Microelectromechanical Systems

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Revision: 3-10-2008 memtalk.ppt
MEMs INDUSTRY OVERVIEW

MEMs Market Size (US$ billions)

<table>
<thead>
<tr>
<th></th>
<th>1995</th>
<th>2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>1.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Inertial Sensors</td>
<td>0.45</td>
<td>0.8</td>
</tr>
<tr>
<td>Fluidic controls</td>
<td>0.01</td>
<td>0.1</td>
</tr>
<tr>
<td>Data Storage</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>Displays</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>Biochips</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>Communications</td>
<td>0.01</td>
<td>1.0</td>
</tr>
<tr>
<td>Other</td>
<td>0.03</td>
<td>0.1</td>
</tr>
<tr>
<td>Total</td>
<td>2.0</td>
<td>6.7</td>
</tr>
</tbody>
</table>

Many new areas are developing and this mix will change dramatically. Source: Micromachines Devices R&D Magazine, Vol.1, No.2, Oct 1996, chart May 2001

Fig. 1. Fundamental changes in device complexity and cost mean that worldwide MEMS revenues should nearly quadruple by 2005.
SINGLE CRYSTAL SILICON

Thickness
10 µm

Wafer Diameter
75 mm
ADVANTAGES
OF
MICRO LITHOGRAPHIC TECHNOLOGY

Structures as small as 0.1 µm
Thickness as small as 5 nm
Electronics on chip
Inexpensive (<$10)
Arrays of sensors as easy as one sensor
Chips with up to a few Billion devices available today
AUTOMOTIVE APPLICATIONS

Manifold Pressure
Barometric Pressure
Turbo Boost Pressure
Oil Pressure
Tire Pressure
Acceleration
Smart Engine Mount
Fuel Level Pressure
Fuel Pump Pressure
Auto Security Systems
Mass Air Metering Flow
Continuously Variable Transmission Pressure
Antilock Braking Pressure and Acceleration
Air Conditioning Compressor Pressure
Accelerometers for Smart Airbag Deployment
SEM PICTURES OF DIAPHRAGM ETCH

700um squares - 20% KOH Etch @ 16 Hrs.

Rosaline Tan & Daniel Ma
April 1998
FLOW PLATES FOR FUEL INJECTION

Variety of different size and shape holes etched through 500 µm thick silicon wafer, Pushkar Merwah 1999
BULK MICROMACHINED ATOMIZER
Pressure Sensor bulk etched from back side of the wafer leaving a silicon diaphragm and ion implanted Piezo Resistors.
**DIAPHRAGM USING KOH ETCH**

20% KOH Etch, @ 72 C, 10 Hrs.
PRESSURE SENSORS
Pressure Sensor with Nitride Diaphragm and Poly Piezo Resistors over Bulk Etched Cavity

300 µm

Jason Trost, 1995
Harris Semiconductor
Mountaintop, PA
TOP SIDE BULK MICROMACHINED SILICON DIAPHRAGM

1. LPCVD 0.8µm Poly
2. Photolithography
3. Etch Poly in SF6 + O2
4. LPCVD 0.8µm Low Stress Si₃N₄
5. Photo Etch Holes
6. Etch in KOH
7. Fill Etch Holes with LPCVD
CAPACATIVE ACCELEROMETER

Figure 1: Capacitive Accelerometer Structure

Movable Mass
Spring
Capacitance

Bulk Silicon Accelerometer
(Courtesy of MCNC)
PIEZORESISTIVE ACCELEROMETER

Two chips
Sensor
Electronics
1 µm Movement
10 Volt Electrostatic Actuation
3 AXIS ACCELEROMETER

Stress Sensitive PMOSFETs
MICROMACHINED MICROACCELEROMETER

United States Patent [19]

[54] MICROMACHINED MICROACCELEROMETER FOR MEASURING ACCELERATION ALONG THREE AXES

[22] Filed: Apr. 9, 1992

[51] U.S. Cl. 523/917 B, 351/280

[56] References Cited

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4,922,286 1/1990 Haries
4,922,286 1/1990 Haries
4,941,788 1/1990 Reuben

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Richard S. Muller, “Heat and Stress-Sensitive Thin—


Primary Examiner—John E. Chapman

Attorney, Agent or Firm—Naima, Haragwey, Devine & Doyle

[57] ABSTRACT

The present invention relates to a micromachined accelerometer employing a single free mass and capable of measuring acceleration along three coordinate axes, and a process for fabricating through micromachining and micromechanical techniques a micromachined accelerometer employing a free mass. A micromachined accelerometer is constructed by first fixing a silicon wafer to a support member and a free mass surrounded by the silicon. The free mass is movable with respect to the support member. Acceleration measurements are obtained by circuits which sense changes in the position of the free mass with respect to an equilibrium position, induced by a change in the rate of acceleration of the accelerometer, and the electromagnetic force required to restore the free mass to its equilibrium position.

18 Claims, 6 Drawing Sheets

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Flow across the heater causes R2 to be warmer than R1. The temperature difference depends on flow rate and specific heat of the gas.
CONSUMER APPLICATIONS

Smart Home Controls
Home Security
Natural Gas Leaks
Swimming Pool
Washing Machines
Dryers
Refrigerators
Air Conditioners
Vacuum Cleaners
Microphones
Fitness Equipment
Scales
TV Screen Projection
Ink Jet Printers
Boat Speedometers
INK JET PRINT INJECTORS
Micro-mirror Cross-section

Inflection point

Movable mirror

Substrate

poly 0   poly 1

Micro-mirror Perspective View

Torsion Hinge

Rochester Institute of Technology
Microelectronic Engineering

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DIGITAL MIRROR LIGHT PROJECTION SYSTEM

![Digital Mirror Light Projection System Image]

Diagram showing the components of a digital mirror light projection system, including a TIR prism, DMD (Digital Micromirror Device), color discs, and integrator rod.
TORSIONAL MIRRORS
FIELD EMISSION TIPS FOR FLAT PANEL DISPLAYS

Alex Raub, 1995, now at National Semiconductor
Santa Clara, CA
FIELD EMISSION FLAT PANNEL DISPLAYS

Integrated Phosphor Field Emission Device

Micro-electromechanical Systems

Color Chart of AVT Phoshors

© March 10, 2008, Dr. Lynn Fuller, Professor
1 µm Aluminum
2.0 µm Gap

Jon Stephan, 1995, now at Intel Corporation
Folsom, CA

ALUMINUM DIAPHRAGM
CAPACITIVE MICROPHONE
IMAGE STABILIZATION
USING MEMS ACCELEROMETER

ANGULAR RATE MEASUREMENT
Miniature MEMs Accelerometer Adds Motion Sensing to Consumer Products

Through refined surface-micromachining technology, Analog Devices has packed the ADXL202E dual-axis integrated MEMS accelerometer into a tiny leadless chip-carrier (LCC) package. The technology also has improved the monolithic accelerometer's resolution, robustness, and stability over temperature while lowering its noise floor. The low-cost package has cut the the motion sensor's price tag as well.

Unlike previous-generation models, the ADXL202E implements a thicker MEMS structure to achieve robustness and lower the noise floor. It can survive a shock of 1000 g, while its noise floor has been reduced to 250 µg/√Hz. With this reduction, the accelerometer can resolve signals as low as 2.5 mg—yet it can still measure acceleration with a full-scale range of ±2 g. The improved process gives the device better stability, too. The drift over temperature is now only 2 mg/°C.

Combining these improvements with a low-cost miniature package, the supplier has opened the dual-axis accelerometer up to new applications. The ADXL202E will bring motion-sensing capabilities to consumer products like disk drives, laptops, and electronic games. PDAs and cell phones will have fewer buttons. Instead, they'll rely on speech and gesture recognition. Researchers are even investigating tilting and motion inputs for these appliances. Such accelerometers will let disk-drive makers relentlessly pursue higher storage densities by minimizing vibrations. They'll also increase a laptop's security by sounding an alarm when it leaves a secure perimeter. In fact, Smart-Moves of Cambridge, Mass., is developing such a security system.

Integrating signal-conditioning circuitry with a microscopic MEMS structure on a single chip, the ADXL202E provides a duty-cycle output that is proportional to acceleration. It uses a single 2.7- to 5.2-V supply for operation, and it consumes less than 250 µA per axis. It comes in an 8-pin LCC that measures 5 by 5 by 2 mm. In 100,000-piece batches, it costs $4.99 each.

Analog Devices Inc., 831 Woburn St., Wilmington, MA 01887; (781) 937-1428; www.analog.com.
INDUCTORS FOR COMMUNICATIONS SYSTEMS

This MEMS-based high-Q inductor from MEMSCAP is integrated directly into an RF chip using the company’s patented "above IC" technology. Photo courtesy of MEMSCAP.
MEMORY

Micromechanical memory on chips allows single wafer computers

by Sunny Bates

At Carnegie Mellon University researchers are trying to design a micromechanical memory that will allow an entire computer system—containing processing unit, random access memory, input/output channels and hard drives—to be implemented on a single wafer. In particular, they have concentrated on building a head slide that is large enough to be worthwhile (initially 2 GB) and yet can still be integrated with the rest of the system. The memory works by using hundreds of micromechanical probes that each interrogate a small area of a magnetic medium. Though they have yet to construct a prototype, their work represents a new approach to the next stage of computer miniaturization.

Conventional chip-based memories rely on improvements in lithography for miniaturization. Essentially, they consist of small circuits that have to be at least a few times the minimum lithographic linewidth in height and width. According to the Semiconductor Industry Roadmap, which forecasts the progress in computing technology, lithography will not produce 2-GB chips until 2011 at the earliest. Today’s commercial process, at 180 nm, can only provide devices that are a few times of MB per square centimeter.

However, micromechanical probe memories—where a small cantilever tip is used to address a point on some sensitive material—can already reach very dense data rates (up to 1 Gbps) and at least in theory. Probe tips can be used to detect individual features as small as 30 nm. If this power is used effectively, the areal density could be 1 GB per cm² or more. The problem is how to exploit the technology in a fast, single-chip configuration.

The Carnegie Mellon team has come up with a scheme that they hope will take care of using the full area of the memory material, keep the speed high, and allow for various alignment problems. The basic idea is shown in Figure 1. An array of read/write tips is fabricated on the top of a chip that has the rest of the computer system laid down around and underneath it. A second wafer, with its bottom surface coated with some magnetic medium, is suspended above the probes. In order to read every bit of the medium, the probe tip must be scanned over the entire area with the memory device taken up with its own circuitry. The CMU scheme achieves this by stepping the entire medium (the top wafer, known as a "media deck") over the bottom, using the mechanism shown in Figure 2. Moving the individual probes by this method allows the "media deck" to be stepped over a large area. The next "media deck" can then be brought into the probe's field of view. The process continues until the entire wafer has been scanned. Further improvements in the design of the mechanical actuator could allow the process to be done in a single step.

Recent designs include a study of power requirements, materials, and processes. These efforts are part of CMU’s Center for Highly Integrated Information and Storage Systems, the goal of which is to develop technologies for scaleable, rewritable, low-cost IC-based mass storage devices, and to consider application for the systems they enable.

Reference:

Sunny Bates is a scientist and journalist based in London, UK. Web: sunnybates.com
BIOMEDICAL APPLICATIONS

Catheter Tip Pressure Sensors
Disposable Blood Pressure Sensors
Respirators
Lung Capacity Meters
Kidney Dialysis Equipment
Infusion Pumps
Barometric Correction of Medical Instrumentation
Reusable Blood Pressure Transducers
Angioplasty
Patient Movement Monitors
Intrauterine Transducers
Intracranial Transducers
Drug Manufacturing
SENSING ELECTRODES
BIOLOGICAL RECORDING ELECTRODES

13 pads each side
made to mate with
standard AMP connector

5400 µm

25000 µm

300 µm

100 µm

700 µm

4700 µm
FLEXIBLE ELECTRODES ON POLYIMIDE

Keith Udut 1999
Dr. Lynn Fuller
Want to develop a device that can measure the force exerted by a single heart muscle cell during contraction.
The initial design consists of six of these 5000µm squares, each with a different type of spring, as shown on the following pages. The final device will most likely be a single square with a single type of spring.
SINGLE CELL FORCE SENSOR CHIP LAYOUT

- Cantilever Beam
  - Electrodes
  - Cantilever beam
  - Cell anchor

- Beam Anchored at Both Ends
  - Measurement electrodes
MICROMECHANICAL CHANGE IN MASS CHEMICAL DETECTION
CHEM FET

[Diagram of a CHEM FET with labels for Odorant, Catalyst-coated gate (sensing layer), Porous metal gate contact, Insulator (silicon oxide), Drain contact, Substrate (p-Si), and other components.]

_Rochester Institute of Technology_  
_Microelectronic Engineering_
SURFACE ACOUSTIC WAVE DEVICES (SAWS)
MICRARRAYS FOR DNA SAMPLING

A new type of DNA microarray incorporates latex beads into a matrix of wells etched into an optical imaging fiber substrate. Such arrays could dramatically increase the speed and sensitivity of DNA sampling. Courtesy of Tufts University.
ARRAYS FOR ELECTROKINETIC LIQUID SEPARATION

Arrays sort biomolecules by size

Injection

Large molecules

Small molecules

Injection

E = applied potential

Sieve

Small molecules

Large molecules

E
CAPACITIVE PRESSURE SENSOR

Kerstin Babbitt, 1997
BSEE U of Rochester
CAPACITIVE PRESSURE SENSORS

0 to 5 mm Hg Pressure Range

Oscillator

Sensor

VDD = -10V

20/100

20/100

20/100

40/20

VO

R load
1 Meg
C load
20 pF

C parasitic = 10 pF

C sensor
5 to 25 pF

2000 µm
SURFACE MICROMACHINED SEALED DIAPHRAGM

Si

$\text{SiO}_2$

Photolithography

Etch in BHF

Si

LPCVD 2.0 µmPoly

Photolithography

Etch Poly in SF6+ O2

Etch SiO2 in BHF
Poly Covered Trench

John Castellana, 1997
BSµE  RIT

2 µm Poly

1.5 µm Gap
TRANSISTOR PRESSURE SENSOR TEST RESULTS

Kerstin Babbitt 1997
Stephanie Bennett 1997
Sheila Kawati 1998
An Pham 1999
Dr. Lynn Fuller
SMART PILL

IN BRIEF

Smart Pill

Researchers at M.I.T. reported last week in Nature that they had built the first prototype “pharmacy on a chip,” a tiny reservoir-filled microchip that could be made small enough to be swallowed or injected and smart enough to release drugs or hormones in a predetermined order.

HOW IT WORKS

1. Dozens of pinprick-size containers are each filled with about 25 nanoliters of liquid, gel or solid and covered with a thin gold film. The chip is then immersed in a liquid containing low concentrations of chloride ions (like those found in human bodily fluids).

2. When a small electric charge is applied to a particular reservoir, the chloride ions react with the gold membrane and dissolve it, releasing the enclosed substance.
SINGLE-CHANNEL IMPLANTABLE MICROSTIMULATOR FOR NEUROMUSCULAR APPLICATIONS
INDUSTRIAL APPLICATIONS

Closed Loop Hydraulics
Sprayers
Pressure Calibrators
Pressure Meters
Digital Pressure Indications
Compressors
Refrigeration Equipment
HVAC
Water Level Measurement
P/I Converters
I/V Converters
Pressure Switches
Transducer Manufacturers
Food processing Equipment
Level Controllers
Strain Gages
MICRO GAS CHROMATOGRAPHY
CHEMIRESISTOR

Simple interdigitated electrodes coated with a chemically sensitive layer that changes the resistance in response to a few ppm of some (or many) chemicals.

Copper-substituted Phthalocyanine conductive polymer is sensitive to CCl4, NH3 and NO2.

Dr. Lynn Fuller
Dr. SKV
Yatin Prayag 1999

Resistor with
25µm gaps
25µm length
7250µm width
Atomic Force Microscope (AFM) Tips

Greg Cestra, 1992, now at Precision Monolithics
Santa Clara, CA
TEST STRUCTURES FOR MEASURING STRESS IN THIN FILMS

Pirouz Magsoudnia, 1991
National Semiconductor
Santa Clara, CA
MICROMOTORS

100 µm

Matt Matessa, 1991, now at Cypress Semiconductor San Jose, CA
GIMBALL STAGES

MICRO POSTS

MICRO CHANNELS

4µm x 30 µm

10µm x 200 µm
GEARS

Brian Porter
Spring 1998
NOZZLES

1 µm
VALVES

Fig. 2. Thermally driven cantilever actuator made of polyimide. Cross-sectional view.
MICROMOLDS

X-ray resist image

Electroplated nickel mold
Optical Systems
Ejection Seats
Inertial Reference Systems
Altimeters and Barometers (gun aiming systems)
Sonobouys
Diagnostic Systems for Military Vehicles
Hydrophones
Scuba Diving
Weapons
OPTICAL SYSTEMS
HINGED STRUCTURES

[Diagram showing hinged structures]

[Microscopic images of hinged structures]
SELF ASSEMBLY HINGE STRUCTURES

Fig. 2. Basic model of the external skeleton. Three-dimensional structure is constructed by bending along the polyimide hinges.
MOVABLE MIRROR
MOEMs
Micro Optical Electro Mechanical Systems
ANGULAR RATE MEASUREMENT
ELECTROMECHANICAL LOCKING MECHANISMS
HOT FILIMENT LIGHT SOURCES

Dave Borkholder, now at Stanford University Palo Alto, CA
STEAM ENGINE

![Image of a steam engine component](image)

Scale: 50 μm
Cantilevers
Springs
Accelerometer
Pressure Sensors
Electrostatic Motor
Magnetic Solenoid
Cantilevers
Springs
Accelerometer
Pressure Sensors
Electrostatic Motor
Hinge Structure with
Diffraction Grating
Heaters
Cantilevers
Springs
Accelerometer
Pressure Sensors
Electrostatic Motor
Mirrors
Diffraction Grating
Gears
Pin Joints
Slider
Microphone
BULK PRESSURE SENSOR COMPLETED DEVICE

AM 11:30
AUG. 12 1999
BULK PRESSURE SENSOR TEST SETUP

Buffer
Differential Amp
Filter

Oscilloscope

Rochester Institute of Technology
Microelectronic Engineering
BULK PRESSURE SENSOR TESTING
BULK PRESSURE SENSOR TEST RESULTS

No pressure

14.7 psi

200 mV

7 psi

Vout when vacuum is switched on and off repeatedly

Vout when vacuum is slowly increased over time giving a linear response for Vout versus pressure
**FUTURE WORK**

Design Improvements
R1 and R2 will increase in value while R3 and R4 will decrease in value. Metal interconnects are better.

Integratration of CMOS OpAmp
Optical Modulators
REFERENCES

11. www-mat.ee.tu-berlin.de/research

2. Read “Silicon as a Mechanical Material”, Kurt E. Petersen, Proceedings of the IEEE Vol. 70, No 5, May 1982. Answer the following questions:
   2.1 What is Young’s modulus for silicon? What is it used for?
   2.2 Name two type of isotropic chemical etches for single crystal silicon.
   2.3 Design a process to etch a 50 µm X 50 µm hole through a 0.020 inch thick (100) silicon wafer.
   2.4 Discuss some applications of the cantilever beam.
   2.5 How can thin diaphragms be made? What are some applications?