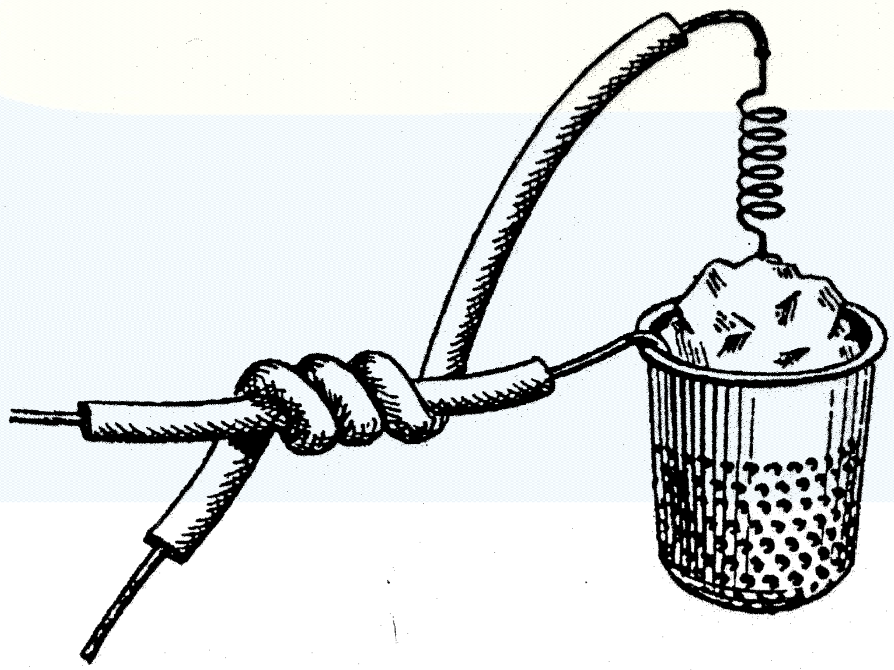
ELECTRONICS Design Division

Sensor devices

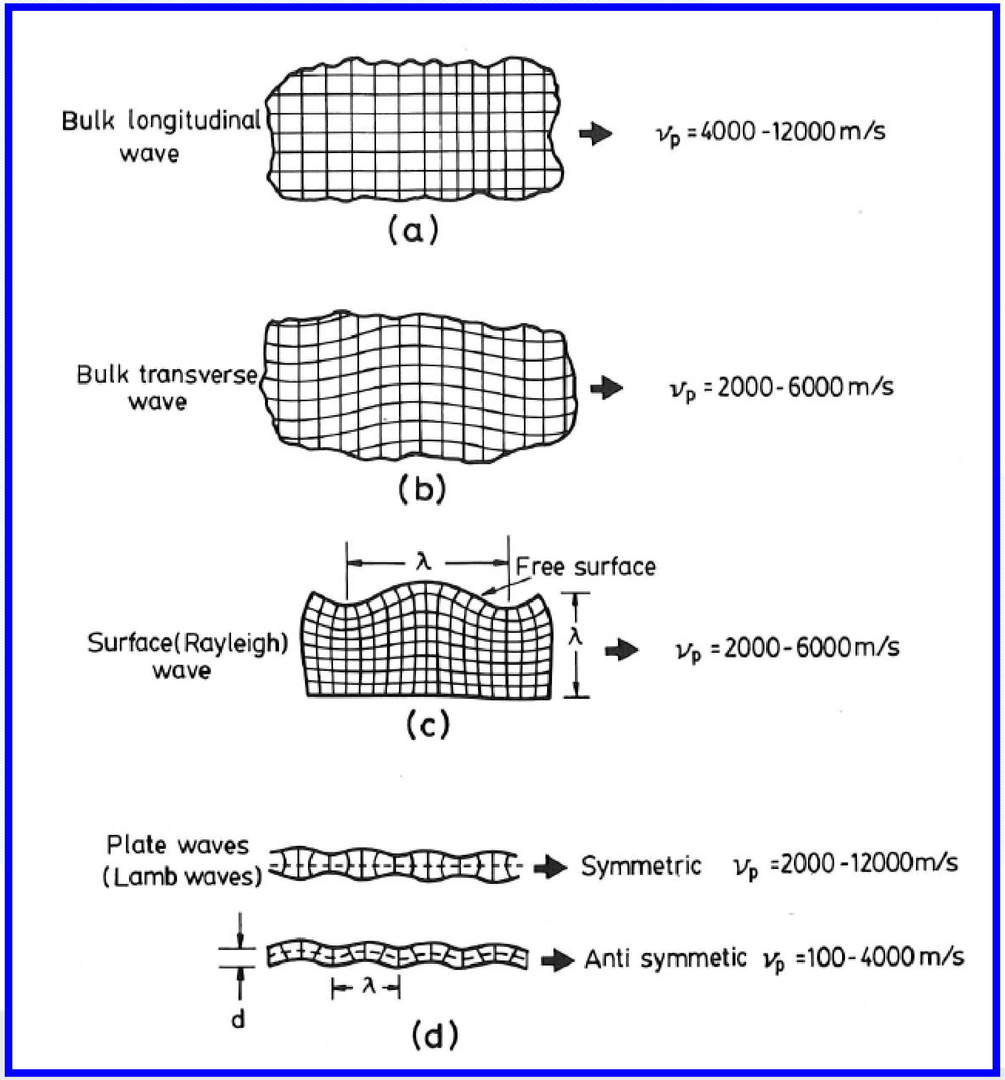


Mittuniversitetet
MID SWEDEN UNIVERSITY

Outline

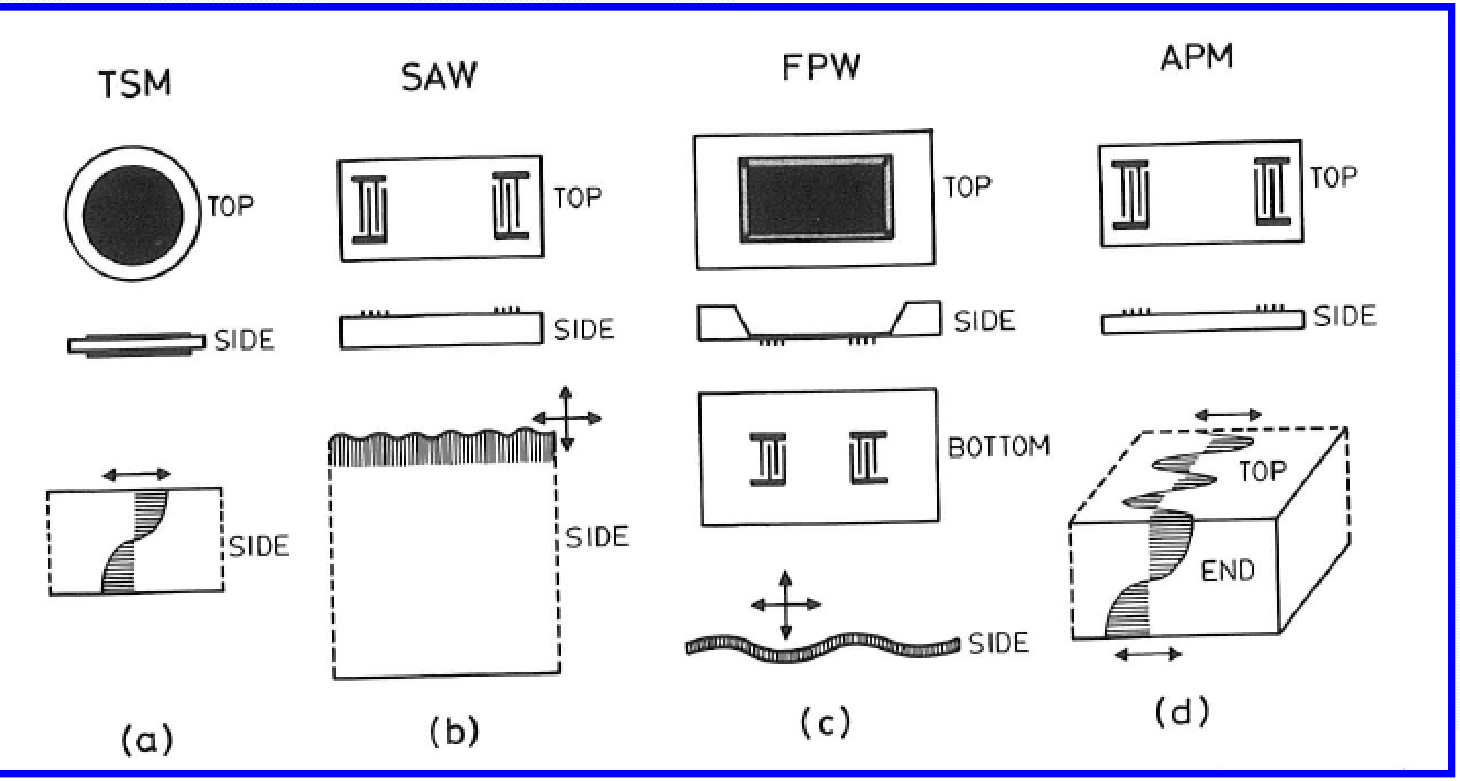
- **3 Acoustic Wave Sensor**
  - **High sensitivity**
    - **chemical vapour, gas sensing**
  - **Oscillation-elastic waves MHz-GHz**
  - **Delay time**

Acoustic Wave Sensors



- Atoms in solid are forced into vibratory motion

Acoustic Wave Sensors



- •TSM thickness shear mode
- •SAW surface acoustic wave
- •FPW flexural plate wave
- •APM acoustic plate mode

Acoustic Wave Sensors

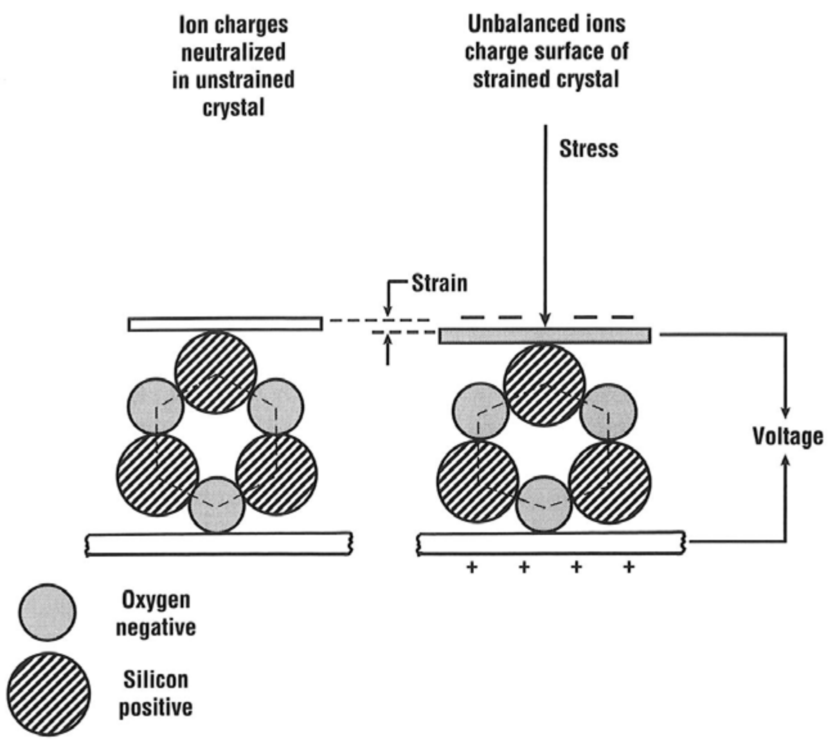


Figure 19.3 Ion position in a piezoelectric crystal lattice such as quartz with and without applied stress *(reprinted with permission from Madou [7]. Copyright CRC Press).*

How can we made the material to oscillate?

Piezoelectric effect!

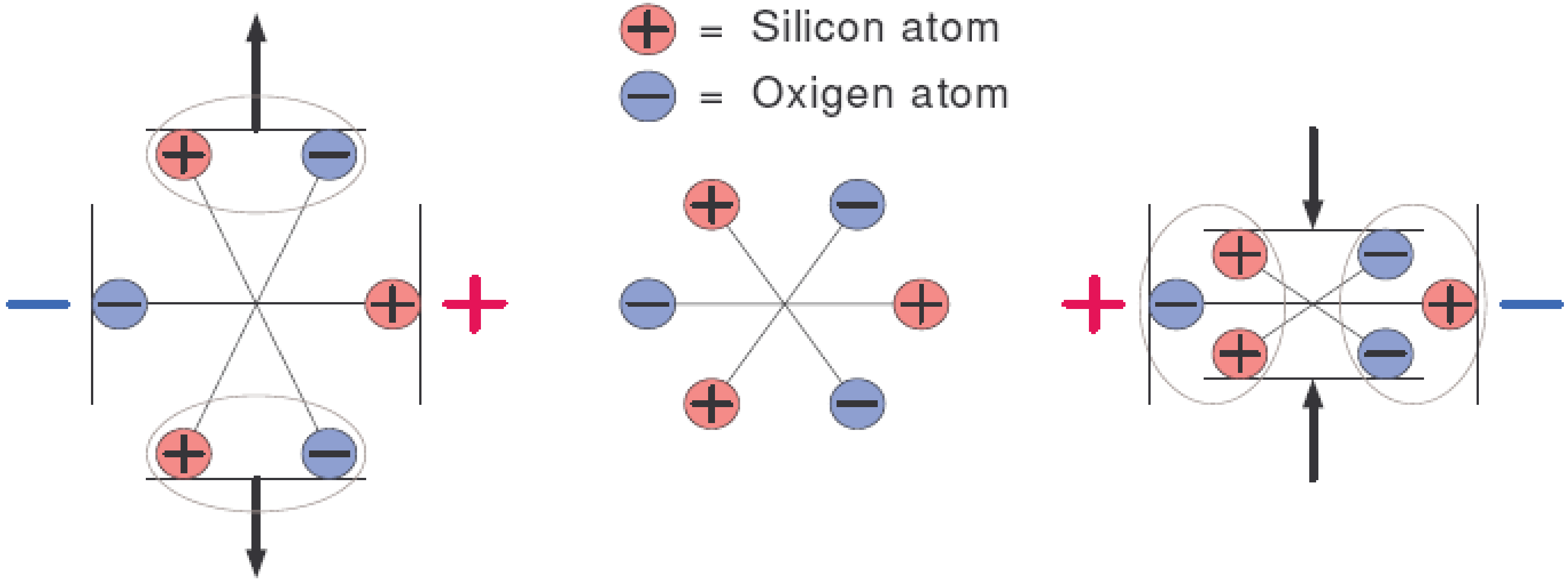
Stress result in voltage

Voltage result in strain

Acoustic Wave Sensors

Piezo-electric effect:

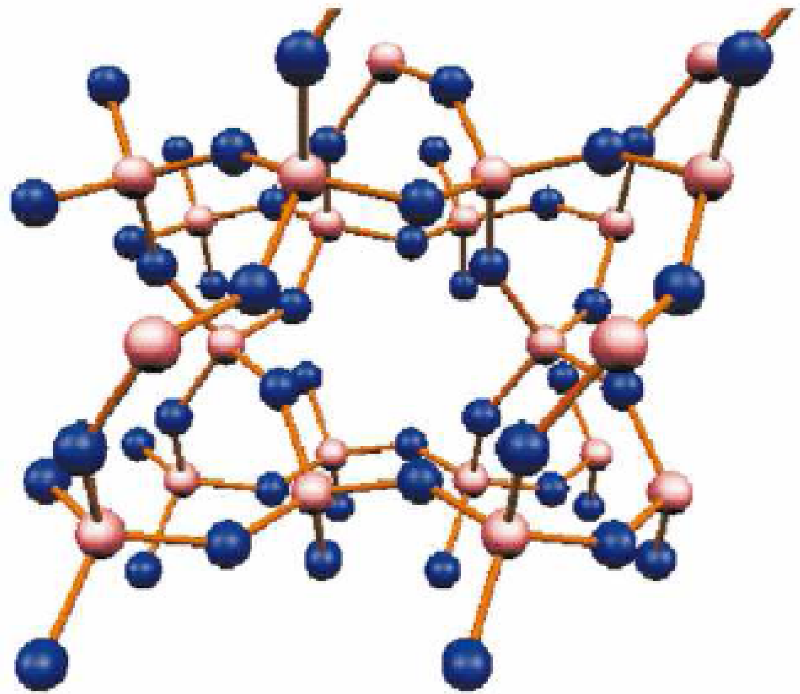
- Mechanical strain ⇒ voltage
- Voltage ⇒ mechanical deformation



Acoustic Wave Sensors
Example of Piezo material

Quartz = SiO_2

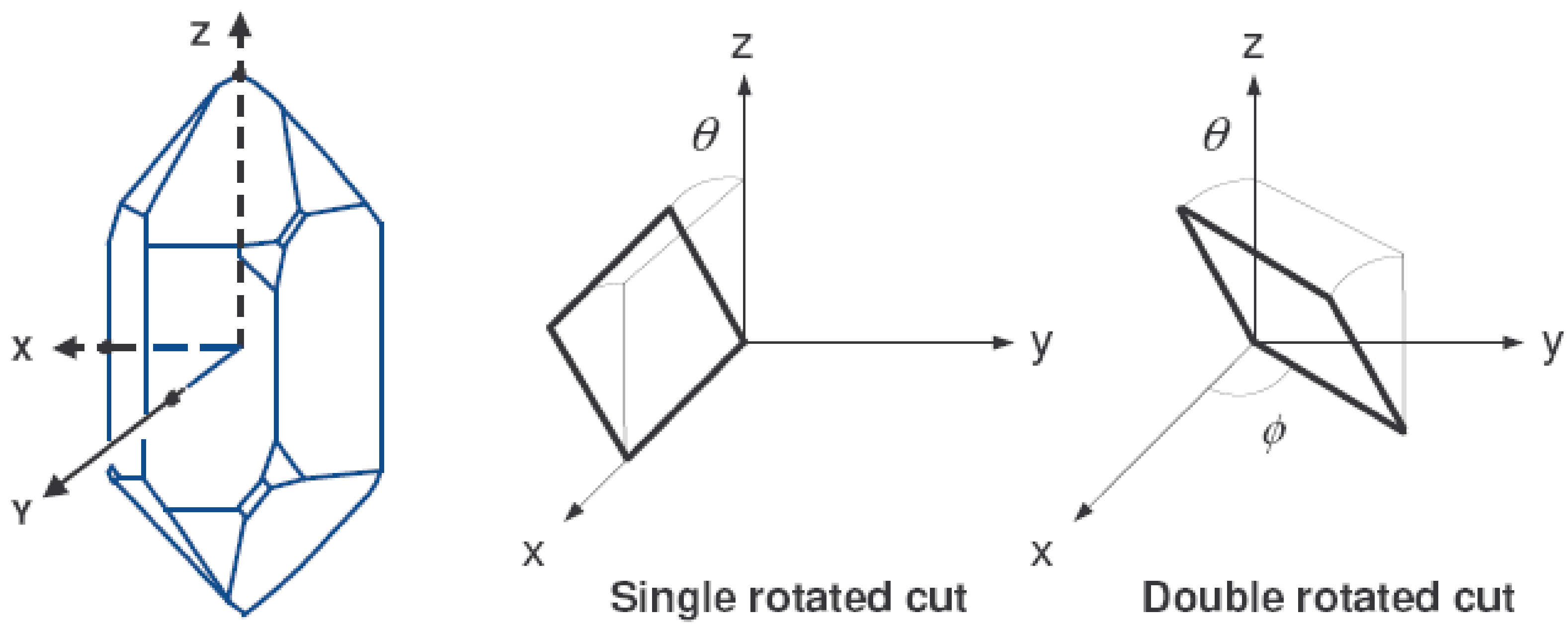
Pink = silicon atoms
Blue = oxygen atoms



Quartz lattice

Acoustic Wave Sensors
Chrystal direction

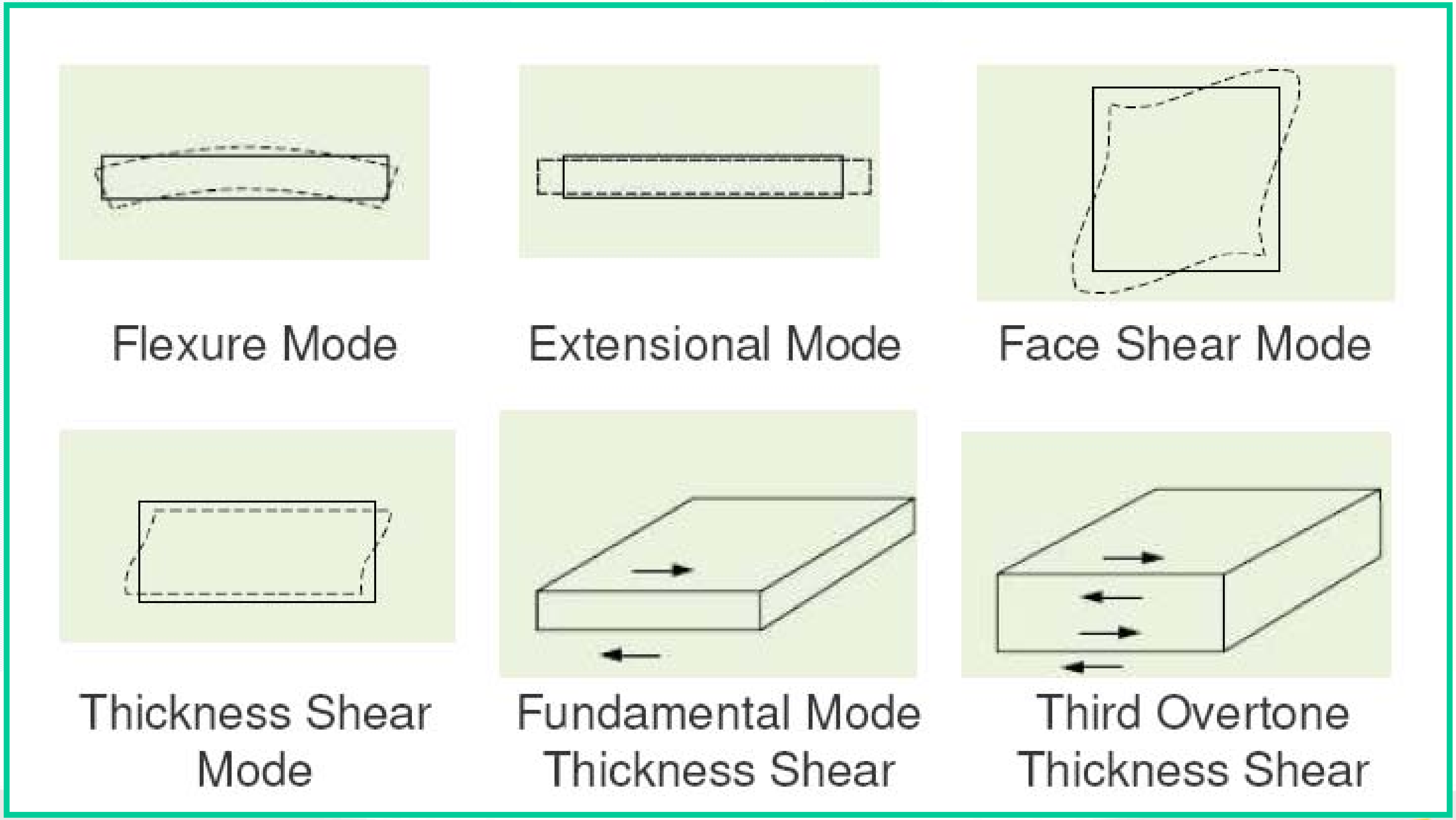
Small disks are cut out of the crystal at given angles.



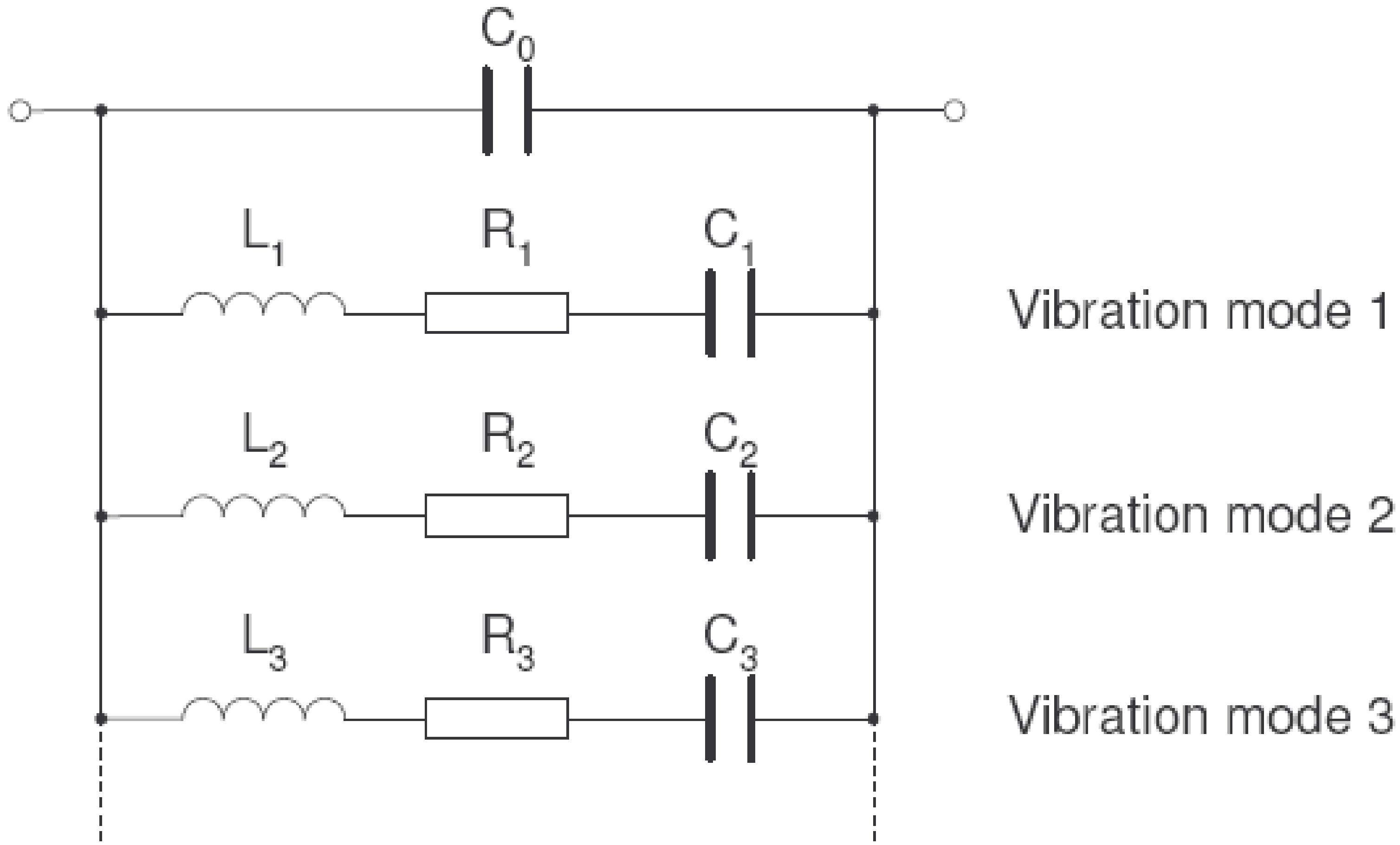
Single rotated cut
(e.g. AT-cut)

Double rotated cut
(e.g. SC-cut)

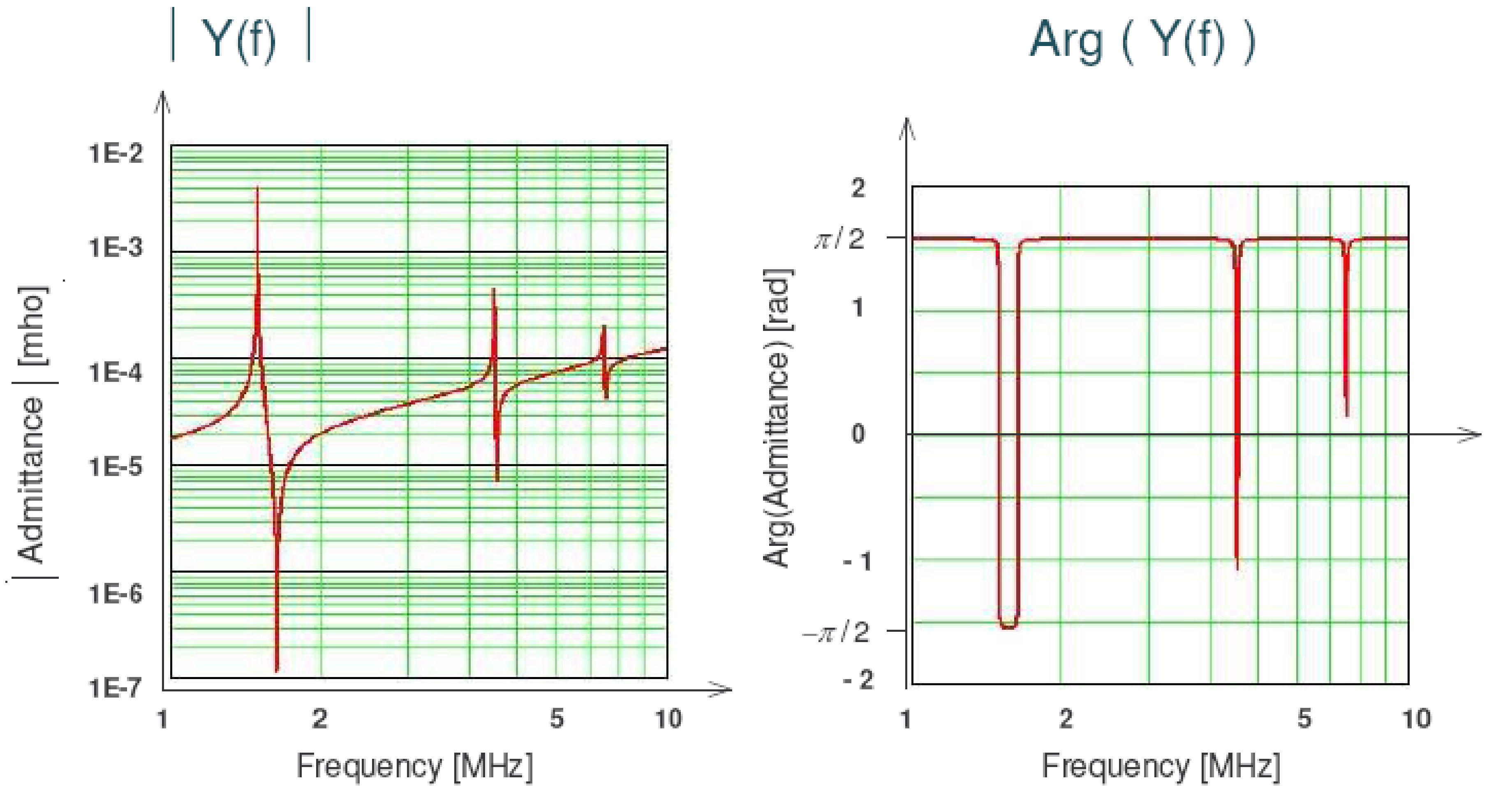
Acoustic Wave Sensors
Vibration Modes



Acoustic Wave Sensors

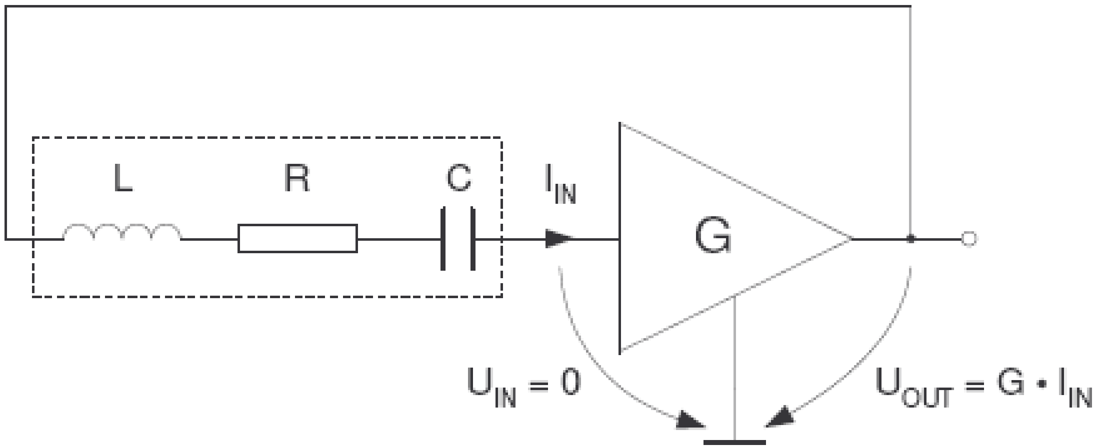


Acoustic Wave Sensors



Mittuniversitetet
MID SWEDEN UNIVERSITY

Acoustic Wave Sensors

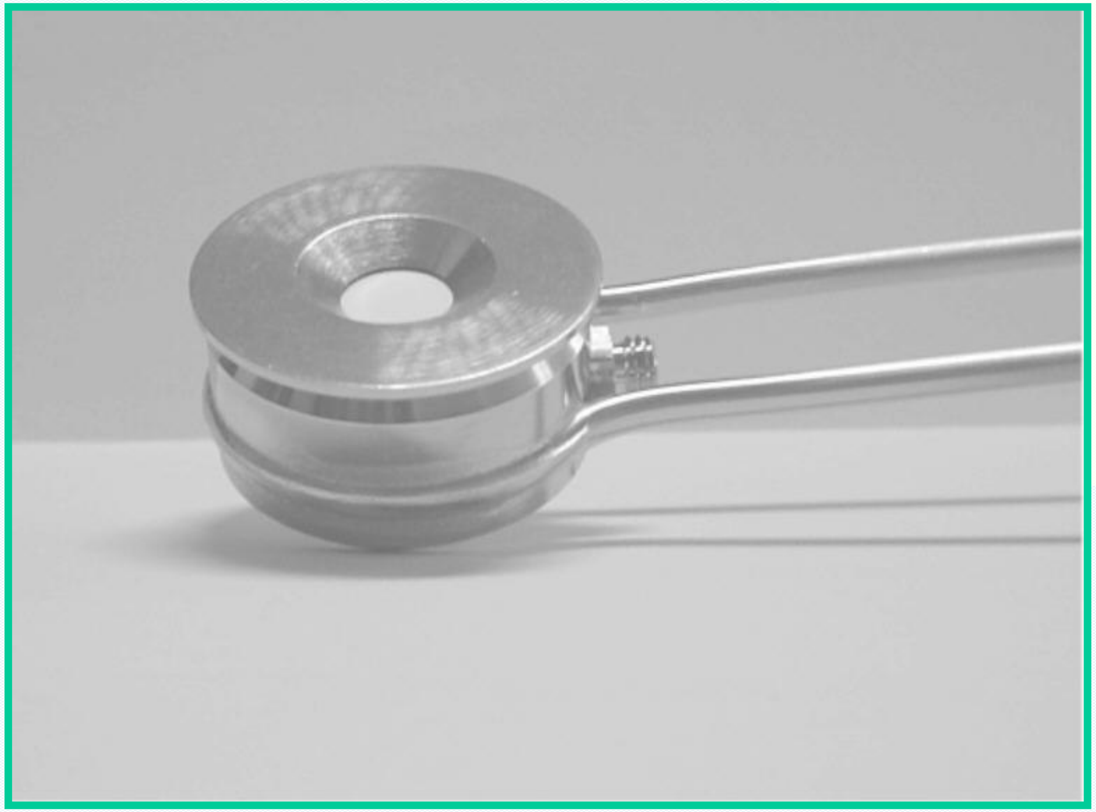


Open Loop Gain: $H(\omega) = G \cdot Y(\omega) = \dfrac{G}{j \cdot \omega \cdot L + R + \dfrac{1}{j \cdot \omega \cdot C}}$

If $G = \dfrac{1}{R}$ and $\omega = \omega_0 = \dfrac{1}{\sqrt{L \cdot C}}$ then $H(\omega = \omega_0) = 1$

$f_0 = \dfrac{\omega_0}{2 \cdot \pi} =$ resonance frequency

Acoustic Wave Sensors
Thin film thickness measurement (TSM)

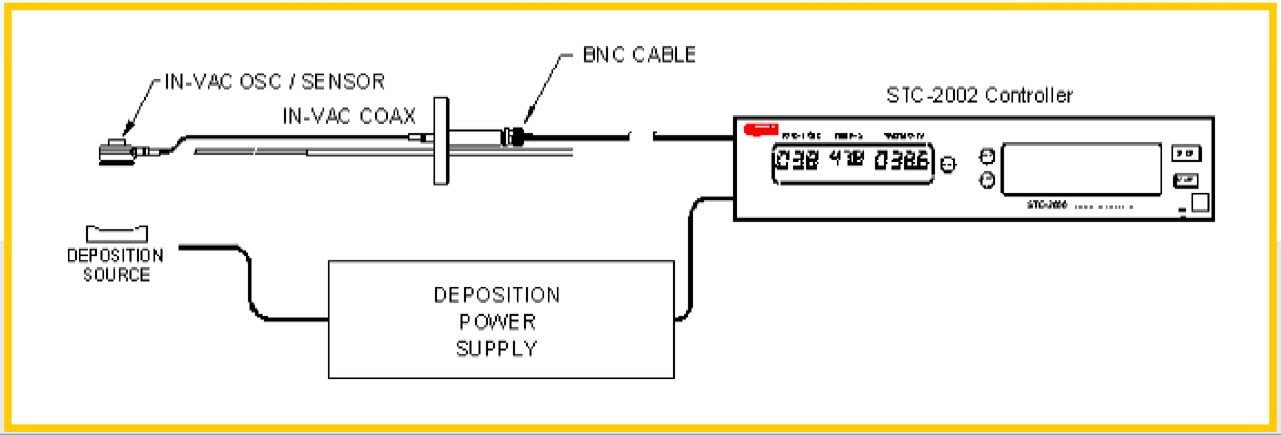


Specifications

- Crystal Sensor: Industry standard 6 MHzMax
- Temperature:

150ºC In-Vac Oscillator Sensor

- Sensor Mounting: Rear of body, #4-40 Tapped
- Materials: 304 SS, Alumina, Teflon
- Crystal: Quartz with Gold Electrodes
- Water Temp: 50ºC
- Connection: Microdot Miniature



Acoustic Wave Sensors
Properties of piezoelectric thin film

1. value of electromechanical coupling;
2. good adhesion to substrate;
3. resistance to environmental effects (e.g., humidity, temperature);
4. VLSI process compatible (e.g., deposition methods and etching);
5. temperature and acceleration sensitivity;
6. cost effectiveness.

Acoustic Wave Sensors
Properties of piezoelectric thin film

- SiO_2 (Quartz)
  - **Natural**
  - **Synthetic**
- ZnO (Zinc Oxide)
  - **High piezoelectric coupling**
  - **stability**
    - Magnetron sputtering
- AlN (Aluminium Nitride)
  - **High acoustic velocity (GHz region)**
  - **Reactive Magnetron sputtering**

Acoustic Wave Sensors
Properties of piezoelectric thin film

- AlN (Aluminium Nitride)
  - **Reactive Magnetron sputtering**

Atmospheric gas	$Ar + N_2$ (1:1) or N_2
Gas pressure	10^{-2}–3×10^{-3} Torr
Substrate temperature	50–500°C
Target material	99.6–99.99% pure Al
Target size	diameter 100 mm, thickness 6 (mm)
Target-substrate spacing	40 mm
Input RF power	100–200 W
Film-thickness range	1–7 μm
Sputtering rate	0.2–0.8 (μm/h)

Acoustic Wave Sensors
Properties of piezoelectric thin film

- $Pb(Zr, Ti)O_3$ (PZT)
  - **Highest Piezo coupling factor (10 times higher)**
  - **Large pyroelectric response (infra red sensitive)**
    - E-beam evaporation
    - RF sputtering
    - Sol-Gel
    - Laser ablation
    - ….

Acoustic Wave Sensors
Properties of piezoelectric thin film

TABLE 2 Application Summary of Three Major Piezo-Films ZnO, AlN, and PZT

Applications	Piezoelectric Materials			
	ZnO	AlN	PZT	Others
Pressure sensors	√			√
Gas sensors				√
Bulk acoustic resonators	√	√		
Plate mode sensors	√			√
Accelerometers	√			√
TV VIF filters	√		√	
SAW devices	√	√	√	
Actuator/translator	√		√	

Acoustic Wave Sensors

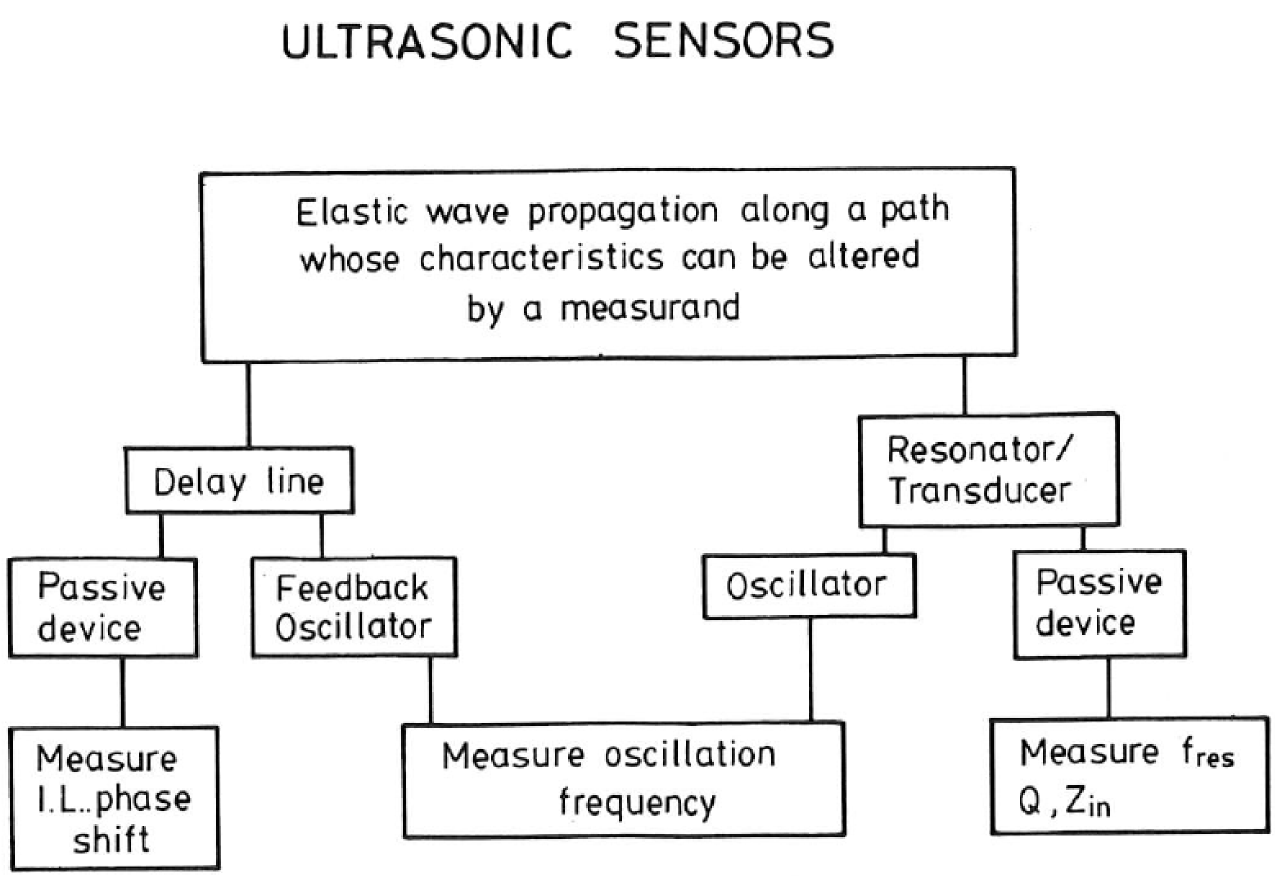


Fig. 6 Measurement options for ultrasonic resonators and delay lines.

Acoustic Wave Sensors

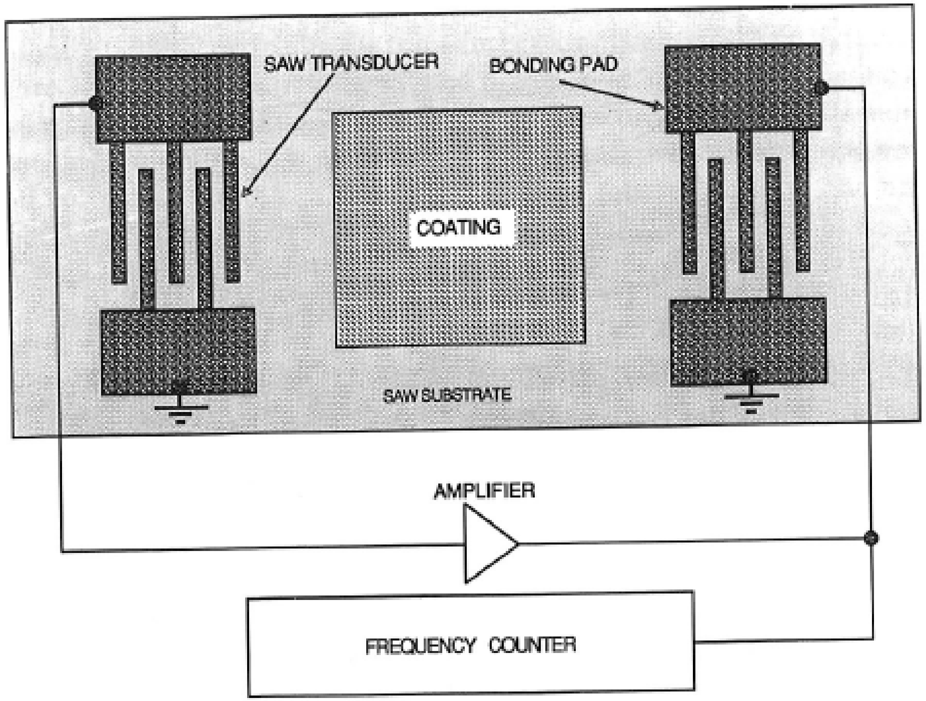


Fig. 17 Schematic of SAW gas sensor concept.

- Gas sensor SAW
- Coating absorb mesurand
- Problem! temperature dependence

Mittuniversitetet
MID SWEDEN UNIVERSITY

Acoustic Wave Sensors

SAW sensor in a twin sensor configuration

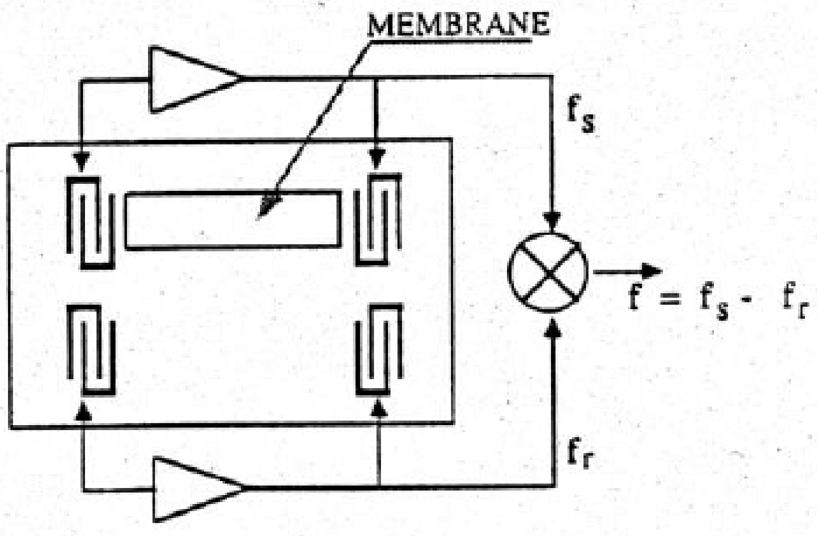


Figure 17: Differential structure for phase shift detection technique (a) and frequency shift detection technique (b).

Acoustic Wave Sensors
Working principle SAW

Surface acoustic wave (SAW)

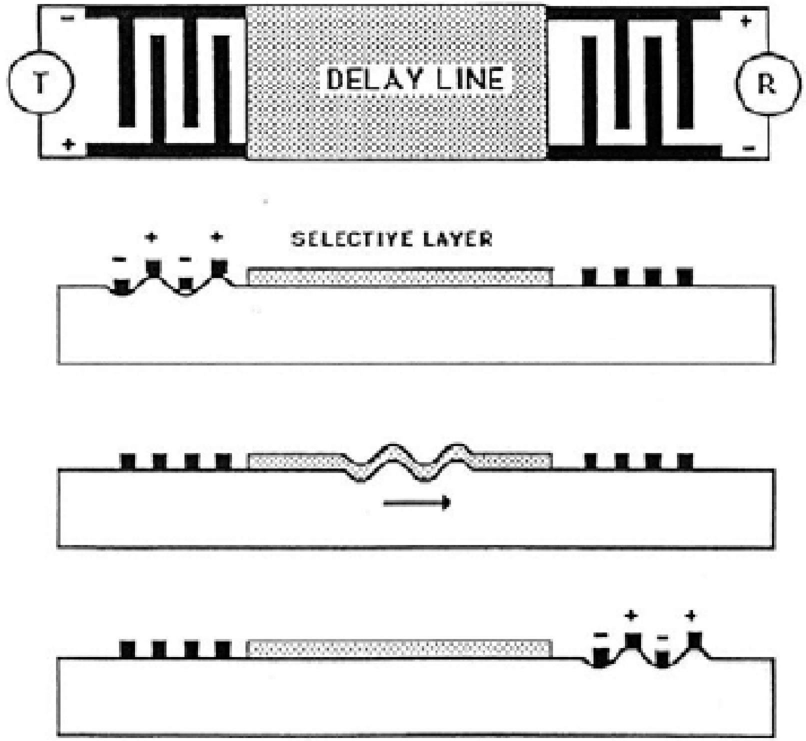


Figure 3-12. Schematic diagram of a SAW sensor with transmitter T, receiver R, and the chemically selective layer deposited on the delay line.

Acoustic Wave Sensors
SAW in a oscillator circuit

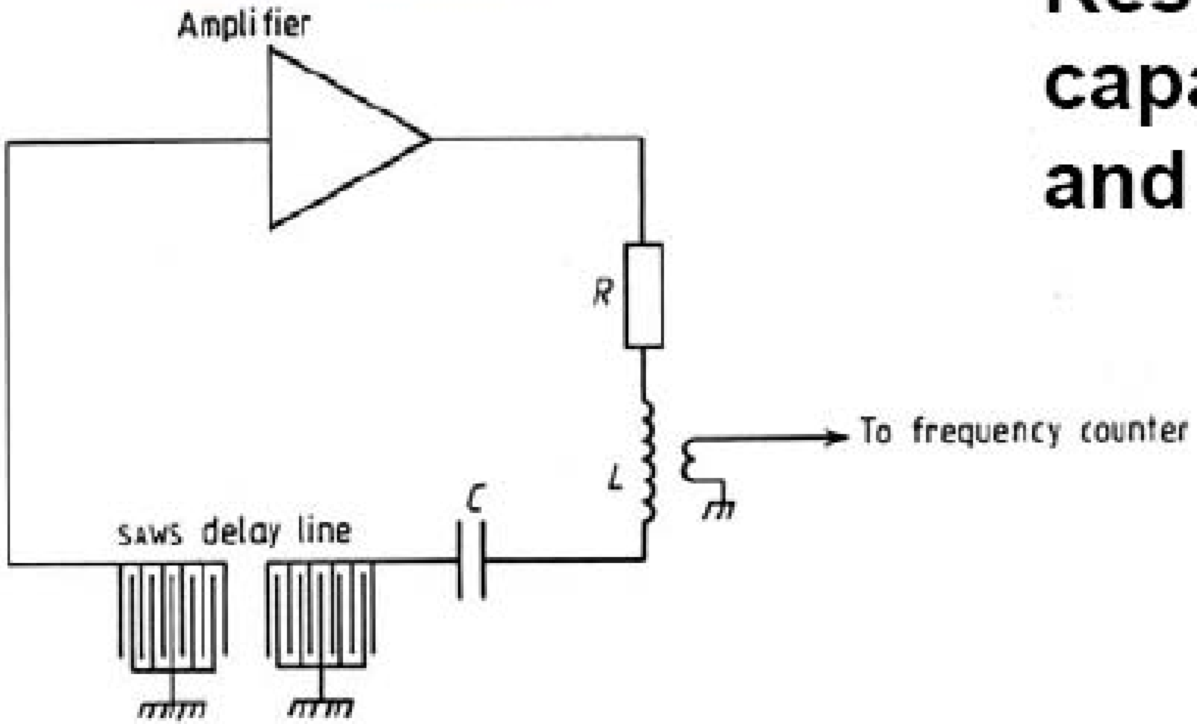


Figure 13.2 Delay line oscillator (schematic representation).

Resistors, capacitors and a coil

Acoustic Wave Sensors

TABLE 4 Summary of Various SAW Chemical Sensors

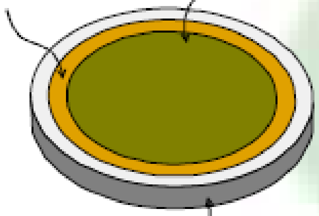
Measurand	Chemical Interface	SAW Substrate	Reference
Organic vapor	Polymer film	Quartz	81–83
SO_2	TEA[a]	Lithium niobate	84
H_2	Pd	Lithium niobate, silicon	85, 86
NH_3	Pt	Quartz	87
H_2S	WO_3	Lithium niobate	88
Water vapor	Hygroscopic	Lithium niobate	89, 90
NO_2	PC[b]	Lithium niobate, quartz	91–93
NO_2, NH_3, CO, SO_2, CH_4	PC[b]	Lithium niobate	94
Vapors of explosives, drugs	Polymer films	Quartz	95
CO_2, Methane	C[c]	Lithium niobate	96

[a] TEA = Triethanolamine.
[b] PC = Phthalocyanine.
[c] C = No chemical interface used. Detection based on changes in thermal conductivity produced by the gas.

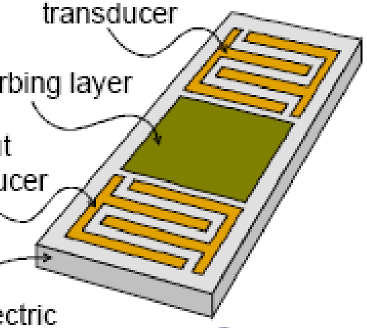
Acoustic Wave Sensors
Comparison between TSM and SAW

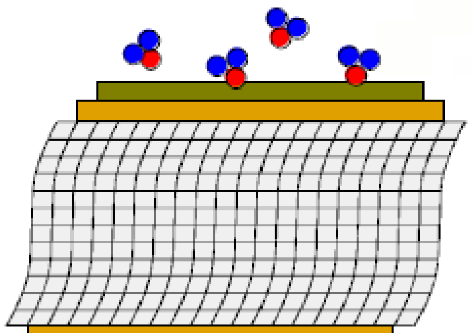
Mass sensitive Resonator sensors

QCM



SAW

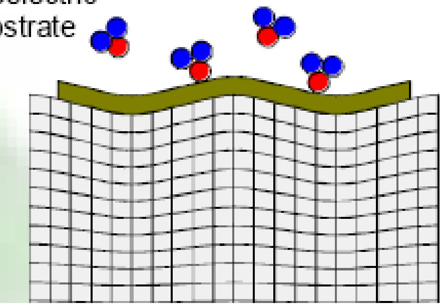




QCM at 10 MHz

and SAW at 100 MHz:

$$\frac{\Delta F_{SAW}}{\Delta F_{BAW}} = \frac{1.3x10^6 100^2}{2.3x10^6 10^2} \approx 60$$



Thickness shear mode:
Typical resonance frequency: 5-30 MHz
For AT cu quartz:

$$\Delta f = -2.3x10^6 f_o^2 \frac{\Delta m}{A}$$

Surface (Rayleigh) wave:
Typical resonance frequency: 100-500 MHz
For YX cut quarts:

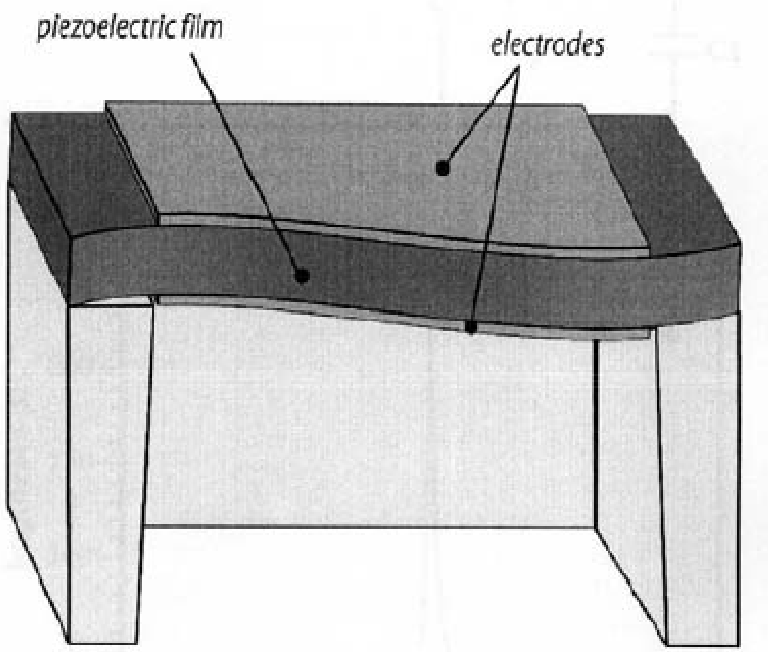
$$\Delta f = -1.3x10^6 f_0^2 \frac{\Delta m}{A}$$

Acoustic Wave Sensors
Example of FPW

AlN based bulk acoustic resonators

Uppsala University, Sweden and S-SENCE

AlN sputter deposited



Bulk resonating thin film (2μm) device

J. Bjurström, D. Rosén, I. Katardjiev, V.M. Yanchev, I. Petrov, (Sweden)
IEEE Trans. Ultrasonics ferroelectr. And freq. Control, 2004

Uppsala, spring 2005, A. Lloyd Spetz

S-SENCE
Linköping University

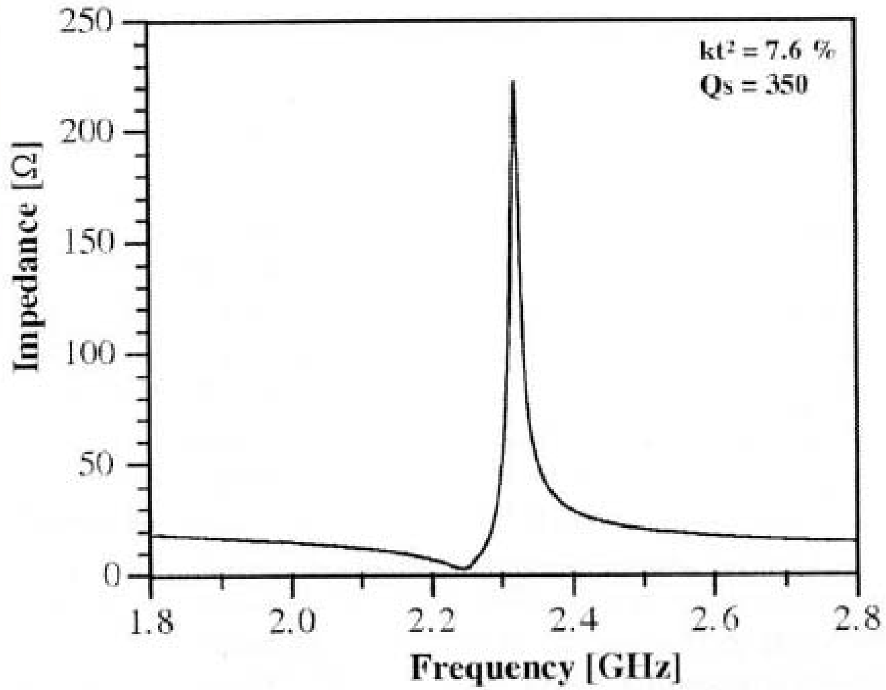
Mittuniversitetet
MID SWEDEN UNIVERSITY

Acoustic Wave Sensors
Example of FPW

AlN based bulk acoustic resonators

Typical resonance frequency of ~ 2GHz

Potential of very high sensitivity



J. Bjurström, D. Rosén, I. Katardjiev, V.M. Yanchev, I. Petrov,
IEEE Trans. Ultrasonics ferroelectr. And freq. Control, 2004

J. Bjurström et al,

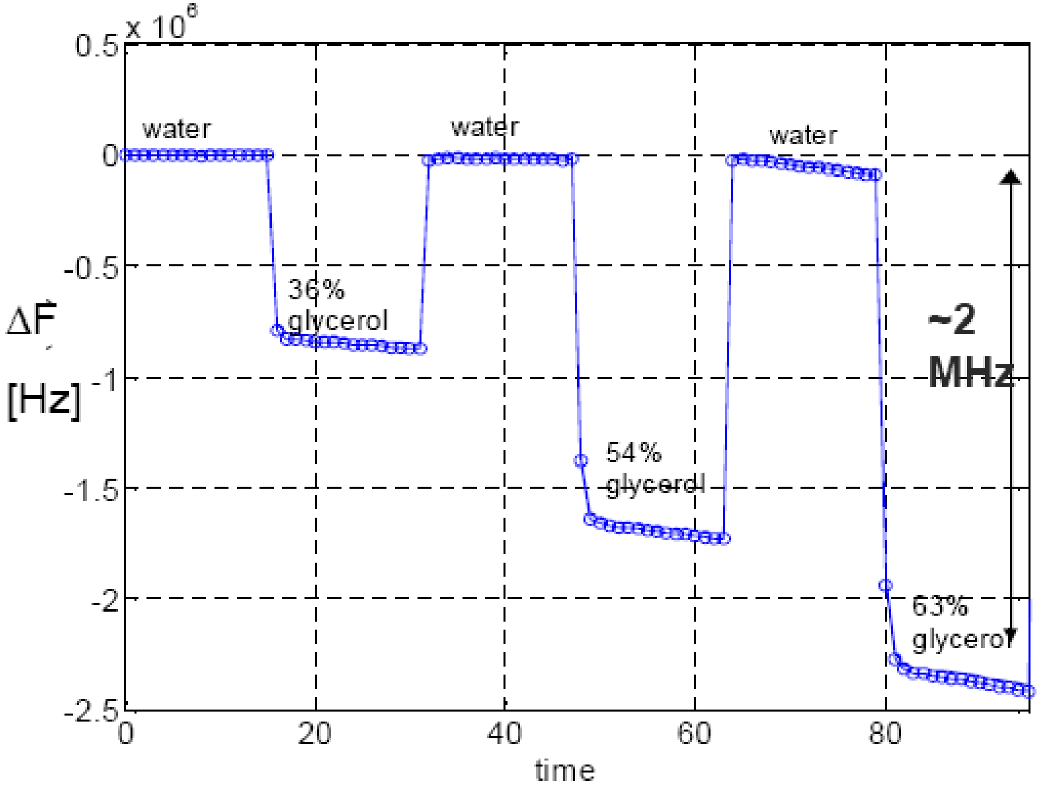
Uppsala, spring 2005, A. Lloyd Spetz

S-SENCE
Linköping University

Mittuniversitetet
MID SWEDEN UNIVERSITY

Acoustic Wave Sensors
Example of FPW

AlN based bulk acoustic resonators as gas and biosensors



Response to different concentrations of glycerol in water

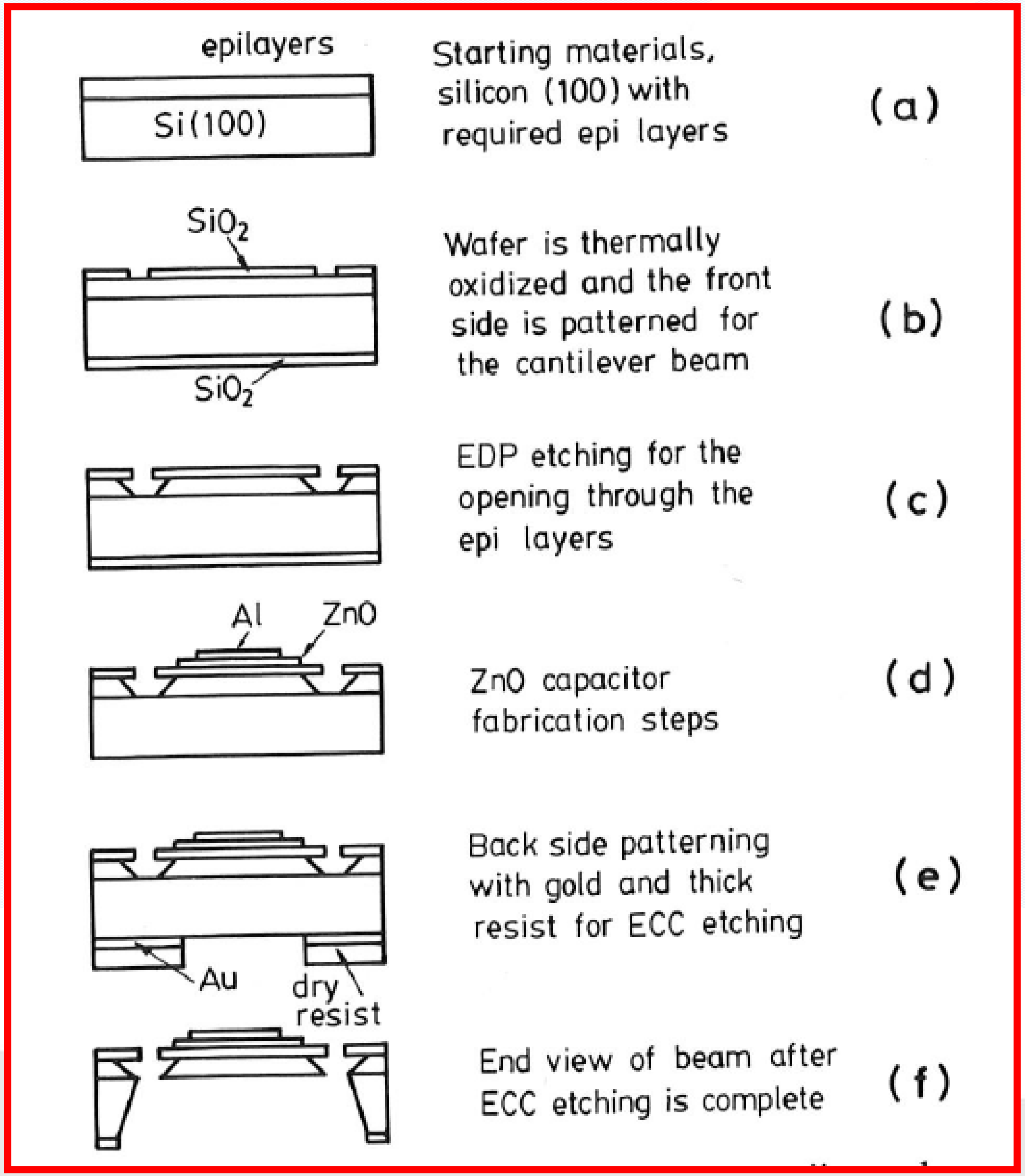
Gunilla Wingqvist, Uppsala University, Sweden

Uppsala, spring 2005, A. Lloyd Spetz

S-SENCE
Linköping University

Mittuniversitetet
MID SWEDEN UNIVERSITY

Acoustic Wave Sensors



- Processing of a Cantilever beam in silicon

Acoustic Wave Sensors

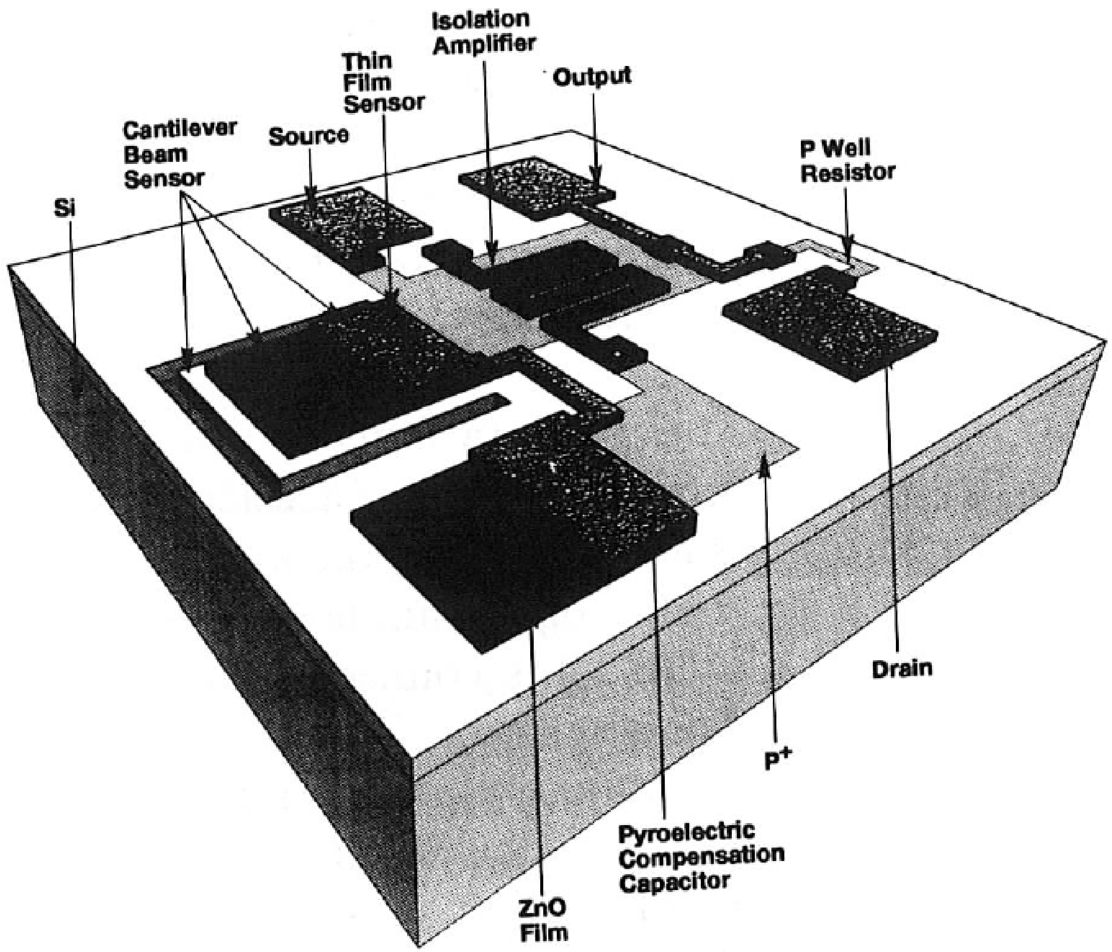
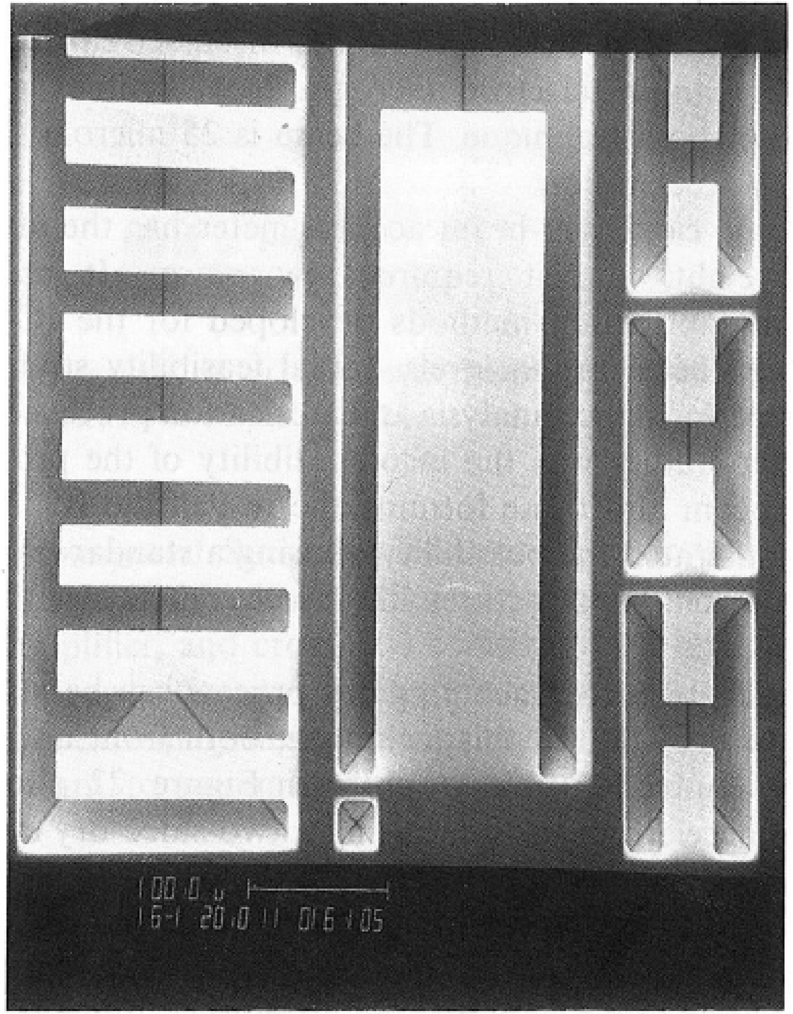


Fig. 18 Schematic of a silicon monolithic cantilever beam.

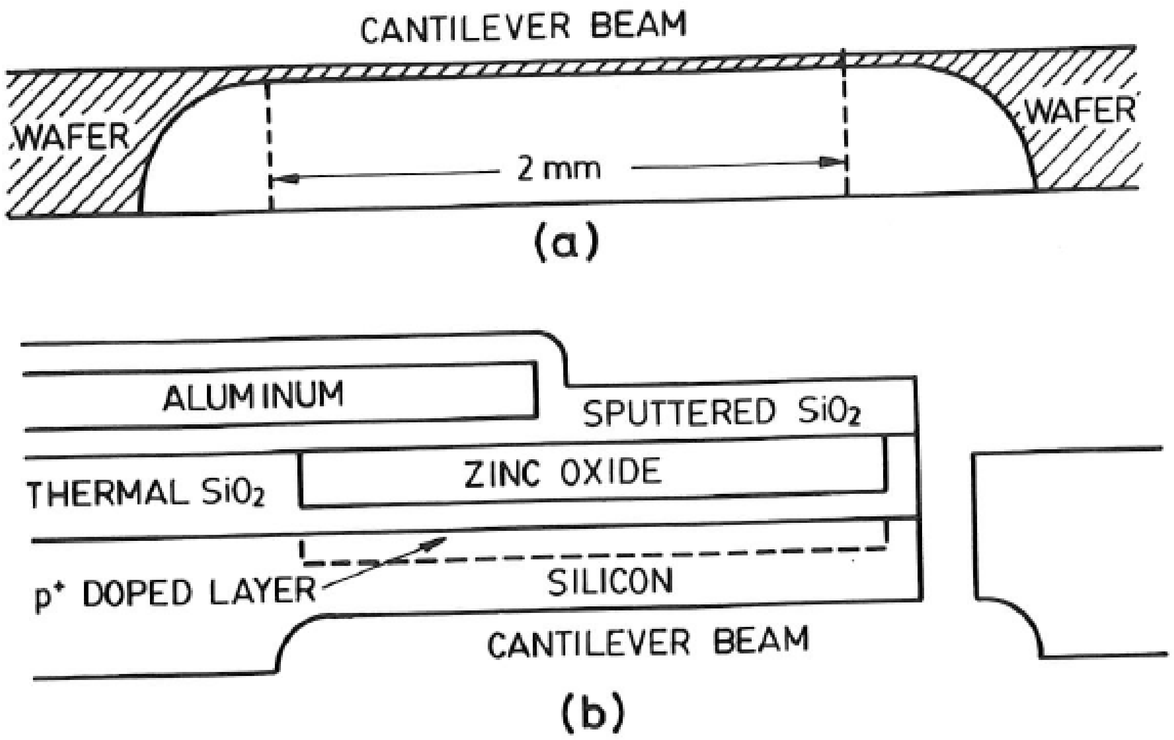
- Monolithic accelerometer compatible with standard processing technology

Acoustic Wave Sensors



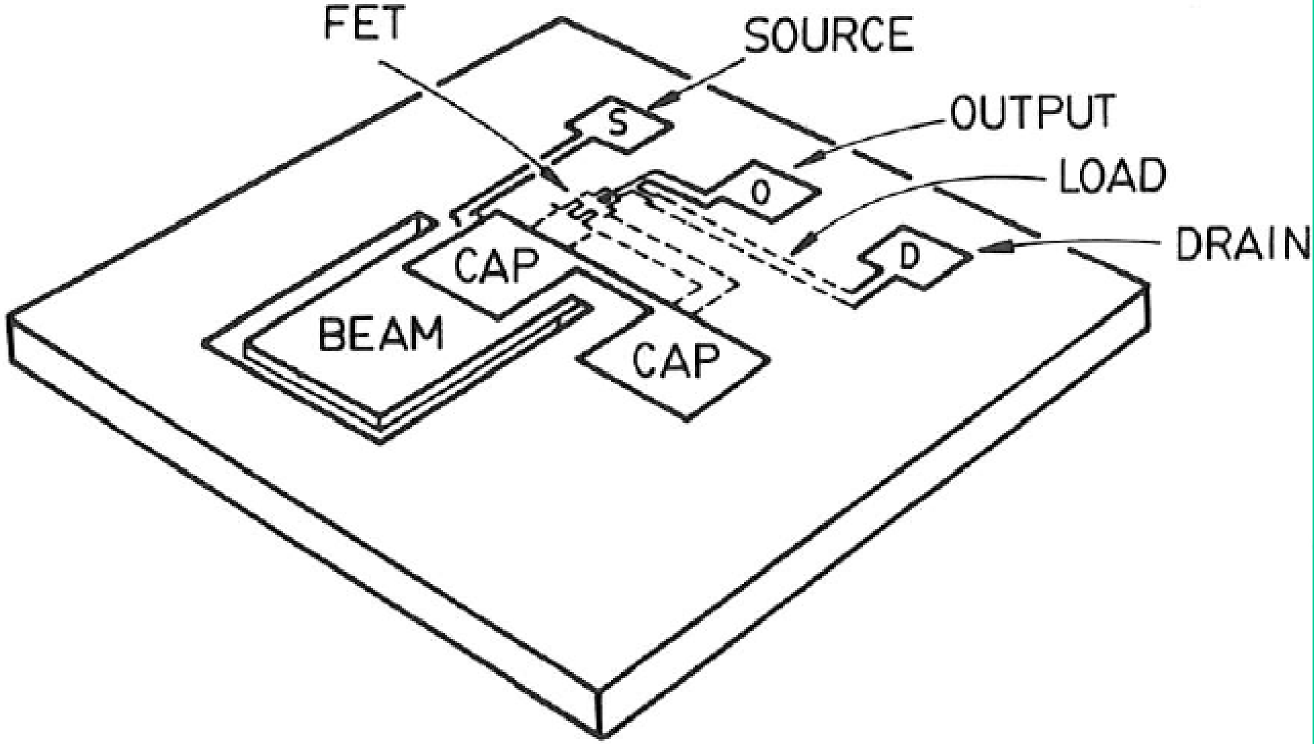
Test structure to investigate etching properties and constraints in fabrication of silicon dioxide cantilever beams

Acoustic Wave Sensors



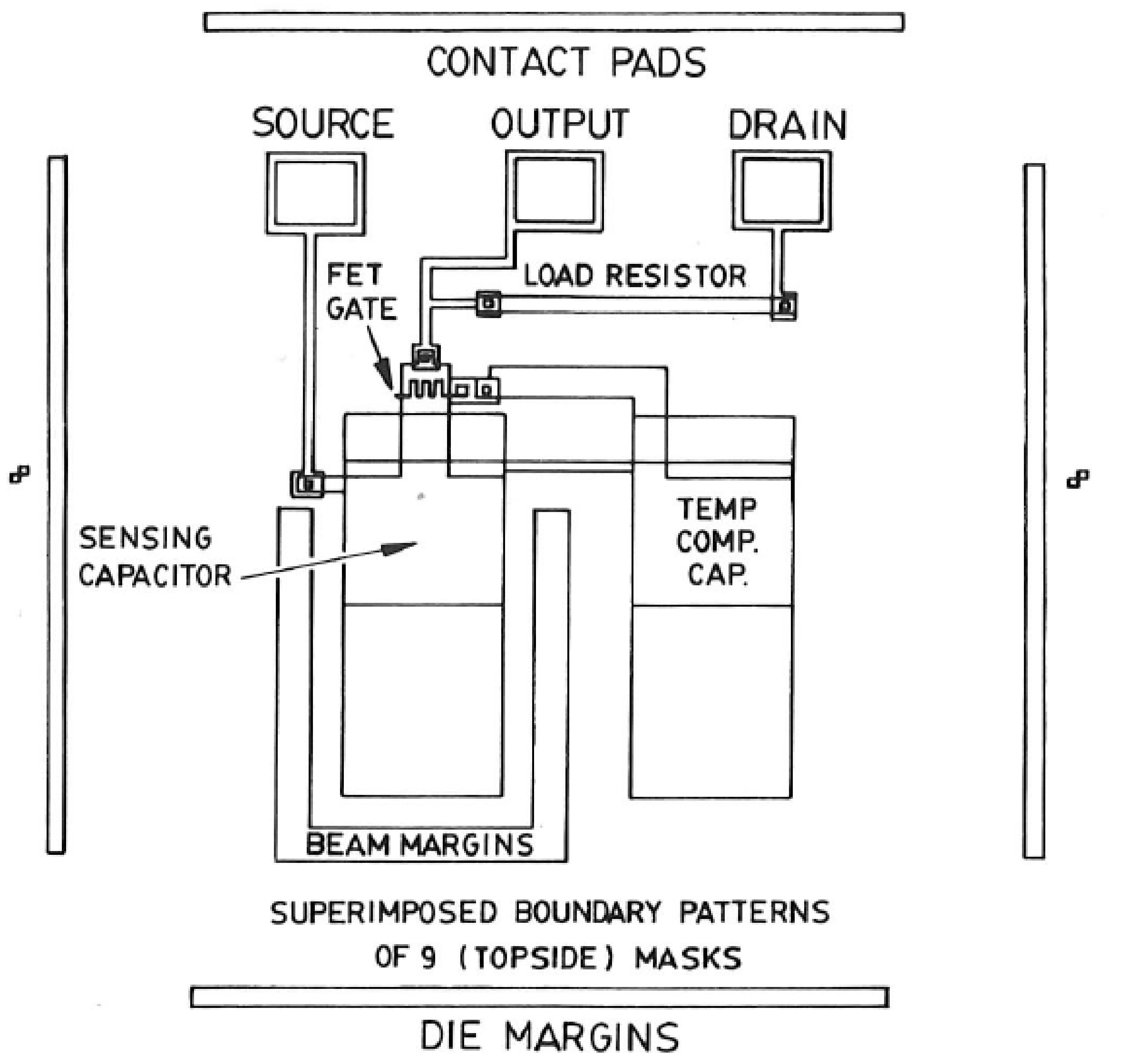
- Cross section of the cantilever-beam accelerometer

Acoustic Wave Sensors



Schematic layout

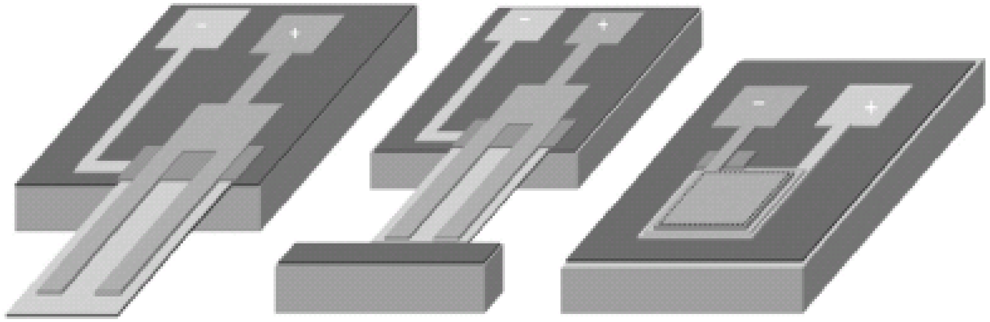
Acoustic Wave Sensors



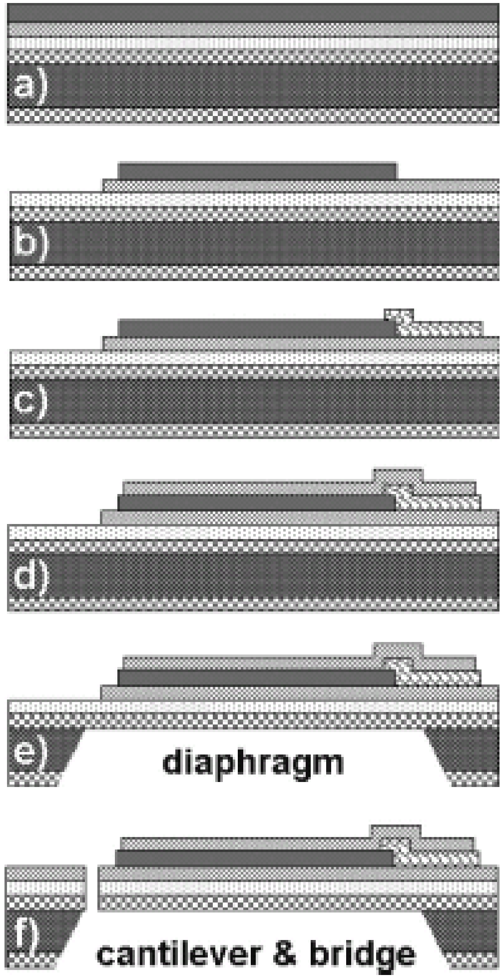
Top view, indicating the use of 9 masks

Acoustic Wave Sensors

Piezoelectric Microtransducers



Pattern	Layer Materials	Layer Thickness (nm)
	Sensing polymer	
	Top electrode	100
	PZT [$Pb(Zr_{0.52}Ti_{0.48})O_3$]	500
	Polyimide (ILD - insulator)	1200
	Bottom electrode (Pt/Ta)	150/20
	Silicon dioxide	300
	Silicon nitride	1200
	Silicon (100-oriented)	475 micron



Acoustic Wave Sensors
FPW Sensor

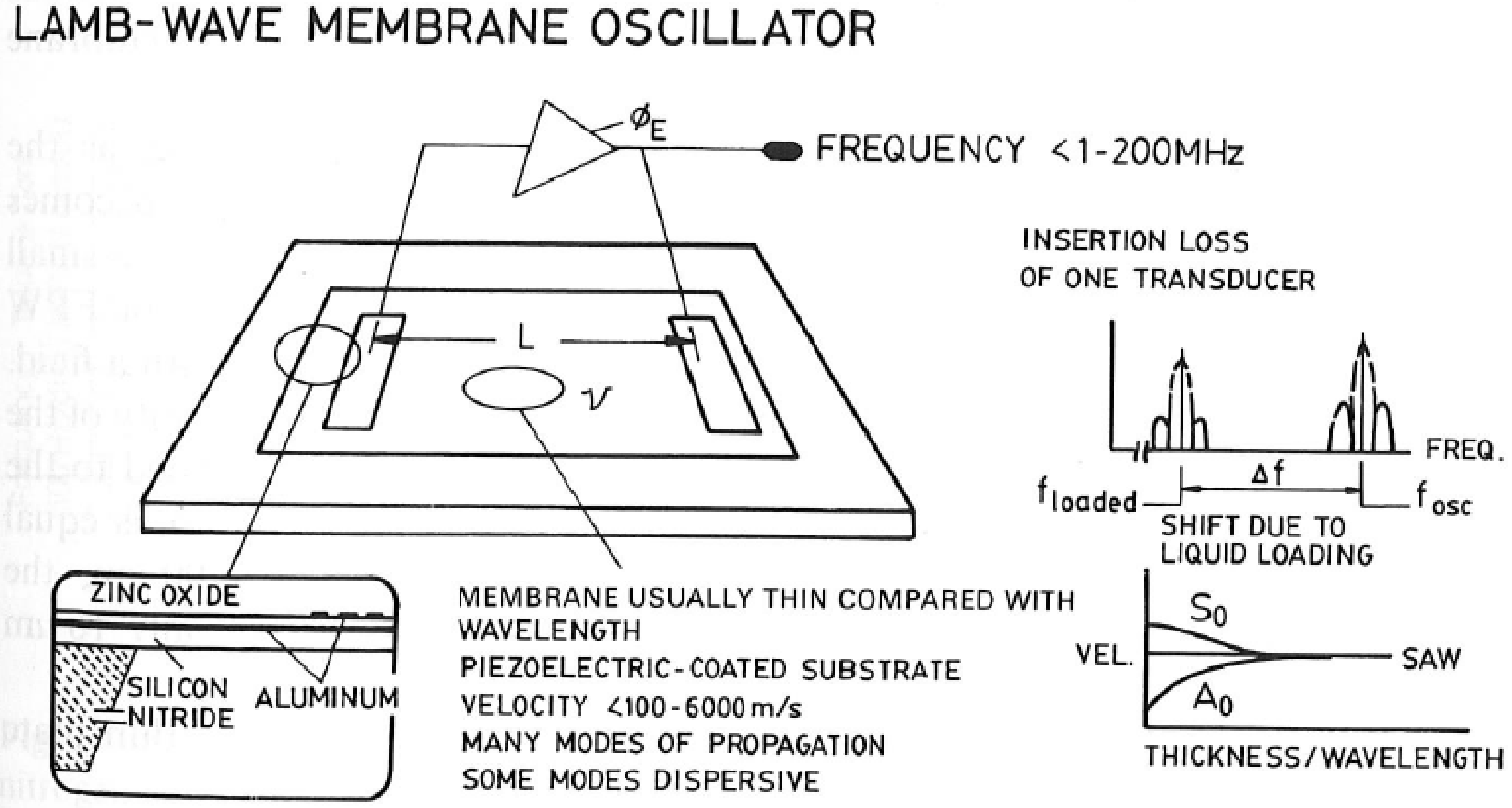


Fig. 28 FPW sensor. Insets show cutaway view of membrane, velocities of A_0 and S_0 modes, and the relatively large decrease of oscillation frequency produced by mass loading.

Acoustic Wave Sensors
Cantilever-Resonator

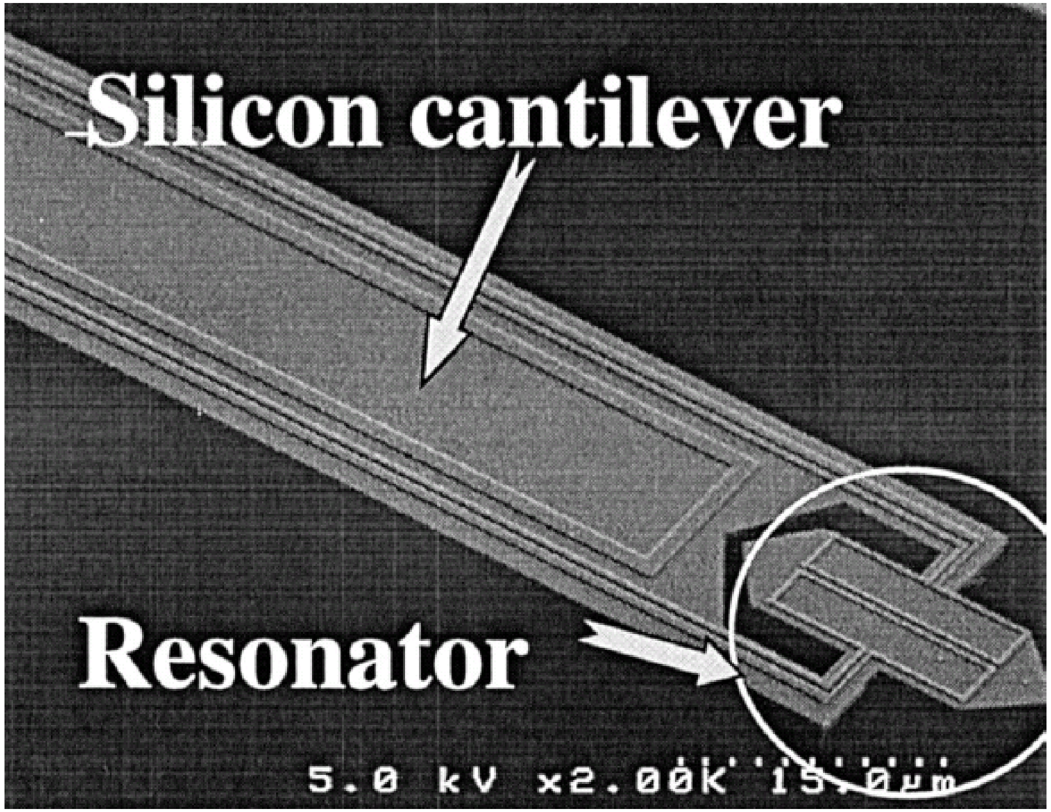


Fig. 8. A close-up view of the torsional resonator.

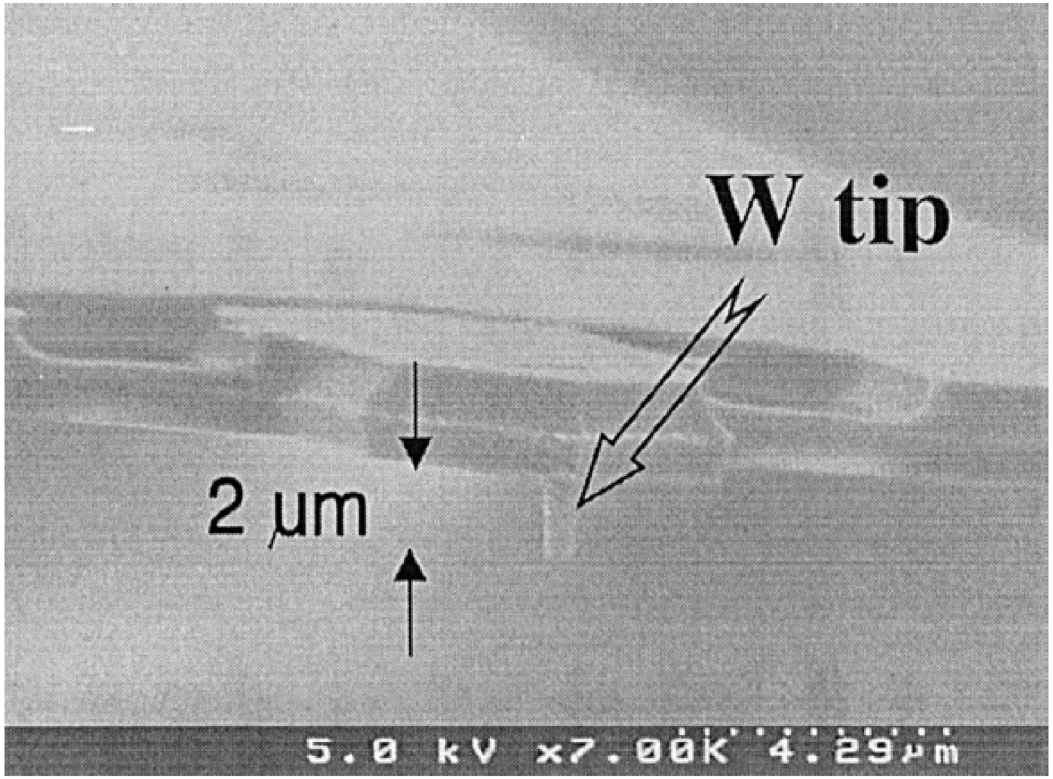


Fig. 9. After release, fabricated tip by FIB.

Acoustic Wave Sensors

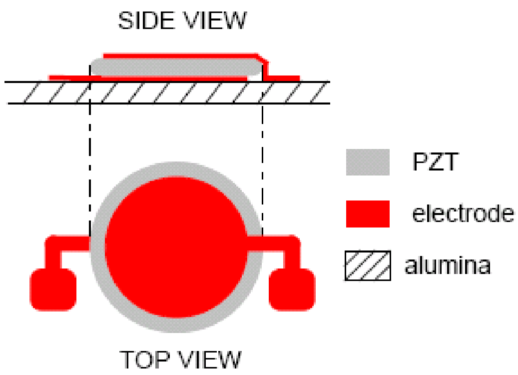


Fig. 1. Structure of a RPL.

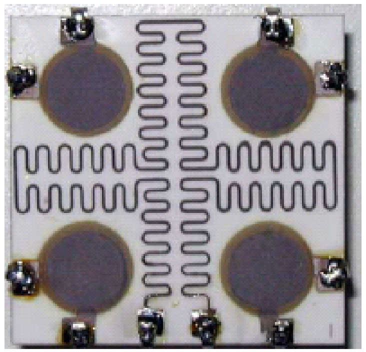


Fig. 2. RPL array.

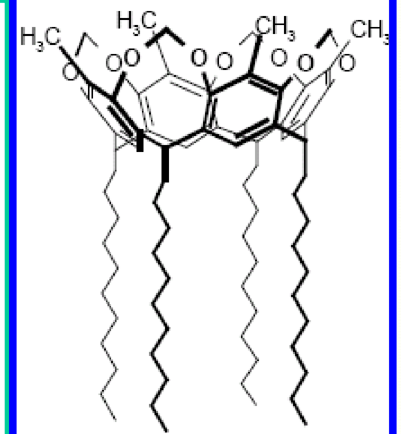


Fig. 3. Me-Cav.

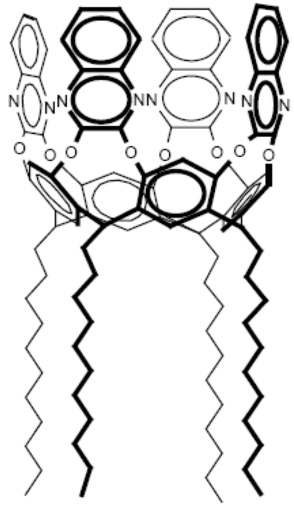


Fig. 4. Qx-Cav.

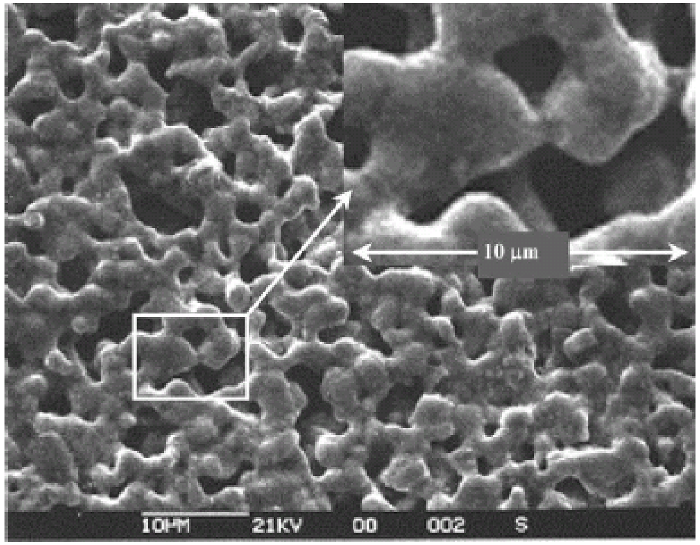


Fig. 5. SEM photograph of the RPL surface.

Surface before deposition of cavitands

Acoustic Wave Sensors

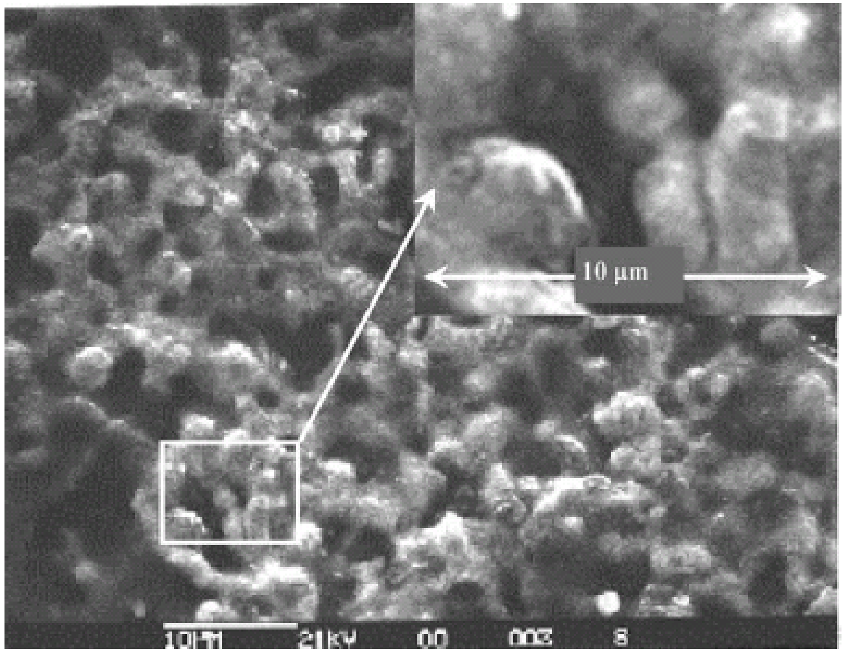


Fig. 6. SEM photograph of the RPL surface sensitized with 40 µl of Me-Cav by casting deposition.

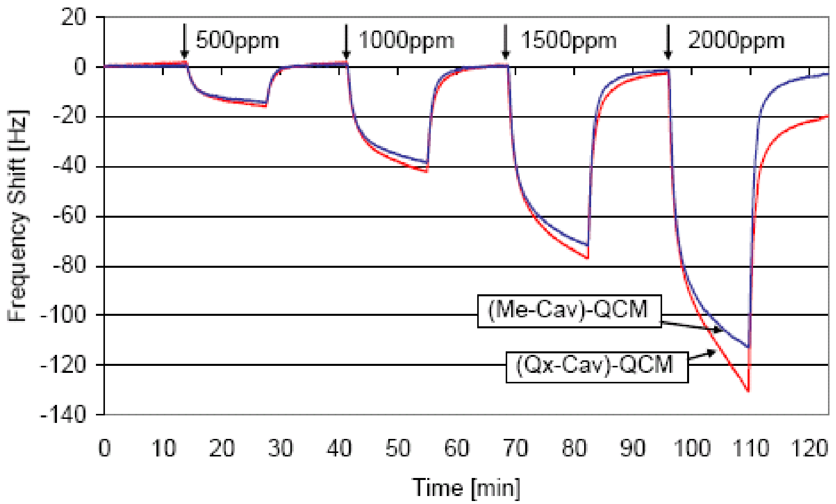


Fig. 10. (Me-Cav)–QCM and (Qx-Cav)–QCM responses to stepping concentrations of toluene at room temperature.

Surface after deposition of cavitands

Measuring concentration of toulene

Mittuniversitetet
MID SWEDEN UNIVERSITY