MEMS Overview

SPEAKER
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TOPIC
• Overview of Micro-Electro-Mechanical Systems (MEMS)

OUTLINE
• Overview of MEMS & Microsystems
• Micromachining & MEMS process technology
• Micro-electro-mechanical devices & microsensors
  - Inertial sensors
  - Pressure sensors
  - Bio-sensors
  - Shock sensors
• Integrated Microsystems

What is MEMS?

• MEMS = Micro-Electro-Mechanical Systems
  - creation of 3-dimensional structures using integrated circuits fabrication technologies and special micromachining processes
  - typically done on silicon or glass (SiO₂) wafers
• MEMS Devices and Structures
  - transducers
    • microsensors and microactuators
  - mechanically functional microstructures
    • microfluidics: valves, pumps, flow channels
    • microengines: gears, turbines, combustion engines
• Integrated Microsystems
  - integrated circuitry and transducers combined to perform a task autonomously or with the aid of a host computer
  - MEMS components provide interface to non-electrical world
    • sensors provide inputs from non-electronic events
    • actuators provide outputs to non-electronic events
Why Use MEMS?

- **Motivation and Benefits**
  - Small Size
  - Light Weight
  - Enhanced Performance & Reliability
    - high resolution devices
    - array of devices
  - Low Cost (from batch fabrication)

- **Applications**
  - Automotive System
  - Health Care
  - Automated Manufacturing
  - Instrumentation
  - Environmental Monitoring & Control
  - Consumer Products
  - Aerospace

- **MEMS-based Microsystems**
  - highly integrated systems
  - sensing
  - actuation
  - computation
  - control
  - communication

Example MEMS-Based Microsystem

"Micro Cluster" Environmental Monitoring Microinstrument
(developed at U-Mich in the 1990s, A. Mason, K. Wise, et. al.)

**Integrated Features**
- Control
  - Microcontroller
  - Power Management
- Communication
  - RF Transceiver
- Sensing
  - Pressure
  - Humidity
  - Temperature
  - Vibration
- Packaging
MEMS Fabrication Technologies

- Applying **Micromachining** to create 3-D structures using 2-D processing

  2-D IC fabrication technology → 3-D structures

- **Micromachining Processes**
  - bulk and surface micromachining
  - isotropic etching
  - anisotropic etching
  - dissolved wafer process
  - deep reactive ion etching
  - anodic and fusion bonding
  - micromolding

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**Surface vs. Bulk Micromachining**

*Bulk Micromachining: Backside etch*

*Surface Micromachined Structure*

*Bulk Micromachining: Front-side Etch pit*
Isotropic Etching of Silicon

- Isotropic etchant
  - etches in all directions
  - forms rounded pits in surface of wafer
- Most common solution
  - HNA: *Mixture of HF, HNO3, Acetic acid (CH3COOH)*

With agitation: Good reactant mass transport

Without agitation

Anisotropic Etching of Silicon

- Anisotropic etchant
  - directional-dependant etch: based on crystal planes
  - forms flat-surface pits in surface of wafer
- Common anisotropic etchants
  - EDP, KOH, TMAH

Anisotropic wet etching using EDP, KOH: (100) surface
- Etch stop on (111) plane
**Anisotropic Etching: Convex vs. Concave Corners**

masking layer not attacked by Si etchant

![Diagram showing convex and concave corners with labels for concave corner, convex corner, cantilever beam, (100) mask layer, (111) silicon, and buried etch stop layer (SiO2 in SOI wafers)].

**Anisotropic Etching of Silicon: Example**

bulk micromachined silicon proof mass
Dissolved Wafer Process

- Structure created by “diffusion masking layer”
  - heavily p-dope silicon (p++)
- Dissolve bulk of silicon to release the p++ structure

Dissolved Wafer Process Example

- Shock Switch
  - weighted cantilever beam with contacts that close by acceleration (shock)
- Fabrication Flow
  - create anchor, weight, support beam, and contact on Si
  - create cavity and contact on glass
  - bond wafers and then dissolve the Si wafer
Deep Reactive Ion Etching (DRIE)

- Reactive Ion Etching = RIE
  - mechanical (ion) etching in plasma for chemical selectivity
- Deep RIE
  - creates high aspect ratio patterns, narrow and deep

Trench-Refill process
- can fill the etched "trench" with another material

Glass-Si Anodic Bonding

- Bonding a glass wafer to a silicon wafer
  - both wafer can (and generally are) patterned with structures
- Application
  - creating sealed cavities on a wafer surface
    - can be sealed in vacuum
  - hermetic packaging
- Lead Transfer
  - need to bring the metal leads out of from sealed cavities
### Silicon-Silicon Fusion Bonding

- Two silicon wafers with/without SiO2 can be bonded
- Advantages: No thermal mismatch
- Needs contamination free, smooth, and flat wafers (e.g. surface roughness ~5Å)

**Process Flow**
- Clean wafers
- Make the surfaces hydrophilic (e.g. dip in Nitric Acid)
- Rinse-Dry
- Place the wafers together apply pressure
- H2 or N2 anneal at 800-1000°C

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### Combined Bulk-Surface Process: Molding

- Etch silicon with high aspect ratio (e.g., DRIE)
- Refill partially with sacrificial layer (e.g. silicon oxide)
- Refill completely with structural layer (e.g. polysilicon)
- Example: U-Mich Precision Inertial Sensor

N. Yazdi & K. Najafi, Transducers’97.
**Combined Bulk-Surface Process:**

**Precision Inertial Sensors**


**Figures**

- Dielectric Layer
- Support Rim
- Silicon Proof mass
- Damping Holes
- Metal Pads

**LIGA Process**

- **LIGA:** Lithographie, Galvanof ormung, Abformung
- Form high aspect ratio structures on top of wafer
- Uses molding and electroplating
- Synchrotron Radiation (X-Ray) used

**Features**

- Aspect ratio: 100:1
- Gap: 0.25µm
- Size: a few millimeters

**Figures**

1. EXPOSURE
2. ELECTROPLATING
3. PMMA REMOVAL

uses multiple polymethyl methacrylate (PMMA) layers
**LIGA Process: Example**


**Monolithic Integration of MEMS and ICs**

**Why Monolithic?**

**Performance:**
- Reduce parasitics due to interconnecting devices
- Reduce noise & crosstalk

**Size:**
- Reduce pin count
- Reduce package volume

**Cost:**
- Integration with signal-processing → better functionality
- Reduce packaging cost
- Self test & calibration at wafer level
IC + MEMS Process Examples

UC Berkeley Integrated CMOS & surface micromachining technology
- CMOS first and MEMS second
- CMOS circuit passivated using silicon nitride
- Tungsten interconnects for CMOS

Sandia Integrated CMOS & surface micromachining technology
- MEMS first in recessed cavity
- CMOS second after planarization

J. Bustillo, R. Howe, R. Muller, IEEE Proceedings Aug. 98

J. Smith et. al., IEDM’95

MEMS Examples

Neural Recording Probes
- Monolithic Integration of Wafer-Dissolved Process and IC Technology

Najafi, Wise, JSSC-21 (6), May 1986
Example: Capacitive Accelerometer

Vertical accelerometer

(a)

(b)

Lateral accelerometer

(a)

(b)

Example: Z-Axis Torsional Accelerometer

Capacitive Accelerometer

3-Axis Monolithic Surface Micromachined Accelerometer

Analog Devices ADXL50

All-Silicon Micro-G Accelerometer

MEMS Overview, Prof. A. Mason
Draper's Tuning Fork Gyroscope

- Perforated masses (tines)
- Drive Combs
- Suspension

GM & UM Ring Gyroscope

- Support Springs
- Sense Vibrating Mode
- Drive Vibrating Mode

Capacitive Pressure Sensors

Consists of two components:
- Fixed electrode
- Flexible diaphragm forming a moving electrode
- Sealed vacuum cavity between the two electrodes

Diaphragm (Upper electrode)

Lower electrode

- Silicon
- Ti/Pt/Au
- Poly-Si
- SiO2/Si3N4/SiO2
- Glass Substrate
- External lead for glass electrode

A. Chavan, K.D. Wise, Transducers'97
**Integrated Microsystems Architecture**

- **Flexible Architectures**
  - reconfigurable
    - new/different sensors can be added
  - sensor bus

**Microsystem Component: Interface Circuit**

- **Generic capacitive sensor interface**
  - sensor readout
  - sensor bus communication
  - programmable operation – useful for range of sensors
Microsystem Component: Shock switch

- System wake-up switch
  - allows events to be captured while system is in sleep mode
  - useful for system-level power management
  - implements several shock thresholds