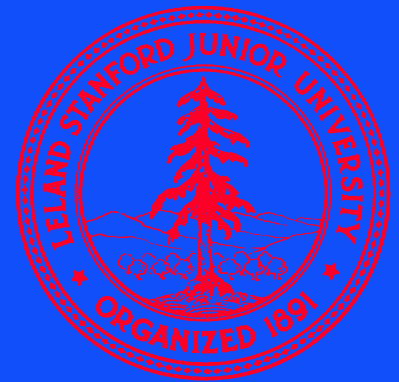
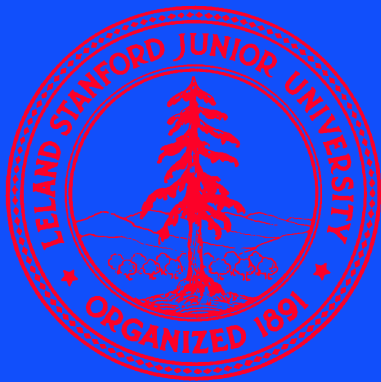
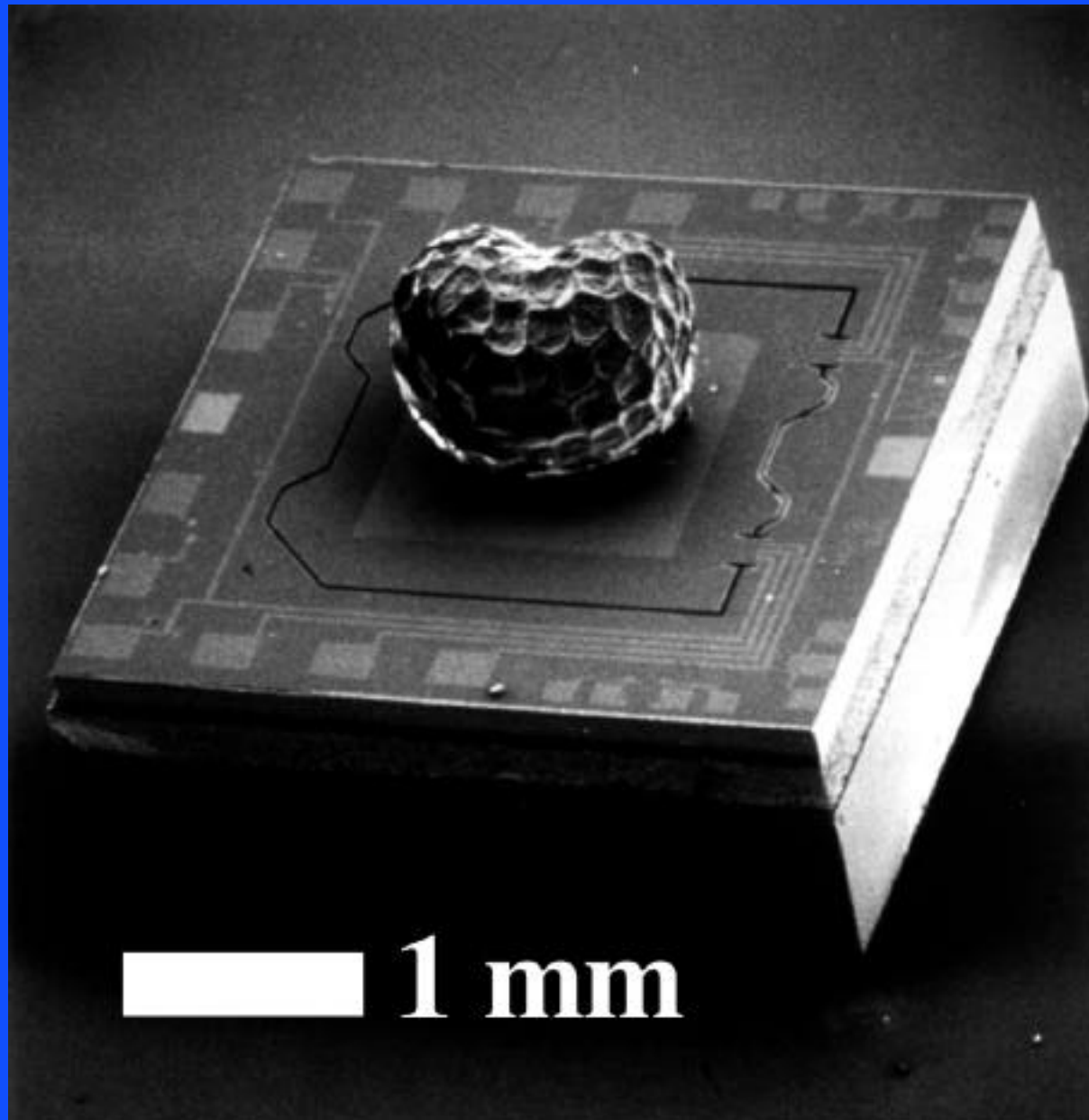


INTRODUCTION

EE312, Prof. Greg Kovacs

Stanford University





Courtesy of
Prof. Kurt
Petersen,
Lucas
NovaSensor

G. Kovacs © 2000

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).

Ages 5 and Up. WARNING: CONTAINS SMALL PARTS

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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.”

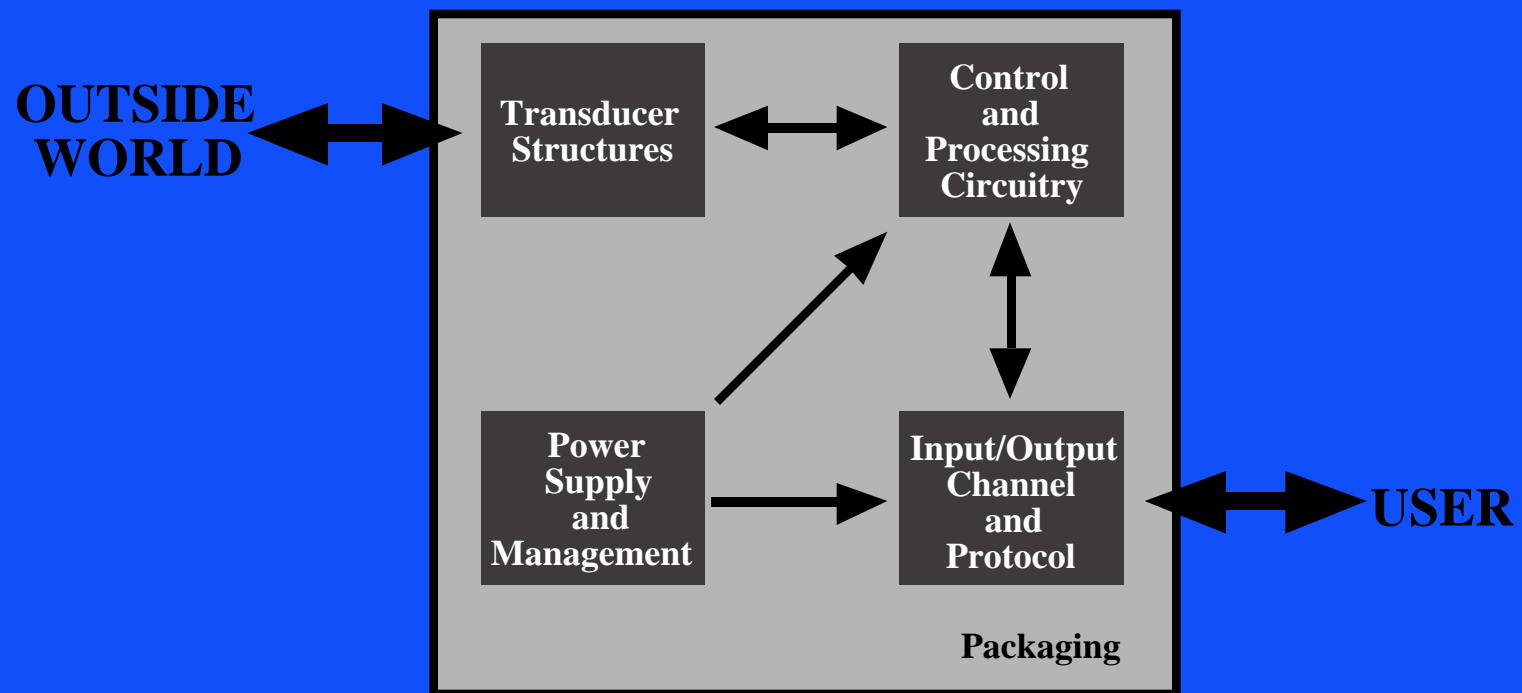
For practical purposes, a transducer is a conduit for information.

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 message) 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 and 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, ...).
- *Euroensors* (European, with broad coverage, held annually).

TECHNICAL DIGEST

SOLID-STATE SENSOR AND ACTUATOR WORKSHOP

Sponsored by the Transducers Research Foundation, Inc.

1996
Hilton Head Island, South Carolina
June 3-6

TRF Catalog Number 96TRF-0001
Library of Congress Number 96-060172



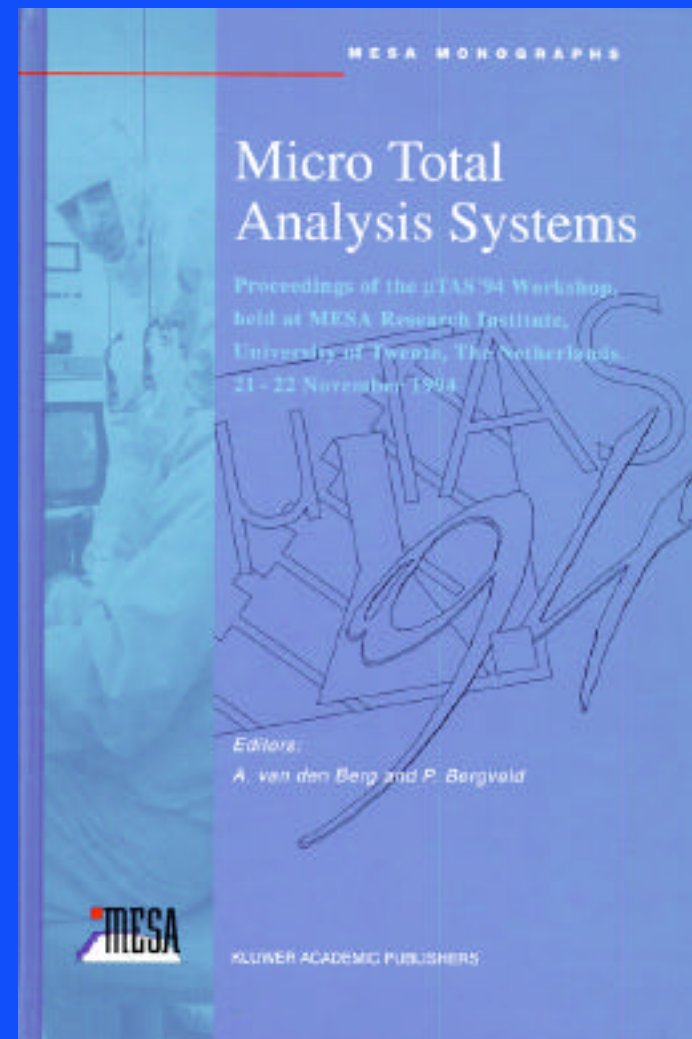
Transducers '99

The 10th International Conference
on Solid-State Sensors and Actuators

Digest of Technical Papers
Volume I



Sendai, Japan
June 7-10, 1999





WHERE TO GET PROCEEDINGS

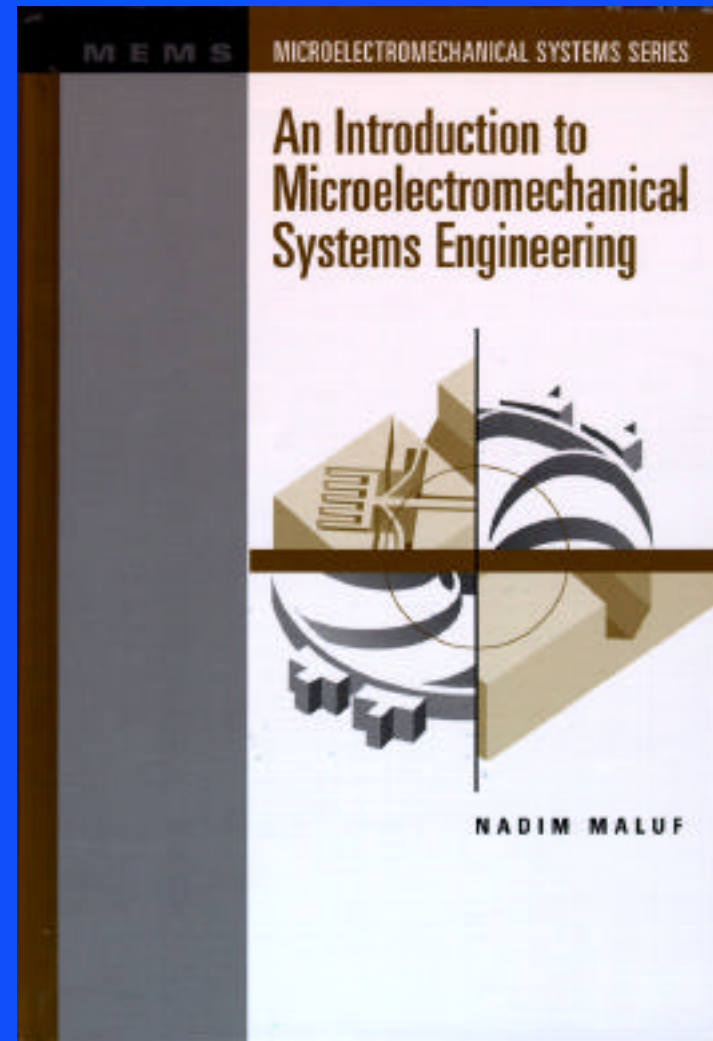
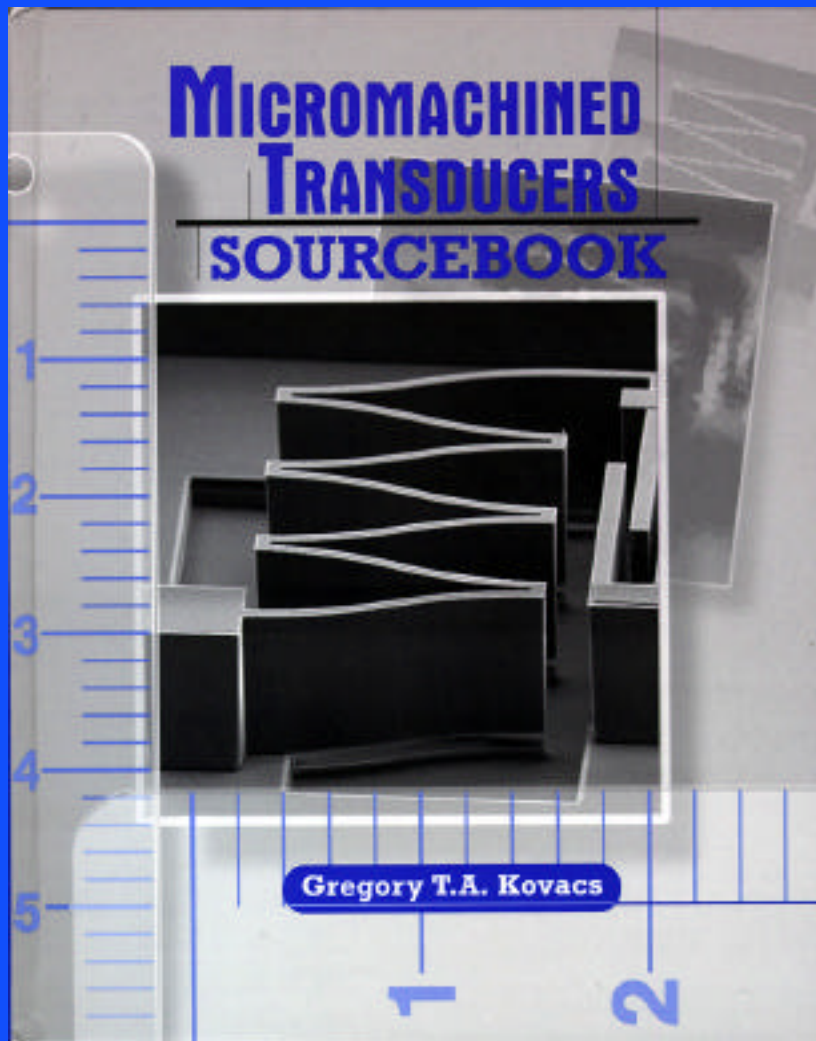
Meeting	Host Organization
Hilton Head	Transducers Research Foundation, Inc., P.O. Box 18195 Cleveland Heights, OH, USA.
Transducers	Variable, depends on host country: 1995 is available from the Royal Swedish Academy of Engineering Sciences, IVA, Box 5073, S-102, 42 Sweden, 1997 is available from the IEEE, at the address given below.
MEMS	IEEE Service Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ, USA.
μ TAS	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.

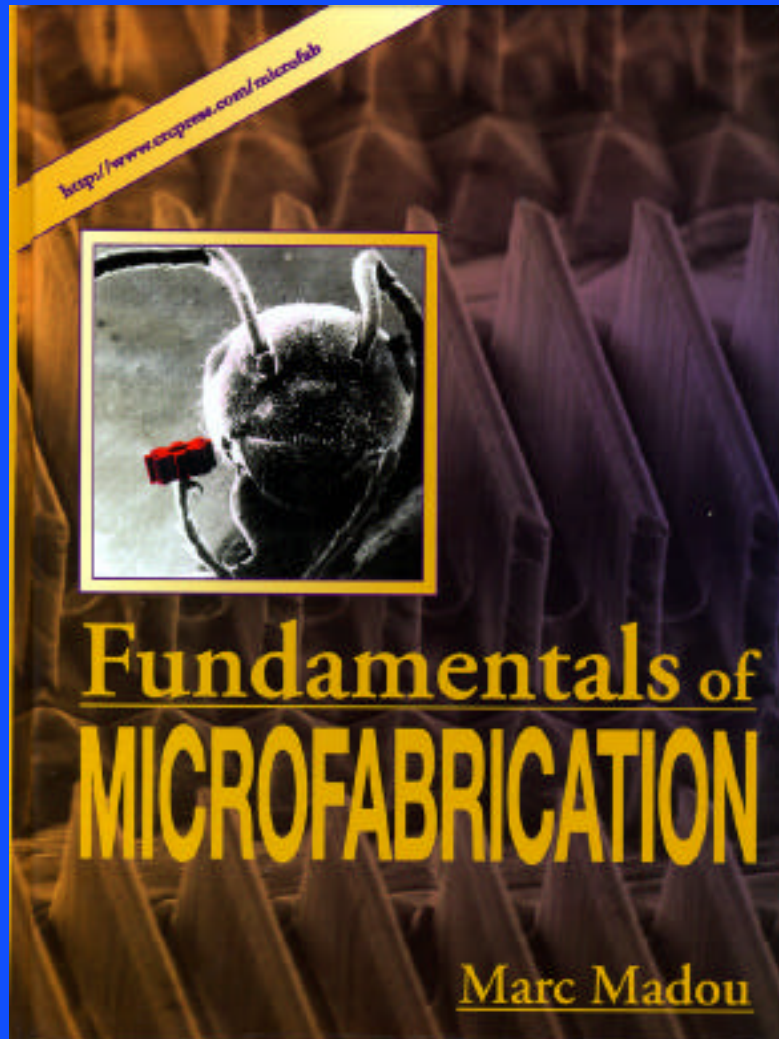
WHY AREN'T THE CONFERENCE PROCEEDINGS ALL IN THE LIBRARY?

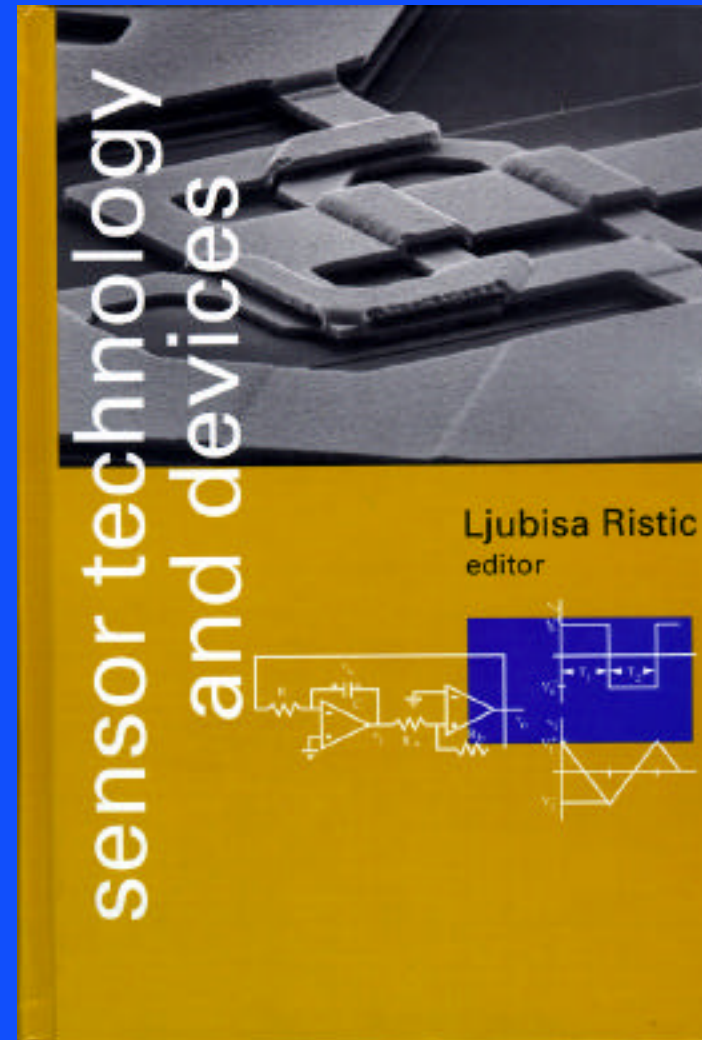
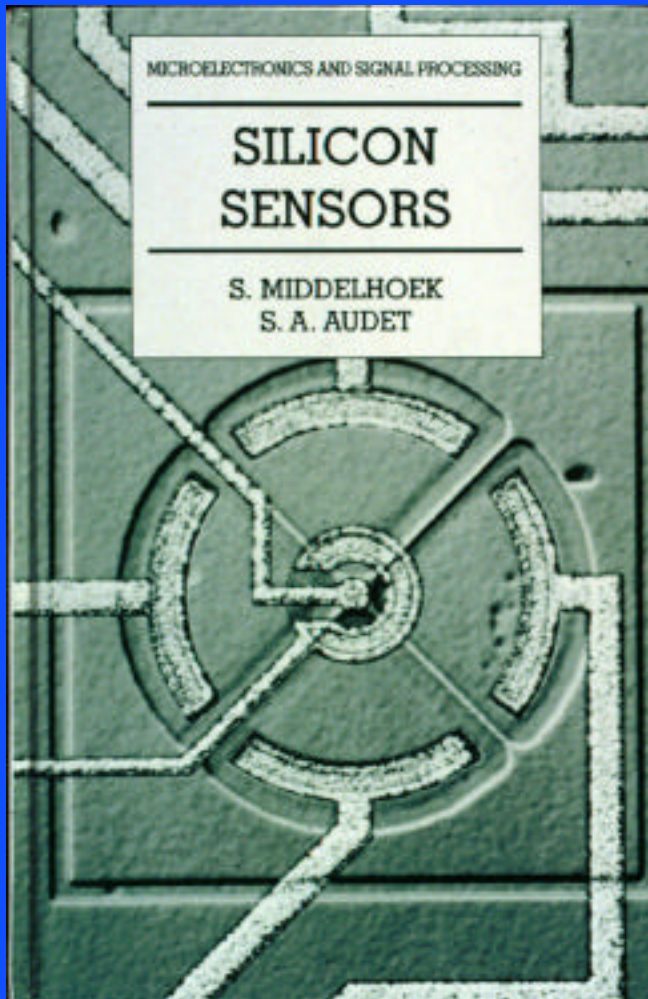
- They are sometimes quite expensive.
- They get trashed easily.
- People tear pages out.
- **Alternative:** some volumes are available at Kovacs' office for on-site browsing or copying only.
- For heavy users, copies should be obtained from the sponsoring organizations - mention you are a student to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







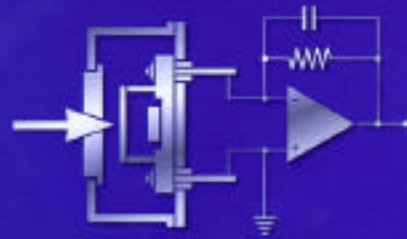
Semiconductor Sensors

Edited by
S.M. Sze

SECOND EDITION

HANDBOOK OF MODERN SENSORS

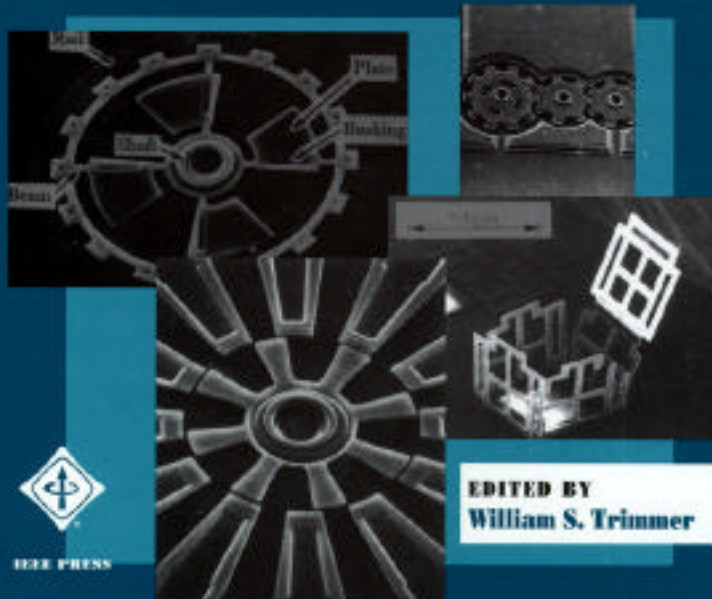
PHYSICS, DESIGNS, and APPLICATIONS



JACOB FRADEN

Micromechanics and MEMS

Classic and Seminal Papers to 1990



EDITED BY
William S. Trimmer

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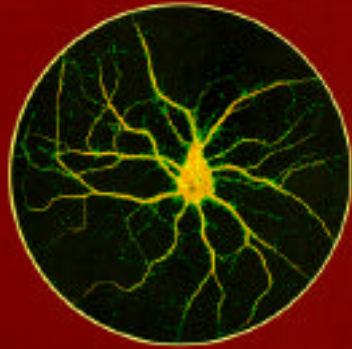
EDITED BY
Richard S. Muller, Roger T. Howe,
Stephen D. Senturia, Rosemary L. Smith,
and Richard M. White



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MOLECULAR BIOLOGY OF THE CELL

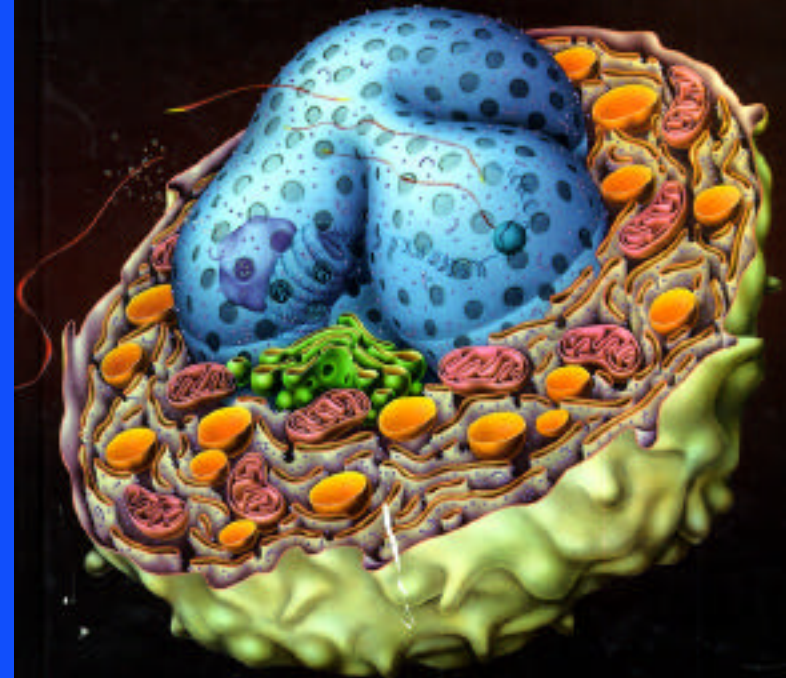
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JOURNALS

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

	
Journal of Microelectromechanical Systems	
A Joint IEEE/ASME Publication on Microstructures, Microactuators, Microsensors, and Microsystems	
MARCH 1997	VOLUME 6 NUMBER 1 IMMYET (ISSN 1057-7157)
2	Editorial W. Trimmer
3	Micromechanical Switches Fabricated Using Nickel Surface Micromachining P. M. Zavracky, S. Majumder, and N. E. McGruer
10	Scratch Drive Actuator with Mechanical Links for Self-Assembly of Three-Dimensional MEMS T. Akiyama, D. Collard, and H. Fujita
18	Fabrication of an S-shaped Microactuator M. Shikida, K. Sato, and T. Harada
25	Elimination of Post-Release Adhesion in Microstructures Using Conformal Fluorocarbon Coatings P. F. Man, B. P. Gogoi, and C. H. Mastrangelo
35	Bulk Silicon Holding Structures for Mounting of Optical Fibers in V-Grooves C. Strandman and Y. Bäcklund
41	Fabrication and Characterization of Truly 3-D Diffuser/Nozzle Microstructures in Silicon M. Heschel, M. Müllenborn, and S. Bönemann
48	Deflection and Maximum Load of Microfiltration Membrane Sieves Made with Silicon Micromachining C. van Rijn, M. van der Wekken, W. Nijdam, and M. Elwenspoek
55	Thermal Characterization of Surface-Micromachined Silicon Nitride Membranes for Thermal Infrared Detectors P. Eriksson, J. Y. Anderson, and G. Sterner
62	Deflection Performance of a Bi-Directional Distributed Polymeric Piezoelectric Micromotor D. Brel and A. J. Modolnik
70	SOLIDIS: A Tool for Microactuator Simulation in 3-D J. M. Fank, J. G. Korvink, J. Bühler, M. Bächtold, and H. Baltes
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 www.sensorsmag.com

November 1996

Volume A57 No. 2

ISSN 0924-6460

SENSORS AND ACTUATORS

A PHYSICAL

Special Issue containing papers from the
Ninth International Workshop on
Micro-Electro Mechanical System
(MEMS-96)
San Diego, CA, USA,
11-15 February 1996

This volume
forms part of
the 1996
subscription
year



October 1996

Volume B2 No. 4
Completing Volume B2

ISSN 0925-4885

SENSORS AND ACTUATORS

B CHEMICAL

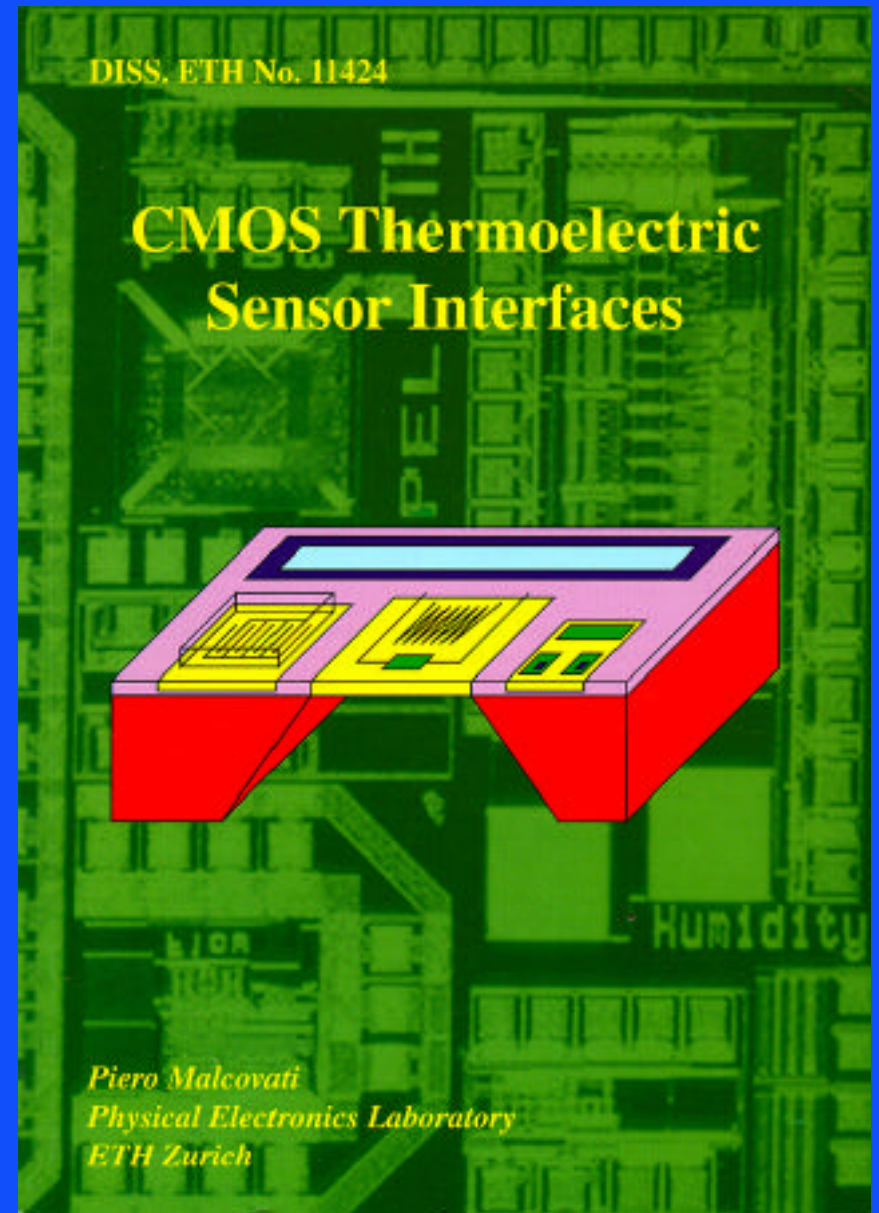


Electronic Access To Journals

<http://www-sul.stanford.edu/collect/ejournals2.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)




Example sources:
<http://patent.womplex.ibm.com>
www.uspto.gov



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!

The MEMS Clearinghouse Homepage 12/22/99 5:31 PM



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Recent Announcements

- 2000 Solid-State Sensor and Actuator Workshop 04-08 Jun 2000
- Sandia Nat'l Labs' MEMS Course Schedule
- BIOS 2000 - Biomedical Optics 22-28 Jun 2000


Industry News

- AMI Receives \$20M Foundry Order from Novalog for Mixed-Signal Chip
- VEH-A AG Says New Report on MEMS Sale is Uptone
- Newport Receives \$1.4M Order for Precision Motion Stage Systems
- Cree Research Accelerates Blue Laser Development Efforts; Forms Strategic Partnership with Microvision, Inc.
- MPI Receives Order from Sundstrand
- Yeha plans consolidation, unit spin-offs

Upcoming Events

- 2000 Solid-State Sensor and Actuator Workshop Abstracts 07 Jun 2000
- IEEE MEMS 2000 Conference 23-27 Jun 2000
- 2000 Solid-State Sensor and Actuator Workshop 04-08 Jun 2000
- Actuator 2000 19-21 Jun 2000

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- MEMS Process Engineer InertialSense Corporation (27 Oct 1999)
- Software Engineer InertialSense Corporation (27 Oct 1999)

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