10.5.3 Thermocouples

The operation of the thermocouples is based on the Seedbeck phenomenon. According to this, when two different metals or alloys contact each other, then, due to their different output work, free electrons are moving from the metal with the smallest output work to the metal with the biggest output work, even if no exterior voltage is applied to them. Thus, the first metal is becoming more positive than the other, causing a 'contact voltage' on the point of contact. If the two free ends have different temperature, an electromagnetic force is developed, which is equal to:

$$E = a + b\Delta T + c\Delta T^2 \text{ (mV)}$$

where a, b, c are constants dependent on the materials involving and ΔT is the temperature difference between the metals. Because the constant c is very small, if the cold contact is in 0°C, then the equation 10.14 is:

$$E = aT^2 + bT \text{ (mV)}$$

where T is the temperature of the hot contact and a and b are constants dependent on the contact type. We also define the neutral temperature T_N as that in which the electromagnetic force is maximized and this is:

$$T_N = -\frac{b}{2a}$$

It is used to determine the measurements area of temperature for a specific contact type.

In practical terms, we don't use a single contact but two contacts, a cold one and a hot one, as shown in Fig. 10.85a. As long as both contacts have the same temperature, the produced voltage is zero and is increasing when the difference in temperature is increasing, up to the transition point, as shown in fig. 10.86b. Many contacts, however, don't have a transition point but those have very small output voltage, i.e. Cu/Ag.

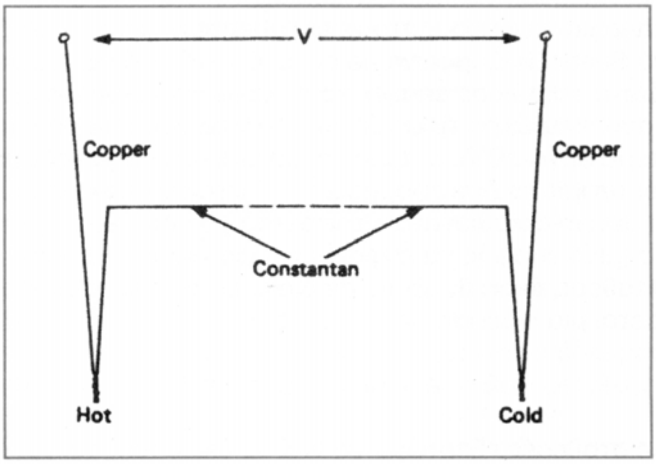


Figure 10.86a

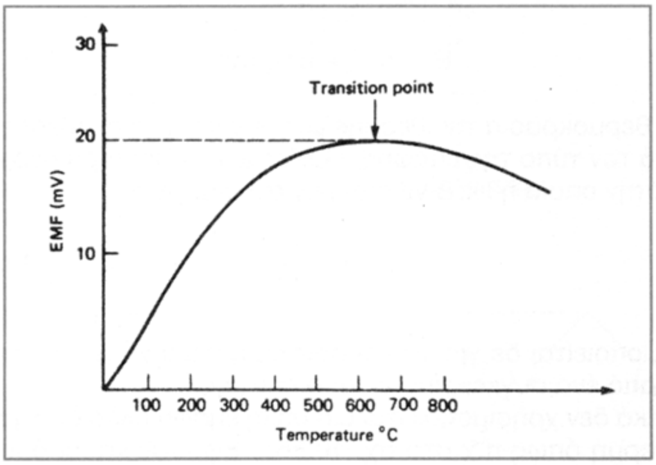


Figure 10.86b

In Table 10.1 we show you the values of electromagnetic force in mV for contacts of platinum and other materials (in couples), when the difference in temperature between them is 100°C for a single contact.

Table 10.1

s/n	Material	electromagnetic force (mV)
1	Constantan	-3.30
2	Nickel	-1.50
3	Aluminum	0.40
4	Manganine	0.65
5	Silver	0.70
6	Copper	0.75
7	Wolfram	0.80
8	Molybdenum	1.20
9	Iron	1.88
10	Silicon	45.00

In the market you will find various types of thermocouples as S, R, J, K, T, N, E which are declaratives of the contact materials. In Table 10.2 you can see some properties of these materials, with English connector codes, because in the USA the negative is red and the positive is white for J, yellow for K, blue for T, purple for E, while in Germany the positive is red and the negative is blue for J, green for K and brown for T. you must be careful because many companies don't conform with these codes. Thus, for AD we have, black for the negative and for the positive green for J, orange for K, blue for L and green for M. When the distance between the thermocouple and the meter is significant, the wires for expansion or correction must be connected to the other two. Their difference is that the expansion wires are manufactured by the same material as the thermocouple and are used in the same temperatures, while the correction wires are manufactured by low-cost metals and are used in much lower temperatures. You must pay special attention to connecting the wires with the appropriate polarization. In Table 10.3 we present you with the codes of the correction wires for the two types, U for inert metals and VX for the metal basis.

The connectors between the thermocouples and the wires are also color-coded. For example, for the UK we have: K is yellow, N is orange, T is blue, J is black and R is green.
It is now obvious that in order to identify completely a thermocouple set, we must know the country and also the company where it was produced.

Table 10.2

s/n	Code	Material	Expansion wires codes	electromagnetic force in 100°C (mV)	Operational temperature range (°C)
1	S	+PtRh/-Pt	+White/-Blue	0.645	0~1400
2	R	+PtRh/-Pt	+White/-Blue	0.647	0~1350
3	K	+NiCr/-NiAl	+Brown/-Blue	4.095	-200~+1100
4	T	+Cu/-CuNi	+White/-Blue	4.277	-200~+400
5	J	+Fe/-CuNi	+Yellow/-Blue	5.268	0~+850
6	E	+NiCr/-CuNi	+Brown/-Blue	6.137	0~+850
7	N	+NiCrSi/-NiSi	+Orange/-Blue	-	-230~+1300

Table 10.3

s/n	Codes	UK	USA	Germany
1	U	+White/-Blue green exterior	+Black/-Red green exterior	+Red/-White white exterior
2	VX	+White/-Blue red exterior	+Brown/-Red red exterior	+Red/-Green green exterior

In Fig. 10.87a, b, c, d we present various thermocouple types.
The uses of thermocouples vary and are depending on the contact type, on the presence of insulation, on their geometrical elements, on the constructing method of the contact, on the requirements of the applications etc.
Thus, the K type has various styles, like industrial style for temperatures (-100~+1100)°C and general applications, insulated with glass or PTFE or MgO for general applications or temperature measurements in ovens, furnaces and exhaust, Probe for small thermal surfaces, industrial Probe, MgO insulated for bathrooms, kilns, furnaces etc.

- The R type is used mostly in ceramic furnaces and glass industries,
- The T type is an economical thermocouple for general applications,
- The J type is used mostly in industrial applications, and
- The N type –improved K type- is used in the same way as K.

Note 1: With thermocouples we manufacture the thermoammeters for AC-DC. The series connection of many thermocouples produces a thermopile for increased production of electromagnetic force.

Figure 10.87a

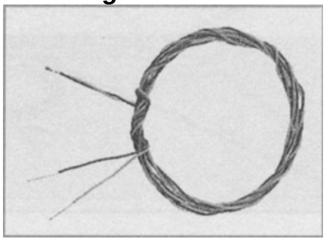


Figure 10.87b

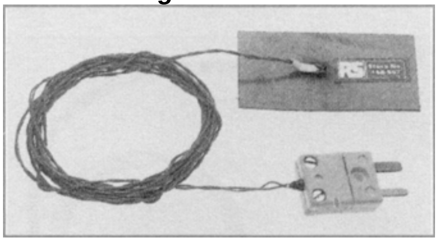


Figure 10.87c

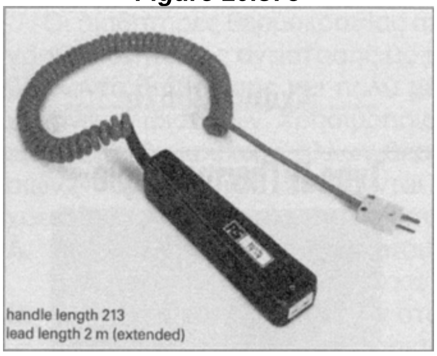
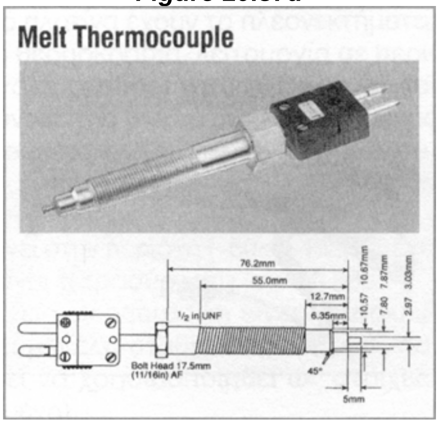


Figure 10.87d



Note 2: The thermocouples are consisted of :

S=90% Pt, 10% Rh, and 100% Pt.

R=87% Pt, 13% Rh and 100% Pt.

J=100% Fe and (57~60)% Cu, (40~43)% Ni or an element of iron-constantan

K=90% Ni, 10% Cr and 95% Ni, 5% Al-Si-Mn or an element of cromel-alumel.

T=100% Cu and (57~60)% Cu, (40~43)% Ni or an element of copper-constantan.

N=84% Ni, 16% Cr-Si-Fe-C and 95% Ni, 5% Cr-Si-Fe-C-Mg or an element of nicrosil-nisil.

E=90% Ni, 10% Cr and (56~60)% Cu, (40~43)% Ni or an element of cromel-constantan.

Figure 10.87e

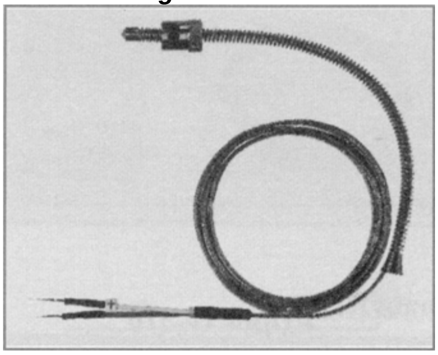


Figure 10.87f

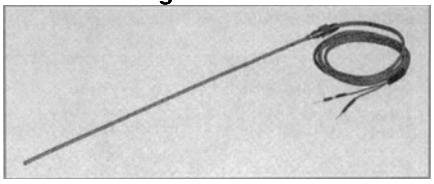


Figure 10.87g

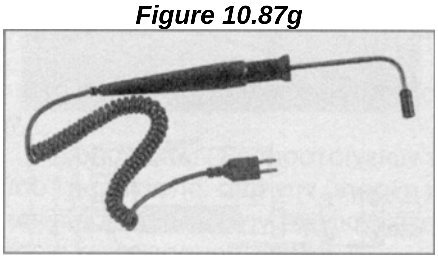


Figure 10.87h

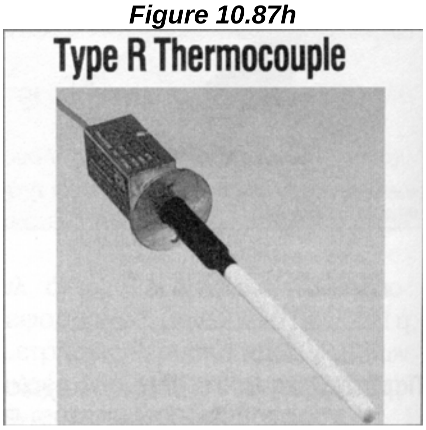


Figure 10.87i

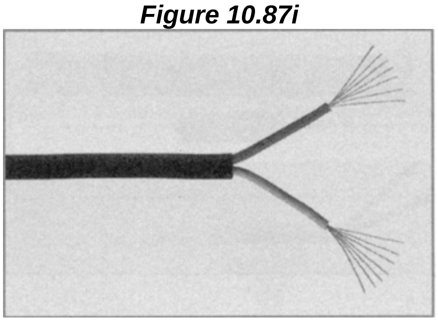
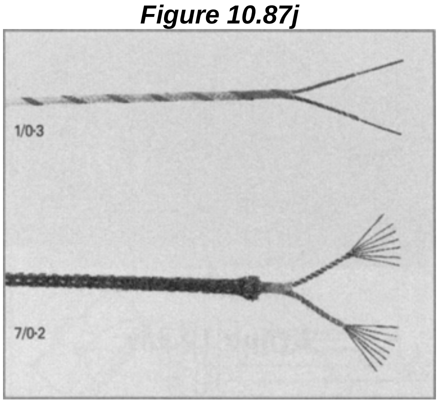


Figure 10.87j



10.7.8 Various Gases, Vapors, Fume

A. The last two decades a new electronic sensors field has been developed, based on semi-conductive materials. This technology applies the property the semiconductors have to vary their resistance when they are within an environment of a gas, as the gas molecules come from the surface of the semiconductor into its mass. As semiconductors of N type we use Fe_2O_3, TiO_2, SnO_2 and ZnO and as semiconductors of P type we use CuO_2, NiO and CoO. Thus, each semiconductor, depending on its mixings and the operational temperature, is more sensitive to a specific gas.

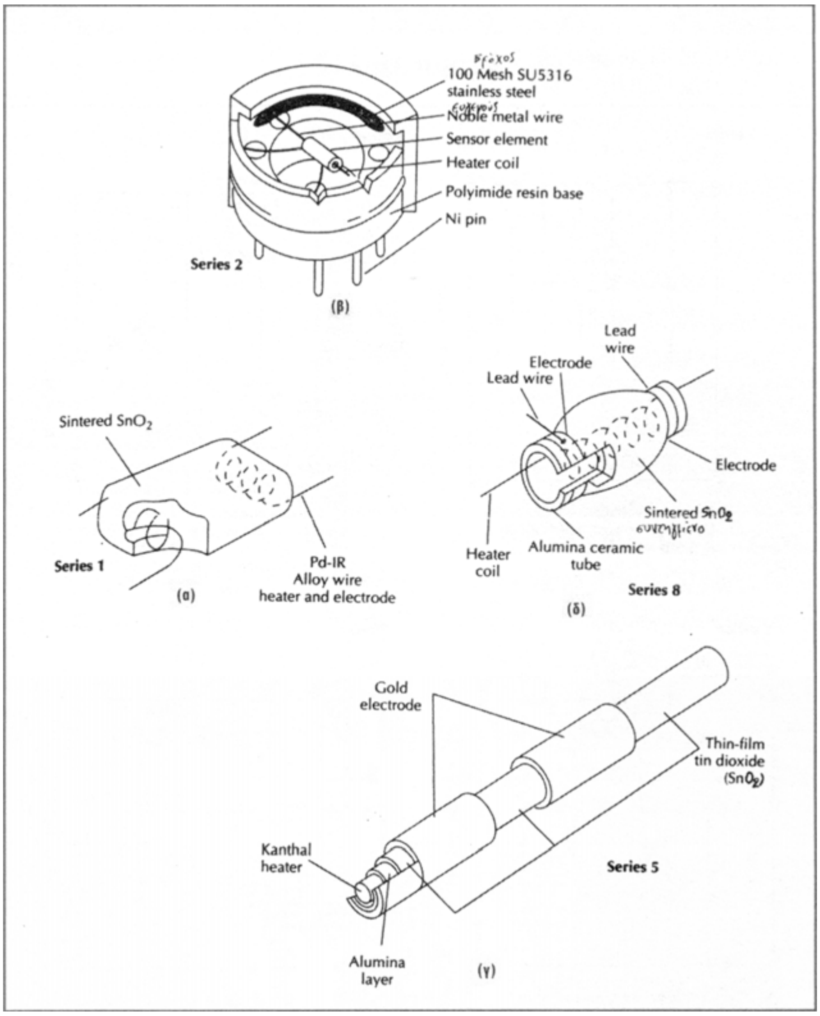


Figure 10.116

The sensor consists of a layer of semiconductive metal oxide, in which there are two convolutions by iridium/palladium and are used as holds. They are the thermal element sensors with Tin dioxide (SnO_2) of the series 1-2-5-8 of FIGARO, shown in Fig. 1.116a, b, c, d. In able 10.5 we present the categories, the applications and the codes of the FIGARO sensors.

In Fig. 10.117a, b, c, d we show the measurement circuits of the sensors of series 1-2-5-8 respectively.

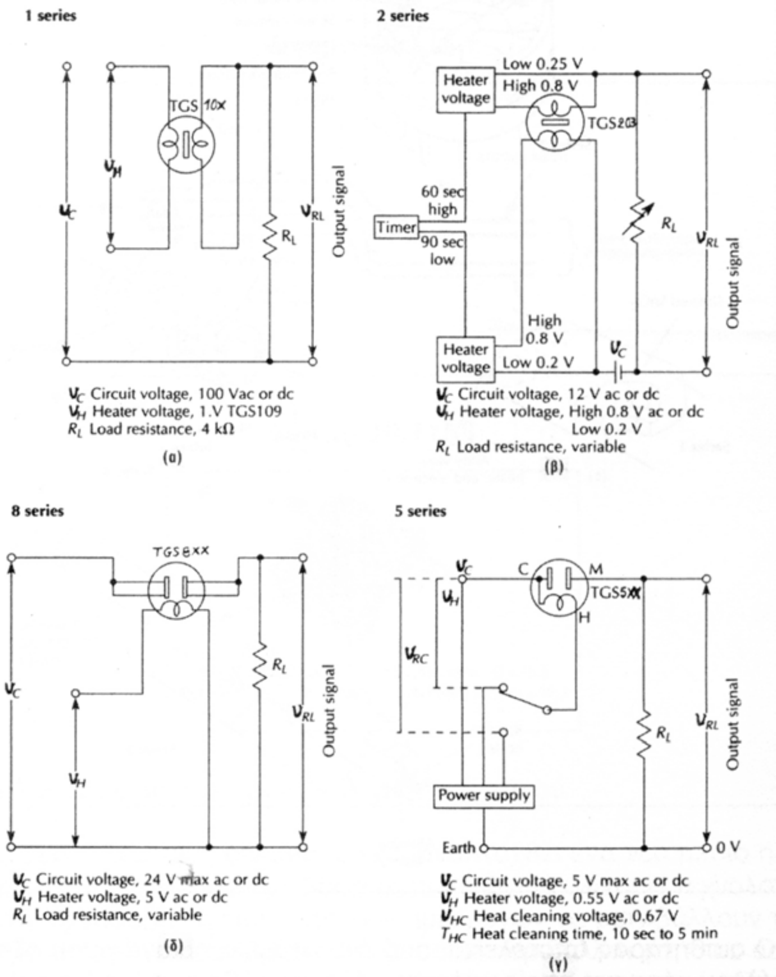


Figure 10.117

Table 10.5

s/n	Category	Code	Applications
1	Flammable gases	TGS 109	LPG* (propane, isobutene) (500~10,000)ppm
		TGS 109T	Natural gas (500~10,000)ppm
		TGS 813 TGS 816 TGS 842	Methane, propane, isobutene " " (500~10,000)ppm
		TGS 815	Methane (500~10,000)ppm
		TGS 821	Hydrogen (500~10,000)ppm
2	Toxic gases	TGS 203	Carbon monoxide (500~10,000)ppm
		TGS 824	Ammonia (30~300)ppm
		TGS 825	Hydrogen sulfide (5~100)ppm
3	Organic dissolver	TGS 822	Alcohol (50~5000)ppm
		TGS 823	Xylene (50~5000)ppm
4	Chlorofluorocarbons (CFCs)	TGS 830	R-113, R-22 (100~3000)ppm
		TGS 831	R-21, R-22 (100~3000)ppm
5	Intense smell gases	TGS 501	Sulphur combinations (0.1~10)ppm
		TGR 590	Ozone (0~200)ppb
6	Ventilation control	TGS 100 TGS 800	Air pollution (cigarette smoke, petrol exhalations) (0~100)ppm
7	Cooking control	TGS 880 TGS 881	Volatile gases, food vapours (gases, vapours, fume)
		TGS 883T	Vapours, volatile gases and food vapours (high sensitivity to water vapours)

**LPG (Liquefied Petroleum GAS)*

For the circuit of series 1, one or both the electrodes can be used as heaters. You can find it in two types: with or without calibration.

The sensor of series 2, that is the TGS203, is used only for tracking CO. Additionally it can be used for tracing hydrogen and ethanole, but with significantly lower sensitivity, almost 10% and 2.5% respectively. The relatively low temperature of the sensor affects its response while the humidity of the environment affects its accuracy. That's why it is overheated for a little time, so as to eliminate humidity and the possible remaining gas molecules from another measurement. This is stabilized at the operational temperature of almost 100°C. During the measurement, at the operational temperature, the heating current is interrupted three times in order to measure the resistance of the semiconductor between the succeeding heatings. During the measurement, the sensor shows resistance R_S, which in series with R_L shapes a voltage divider. The output voltage U_{RL} is proportional to the CO levels. FIGARO offers the microcontroller FISC5401 which controls the gas sensors.

The microcontroller provides current (high) when overheated for 60 seconds and then it is reduced (low) for 90 seconds (total time 150 seconds). During the reduction, the heating current is interrupted three times, for a duration of 28msec, 27msec and 500msec). during the last interruption, the voltages U_{RL} and U_{ref} are compared and if $U_{RL} > U_{ref}$, an alarm is introduced. In Fig. 10.118a, you can see the variation of the ratio R_S/R_0 in conjunction with the gas levels, for TGS203. R_0 is the sensor resistance in overheating mode and R_S is its resistance in interruption mode.

The series 5 sensor, that is TGS501, is used mostly for tracking down the sulphur combinations as well as ethanole. It is a low current sensor with three main elements SnO_2, a couple of gold electrodes and a heater coated with aluminium. In Fig. 10.118b you can see the variation R_S/R_0 in conjunction with the gas levels in ppm. The sensor TGS590 is used to measure ozone. The NO_x and the cigarette smoke affect its accuracy and its sensitivity. It is applied to the measurement of the performance of the ozone splitting filters in air-conditioners. The sensor is not behaving linearly and its stability is considered satisfying for measurements lasting up to 100 days. The microcontroller 80C535A cooperates with TGS590. The sensor is overheated for 3 minutes with voltage $0.8V_{DC}$, then its operation stabilizes for 3 minutes with voltage $0.5V_{DC}$ and then, another measurement is done for 3 minutes.

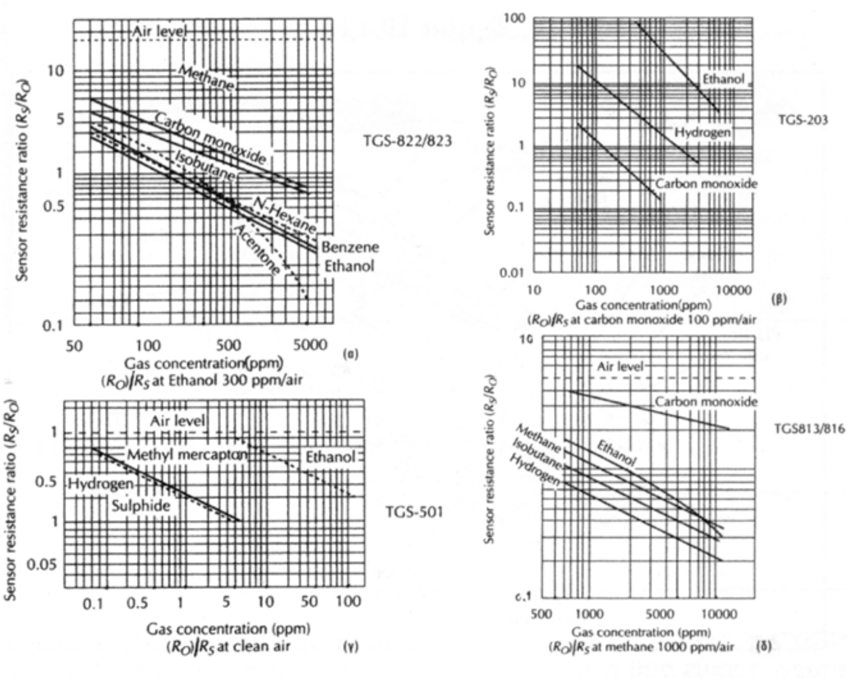


Figure 10.118 (a, b, c, d)

The series 8 sensors are high reliable and low cost sensors. The heating coil shows resistance of 30Ω. The semiconductor SnO_2 is placed on the ceramic material. These sensors are much affected by humidity and environmental temperature and so, the place they are going to be placed on must be investigated thoroughly, as well as the task they are going to perform (tracking down or leaking the gas, fan-control or monitoring the air) and the gas which will be traced. In Fig. 10.118c and d, we show you the variation R_S/R_0 in conjunction with the gas levels.

B. In Fig. 10.119, we show you the structure of the oxide sensors of type GS, of the KE25/KE50. It is used in medicine, in anaesthesia meters, in brooders, in air-conditioners, in refrigerators etc. In the sensor, the oxygen molecules are diffusing through the non-spongy teflon film in the electrochemical element. There, the gas is reduced by the gold electrode and a current flows between the anode of lead and the cathode of gold, in proportion with the oxygen levels in the gas.

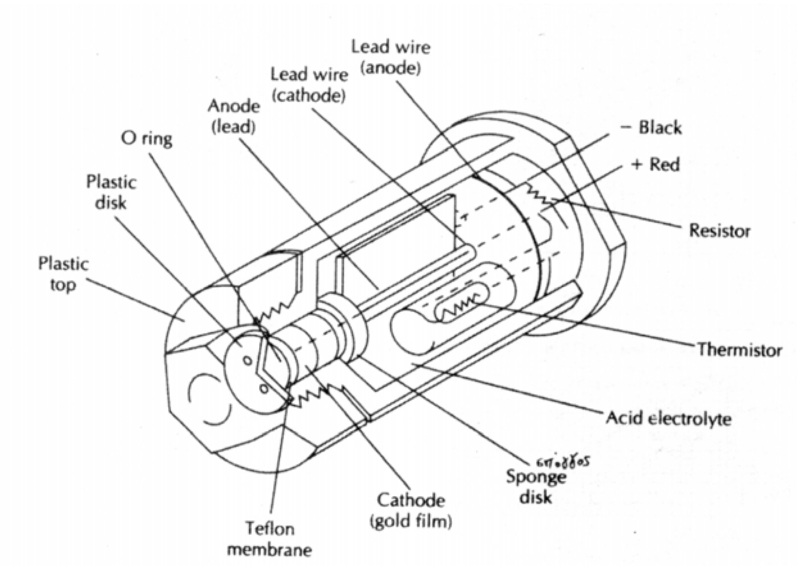


Figure 10.119

C. In Fig. 10.120a, b, we show you the structure of a gas sensor, of a oxide-metal film by Teknetron. These microelectrochemical sensors consist of a sublayer material with an open end and an electrode permeable by the gas, for its tracing. The gas diffuses to the back of the sensor. This straightforward diffusion of the gas gives fast linear response at the sensor. Their advantage is the low demand on power and the high selectivity.

A new category of FETs, the CHEMFETs (CHEMical Field-Effect-Transistors), consist of a chemically sensitive layer which is placed on the port of a FET. Palladium is sensitive to hydrogen and to gas hydrocarbons, and when laid down on gold, it is sensitive to propylene etc.
The ISFETs (Ion-Sensitive FETs) belong to another category; they must use an ion-selective film which is placed on the insulated ISFETs.

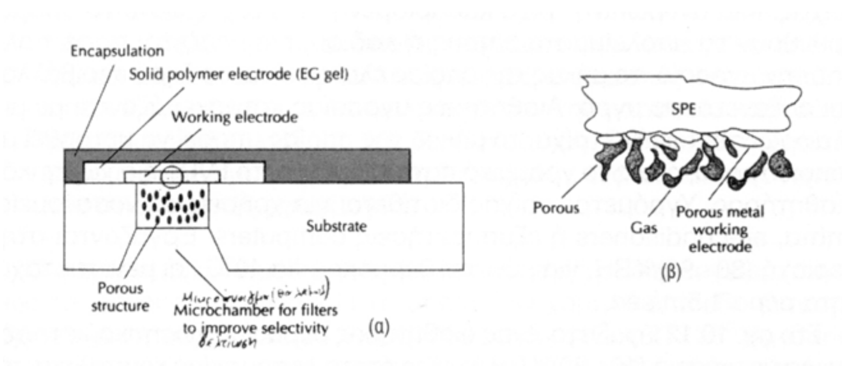


Figure 10.120