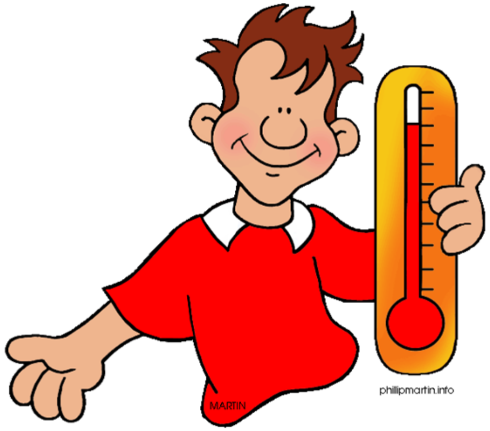
Temperaturmåling



- Sensor-elementet mottar eller avgir varme i fht objektet
- Enten oppnås **likevekt**, dvs de får samme temperatur, eller så **predikeres** temperaturen ut fra endringsforløpet

$$T_S = T_B - (T_B - T_0)\frac{r_1}{r_2} = T_B - \Delta T\frac{r_1}{r_2}$$

- $T_S \neq T_O$
- Poeng å redusere r_1 og øke r_2
- Kan redusere r_1 (og øke r_2) ved å bygge sensoren inn i objektet

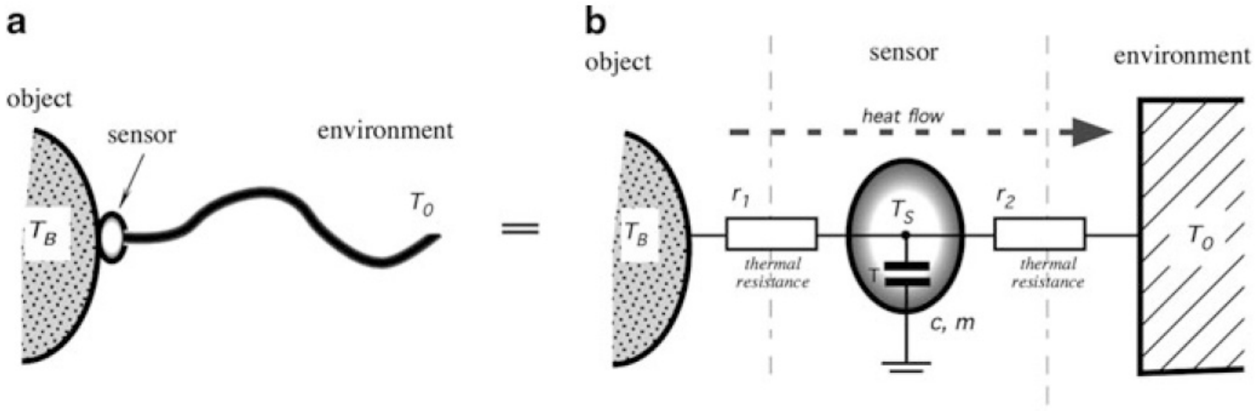


Fig. 16.1 Temperature sensor has thermal contacts with both the object and the connecting cable (**a**); equivalent thermal circuit (**b**)

Innebygget sensor

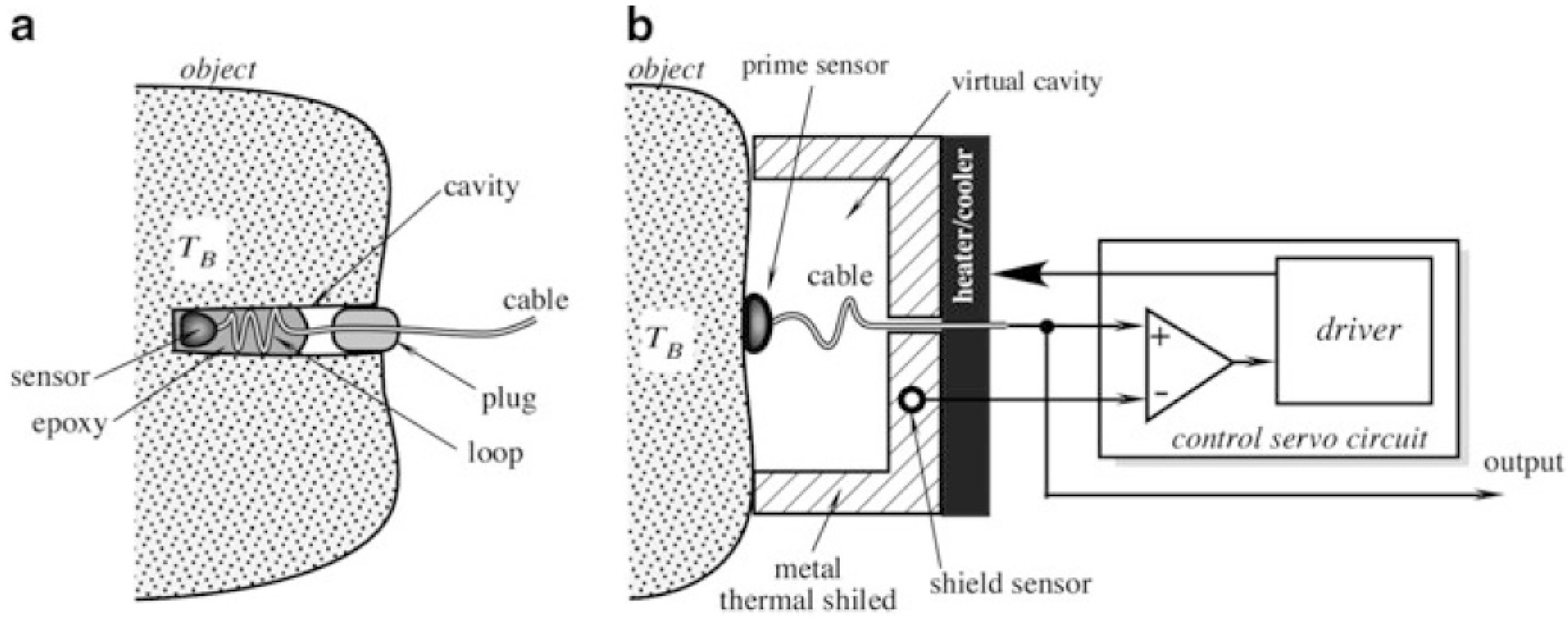


Fig. 16.2 Imbedded temperature sensor (**a**) and surface temperature sensor with an active driven thermal shield (**b**)

$$dQ = \alpha_1 (T_B - T_S) dt, \tag{16.3}$$

where $\alpha_1 = 1/r_1$ is the thermal conductivity of the sensor–object boundary. Note that T_s is changing. If the sensor has an average specific heat c and mass m, the heat absorbed by the sensor is

$$dQ = mcdT. \tag{16.4}$$

Equations (16.3) and (16.4) are equal and yield the first-order differential equation

$$\alpha_1 (T_B - T_s) dt = mcdT. \tag{16.5}$$

We denote thermal time constant τ_T as

$$\tau_T = \frac{mc}{\alpha_1} = mcr_1,$$

then the differential equation takes form

$$\frac{dT}{T_B - T_s} = \frac{dt}{\tau_T}.$$

This equation has a solution

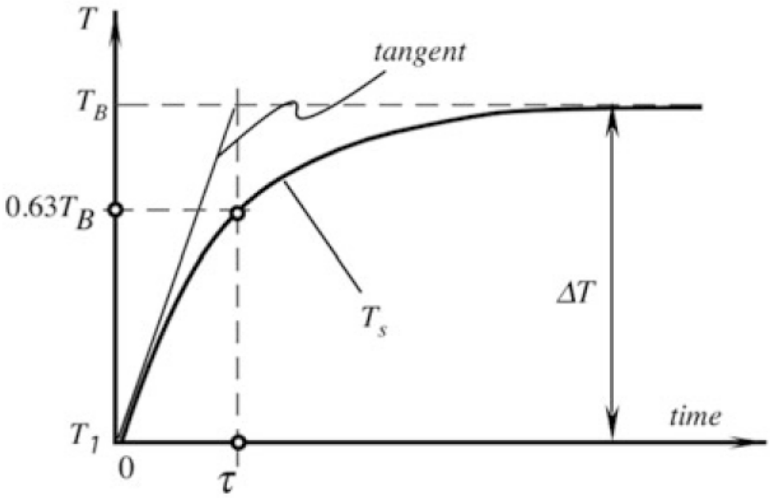


Fig. 16.3 Temperature changes of a sensor (the sensor is ideally coupled to an ideal object)

$$T_s = T_B - \Delta T e^{-\frac{t}{\tau_T}}. \tag{16.8}$$

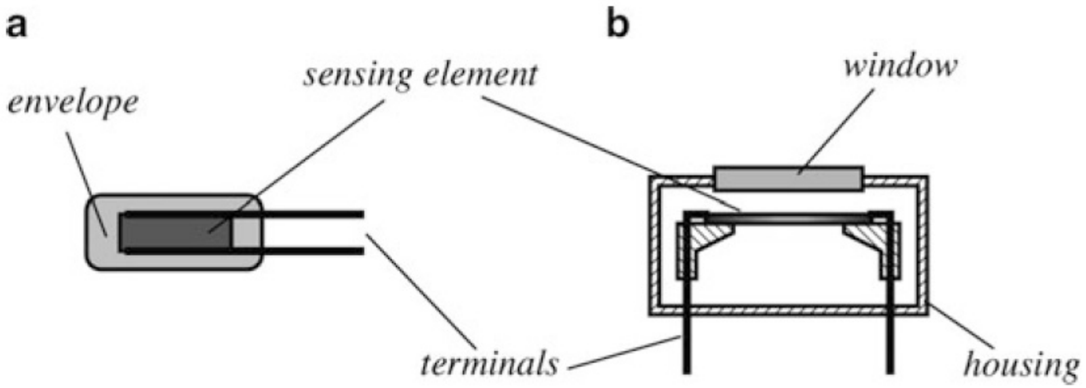


Fig. 16.6 General structures of temperature sensors: Contact sensor (**a**) and noncontact thermal IR radiation sensor (**b**)

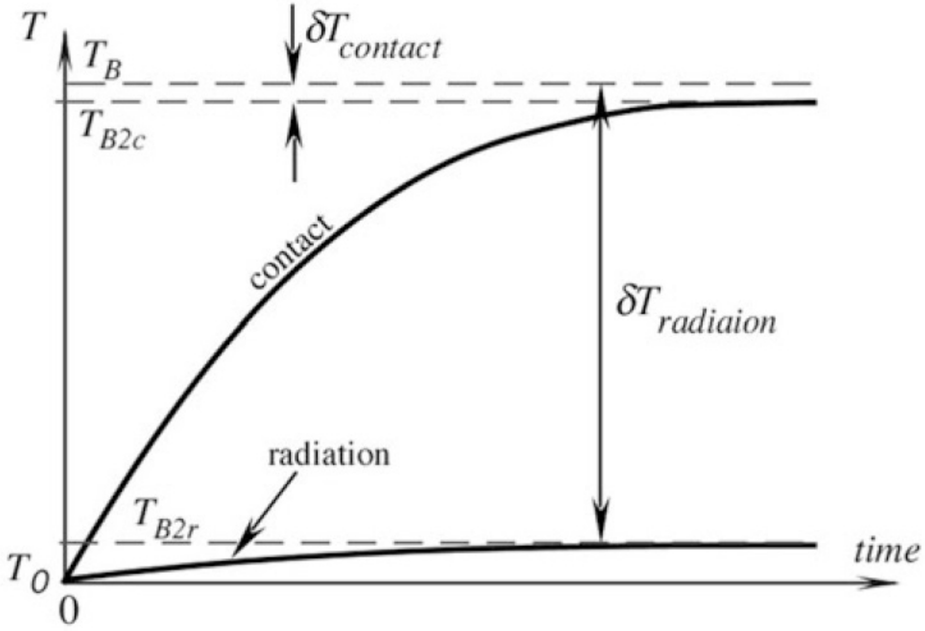


Fig. 16.5 Difference in thermal responses between contact and noncontact (IR radiation) temperature sensors

Temperatur -referanser

Point description	°C
Triple point[a] of hydrogen	−259.34
Boiling point of normal hydrogen	−252.753
Triple point of oxygen	−218.789
Boiling point of nitrogen	−195.806
Triple point of argon	−189.352
Boiling point of oxygen	−182.962
Sublimation point of carbon dioxide	−78.476
Freezing point of mercury	−38.836
Triple point of water	0.01
Freezing point of water (water–ice mixture)	0.00
Boiling point of water	100.00
Triple point of benzoic acid	122.37
Freezing point of indium	156.634
Freezing point of tin	231.968
Freezing point of bismuth	271.442
Freezing point of cadmium	321.108
Freezing point of lead	327.502
Freezing point of zinc	419.58
Freezing point of antimony	630.755
Freezing point of aluminum	660.46
Freezing point of silver	961.93
Freezing point of gold	1,064.43
Freezing point of copper	1,084.88
Freezing point of nickel	1,455
Freezing point of palladium	1,554
Freezing point of platinum	1,769

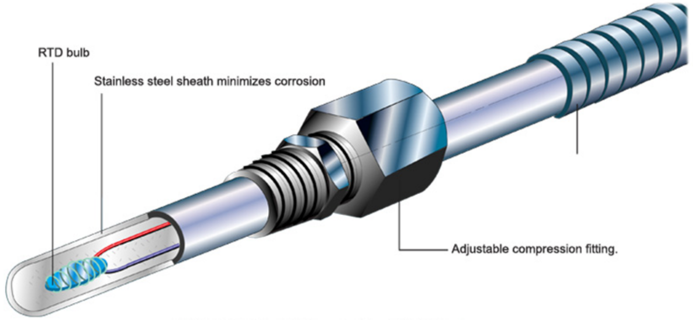
[a] Triple point is equilibrium between the solid, liquid, and vapor phases.

Termoresistive sensorer

- Tre typer
  - Resistance Temperature Detectors (RTD)
    - Metaller. Alltid PTC. Pt mye brukt. Wolfram brukes over 600 °C
  - Semiconductor (PN-junction) Detectors
    - Si er egentlig NTC, men hvis dopet har det PTC ved lavere temperaturer. Typisk 0.7 % pr. °C
  - Thermistors (keramer eller polymer)
    - Både NTC (best) og PTC
    - Resistans S:

$$\ln S = A_0 + \frac{A_1}{T} + \frac{A_2}{T^2} + \frac{A_3}{T^3}$$

    - Tre metoder:
      - **Simple method**. De to siste leddene fjernes. Enkel og god.
      - **Fraden model**. To siste ledd fjernes og andre ledd modifiseres. Mer nøyaktig men fortsatt rimelig.
      - **Steinhart-Hart model**. Nest siste ledd fjernes. Mest nøyaktig og dyrere (mer kalibrering er påkrevd).



RTD (Resistance Temperature Detector)

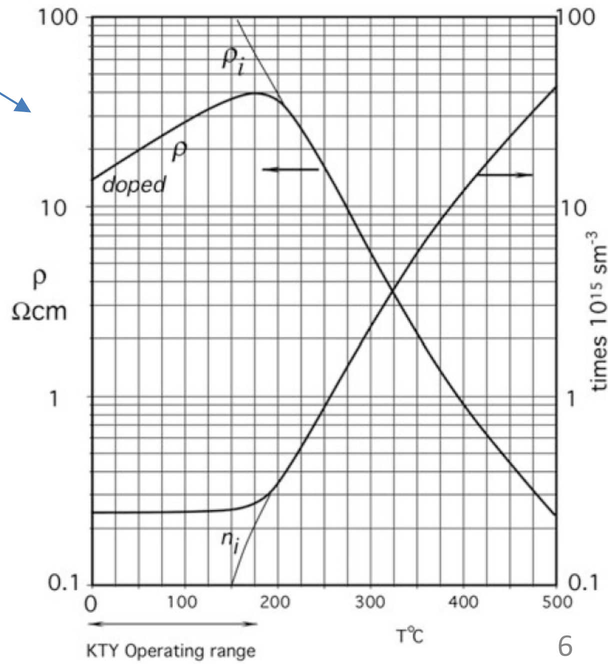


Fig. 16.7 Resistivity and number of free charge carriers for *n*-doped silicon

Selvoppvarming av NTC termistorer

- Brukes aktivt i noen sensorer (strømning, termisk stråling, osv)
- Får en positiv-feedback-effekt hvis ikke effekten holdes under en viss grense.

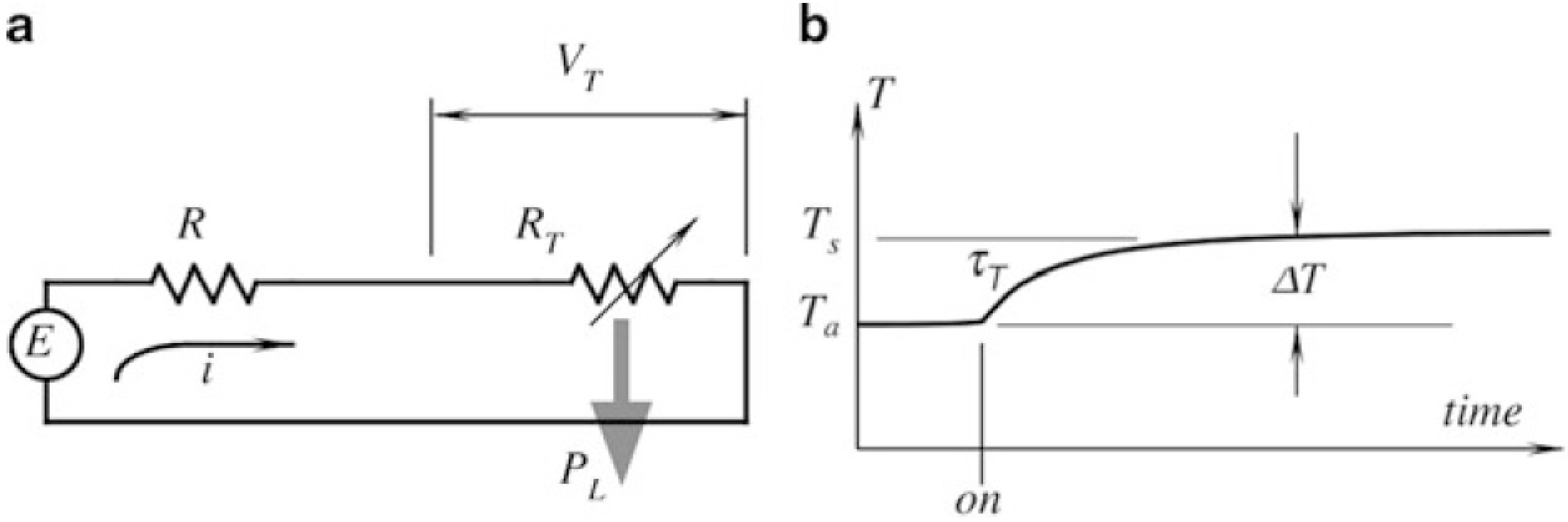
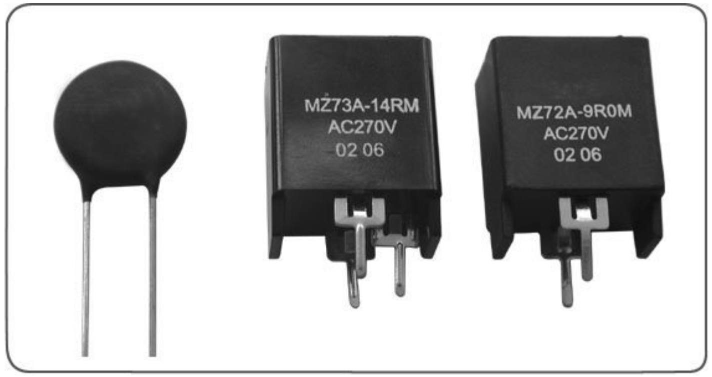
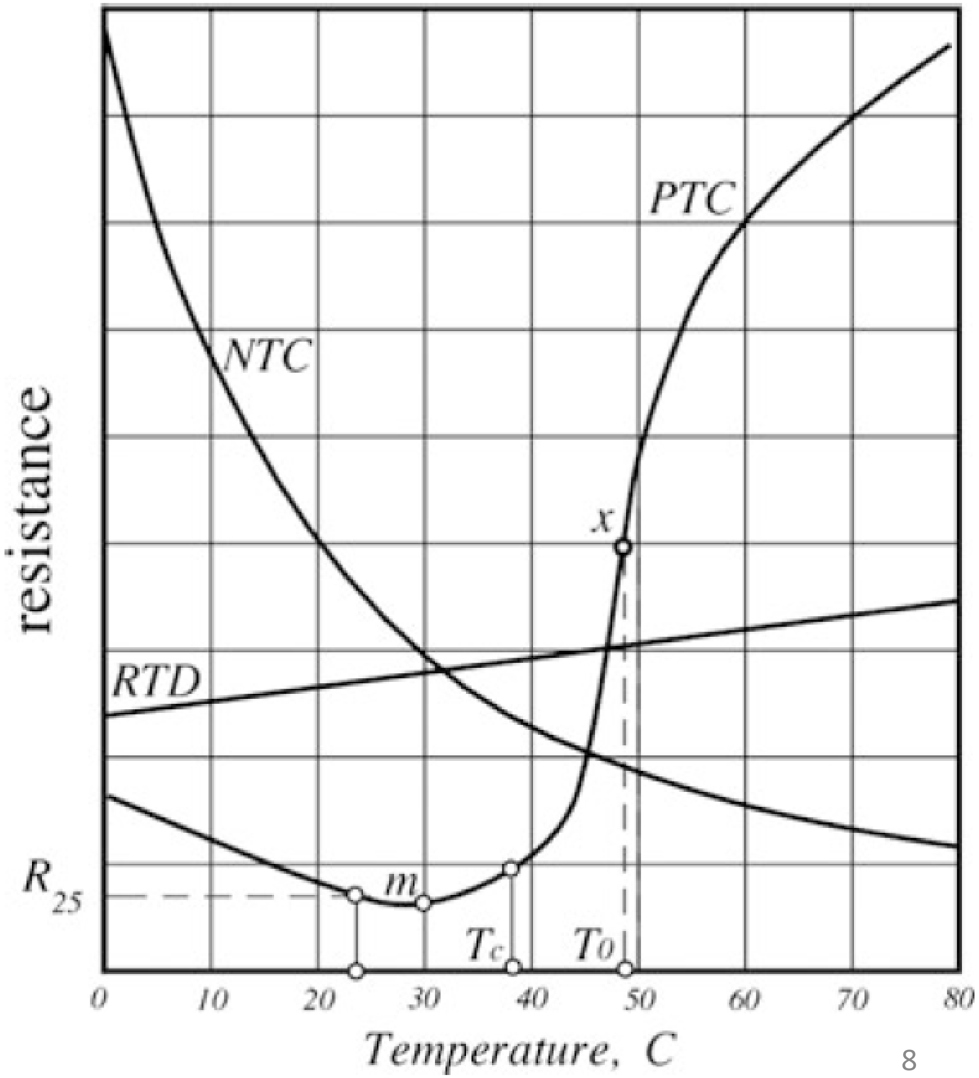


Fig. 16.13 Current passing through thermistor causes self-heating (**a**) and temperature of thermistor rises with thermal time constant τ_T. P_L is thermal power lost to surroundings (**b**)

PTC-termistorer

- Alle metaller har PTC (men er lite sensitive)
- Noen keramer har PTC og er veldig sensitive





Thermocouples / thermopiles

Termoelektriske lover:

1. Homogen krets + varme ≠ strøm
2. Alle junctions på samme temperatur → ingen strøm uansett kombinasjon av materialer
3. $V_{13} = V_{12} + V_{23}$

Thermocouple-spenninger er små → thermopile

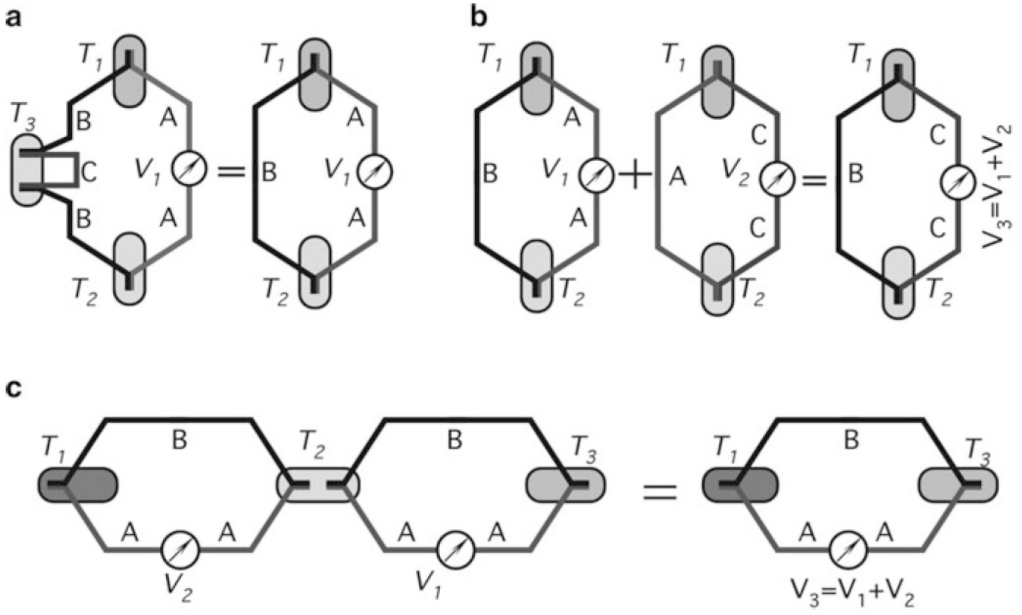


Fig. 16.18 Illustrations for the laws of thermocouples

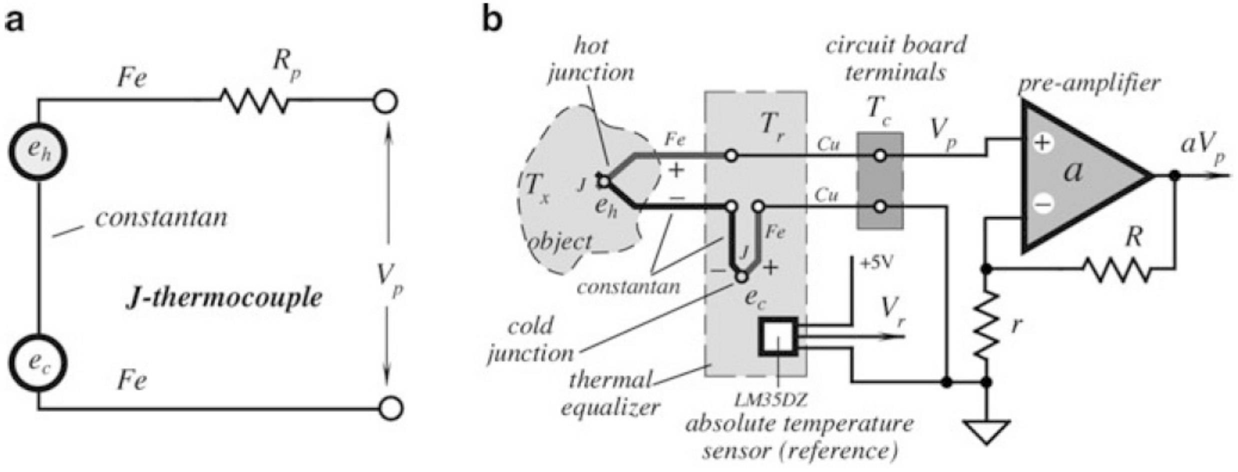


Fig. 16.19 Use of a thermocouple equivalent circuit of a thermocouple (**a**) and front end of a thermometer with a semiconductor reference sensor (**b**)

Halvleder-overgang-sensor

- Veldig lineær sammenheng

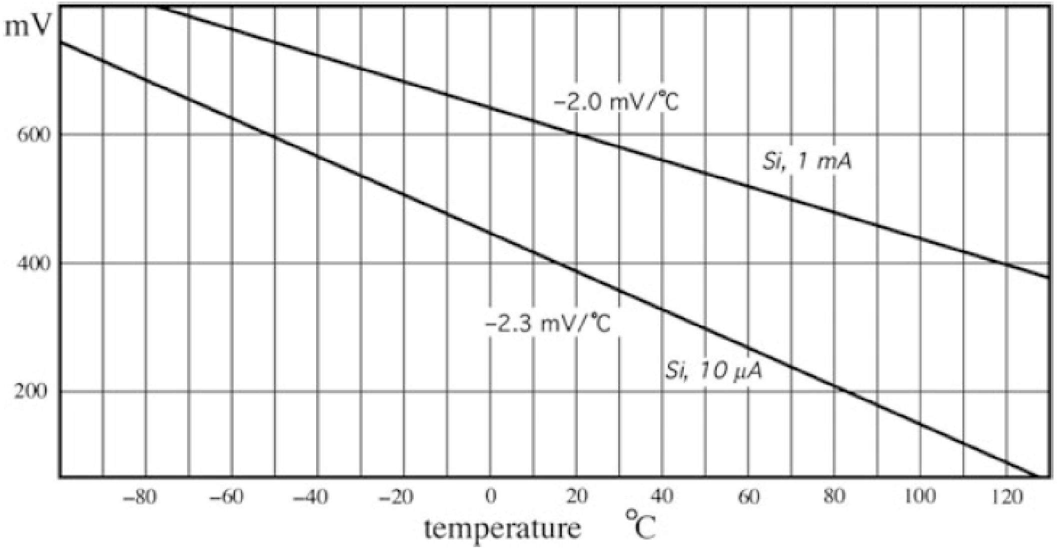


Fig. 16.22 Voltage-to-temperature dependence of a forward biased semiconductor junction under constant current conditions

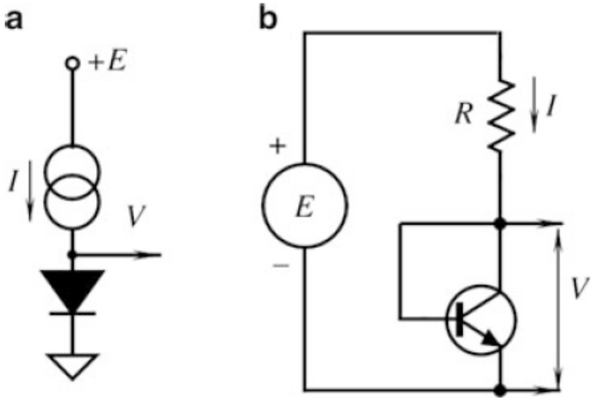


Fig. 16.23 Forward biased *pn*-junction temperature sensors Diode (**a**) and diode-connected transistor (**b**)

Optiske sensorer: Fluoro-optisk

- Etterglødingen er avhengig av temperaturen
- Bruker ofte fosfor
- Belyses med UV eller blått lys

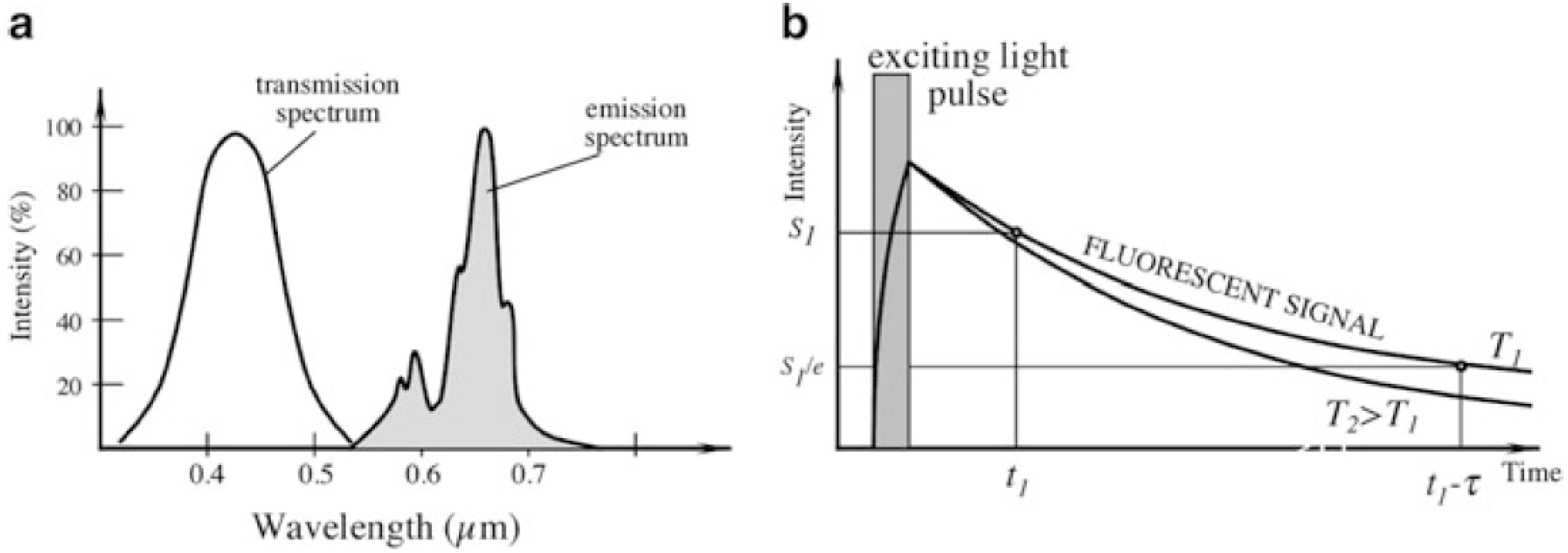
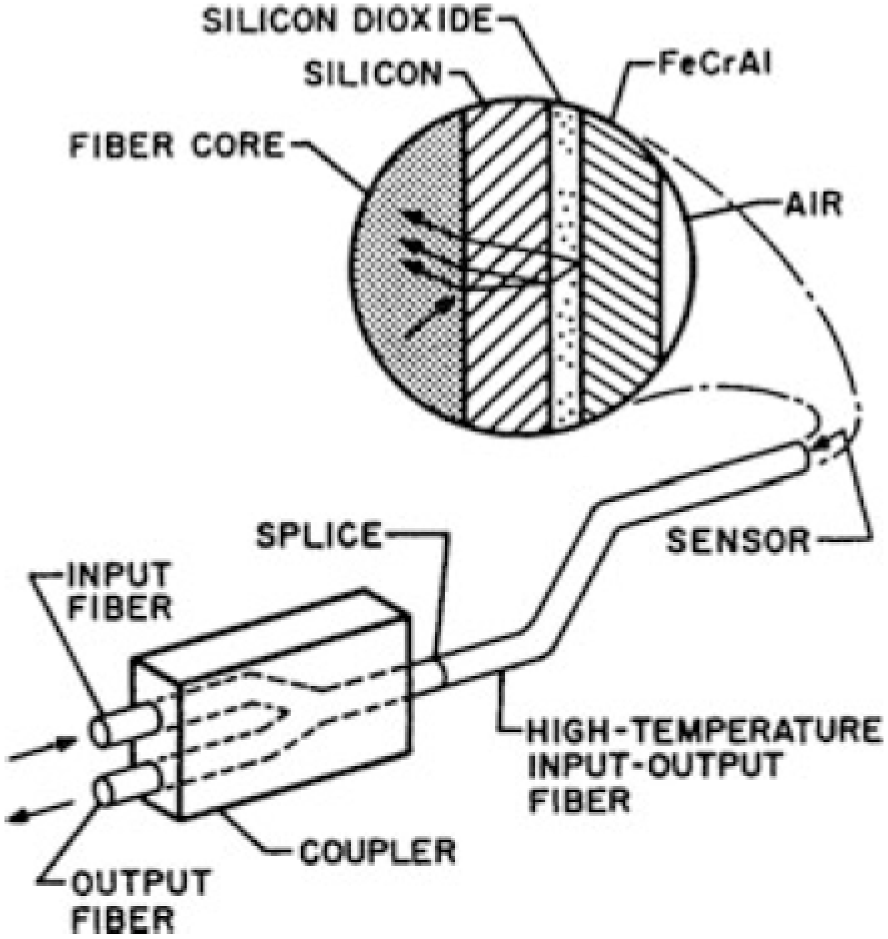
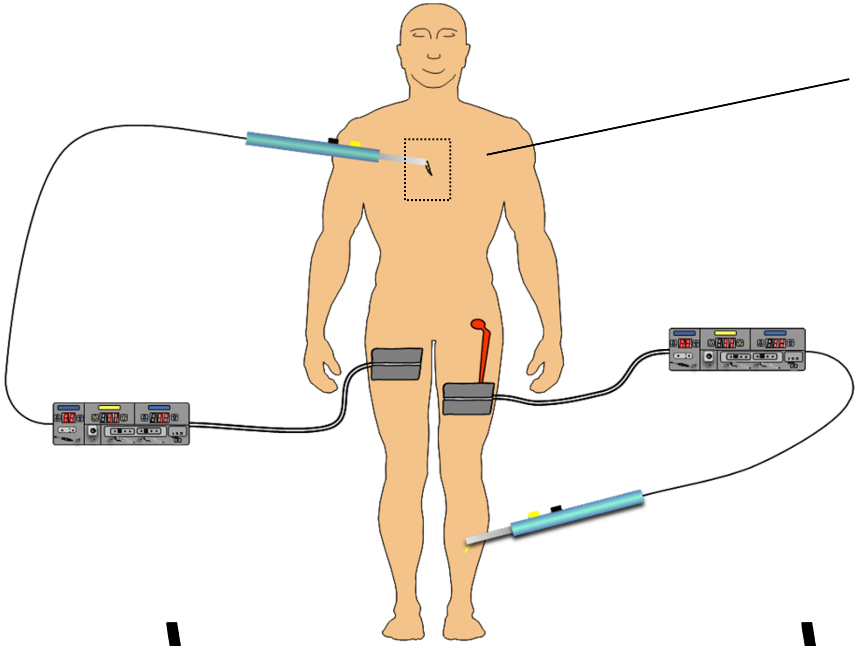


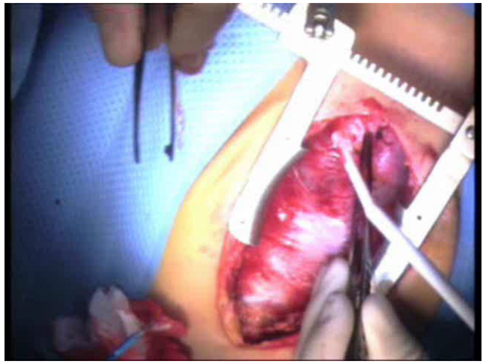
Fig. 16.27 Fluoroptic method of temperature measurement: Spectral responses of the excitation and emission signals (**a**) exponential decay of the emission signal for two temperatures (T_1 and T_2) (**b**); where e is the base of natural logarithms, and τ is a decay time constant (adapted from [17])

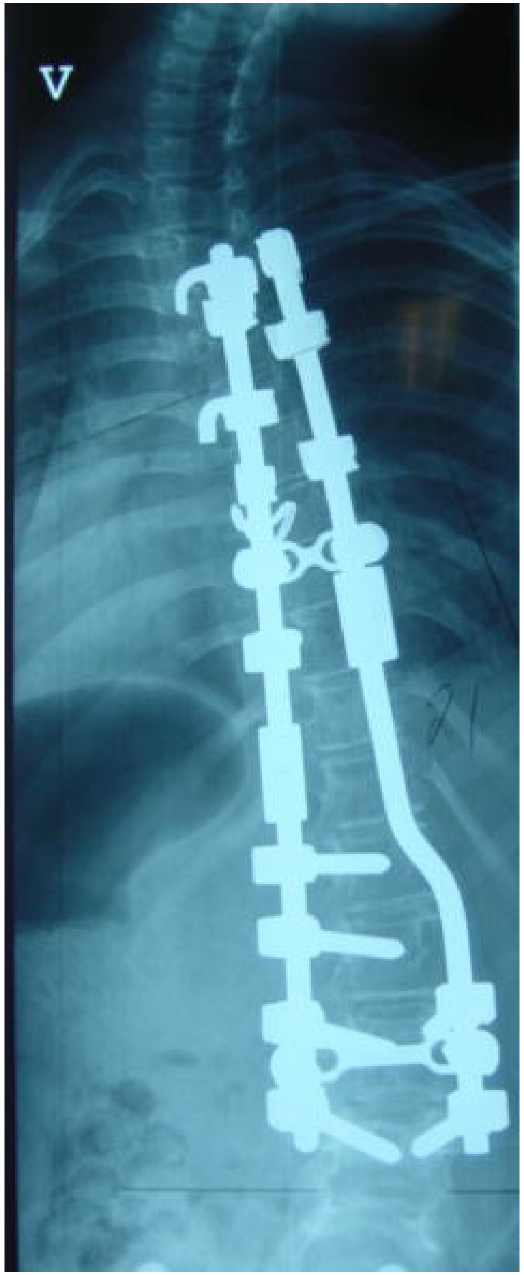
Optiske sensorer: Interfermometrisk

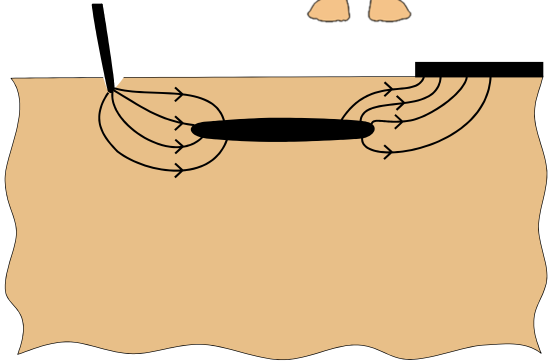
- Brytningsindeksen til Si er temp-avhengig
- Dette gir endret lys-vei og dermed faseforskyvning
- → Endring i intensitet i modulert signal

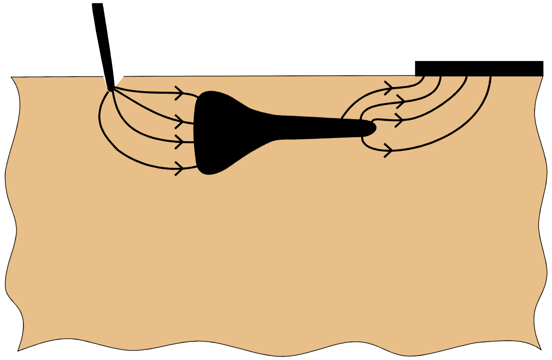


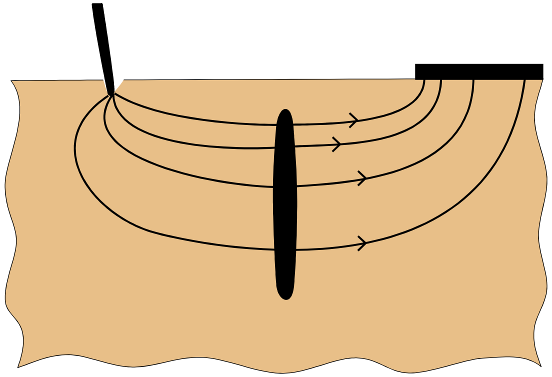








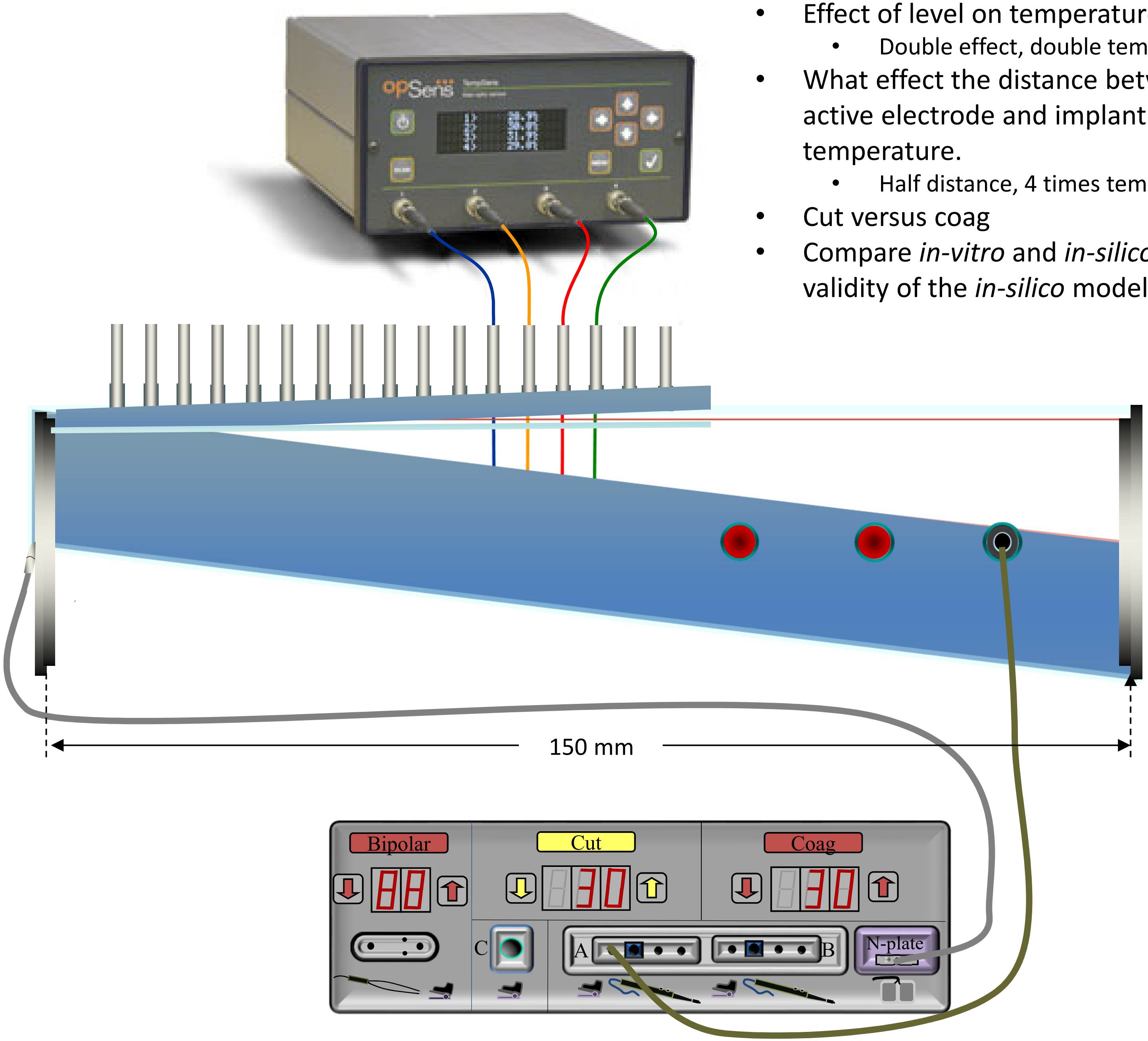




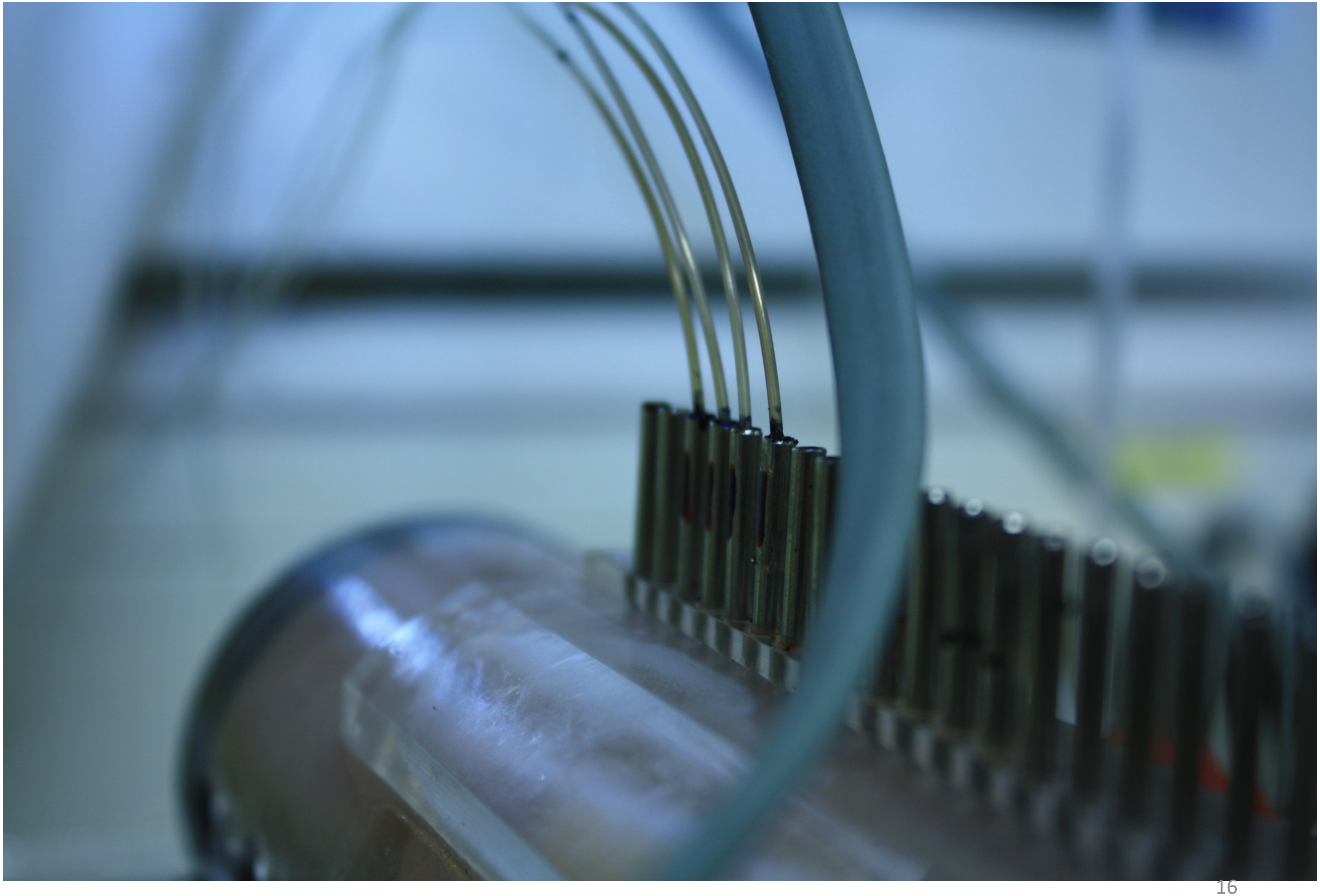
Project material from:
Tormod Martinsen, MTV/OUS

Some aims (short versions):

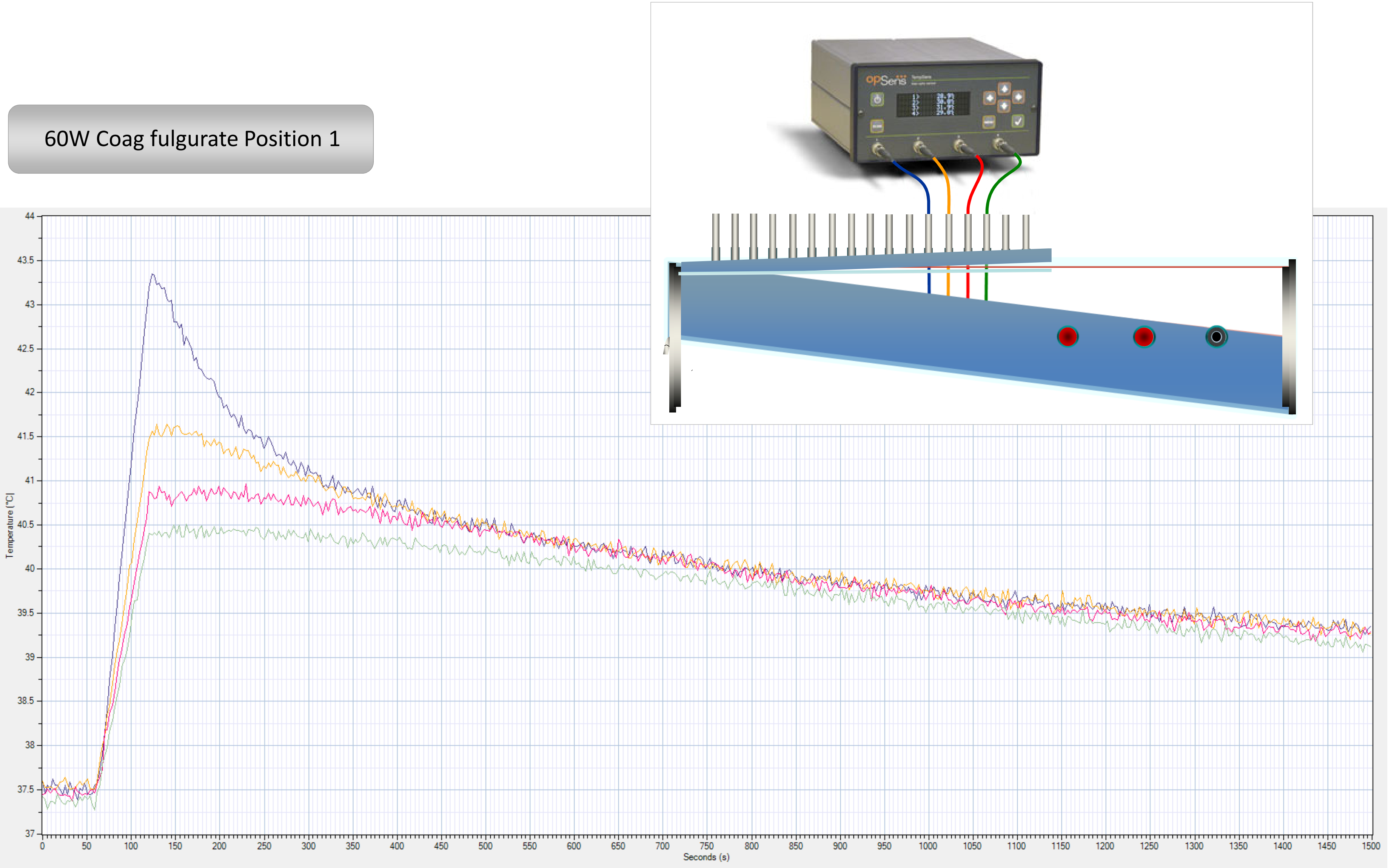
- Effect of level on temperature?
  - Double effect, double temperature?
- What effect the distance between electrosurgery active electrode and implant has on the temperature.
  - Half distance, 4 times temp?
- Cut versus coag
- Compare *in-vitro* and *in-silico* model, verify the validity of the *in-silico* model



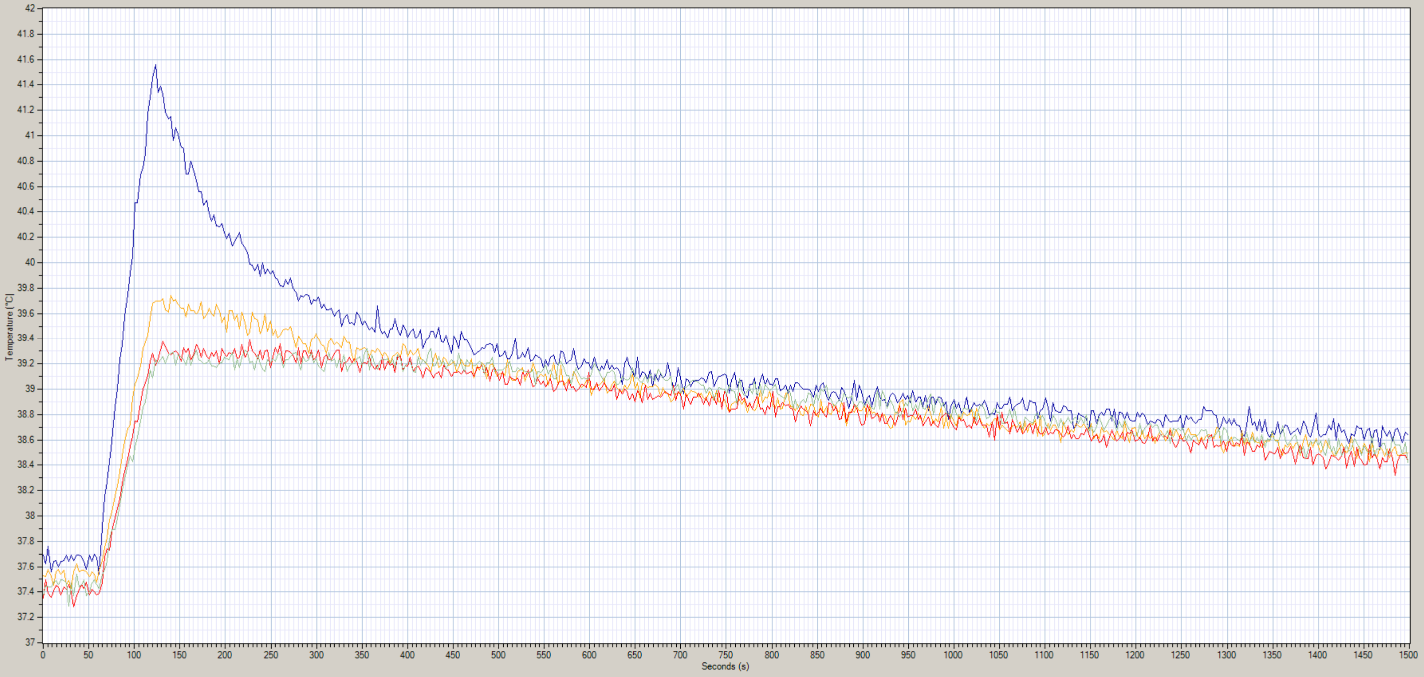

opSens
Reg.nr. 4599
37.2 °C
IPS
CONSIGNE
REGLAGE
DIAGNOSTICS Pasteur
Tormod Martinsen



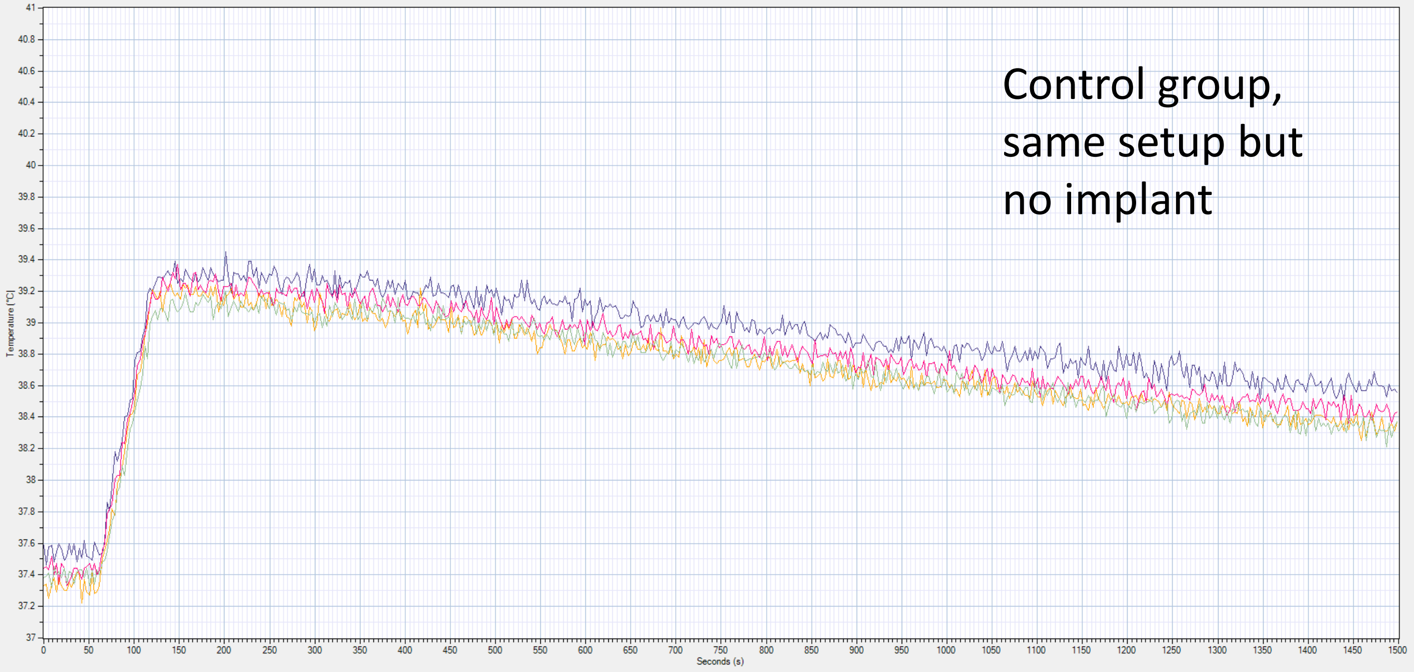
60W Coag fulgurate Position 1



M8 30W Coag
fulgurate P2



M7 30W Coag
fulgurate P2 K1



Control group,
same setup but
no implant

Optiske sensorer: Termokrom

- Temperaturavhengig spektral absorbsjon av synlig lys

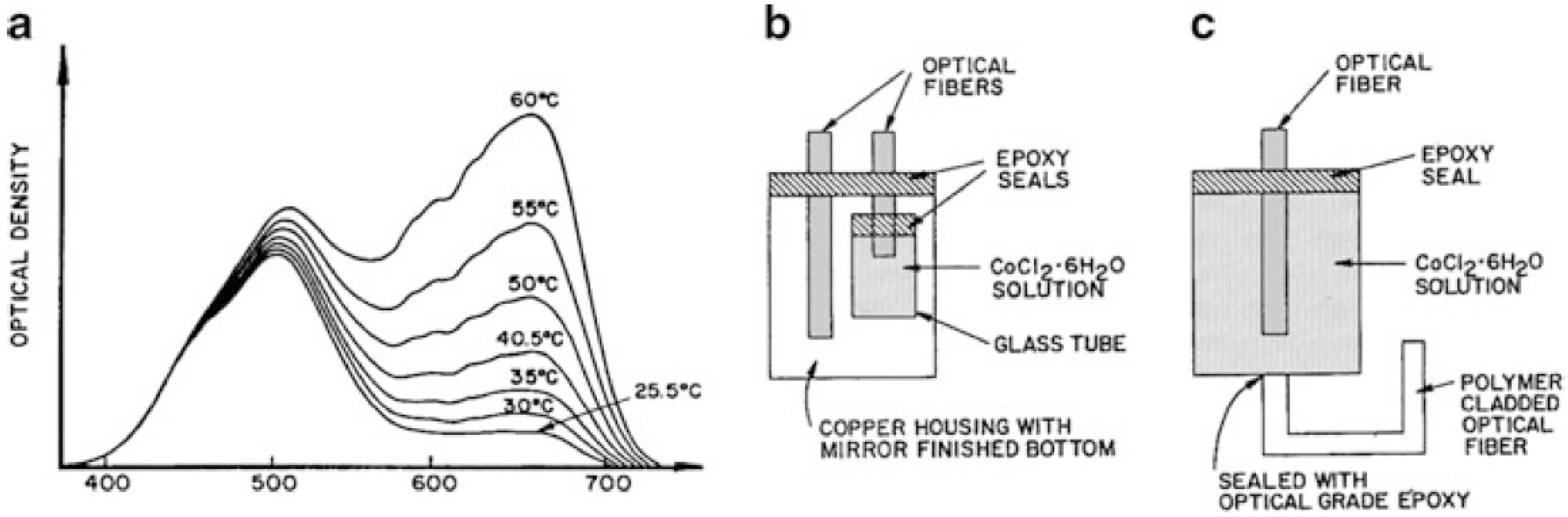


Fig. 16.30 A thermochromic solution sensor. Absorption spectra of the cobalt chloride solution (**a**); reflective fiber coupling (**b**); and transmissive coupling (**c**) (from [22])

Akustisk sensor

Tørr luft:

$$\upsilon \approx 331.5\sqrt{\frac{T}{273.15}}\ \mathrm{m/s}$$

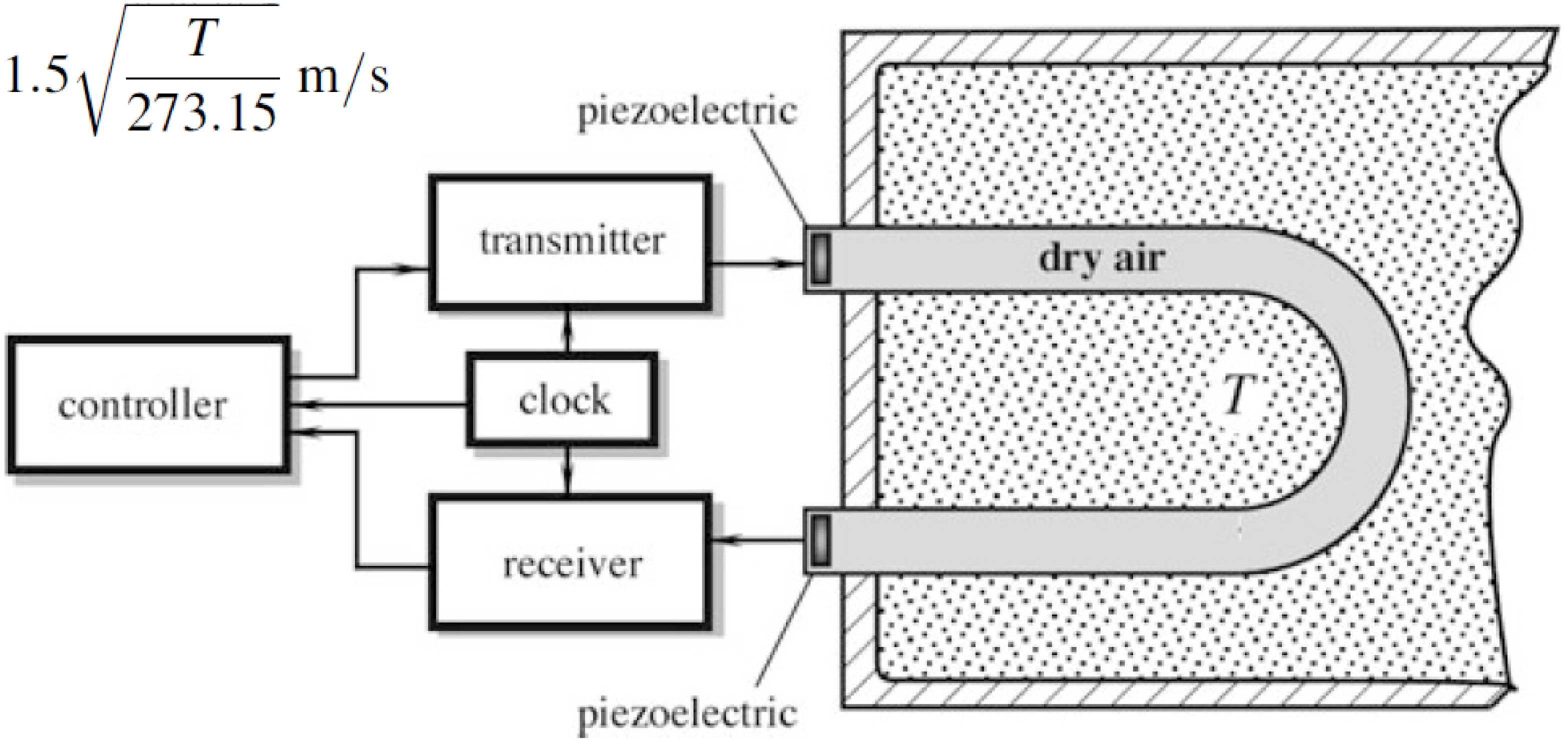
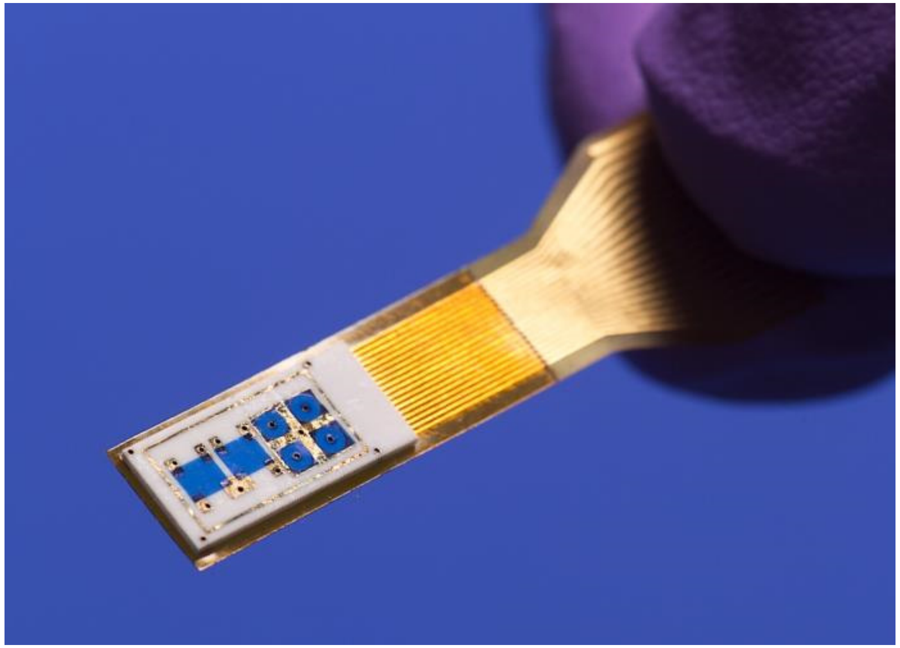


Fig. 16.31 Acoustic thermometer with an ultrasonic detection system

Kjemiske sensorer

- Sensitivitet (her: oppløsning) og spesifisitet
- Tre typer, basert på endring i:
  - Elektriske / elektrokjemiske egenskaper
  - Fysiske egenskaper
  - Optiske egenskaper



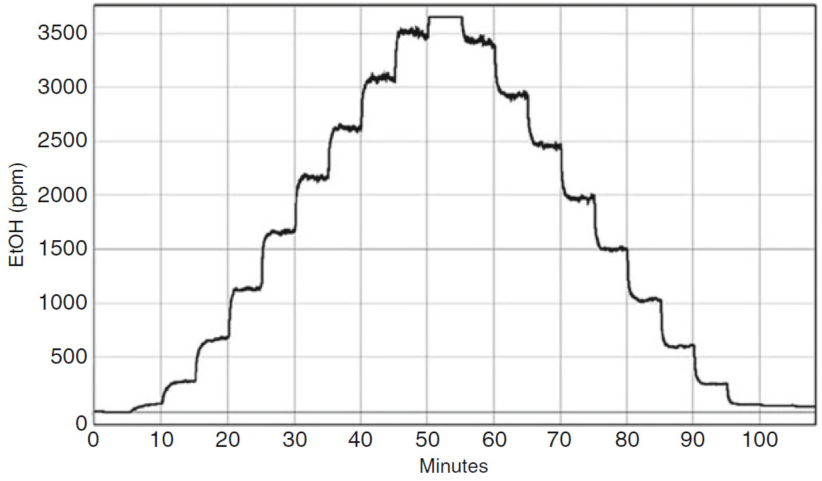


Fig. 17.2 Metal-oxide-semiconductor-based sensor response to increasing and decreasing concentrations of ethanol

Eksempel på spesifisitet (Volatile Organic Compound – VOC)

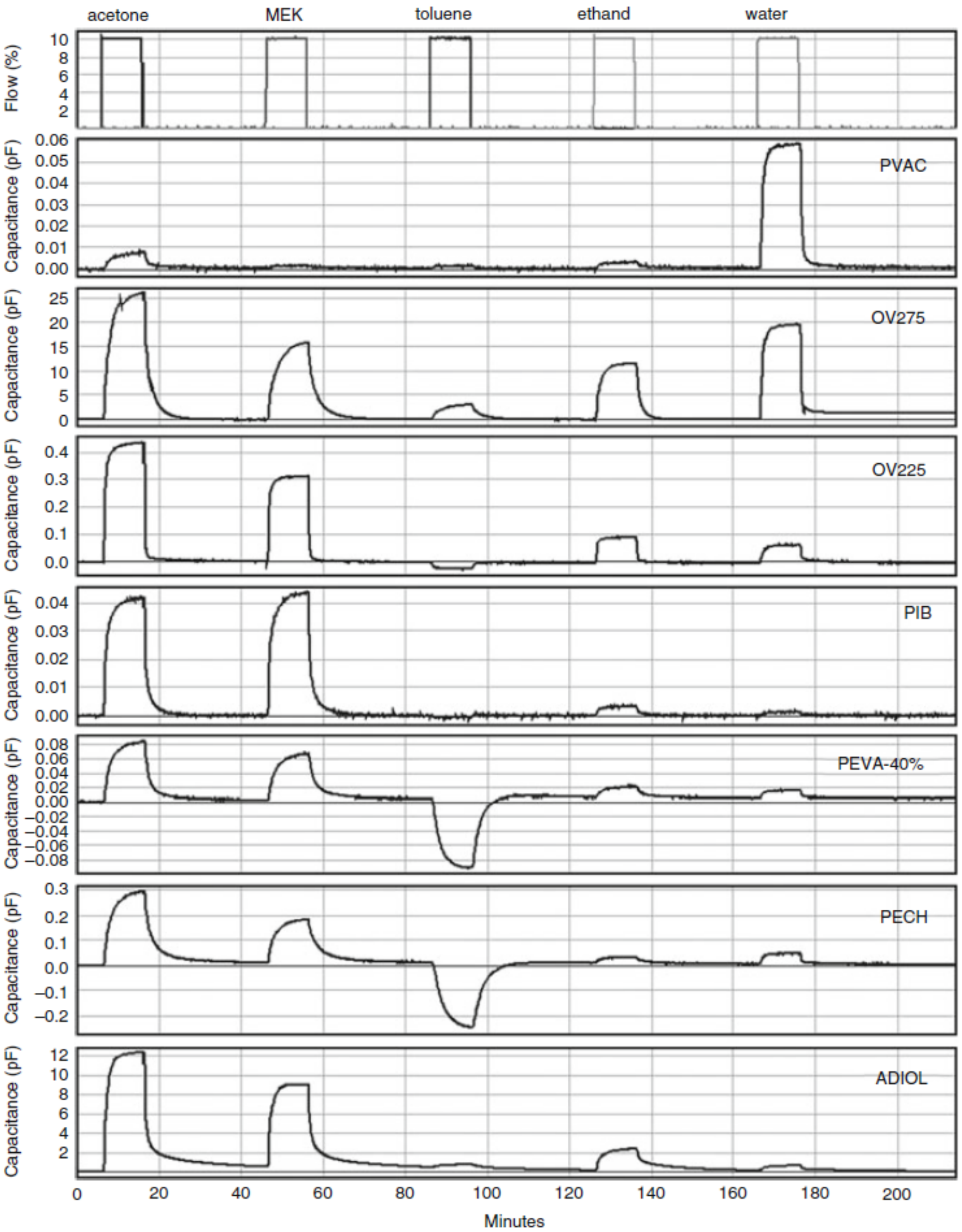
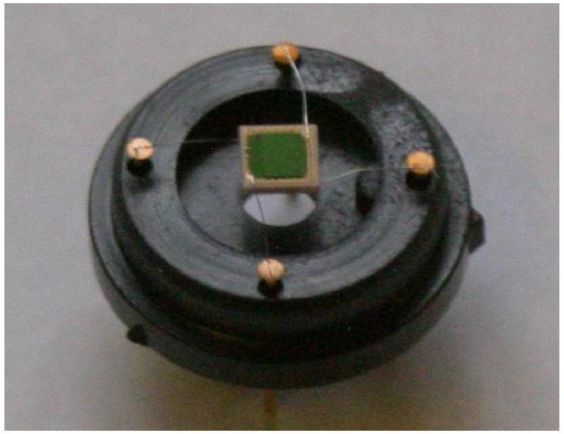


Fig. 17.3 Response of a capacitive VOC sensor array containing seven differently absorbing polymer-coated chemicapacitors to pulses of acetone, methyl ethyl ketone, toluene, ethanol, and water at 25°C

Metalloksyd-sensor

- Resistansen endres ved endrede kjemiske omgivelser (gass)
- NTC termistor for å kompensere for temp-endringer



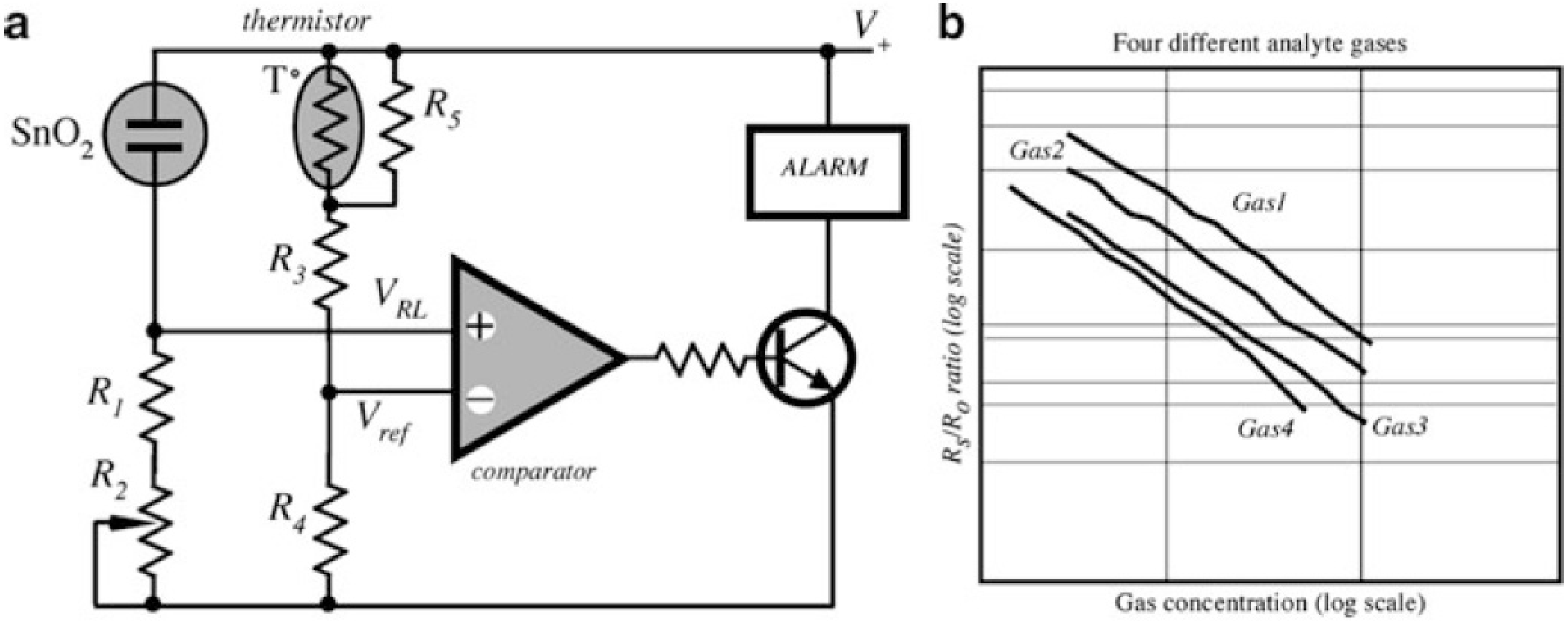
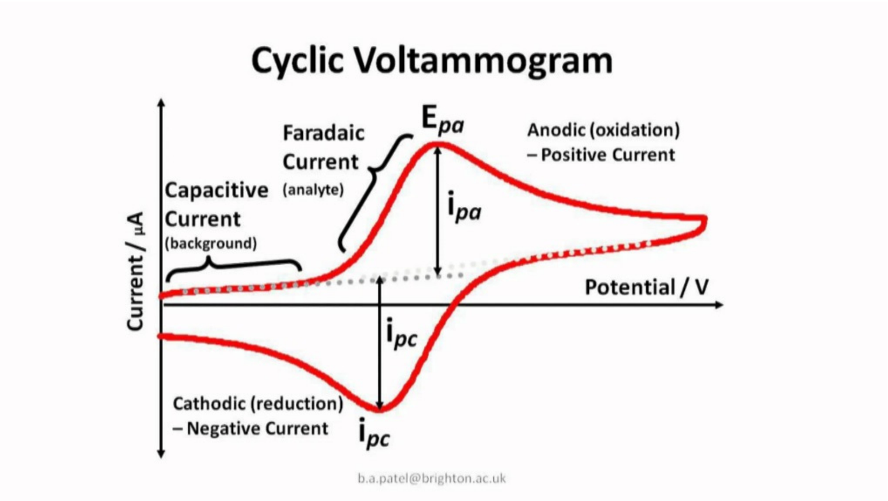


Fig. 17.4 SnO_2 Wheatstone bridge circuit (**a**) used for metal-oxide sensors and responses to different gases (**b**)

Elektrokjemiske sensorer



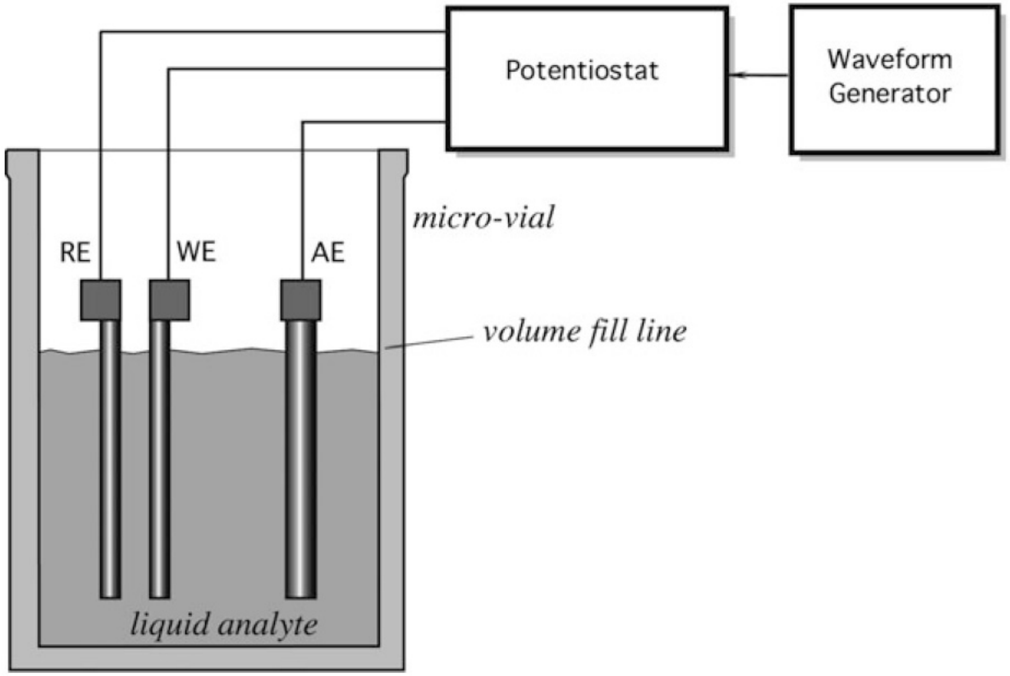
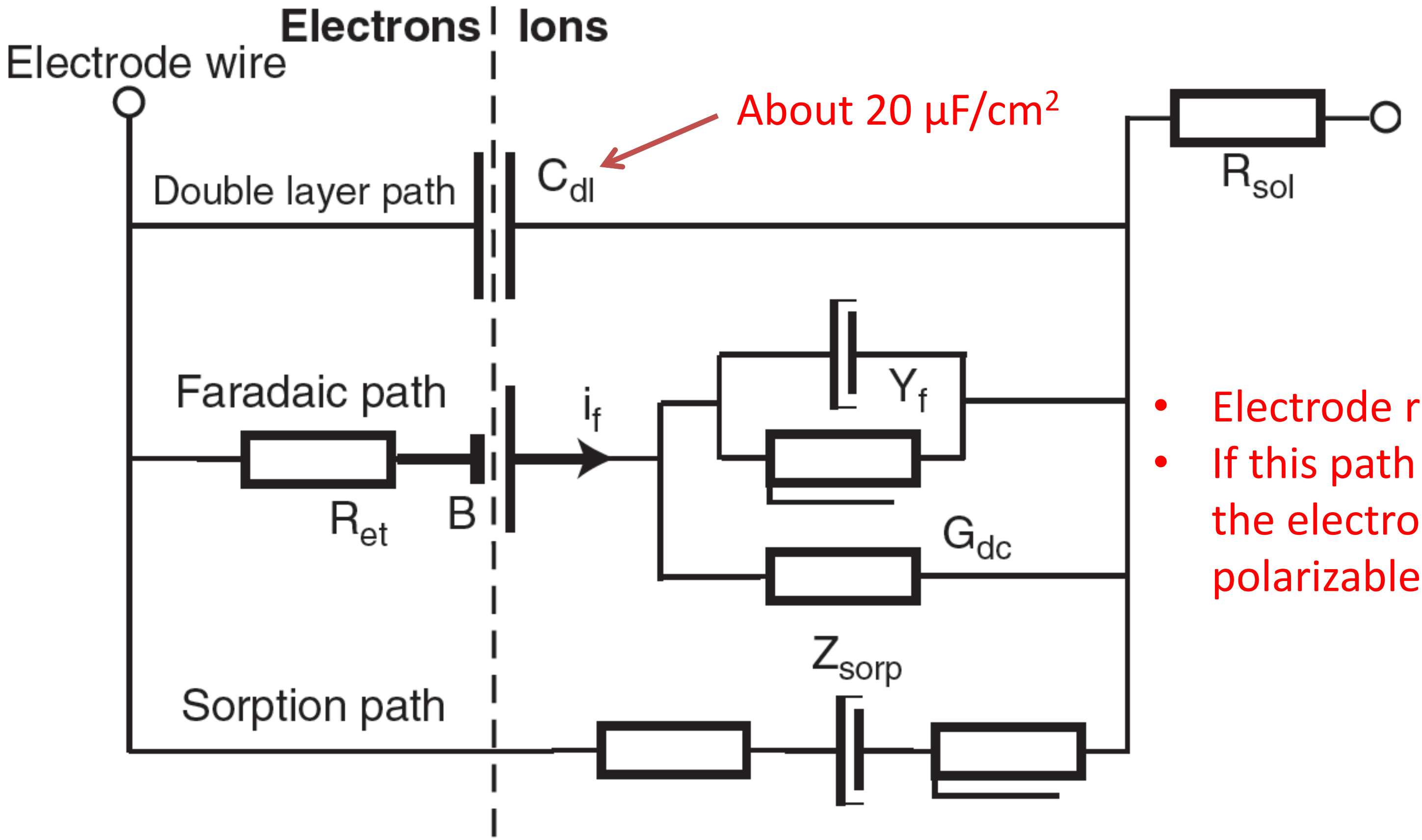


Fig. 17.5 Electrochemical-sensor electrode set

- Måler spenning, strøm eller konduktans
- Working, Auxiliary og Return electrodes
- To-elektrode-systemer brukes også
- Potensiometriske sensorer måler halvcellepotensial
- Amperometriske sensorer måler Faradaisk strøm pga redox-prosesser

Electrode polarization impedance



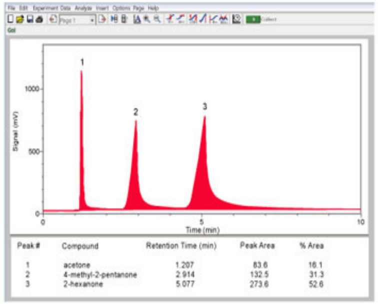
About 20 µF/cm^2

- Electrode reactions
- If this path is missing, the electrode is polarizable

- Adsorption/desorption of species at the electrode surface
- No electron exchange
- May dominate for noble metals

Kapasitive sensorer

- Absorberende polymer som dielektrikum
- F.eks. hygrometer



Peak #	Compound	Retention Time (min)	Peak Area	% Area
1	acetone	1.207	83.6	16.1
2	4-methyl-2-pentanone	2.914	132.5	31.3
3	2-hexanone	5.077	273.6	52.6

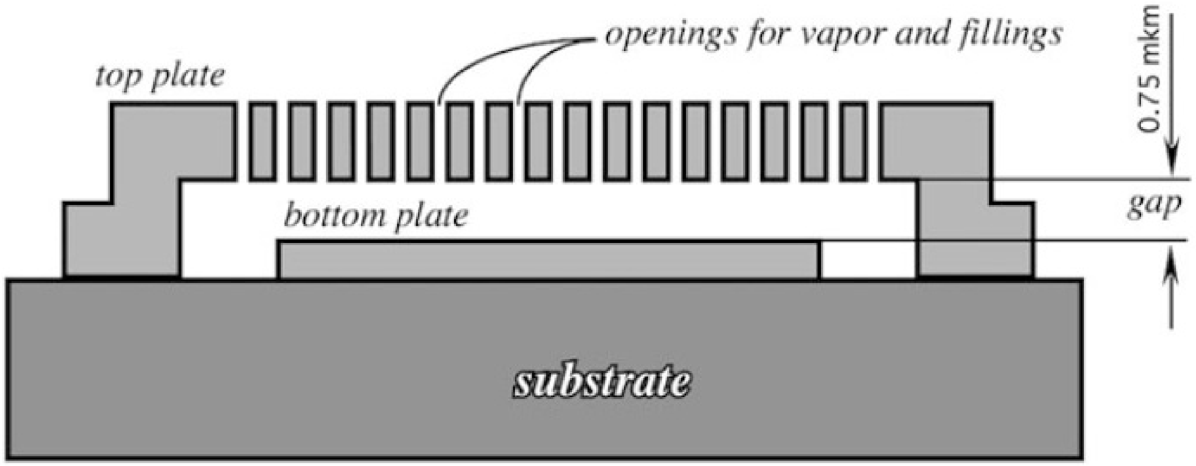


Fig. 17.9 Cross-section diagram of the parallel-plate capacitor showing the 0.75 μm gap

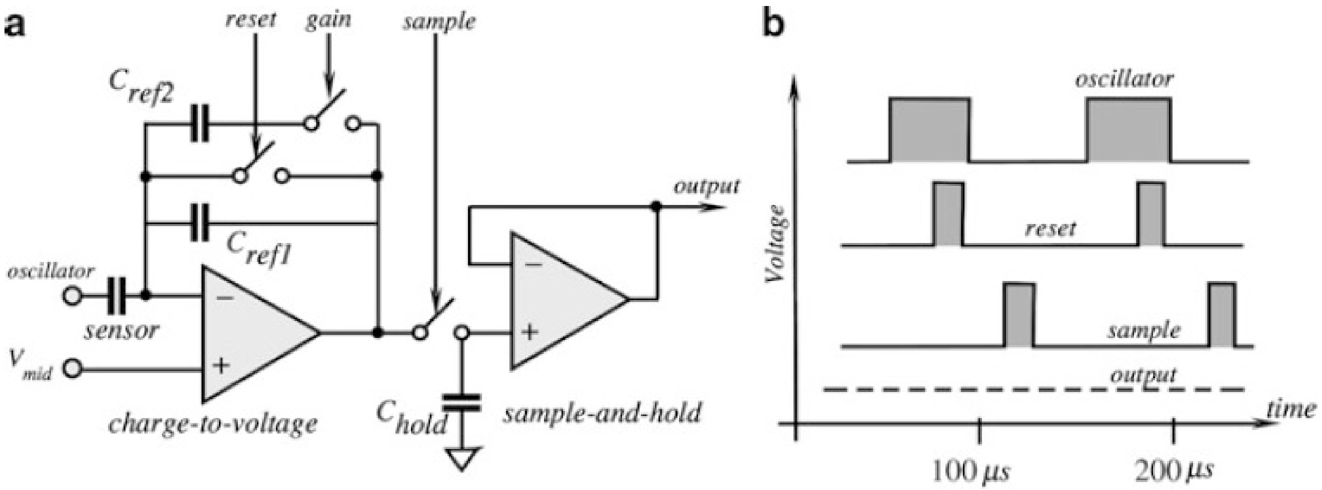


Fig. 17.10 Capacitance measurement circuit (**a**) and timing diagrams (**b**)

Fotoioniserende detektor

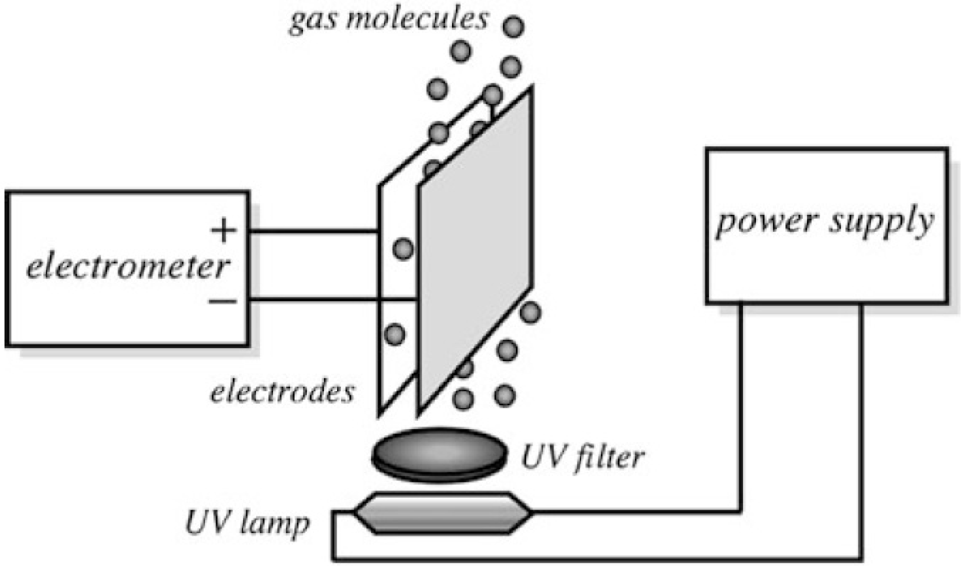


Fig. 17.13 Concept of PID detector

- UV-lys ioniserer molekyler → strøm i E-felt
- Lysets energi bestemmer hvilke gasser som kan ioniseres

Fysikalske transdusere

(ingen kjemisk reaksjon)

- Prøvematerialet absorberer det aktuelle stoffet.
- Akustisk sensor. Frekvensen reduseres når massen øker. Resonans eller forsinkelseslinje.
- Mikrokantilever (vektstang). Bøyes pga endrede overflatespenninger (ikke pga vekt).
- Ionemobilitetsspektrometer.
- Termiske sensorer. Eksoterme eller endoterme reaksjoner.

Akustisk sensor

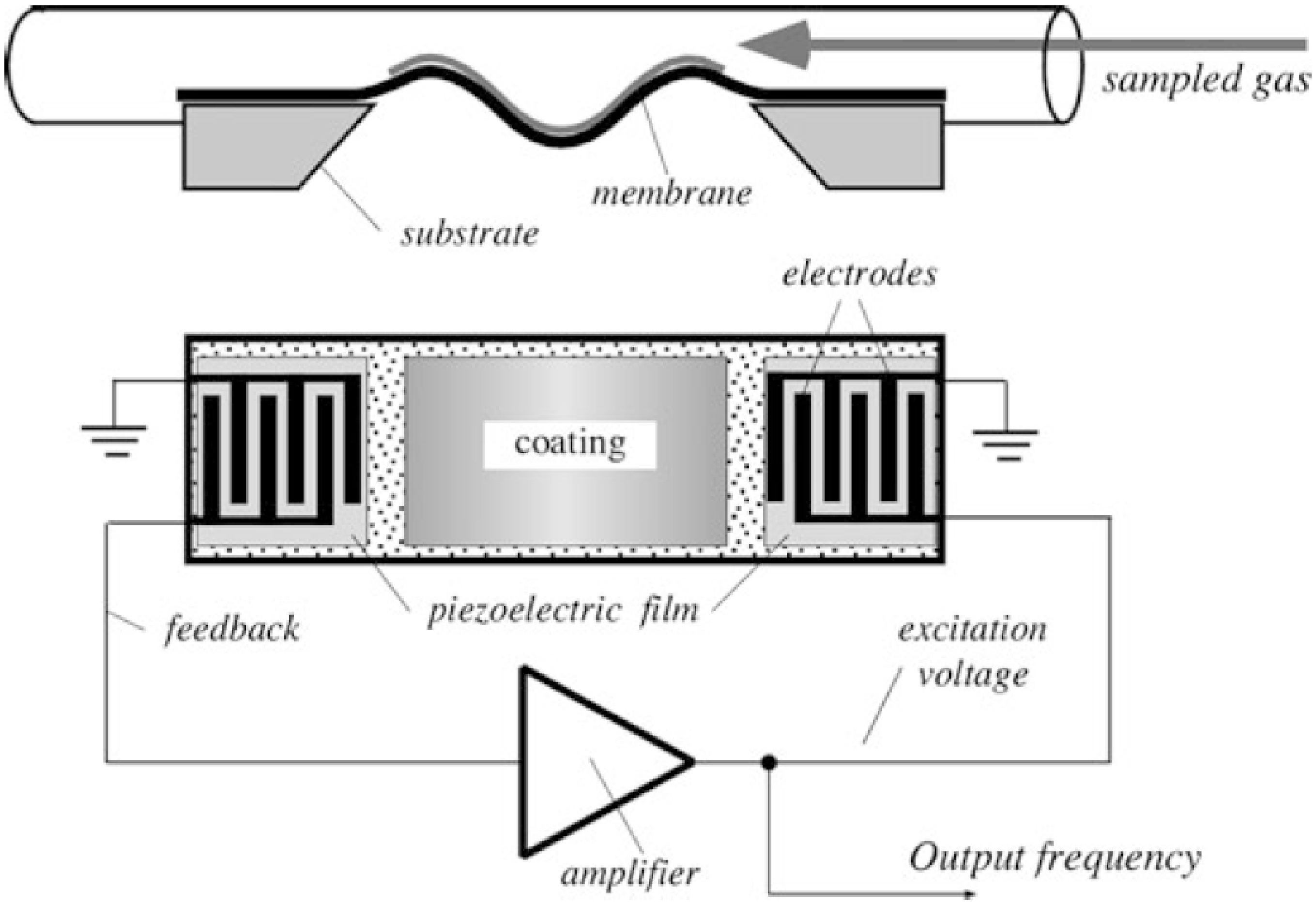
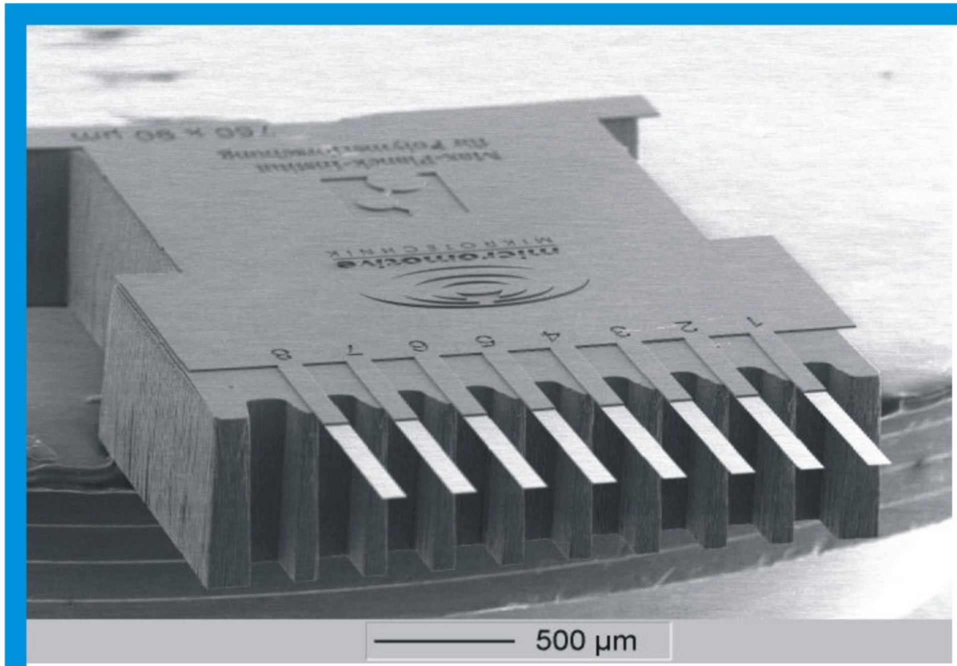
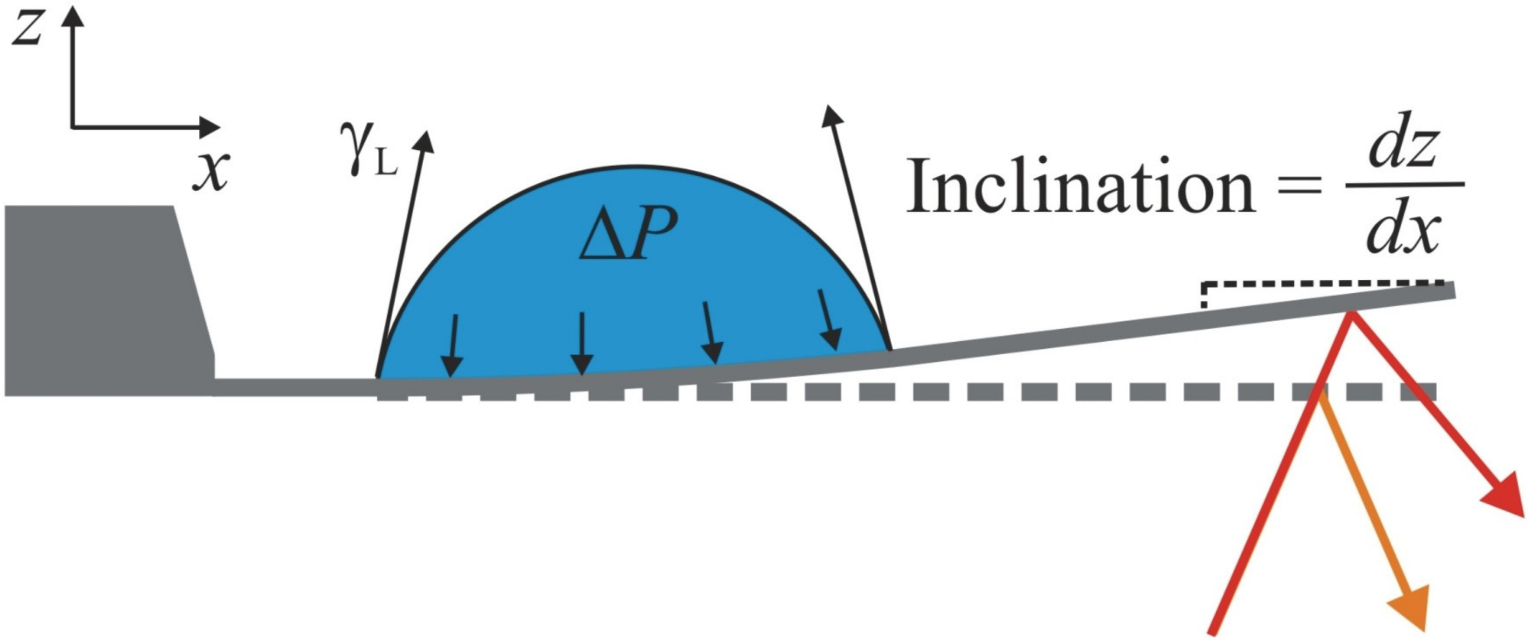


Fig. 17.15 Flexural plate SAW gas sensor (deflection of the membrane is exaggerated for clarity)



Mikrokantilever



Mobilitets-spektrometer

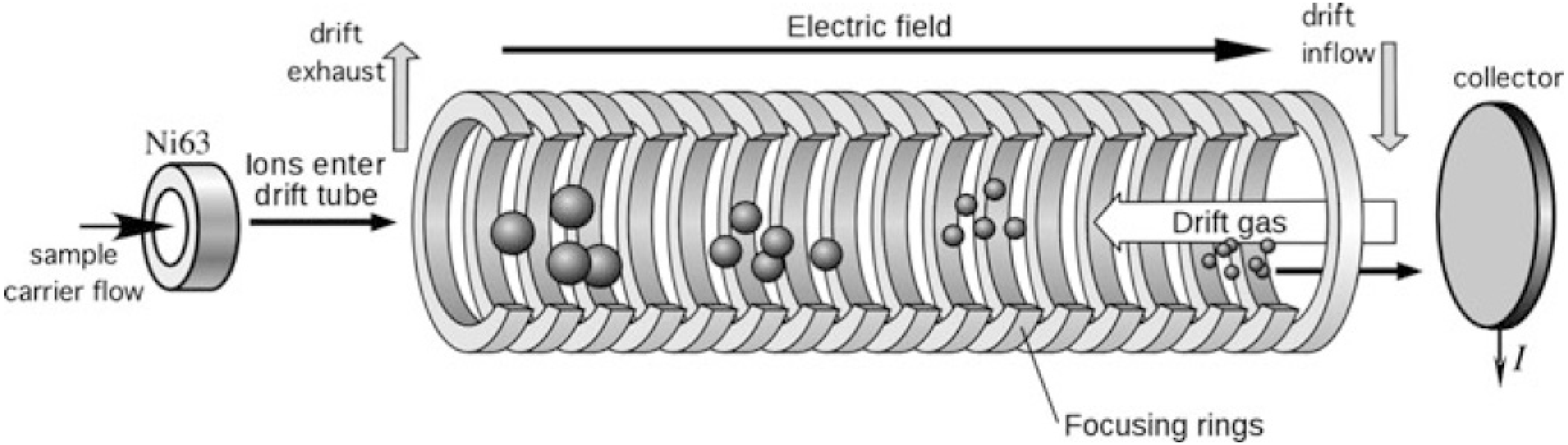


Fig. 17.18 Principle of ion mobility spectrometry

Optiske transdusere

- Absorbsjon av forskjellige bølgelengder (ofte IR)
- Refleksjon (fiberoptisk)

Figure 1: Oxygen indicator materials can be coated onto probes and other substrates for *in situ* measurements.

Biosensor

- Ofte ensymer som virker som katalysatorer.
- Det kjemiske produktet registreres med en annen metode.