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DEPARTMENT OF BIOMEDICAL ENGINEERING

VI Semester

BIOMEDICAL DEVICE DESIGN

2.3 MEMS Sensors in Healthcare

➢ Introduction

MEMS (Micro-Electro-Mechanical Systems) are miniature devices, typically 1 µm to 1 mm in size, that integrate mechanical elements (beams, diaphragms, masses), sensors, actuators and electronics on a single silicon chip. They are fabricated with the same photolithography, deposition and etching processes used for integrated circuits (**bulk and surface micromachining**), so they can be mass-produced at very low cost. MEMS sensors are the reason why smartphones, smart-watches and wearable health patches are now able to measure motion, pressure, sound and chemical quantities.

➢ Advantages of MEMS Sensors for Medical Devices

- ✓ **Miniaturisation:** small enough for implants, catheters and wearable patches.
- ✓ **Low power consumption:** microwatt to milliwatt operation suits battery-powered devices.
- ✓ **Low cost and batch fabrication:** disposable, single-use sensors reduce cross-infection.
- ✓ **High sensitivity and integration:** the sensing element and the signal-conditioning ASIC can be placed in one package.
- ✓ **Reliability and repeatability** compared with hand-assembled sensors.

➢ MEMS Fabrication in Brief

1. **Substrate preparation:** a clean silicon wafer (or SOI wafer) is oxidised.
2. **Photolithography:** a pattern is transferred to the wafer using photoresist and a mask.
3. **Deposition:** thin films of polysilicon, metal or silicon nitride are deposited (CVD, sputtering).
4. **Etching:** *bulk micromachining* etches into the silicon (KOH wet etch, DRIE) to form cavities and diaphragms; *surface micromachining* builds up and removes sacrificial layers to release free-standing structures.
5. **Bonding, packaging and calibration:** wafer bonding seals the reference cavity and the die is packaged with its ASIC.

➢Types of MEMS Sensors and Their Working

1. MEMS accelerometer

A MEMS accelerometer is a **spring–mass–damper system**. A tiny proof mass is suspended by flexible silicon springs. When the device accelerates, inertia makes the mass lag behind the frame, so the displacement is x = m·a / k. The displacement is sensed **capacitively**: the mass carries movable comb fingers that move between fixed plates, changing the capacitances C_1 and C_2 differentially. A switched-capacitor circuit converts ΔC into a voltage. Other transduction methods are piezoresistive and piezoelectric.

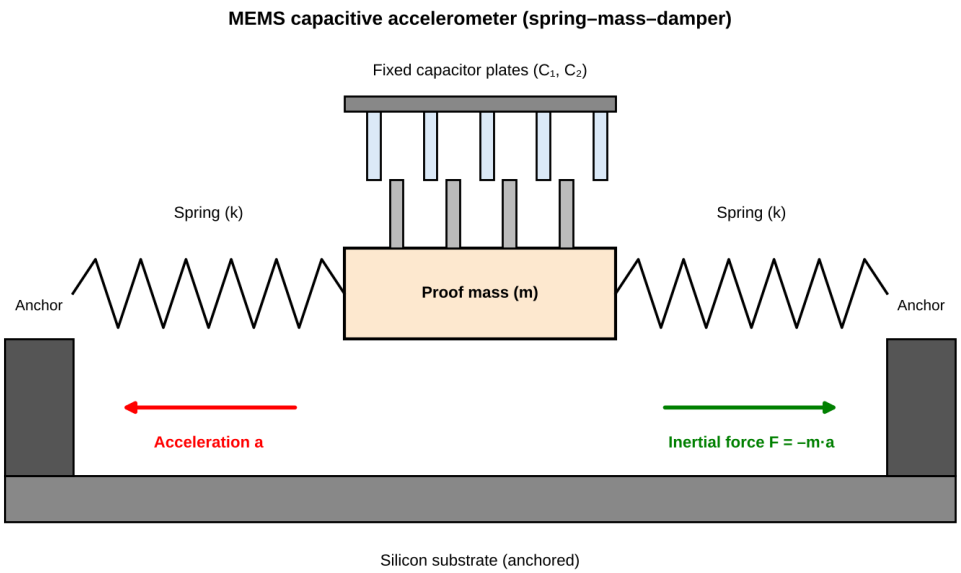

Fig. 2.15 Structure of a MEMS capacitive accelerometer

$$\textit{Displacement } x = m \cdot a / k \qquad \Delta C \propto x \qquad Vout \propto \Delta C$$

Healthcare applications: step counting and activity monitoring; fall detection for the elderly; gait analysis and tremor monitoring in Parkinson's disease; sleep monitoring; rate-adaptive **pacemakers** that raise heart rate during exercise; detection of patient position in ventilators and hospital beds.

2. MEMS gyroscope

A MEMS gyroscope measures angular rate using the **Coriolis effect**. A proof mass is driven to vibrate at resonance along one axis (drive mode). When the device rotates with angular velocity Ω, a Coriolis force F = 2m(v × Ω) acts perpendicular to the vibration and excites a second (sense) mode, whose amplitude, sensed capacitively, is proportional to Ω. Combined with accelerometers it forms a 6-axis **inertial measurement unit (IMU)**. Applications: posture and balance assessment, rehabilitation exercises, robotic surgery tool tracking and prosthetic limb control.

3. MEMS pressure sensor

A **piezoresistive MEMS pressure sensor** has a thin silicon diaphragm over a sealed cavity. Four piezoresistors diffused near the edges of the diaphragm are connected as a **Wheatstone bridge**. Applied pressure deflects the diaphragm and stresses the resistors: two increase in resistance and two decrease, so the bridge produces an output voltage proportional to pressure. **Capacitive** MEMS pressure sensors

instead measure the change in gap between the diaphragm and a fixed electrode and are more sensitive and have lower temperature drift.

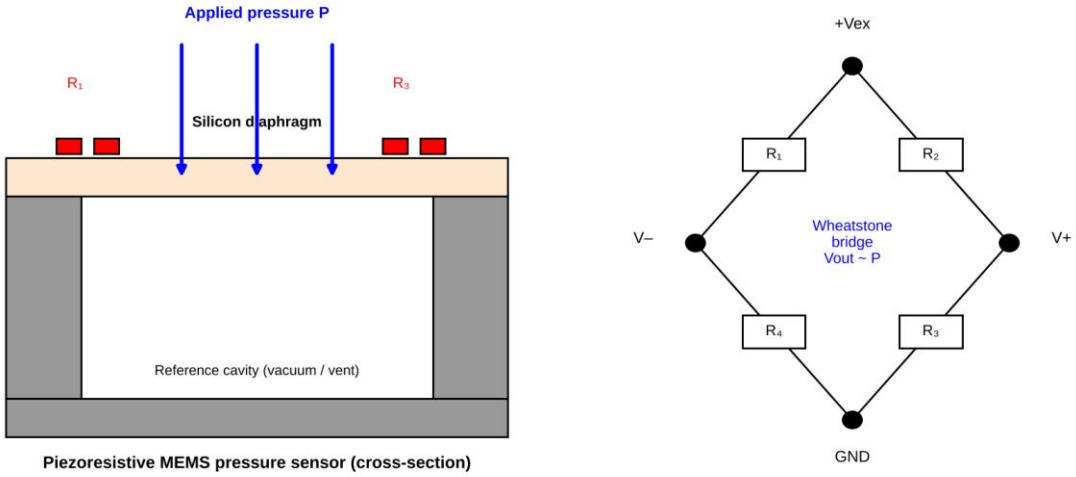

Fig. 2.16 Piezoresistive MEMS pressure sensor and its Wheatstone bridge

$$Vout = Vex \times (\Delta R / R) \propto Applied\ pressure$$

Healthcare applications: disposable blood-pressure transducers (invasive BP), oscillometric cuffs, intra-ocular and intracranial pressure monitoring, ventilators and CPAP machines, infusion-pump occlusion detection, and catheter-tip sensors.

4. Other MEMS devices

- ✓ **MEMS microphones:** capacitive diaphragm used in hearing aids and digital stethoscopes.
- ✓ **MEMS flow and gas sensors:** micro-heater and thermopile sensing for respiratory flow and CO_2/anaesthetic gas.
- ✓ **Microfluidic chips (lab-on-a-chip):** channels, pumps and valves for blood analysis, glucose and DNA testing at the point of care.
- ✓ **Micro-needles:** painless drug delivery and interstitial fluid sampling.
- ✓ **MEMS ultrasonic transducers (CMUT/PMUT):** compact imaging probes.
- ✓ **Bio-MEMS and implantable sensors:** neural probes and drug-delivery pumps.

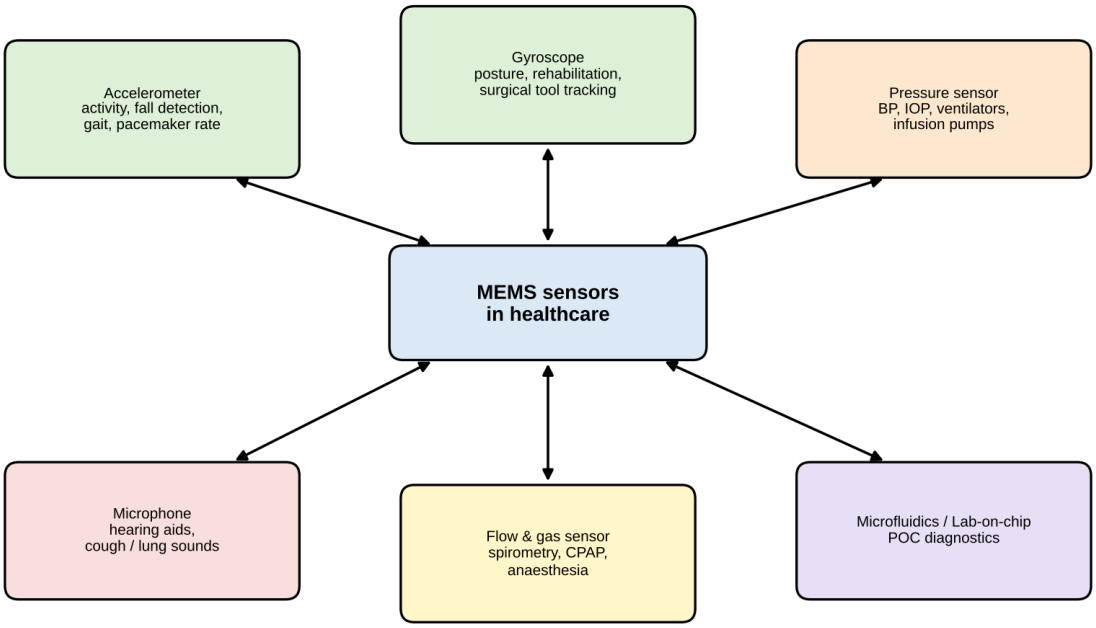

Fig. 2.17 Applications of MEMS sensors in healthcare

Comparison of the major MEMS sensors

Sensor	Principle	Measurand	Medical use
Accelerometer	Inertia + capacitive sensing	Linear acceleration	Fall detection, activity, pacemaker
Gyroscope	Coriolis force	Angular rate	Posture, rehabilitation, surgery
Pressure sensor	Piezoresistive / capacitive diaphragm	Pressure	BP, IOP, ventilator
Microphone	Capacitive diaphragm	Sound pressure	Hearing aid, stethoscope
Flow sensor	Thermal / differential pressure	Gas flow	Spirometer, CPAP

➢Limitations and Challenges

- ✓ Sensitivity to temperature and requirement for calibration and compensation
- ✓ Packaging stress, stiction and long-term drift
- ✓ Biocompatibility and sterilisation for implantable MEMS
- ✓ Need for hermetic sealing and noise reduction in very small structures

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