INTRODUCTION TO MICROSENSORS

- Microsensors presentation
- Reasons for miniaturization
- History and technology of microsensors
- Scaling laws - numerical examples
- Application examples and markets
Reasons for miniaturization

The reasons for miniaturization of sensors are the same as for electronics:

- Cost
- Reliability
- Applicability
- Performance
- New functions
Transducer effects in silicon and other compatible materials

† *Transducer effects in silicon - electrons are the information carrier*

<table>
<thead>
<tr>
<th>Energy domain</th>
<th>I/Out</th>
<th>Resistor, inductance, capacitive</th>
<th>Modulating</th>
<th>Transistor</th>
<th>Examples of smart transducers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation</td>
<td>Volta effect, solar cell, Not known</td>
<td>Photoconductor</td>
<td>Photodiode</td>
<td>Phototransistor</td>
<td>Photo-IC, CCD, Accelerometer, Piezo IC</td>
</tr>
<tr>
<td>Mechanical</td>
<td></td>
<td>Piezoresistivity</td>
<td>Piezojunction</td>
<td>Piezotransistor</td>
<td></td>
</tr>
<tr>
<td>Thermal</td>
<td>Seebeck effect, thermocouple</td>
<td>R = f(T)</td>
<td>Reverse biased I_{rev} = f(T)</td>
<td>Forward biased U_{BE} = f(T)</td>
<td></td>
</tr>
<tr>
<td>Electrical</td>
<td>Thermal energy, resistance</td>
<td>Electric field MOSFET Magnetoresistor</td>
<td>Electric field FET Magnetic diode</td>
<td>Dual gate MOSFET Hall effect</td>
<td></td>
</tr>
<tr>
<td>Magnetic</td>
<td>Maxwell diffused coil, Galvanic</td>
<td>Ion concentration</td>
<td>Not known</td>
<td>ISFET</td>
<td></td>
</tr>
<tr>
<td>Chemical</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Smart nose</td>
</tr>
</tbody>
</table>
Scaling Laws

With miniaturization will some effects be advantageous, some disadvantageous:

\[ \text{acceleration } a = \frac{F}{m} = \left[ L^F \right] \cdot \left[ L^{-3} \right] \]

\[ \text{response time } t = \sqrt{2x \over a} = \sqrt{2x m \over F} = \left[ L^1 \right] \cdot \left[ L^3 \right] \cdot \left[ L^{-F} \right] \frac{1}{2} \]

\[ \text{power generation } P = F x \over t \quad \text{and} \quad \frac{P}{V} = \frac{F x}{tV} \]
### Scaling Laws

<table>
<thead>
<tr>
<th>Condition</th>
<th>F</th>
<th>a</th>
<th>t</th>
<th>P/V</th>
</tr>
</thead>
<tbody>
<tr>
<td>electrostatics with E prop. to $L^{-1/2}$,</td>
<td>$L^1$</td>
<td>$L^{-2}$</td>
<td>$L^{3/2}$</td>
<td>$L^{-5/2}$</td>
</tr>
<tr>
<td>or surface tension</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>electrostatics with const. E,</td>
<td>$L^2$</td>
<td>$L^{-1}$</td>
<td>$L^1$</td>
<td>$L^1$</td>
</tr>
<tr>
<td>or pressure forces, muscles</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>magnetics</td>
<td>$L^3$</td>
<td>$L^0$</td>
<td>$L^{1/2}$</td>
<td>$L^{1/2}$</td>
</tr>
<tr>
<td>(const. heat flow)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>magnetics</td>
<td>$L^4$</td>
<td>$L^1$</td>
<td>$L^0$</td>
<td>$L^2$</td>
</tr>
<tr>
<td>(const. current density)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Scaling Laws

\[ \log Y = 1.458 + 0.6748 \log X \]
Scaling Laws

\[ Q = -\lambda A(T_0 - T_{\text{ext}}) = \rho c_p V \frac{dT}{dt} \]

\[ \frac{T - T_{\text{ext}}}{T_0 - T_{\text{ext}}} = e^{-\frac{\lambda A}{\rho c_p V} t} \]

1/time constant

Assuming equilibrium in 
t = 4 time constants: 
a Ø 50 µm Ni rod reaches 
equilibrium 
in 0.02 s and a Ø 2.5 mm rod in 5 s.

Keller et al. Transducers'95
Microsensor Technology

Developed from the technology of microelectronics:

- Photolithography
- Etching and thin film deposition
- Batch production
- Materials: mostly silicon, metals, quartz, glass, and polymers
- Specialized testing and packaging
Microsensor Technology

masking and etching on armor (fifteenth century)

first photolithography followed by etching (Lemîtres, 1827)
Microsensor Technology

MOSFET Process

1. Thermal doping
   - 10 µm: p-Si
   - 100 µm: n-Si

2. Oxide layer
   - 1 µm: SiO₂
   - 10 µm: p-Si

3. Deposit photoresist
   - 1 µm: SiO₂
   - 10 µm: p-Si

4. Dissolve resist

5. Etch oxide in H

6. Remove resist, regrow oxide and deposit polysilicon (n⁺-Si)

7. Define gate & etch

8. Oxidise & window for metallisation

9. Etch oxide & dope silicon

10. Source, gate, drain
Microsensor Technology

Wet bulk micromachining

1. Deposit Photoresist
2. Open Contacts
3. Silicon Wafer
4. Deposit Aluminum
5. UV Light Mask
6. Pattern Aluminum
7. Develop Resist
8. Pattern Back Oxide
9. Implant Boron
10. Anneal and Oxidation
11. Silicon Etch
Microsensor Technology

Selective anodic etching
Microsensor Technology

Bulk wet etch micromachining
Microsensor Technology

Deep reactive ion etching
Microsensor Technology

Surface micromachining

1. Oxidation
   - 0.25 µm of oxide
   - Substrate: n⁺-Si

2. LPCVD deposit of nitride
   - 0.1 µm of nitride
   - n⁺-Si

3. Deposit spacer layer
   - 2 µm of PSG

4. Deposit photoresist pattern & etch base window
   - Resist
   - n⁺-Si

5. Remove resist & deposit polysilicon
   - 0.3 µm of poly Si
   - n⁺-Si

6. Etch out microstructure
   - n⁺-Si

7. Etch out spacer layer (PSG)

8. Metallisation
Microsensor Technology

Examples of surface micromachining

Keller et al. Transducers'95
MST Transducer Market Projection

- New emerging products in the introduction phase
- Products that already existed in 1996 but that have been steadily improved