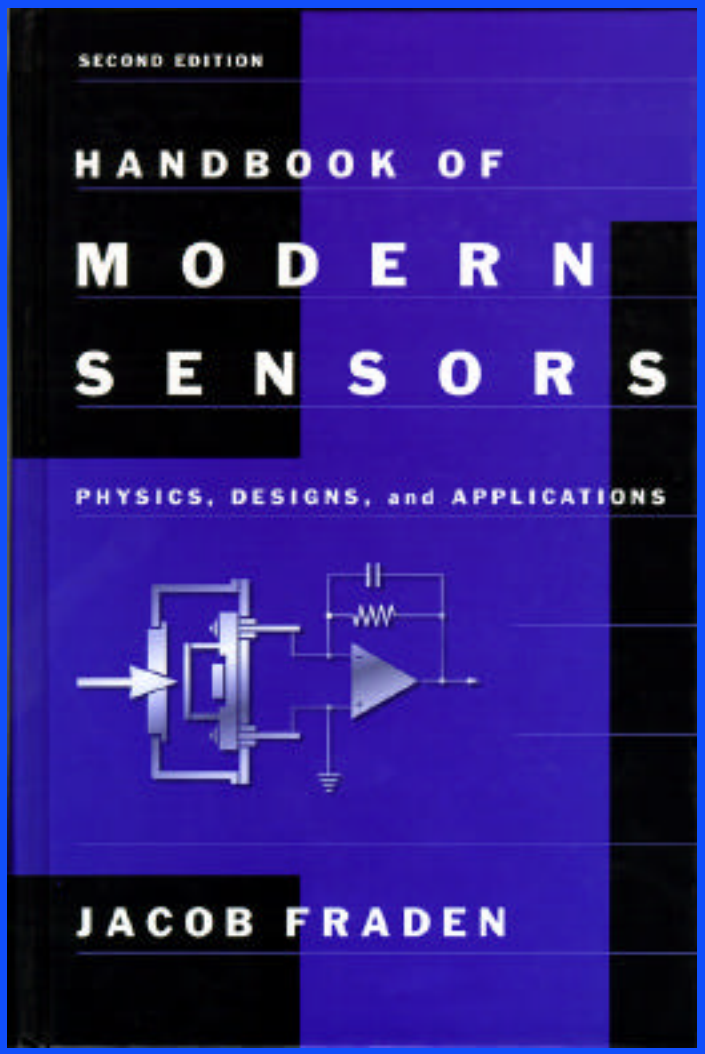
- Fraden, J., "Handbook of Modern Sensors," Second Edition, American Institute of Physics Press, Woodbury, NY, 1996.
- Gardner, J. W., "Microsensors: Principles and Applications," John Wiley and Sons, Inc., Chichester, West Sussex, UK, 1994.
- Hauptmann, P., "Sensors: Principles and Applications," Prentice-Hall International (UK), Hertfordshire, UK, 1991.
- Janata, J., "Principles of Chemical Sensors," Plenum Press, New York, NY, 1989.
- Khazan, A. D., "Transducers and Their Elements: Design and Application," Prentice-Hall, Inc., Englewood Cliffs, NJ, 1994.
- Kovacs, G. T. A., "Micromachined Transducers Sourcebook," WCB/McGraw-Hill, New York, NY, 1998.
- Kress-Rogers, E. [ed.], "Handbook of Biosensors and Electronic Noses: Medicine, Food and the Environment," CRC Press, Inc., Boca Raton, FL, 1997.
- Madou, M., "Fundamentals of Microfabrication," CRC Press, Inc., Boca Raton, FL, 1997.
- Madou, M. J., and Morrison, S. R., "Chemical Sensing with Solid State Devices," Academic Press, Inc., San Diego, CA, 1989.
- Middelhoek, S., and Audet, S. A., "Silicon Sensors," Academic Press, Inc., Boston, MA, 1989.
- Muller, R. S., Howe, R. T., Senturia, S. D., Smith, R. L., and White, R. M. [eds.], "Microsensors," IEEE Press, New York, NY, 1991.
- Noltingk, B. E. [ed.], "Instrumentation Reference Book," Second Edition, Butterworth-Heinemann, Ltd., Oxford, UK, 1995.
- Norton, H. N., "Handbook of Transducers," Prentice-Hall, Inc., Englewood Cliffs, NJ, 1989.
- Ristic, Lj. [ed.], "Sensor Technology and Devices," Artech House, London, 1994.
- Sze, S. M., "Semiconductor Sensors," John Wiley and Sons, Sommerset, NJ, 1994.
- Trimmer, W. S., "Micromechanics and MEMS: Classic and Seminar Papers to 1990," IEEE Press, New York, NY, 1997.

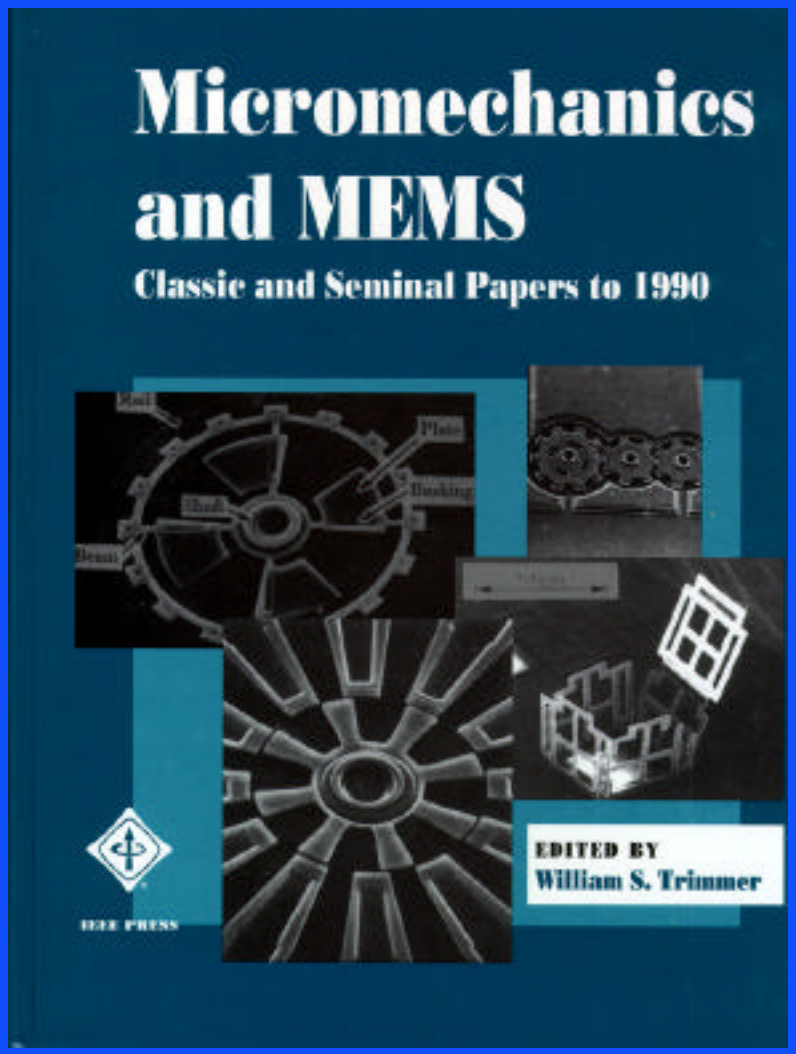


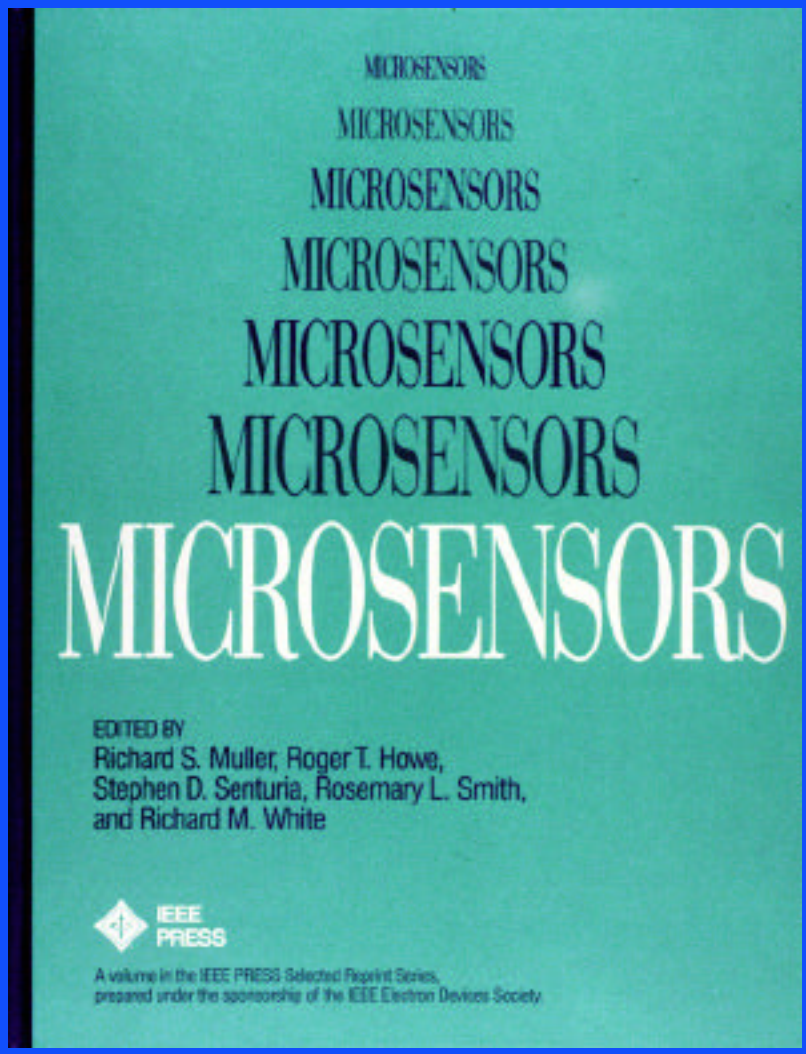


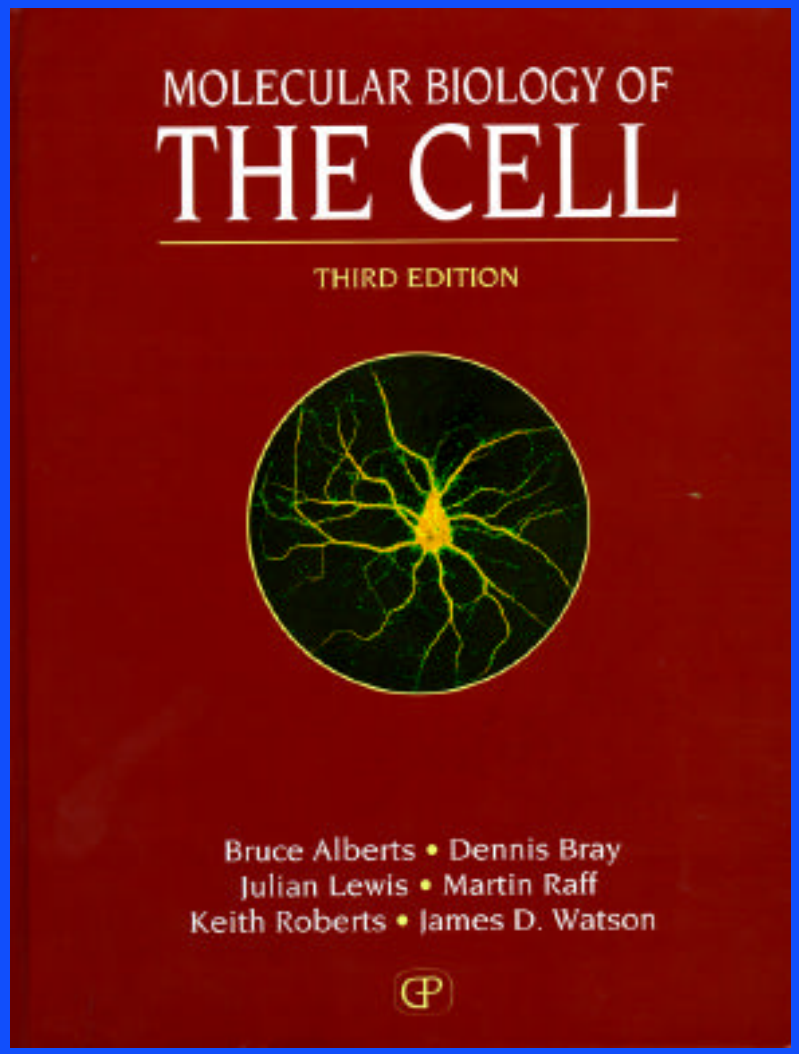


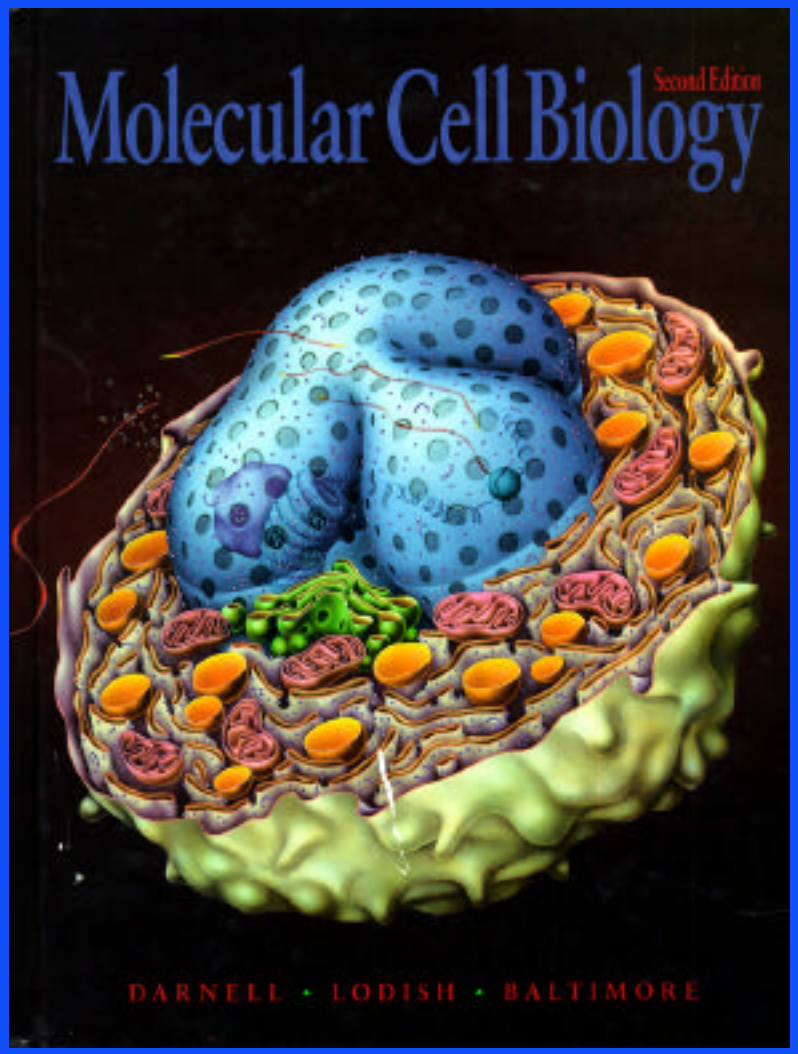












JOURNALS

A) Journals with a primary focus in the MEMS area:

Sensors and Actuators A (Physical)

Sensors and Actuators B (Chemical)

Sensors and Actuators C (Materials)

IEEE/ASME Journal of Microelectromechanical Systems (JMEMS)

Journal of Micromechanics and Microengineering

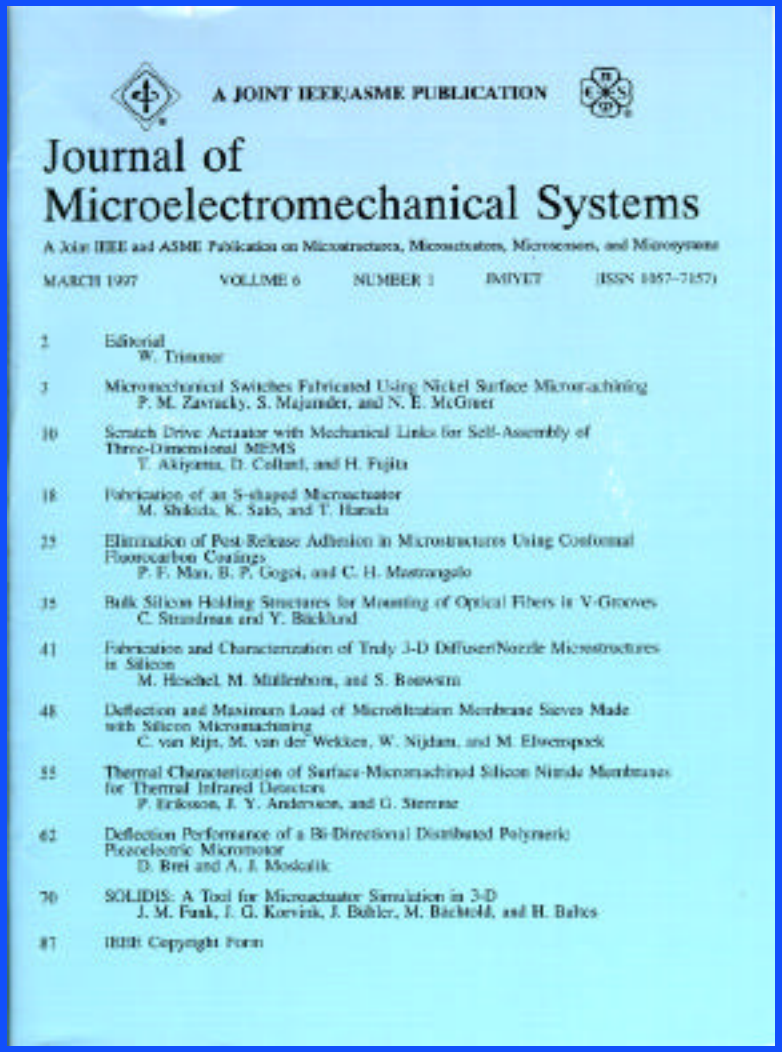
B) Journals with information of interest to the MEMS community and occasional MEMS papers:

IEEE Electron Device Letters

Journal of the Electrochemical Society

Journal of the Vacuum Society

Proceedings of the SPIE — International Society for Optical Engineering

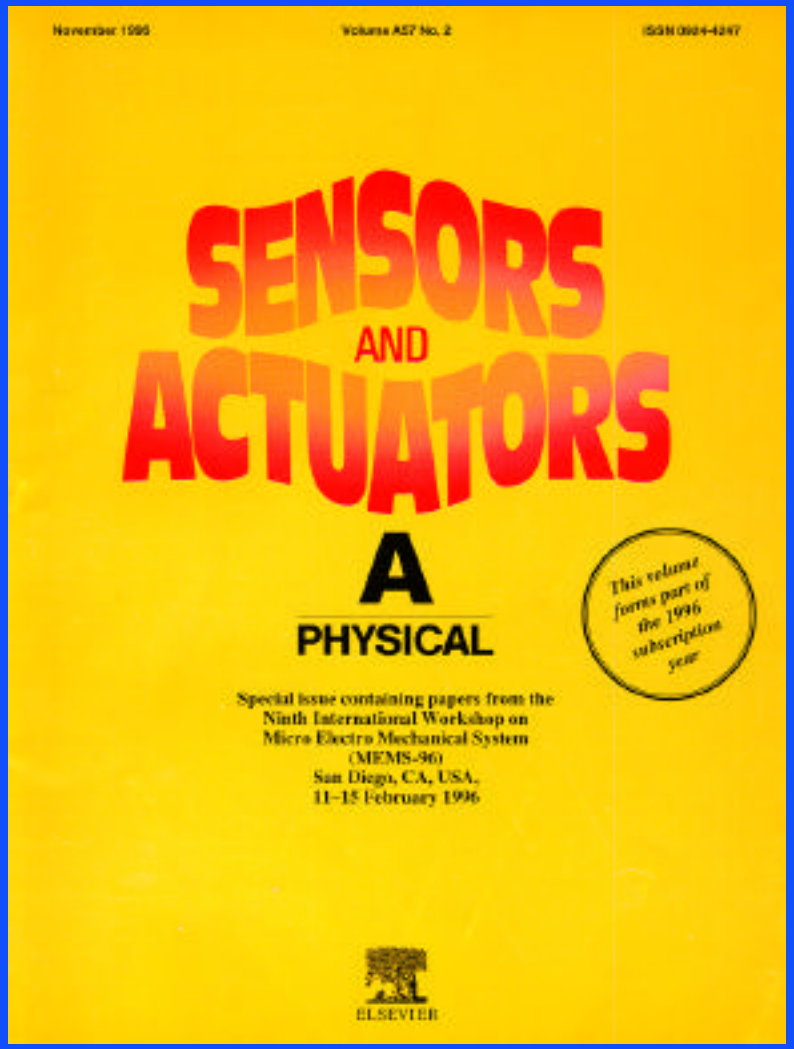


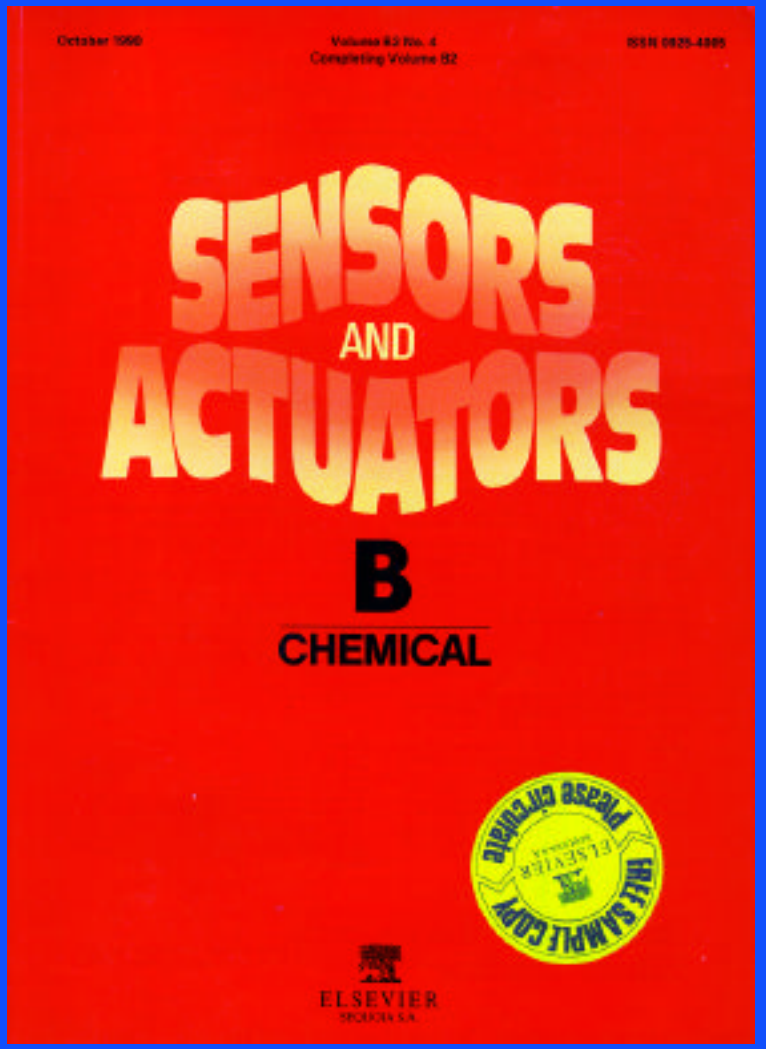
A JOINT IEEE/ASME PUBLICATION

Journal of Microelectromechanical Systems

A Joint IEEE and ASME Publication on Microstructures, Microactuators, Microsensors, and Microsystems

MARCH 1997 VOLUME 6 NUMBER 1 JMSYET ISSN 1057-7157



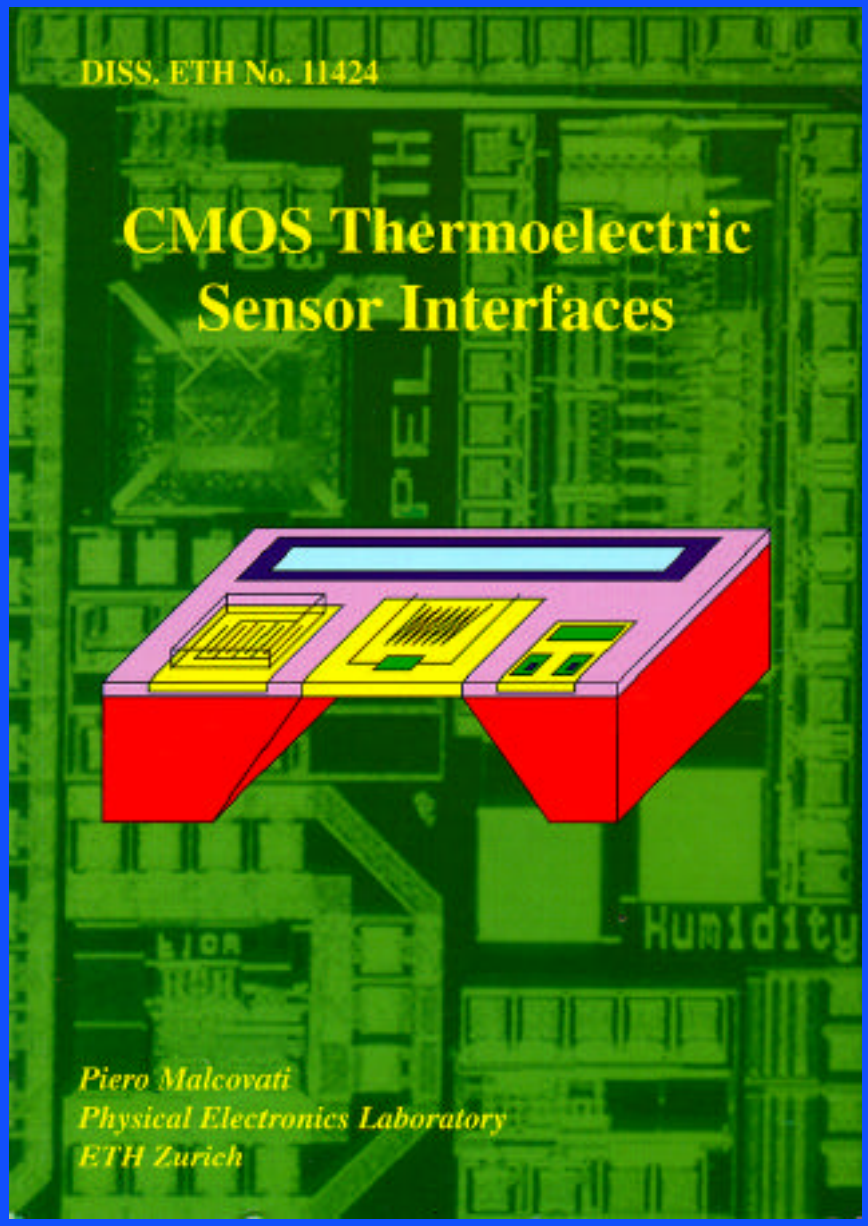


Electronic Access To Journals

http://www-sul.stanford.edu/collect/ejourns2.html

THESES

- **In evolving fields, graduate theses are often-overlooked goldmines of useful information.**
- **North American M.S. and Ph.D. theses can be obtained through University Microfilms, Inc. (300 North Zeeb Road, P.O. Box 1346, Ann Arbor, MI 48106-1346, Phone: (313) 761-4700)**



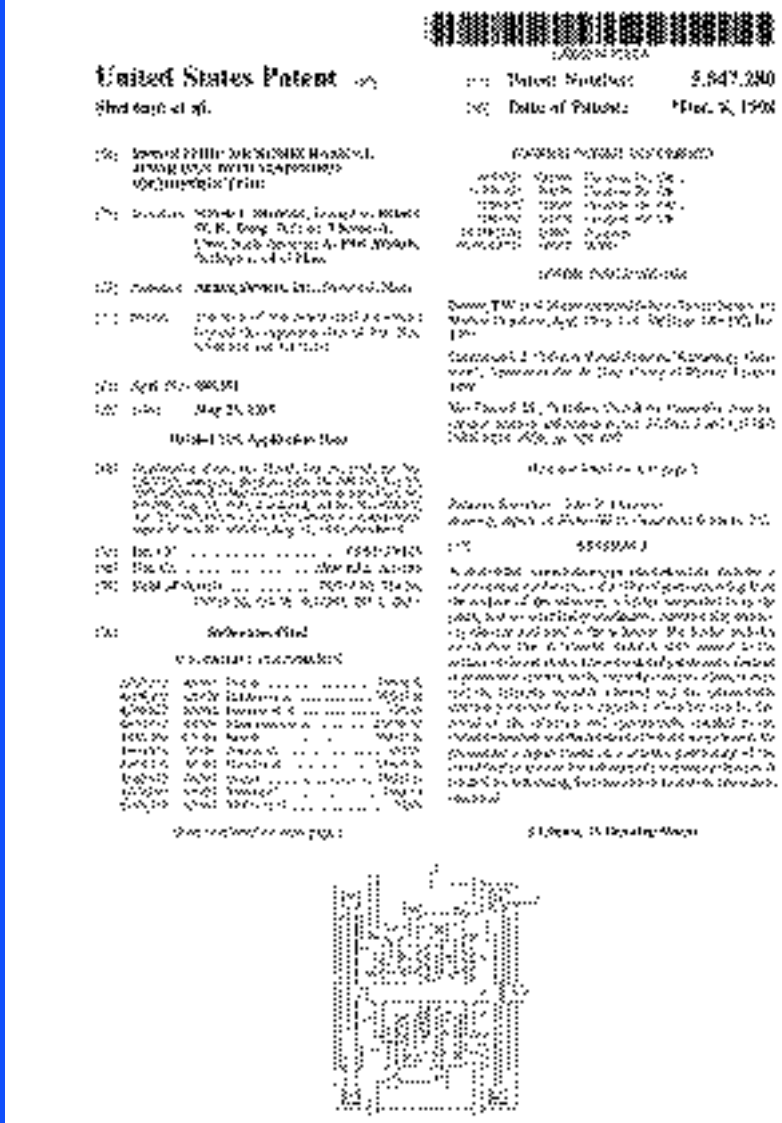
Do Not Forget

PATENTS!!!

Example sources:

http://patent.womplex.ibm.com

www.uspto.gov


United States Patent

WEB SITES

- There are many web sites dedicated to micromachining, or “MEMS.”
- The best place to start is with a comprehensive search (to hit new sites) and a look at: http://mems.isi.edu/.
- For all web searches, the user must beware that many url’s point to “cob-web” sites!