Opportunites of MEMS in the Application of Detection, Localization, and Neutralization of Unexploded Ordinances

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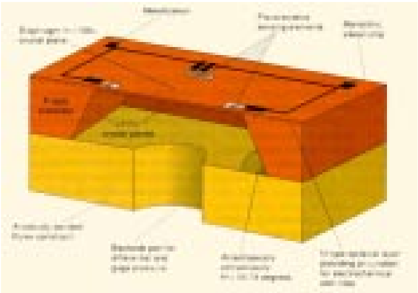
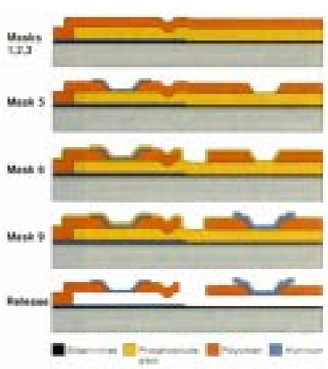
Bulk-micromachined pressure sensor



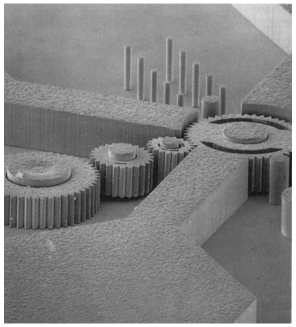
A bulk-micromachined pressure sensor — shown in cross-section — contains a thin silicon diaphragm formed by etching the silicon wafer with alkali-hydroxide. The deflection of the diaphragm depends upon pressure and is sensed by boron-doped piezoresistors.

Surface Micromachining



In the surface micromachining process, a sacrificial layer is grown or deposited and patterned, and then removed wherever the mechanical structure is to be attached to the substrate. Then, the mechanical layer is deposited and patterned. (To make more complex structures, additional layers of mechanical and sacrificial materials can be used.) Finally, the sacrificial layer is etched away to release the mechanical structure.

LIGA Fabrication



In the sacrificial LIGA technique, a magnetic micromotor and assorted microgears are selectively plated onto a sacrificial layer deposited on a silicon substrate. Afterward, the moving parts are freed by selectively etching and undercutting the sacrificial layer. The structure shown was designed for friction testing, and being approximately 300 µm across, can achieve very high angular velocity because of its low inertial mass.

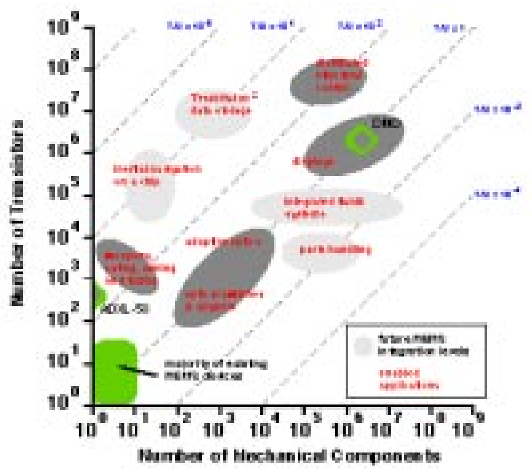
Micromechanical Systems

Perception and control of environment slide

Motivation

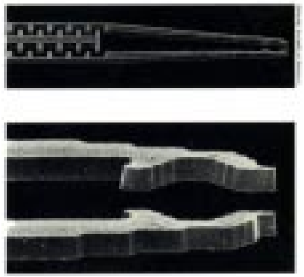
The ultimate goal of MEMS/MOMS is to integrate coordinated motions of basic microactuators, passive/active optical components, microsensors, and microelectronics in order to realize a complete pre-assembled system that can be mass produced with low unit cost.

Development of MEMS Technology



Log-log plot of number of transistors merged with number of mechanical components for MEMS devices and systems. Contours of equal transistors-to-mechanical-components ratios (T/M) are lines of 45˚ slope. Lines representing T/M ratios ranging from 10-4 to 106 are shown for reference. The resulting map represents a quantitative way to measure and track MEMS technology advances across different application areas [50].

Microgripper

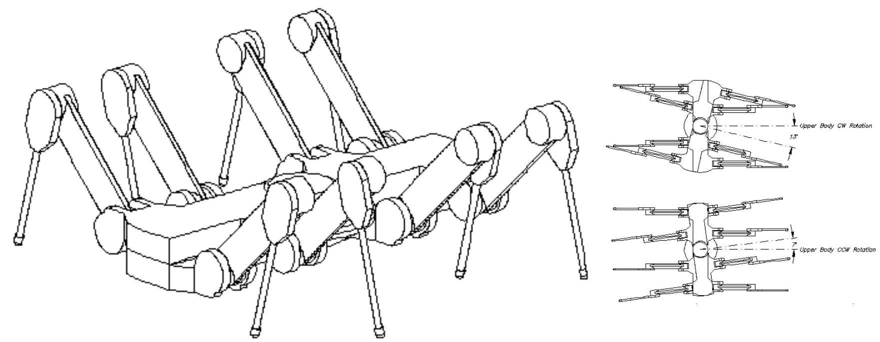


The Berkley Sensor and Actuator Center in California constructed these microgrippers with released-polysilicon surface-micromachining. They are actuated by electrostatic forces. This and other microdevices similarly fabricated could be a boon to retinal, nerve, and other microsurgical and diagnostic techniques.

Biologically-Inspired MEMS-Sensor Based Demining Robots

- biological inspiration
- MEMS sensors
- robotics
- neural networks
- multiple sensor fusion

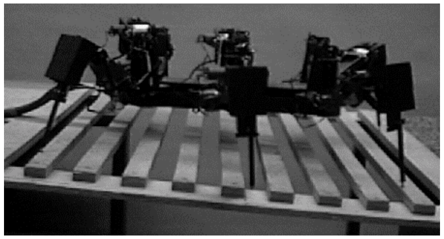
K^{2}T BUG

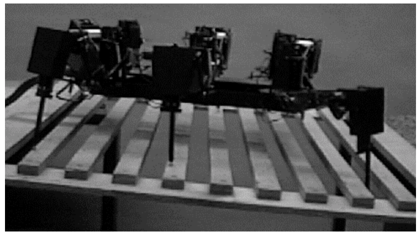


Biologically-Inspired Robots

Robot II: Similar to Stick-Inspect

CWRU Robot II (not used)





Demonstration of search reflex walking across slatted surface

Sensors Benefited By MEMS

- infrared
- olfactory
- magnetic
- acoustic
- tactile
- electromagnetic

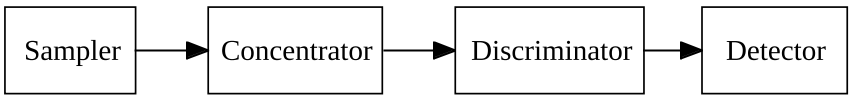
Biologically Inspired Sensor Systems

- sensor arrays
- neural network based data compression
- neural network sensor fusion

MEMS Sensor Array Signal Processing

- reduce effects of individual sensor noise
- accomodate sensor-to-sensor variation
- perform data compression
- multi-sensor fusion
- automatic compensation for sensor drift and failure

MEMS Olfaction Sensors



Vapor detector system diagram

MEMS Amenable Detection Techniques for Olfaction

- chemiluminescence
- thermal conductivity
- biosensor arrays
- microbalances

On-Chip Continuous Chemical Analysis

Integrated Normally-Closed Valve

Polyimide Spring biased Actuator Pump

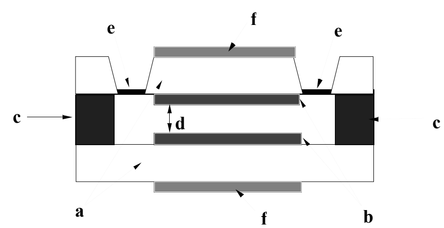
Assembled Micropump

Chemiluminescence

- micromachined separation column
- resistive heater to pyrolize explosive vapors
- selection optical IR detection

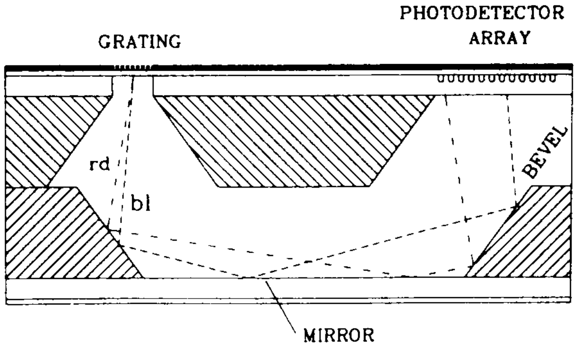
Tunable Infrared Filters

- etch support structures on doubled sided polished (100) wafers
- deposit multilayer dielectric ZnSe and ThF_4 optical coatings through a KOH etched shadow mask
- use additional dielectric coating layers to obtain desired etalon spacing
- bond wafers together using low melting point metals



Generic tunable optical filter. Note: (a) the support material, (b) the reflective coating and (c) the spacer structures The gap width (d) may be changed by deflecting the flexible support regions (e). Antireflective coatings (f) may be included on the device.

ASIMs



Spectrometer with integrated grating and detector array fabricated in (100) silicon.

Kwa and Wolffenbuttel, (Delft) Sensors and Actuators A, 1992.

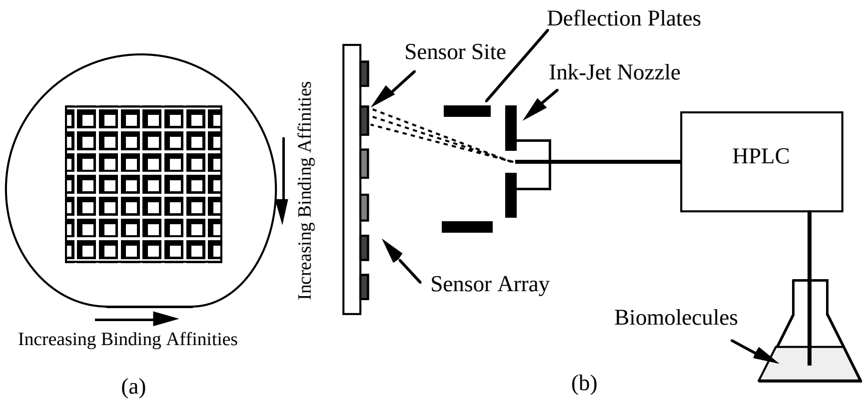
Thermal Conductivity

- micromachined separation column
- micromachined hot-wire anemometer

Biosensor Arrays

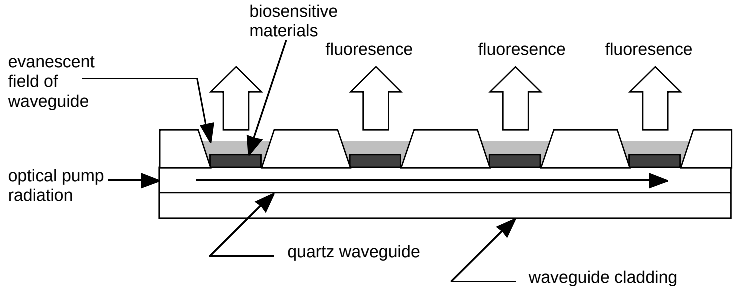
- patterned array of receptors (antibodies)
- fluorescently tagged antibodies
- optical detection of displaced antigens
- strong binders will require modulating the “on” and “off” rates of the receptors
  - » temperature ramping
  - » changing the ionic concentration
  - » changing the pH

Biomolecular Array Receptor Fabrication



(a) gradient in binding affinities across wafer; (b) system to deposit biomaterial at specific sensor sites

Optical Biosensor Array



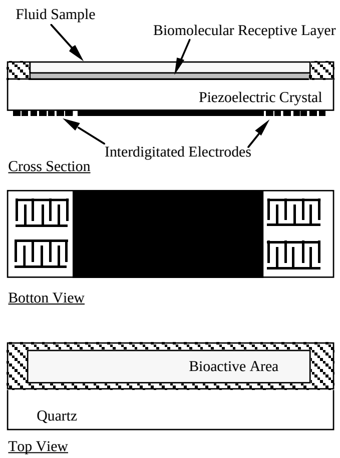
Evanescent Wave Optical Waveguide Biosensor

Biosensor Arrays

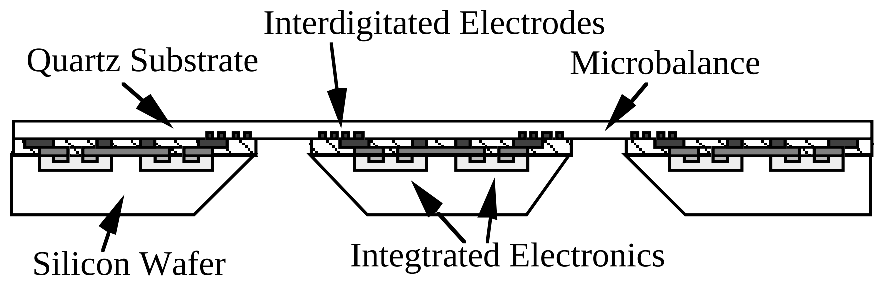
Piezoelectric Microbalances

- resonant microbalance is very sensitive (sub-nanograms)
- selectivity to be achieved using biomolecular receptor layer
- quartz to silicon wafer bonding
- arrays of selective resonant microbalances

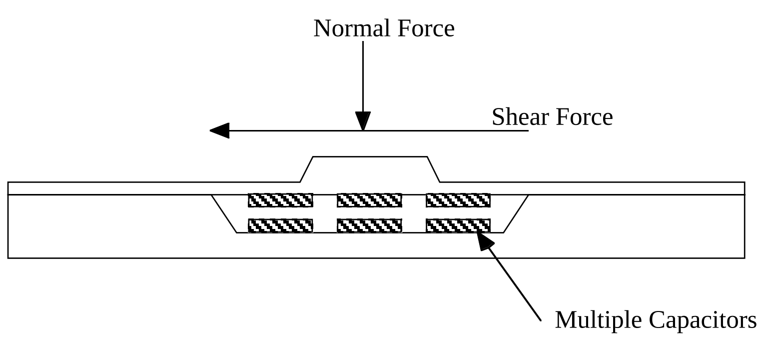
Quartz Microbalance



Integrated Piezoelectric Microbalance Array

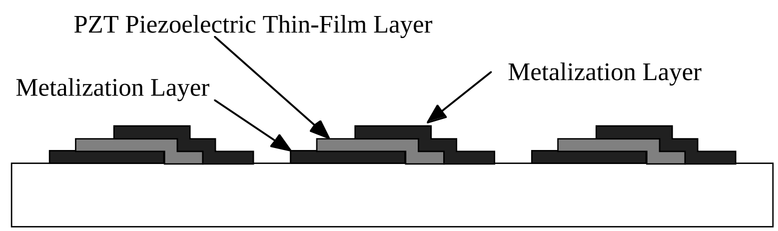


MEMS Tactile Sensor



- normal force - equal change on all capacitors
- shear force - unequal capacitance changes

MEMS Acoustic Sensor Array



MEMS Environmental Sensors

- temperature - thin-film Pt or Ni thermistors
- humidity - capacitive dielectric sensor
- wind direction & speed - multiple surface micromachined hot-wire anenometers
- enhance biosensor by fusing with this environmental data

MEMS Navigation Sensors

- micromachined accelerometers and gyroscopes
- BF Goodrich/CWRU work producing inertial grade devices using thick (10-20μ) polysilicon layers to increase the proof mass
- achieving μ-g sensitivity with dynamic range of ±50g

Other Sensor Modalities

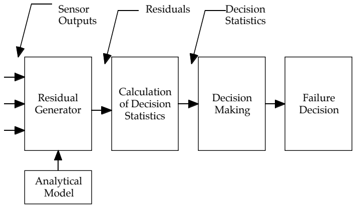
- ground penetrating radar
- wideband, uncooled infrared detector arrays
- electromagnetic pulse-induction (PI)

Autoassociative neural net based memory to detect and compensate for sensor variation, drift, and failure in MEMS sensor arrays

Classical Approach sensor failure detection and correction

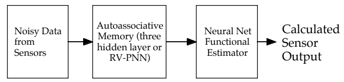
- Hardware redundancy with voting schemes
- Analytical Redundancy - model based approach, but difficult to define/solve the model

Chow, E. and A. S. Willsky, "Analytical Redundancy and the Design of Robust Failure Detection Systems", in IEEE Transactions on Automatic Control, vol. AC-29, no. 7, pp. 603-614, Jul 1984.



Neural Net Based Sensor Processing

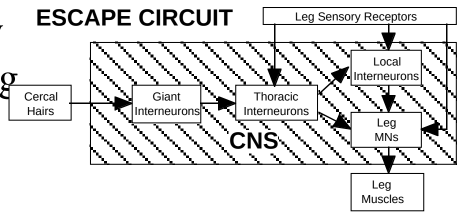
- Model based- learn model from training samples
- Use random vector enhanced autoassocitive memory as non-linear Principal Component Analysis to correct for noise, distortion and partial inputs



Dukki Chung and Francis Merat , "Sensor Failure Detection/Correction Using Autoassociative Memory," Ohio Aerospace Institute Neural Network Symposium and Workshop 95, August 1995.

Arthopod Inspired Mechanisms

- cockroach escape mechanism - turns away from rapidly accelerating wind puffs of a lunging predator
- use intracellular recording and dye injection to identify neural components



»cercial hairs detect wind

»giant interneurons identify wind direction

»thoraicic interneurons form an interconnected network which excite/inhibit the motor neurons

Engineered Systems

- sensor redundancy using neural network autoassociative memory
- feature extraction and data compression using self-organizing networks
- high-level reasoning using fuzzy logic systems to combine evidence

$$Prob(k) = \frac{\sum_{i=1,2} z(k,i) \times Out(k,i)}{\sum_{i=1,2} z(k,i)} \quad k = 1,2,3$$

$$Classification = \left\{ k \mid \max\left(Prob(k)\right) \; for\ all\ k \right\}$$

Remarks

- build upon existing robot platform
- use sensor arrays with sensor fusion
- produce low-power, low-weight integrqated MEMS sensor arrays
- use biological data to design sensor signal processing