Lecture 11/18/22

Chemical Sensors (Architectures)

1) Introduction

The "*analyte*" is the chemical we desire to sense.

A chemical sensor consists of two parts:

(1) Chemically sensitive layer

With one type of chemically sensitive layer, it reacts with the analyte, resulting in a corresponding change in some electrochemical property, such as resistivity or electrical permittivity. With a second type, the chemically sensitive layer produces a change in a mechanical property, such as mass or strain.

Sometimes the chemical process of the chemically sensitive layer is reversible, yielding a continuous use sensor. Example: a relative humidity sensor.

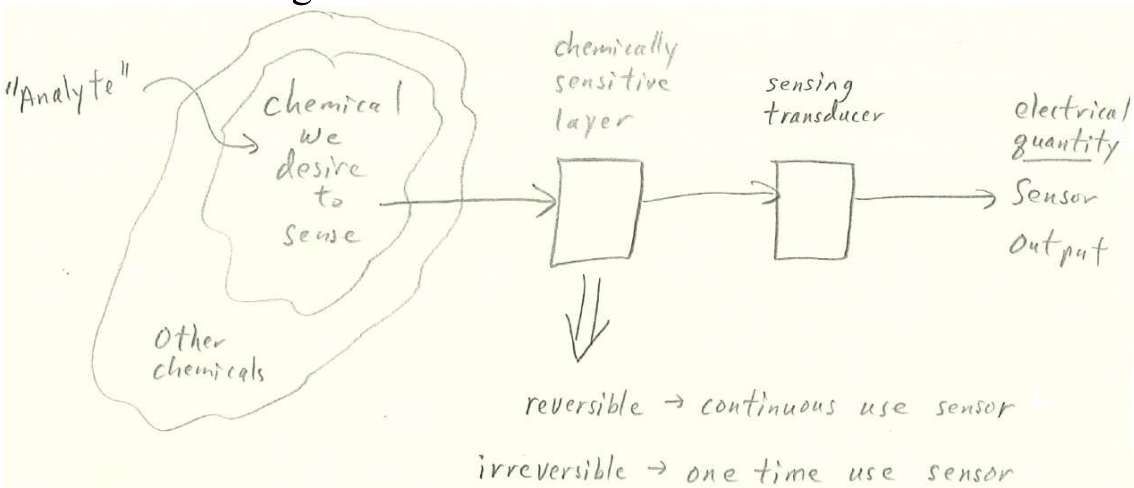
Sometimes the chemical process of the chemically sensitive layer is irreversible, yielding a one-time use sensor. Example: a disposable blood glucose sensor.

(2) Sensing transducer

With one type of chemically sensitive layer, the sensing transducer converts the change in an electrochemical property into a change in an electrical parameter (resistance, capacitance, voltage, etc.). With a second type of chemically sensitive layer, it converts the change in a mechanical property into a corresponding change in an electrical property (resistance, frequency, voltage, etc.)

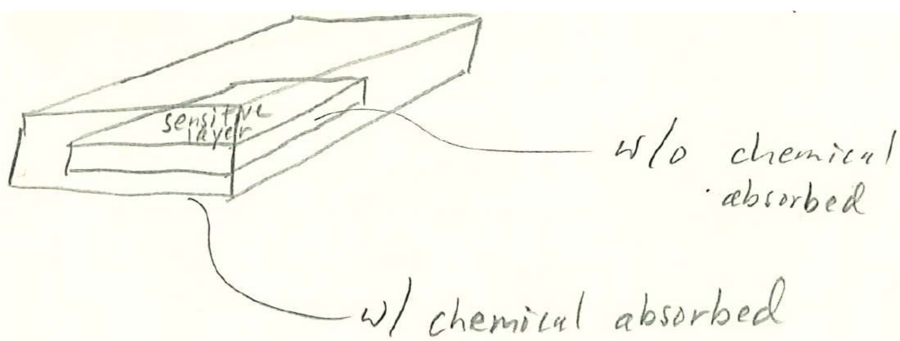
Lecture 11/18/22

Consider this diagram:

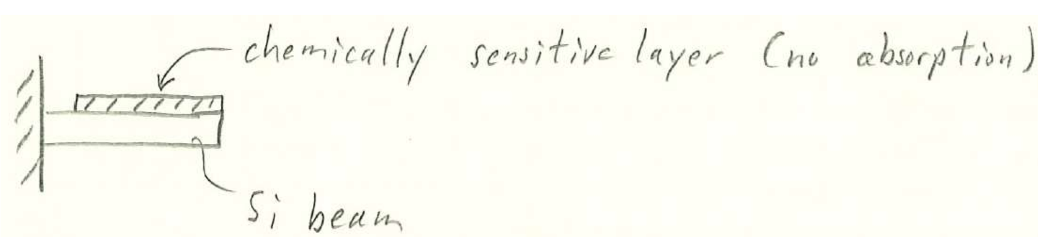


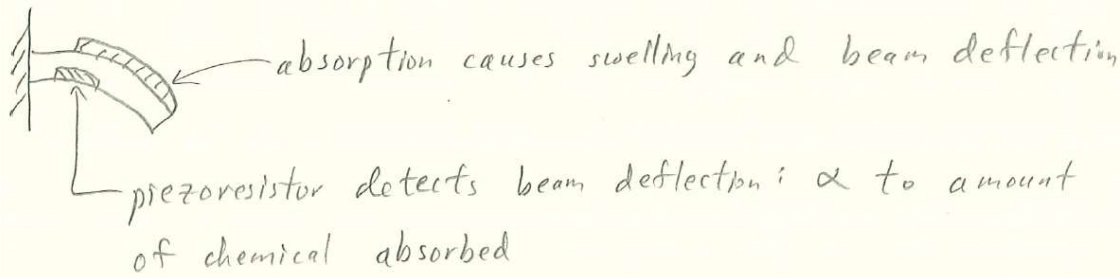
2) Chemical sensor architecture 1: chemically sensitive layer produces a mechanical strain

The chemical absorption by the chemically sensitive layer causes the layer to volumetrically change (example: swelling).

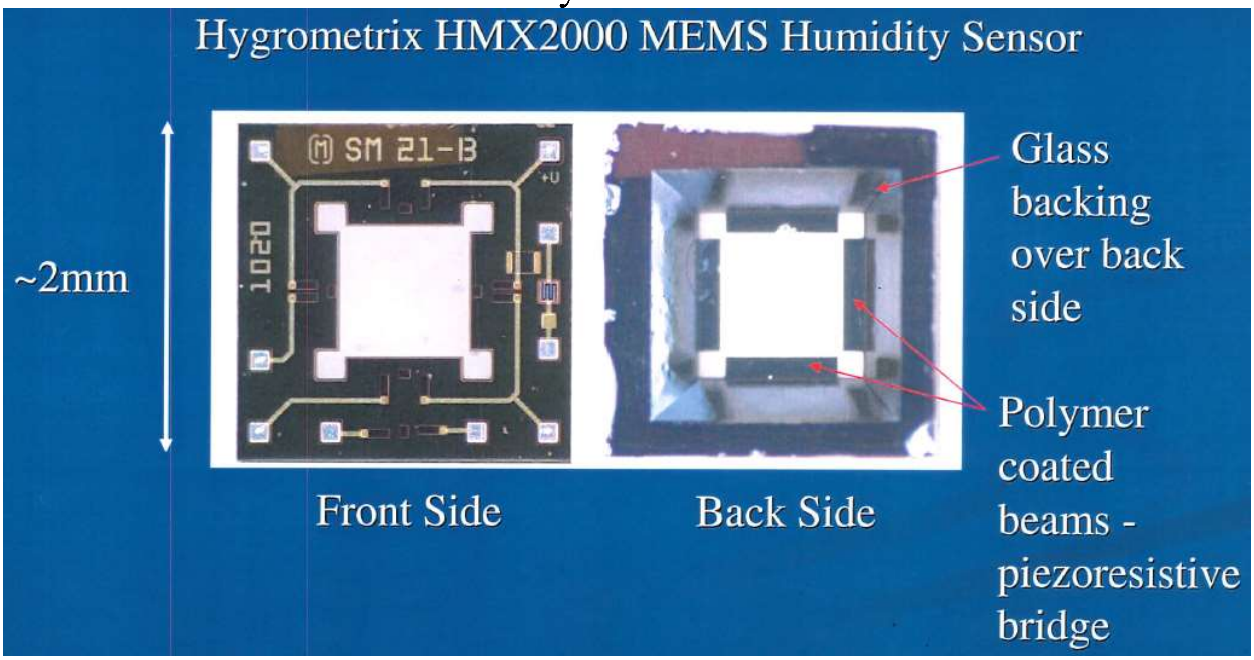


The chemically sensitive layer can be attached to a beam that deflects as the layer swells. The deflection can be detected using piezoresistors.





Consider the HMX2000 humidity sensor:



3) Chemical sensor architecture 2: conductimetric devices

The sensed gas interacts with the chemically sensitive layer and changes the electrical conductance (resistivity).

The typical sensor is the Taguchi-type tin-oxide sensor.

This sensor type uses a joule heater to heat the tin-oxide layer to ~300 – 400°C (typically).

This elevated temperature does three beneficial things:

(1) It improves sensor specificity.
(2) It results in a faster response time.
(3) Above 100°C, humidity effects are eliminated.

The sensor response metric is G_s/G_o, where:

G_s is the sensor's conductance for a specific gas of fixed concentration.

G_o is the sensor's conductance in air.

Different tin-oxide compounds have different specificities:

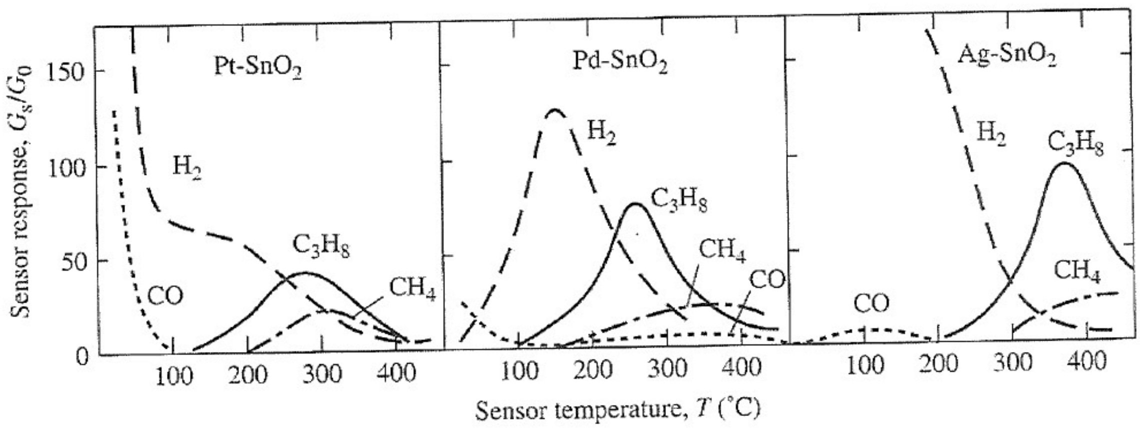


Figure 8.52 Variation of the response of three doped tin oxide gas sensors with temperature for four different gases. Adapted from Yamazoe *et al.* (1983)

This is how those sensors work:

(1) The heated tin-oxide attracts O_2 molecules that abstract an electron from the tin oxide → chemisorption.

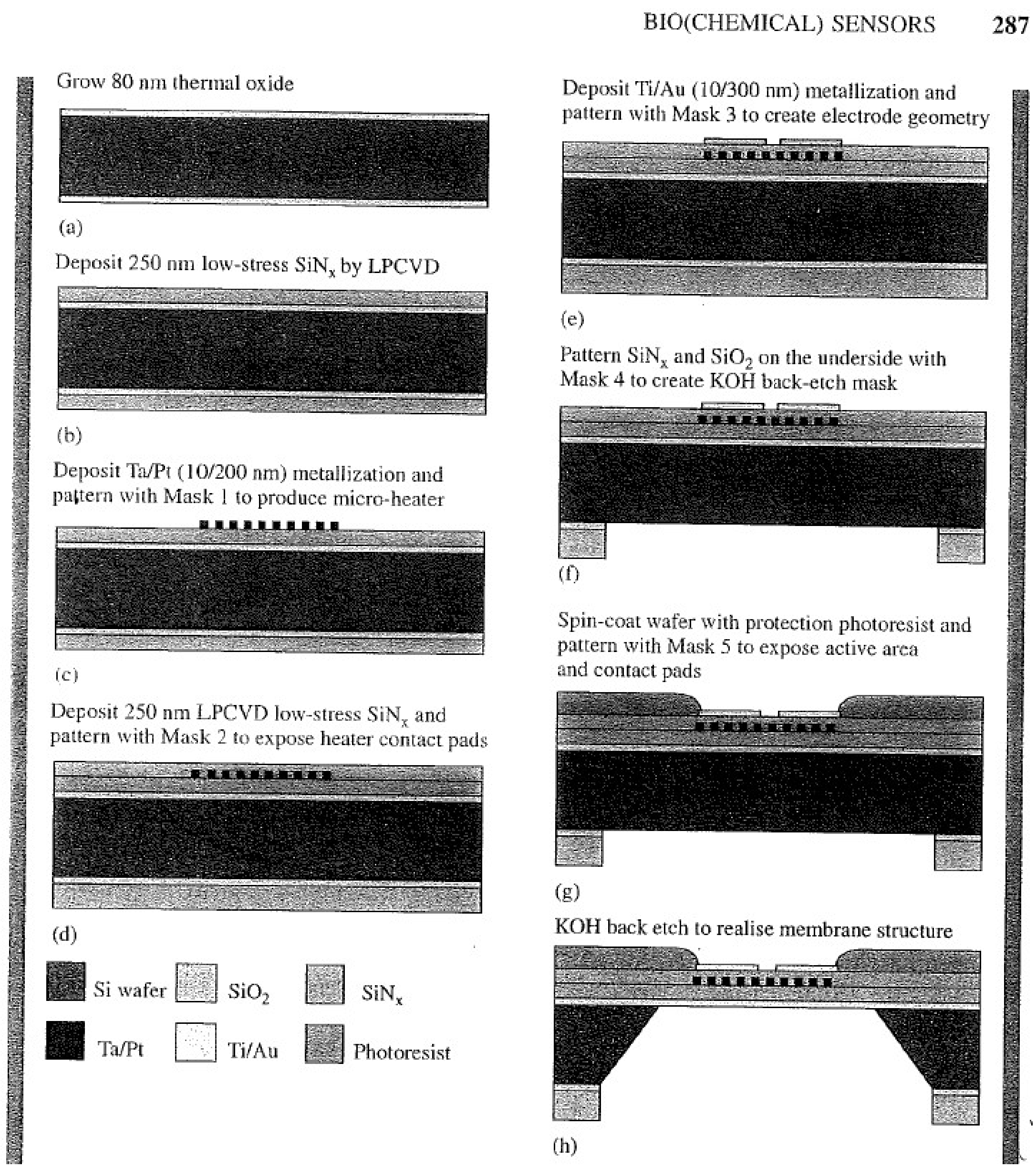
(2) The analyte gas molecule reacts with the chemisorbed O_2 molecule, releasing it and electrons in the tin-oxide material:

Example: $CO + O_{ad}^{-}(SnO_{2x}) \rightarrow CO_2 + SnO_{2x} + e^{-}$

Lecture 11/18/22

(3) The released electrons result in increased electron carrier density and increased electrical conductivity.

Conductimetric sensors can be manufactured with MEMS technology:



On-chip heaters are realized on diaphragms or bridge structures.

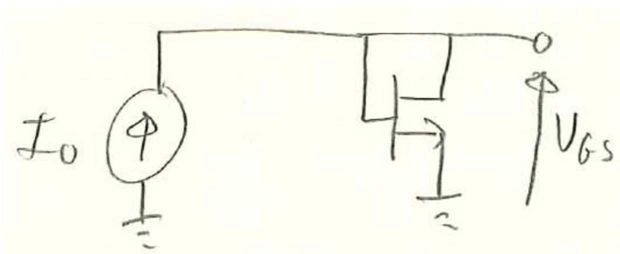
The chemically sensitive layer is placed on top of the heater (that would be step (i) above) and cured/processed.

4) Chemical sensor architecture 3: potentiometric devices

The is a MOSFET transistor with a gate made with a gas-sensitive catalytic metal.

This gate material/structure allows the gas to flow through the gate electrode and affect the dielectric material beneath it.

Consider this circuit:



I_o is a controlled, constant current applied to the circuit. The resulting V_{GS} is then measured.

Observe that $V_{GS} = V_{DS}$

$$i_D = I_o \approx \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_T)^2$$

The presence of the specific gas changes V_T, the threshold voltage, thereby changing V_{GS} for a constant I_o: if $V_T\uparrow$, then $V_{GS}\uparrow$.

Ionizing radiation has a similar effect in the V_T of a MOSFET, where charges get trapped in the oxide layer under the gate due to the ionizing radiation. So, a MOSFET can be used to detect an ionizing radiation event.