VERSAILLES 1970

IMEKO AFCET

IMEKO V.

25—30 May 1970

Versailles

B-305

HIGH-PRESSURE GAUGES WITH ELECTRIC SENSORS

by

E.CZAPUTOWICZ, J.JANKOWSKI, M.ŁAPIŃSKI, R.WIŚNIEWSKI

W.WŁODARSKI

Poland

Basic Parameters of a Secondary High-pressure Sensor

If $\varkappa$ is the given physical property, the basic parameters of the secondary high-pressure sensor are [1]:

$\alpha_\varkappa = [\partial\varkappa/(\varkappa_0 \partial P)]_T$ - pressure sensitivity coefficient;

$\beta_\varkappa = [\partial\varkappa/(\varkappa_0 \partial T)]_P$ - temperature sensitivity coefficient;

$\gamma_\varkappa = \beta_\varkappa / \alpha_\varkappa = (\partial P/\partial T)_\varkappa$ - temperature coefficient of the pressure reading shift;

$z_\varkappa = \alpha_\varkappa / \gamma_\varkappa = \alpha_\varkappa^2 / \beta_\varkappa$ - coefficient of pressure quality.

The last coefficient, introduced by Czaputowicz [2] seems to be the best indicator of the suitability of a given physical property of a sensor for high-pressure measurements. It is important that the absolute value of the coefficient of pressure quality $|z_\varkappa|$ be possibly high. In the present paper only electric properties will be discussed. All values of pressure are given in atmospheres, where:

$$1 \text{ atm} = 1 \text{ kg/cm}^2 = 0.0980665 \text{ MN/m}^2$$

High-pressure Resistance Gauges with Metal Sensors

The manganin sensor is one of the most populare resistance metal sensors for measurements of high pressures [3]. The relative change of electric resistivity with increasing pressure and temperature for Russian and German manganin is diagramatically presented in Fig.1

In the range up to 6000 atm $\alpha = [\partial R/(R_0 \partial P)]_T$ decreases linearly with the growing pressure:

$$\alpha_P = \alpha_0 + \alpha_1 \cdot P \qquad (1)$$

where α_0 dependes on the kind of wire, its diameter, and heat treatment [2]. At room temperatures we have:

$$\alpha_0 = (2{\cdot}0 - 2{\cdot}6) \times 10^{-6}\ \text{atm}^{-1}$$
$$\alpha_1 \approx -5 \times 10^{-12}\ \text{atm}^{-2}$$

For two kinds of wire α_0 increases with growing temperature (cf. Fig.1) where

$$\delta = [\partial \alpha_0 / (\alpha_0 \partial T)]_P = 1 \times 10^3\ \text{deg}^{-1}$$

but $\alpha_1 \approx$ const. in the range 15 to 30°C.

In the range 6000 to 16,000 atm. α_P also decreases linearly with growing pressure (Fig.2) but at a rate about half that observed up to 6000 atm. The relative variations of resistivity with growing temperature are given for all manganin wires by the following parabolic function [3]:

$$\Delta R/R_{20} = at^2 + bt + c \qquad (2)$$

where a,b,c depend on the kind of wire, heat treatment and the range of pressures (Table 1).

Czaputowicz constructed a new kind of manganin sensor consisting of two kinds of wire, Russian and German, connected in series. In this sensor $\beta = [\partial R/(R_0 \partial T)]_P$ is about ten times less than in the standard Russian, English or German manganin wires in the temperature range 17 to 27°C and the maximum error in the pressure reading due to temperature variation is only 2 atm. It allows for measuring both relatively small pressures (up to 1000 atm) and dynamic pressures [4].

High-pressure Resistance Gauges with Semiconductor Sensors

The application of pure (non-doped) semiconductor crystals of Te and InSb as high-pressure sensors was discussed by the present authors at the IMEKO-IV Conference [1]. However, since in practice all semiconductor materials are contaminated, it seems justified to express the basic parameters of the semiconductor resistive sensor by the value of the effective energy gap E^* and the effective energy gap pressure coefficient $a^* = (\partial E^*/\partial P)_T$ which fulfil the equation:

$$R/R_0 = \exp\ (E^* - a^*P)/(2kT) \qquad (3)$$

In the first approximation we have:

$$\alpha = a^{*}/2kT \qquad \beta = -E^{*}/2kT^{2}$$

$$\gamma = -E^{*}/a^{*}T \qquad z = -a^{*2}/2kE^{*}$$

For Te and InSb we have the averaged values:

$$E^{*}_{Te} = 0{\cdot}25\,eV \qquad a^{*}_{Te} = -1{\cdot}8 \times 10^{-5}\,eV/atm$$

$$E^{*}_{InSb} = 0{\cdot}18\,eV \qquad a^{*}_{InSb} = 1{\cdot}5 \times 10^{-5}\,eV/atm$$

The basic parameters for these crystals are listed in Table 2. Some selected, experimental results for Te are given in Fig.3. The most important disadvantage of the gauge with a single semiconductor crystal is its temperature dependence; greatest difficulties are caused by temperature variations due to pressure changes. Two of the present authors [5] reduced considerably the effect of temperature on the accuracy of the readings by connecting Te and InSb crystals in the neighbouring branches of a Wheatstone bridge (Table 2, item 6). Very recently Czaputowicz found that Te monocrystals can be prepared whose resistivity in the range 10 to 50°C is a parabolic function of temperature (cf. Eq.2). Since the maximum of the function is at 30°C, we obtain a new practical possibility of temperature compensation (cf. Tables 1 and item 7).

On the Possibilities of Applying Planar Transistors as High-pressure Gauges.

The effects of hydrostatic pressure on the p-n junction where measured [6-8]. Włodarski examined some properties of a silicon n-p-n planar transistor (OE, OB connections). From the experimental data two groupes of results were selected:

$I_c = f(P,T)$ where: V_{CE} = const., V_{BE} = const., for which $|z|$ = max, and

$V_{BE} = f(P,T)$ where: V_{CE} = const., I_C = const., for which $|z|$ = min.

The largest variation in the collector current for a given pressure system is observed for the common emitter mode of operation of the transistor. Any change in the base current due to the application of pressure is multiplied by the

multiplication current factor of the transistor. Some experimental data are presented in Figs. 4,5,6 and 7, and the basic parameters in Table 2.
Silicon has high values of E^{*}, $|\beta_R|$, $|\gamma_R|$ where: R - resistivity and also shows a relatively high melting point. This is why silicon planar transistors may be used for measuring high pressures at elevated temperatures.

The comparison of the coefficients of pressure quality for all the examined electric sensors is presented in Table 2 and Fig.8. Further studies on the application of metals and semiconductors as electric high-pressure sensors are in progress.

References

[1] Łapiński,M., Czaputowicz,E., Włodarski,W., Karwowski,M., Acta Imeko IV, PO-137, p. 93.

[2] Czaputowicz,E., Thesis, Warsaw Technical University, 1967

[3] Czaputowicz,E., Jankowski,J., Materiały III Krajowej Narady Techniki Wysokich Ciśnień, Warszawa 1969 (Proceedings of the 3rd National Conference on High-pressure Technique, Warsaw, 1969).

[4] Wiśniewski,R., as in 3

[5] Czaputowicz,E., Włodarski,W., Patent PRL No 55669.

[6] Hall,H.H., Bardeen,I., Pearson,G.I., Phys. Rev. 84, 1, 129, 1951.

[7] Jayaraman,A., Sikorski,M.E., Irvin,I.C., Yates,G.H., J. Appl. Phys. 38, 11, 4454, 1967

[8] Mason,W.P., Physical Acoustics - Principles and Methods, v.I, Methods- and Devices. Part B, Academic Press, New York, - London, 1961.

Figure Captions

Fig.1. Pressure and temperature variation of relative resistivity for Russian (1) and German (2) manganin

Fig.2. Pressure variation of the relative changes of the pressure sensitivity coefficient for Russian manganin sensors (1,2,3)

Fig.3. Pressure variation of resistivity for two tellurium monocrystals
1,2 - $a^{*} = 1{\cdot}75 \times 10^{-5}$ eV/atm (R_o = 19,6 ohm)
3,4 - $a^{*} = 1{\cdot}48 \times 10^{-5}$ eV/atm (R_o = 6,5 ohm)

Fig.4. $I_c = f(V_c)$ as a function of pressure and temperature for a planar transistor (OE connection)
1 - P_{atm}, 20°C; 2 - P_{atm}, 22°C; 3 - 4000 atm, 20°C;
4 - P_{atm}, 24°C; 5 - 4000 atm, 22°C; 6 - P_{atm}, 26°C;
7 - 4000 atm, 24°C; 8 - 4000 atm, 26°C.

Fig.5. The relative changes of V_{BE} as a function of pressure for a planar transistor (OE connection)
1,2,3 - transistor 12; I_B: 30, 20, 10 µA
4,5,6 - transistor 13; I_B: 30, 20, 10 µA
7,8,9 - transistor 12; I_C: 2 mA, 500 µA, 100 µA.

Fig.6. $I_C = f(U_{BE})$ for a planar transistor (OE connection)
1 - atmospheric pressure; 2 - 6000 atm

Fig.7. The relative changes of U_{BE} as a function of temperature for a planar transistor (OE connection)
1,2,3, - I_C = 2 mA; P : atmospheric, 2500 atm, 5000 atm
4,5,6 - I_C = 500 µA; P : atmospheric, 2500 atm, 5000 atm

Fig.8. Coefficient of pressure quality for electric sensors
1,2,3 - manganin sensors (item 1,2 and 3 in Table 2)
4,5,6,7 - Te, InSb sensors (item 4,5,6 and 7 in Table 2)
10, 11 - planar transistor sensor (item 10 and 11 in Table 2).

Table 1.

Values of Coefficients a,b,c in Eq.2 (in the temperature range 0 - 50°C)

	Electric Sensor	a x 10^{-7} $[deg^{-2}]$	b x 10^{-5} $[deg^{-1}]$	c x 10^{-4}	$(\frac{\Delta R}{R_o})_{max}$ x 10^{-5}	t_{max} [deg]
1	German manganin at atmospheric pressure†	-4·1	1·26	-0·88	0·88	15·4
2	German manganin at 6000 atm	-3·57	1·82	-2·2	1·07	25·5
3	Russian manganin before heat treatment	-6·2	3·5	-4·5	4·25	28·2
4	Russian manganin after heat treatment	-4·65	2·38	-2·91	1·42	25·6
5	Russian manganin as in (4) at 3000 atm and 6000 atm	-4·1	3·11	-4·58	12·8	37·8
6	German-Russian manganin sensor‡	-4·35	1·82	-1·89	0·06	21·0
7	Te* (selected crystal)	-540	350	-490	770	32·4
8	InSb* (selected crystal)	0	-0·085	1700	-	-
9	Te + InSb**	-500	260	-330	126	26·0

†Before and after heat treatment.

‡Sensor constructed by Czaputowicz by connecting German and Russian manganin (as in items (2) and (4)).

*In the temperature range 15 - 30°C.

**Monocrystals Te ($R_{Te} \approx 12.5$ ohm) and InSb ($R_{InSb} \approx 1$ ohm) connected in series.

Table 2.

Basic Parameters of Electric Sensors for High-pressure Measurements (averaged values in the temperature range 15-25°C and in the pressure range up to 2000 atm)

	Electric Sensor	$\varkappa$	$\alpha_\varkappa$ x 10^{-6} $[atm^{-1}]$	$\beta_\varkappa$ x 10^{-5} $[deg^{-1}]$	$\gamma_\varkappa$ $[atm \cdot deg^{-1}]$	$Z_\varkappa$ $[deg \cdot atm^{-2}]$
1	German manganin	R_G	2·1	-0·4	-1·9	-11
2	Russian manganin†	R_R	2·4	0·5	2·08	11·5
3	German-Russian manganin‡	R_{1+2}	2·25	0·1	0·44	51·1
4	Te	R_{Te}	-360	-1700	47	-76
5	InSb	R_{InSb}	300	-1200	-40	-75
6	Te(4) - InSb(5)*	R	-330	-250	7·5	-440
7	Te (selected crystal)	R_{Te}	-100	100	-10	100
8	InSb (selected crystal)	R_{InSb}	200	-900	-45	-44·4
9	Te(7) + InSb(8)**	R_{7+8}	-100	70	-7·0	142
10	Planar transistor U_{CE} = const. U_{BE} = const.	I_c	67	7200	1074	0·62
11	Planar transistor U_{CE} = const. I_c = const.	U_{BE}	2·3	-240	-1043	-0·022

† After heat treatment. ‡ As in Table 1, item 6.

* In the neighbouring branches of a Wheatstone bridge.

** As in Table 1, item 9.

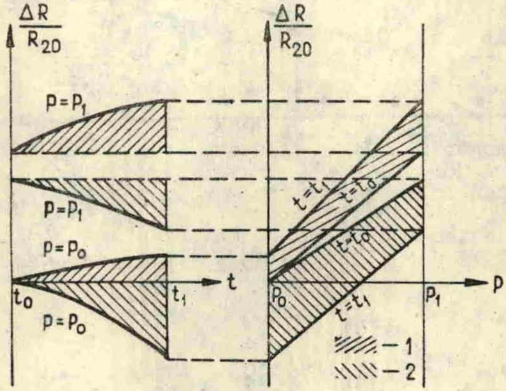


Fig. 1

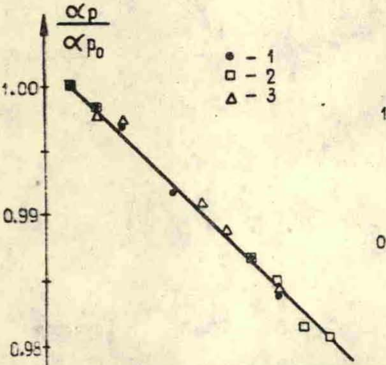


Fig. 2

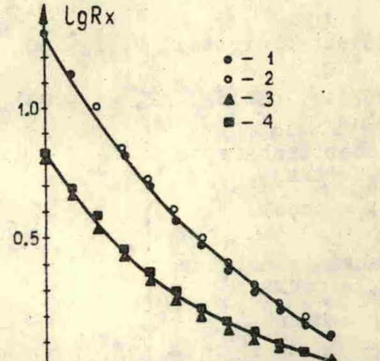
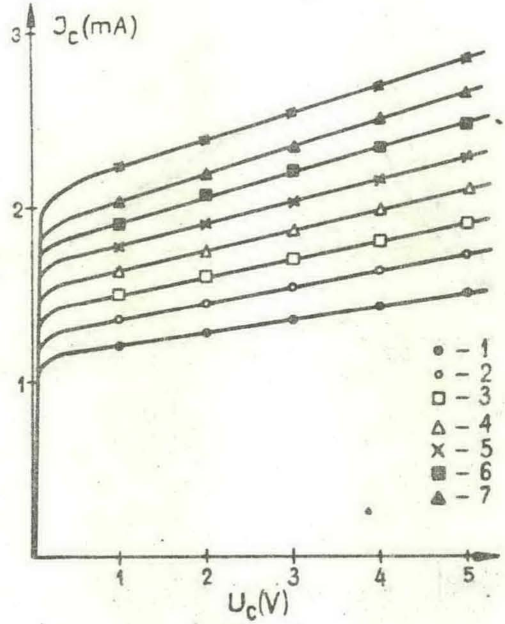
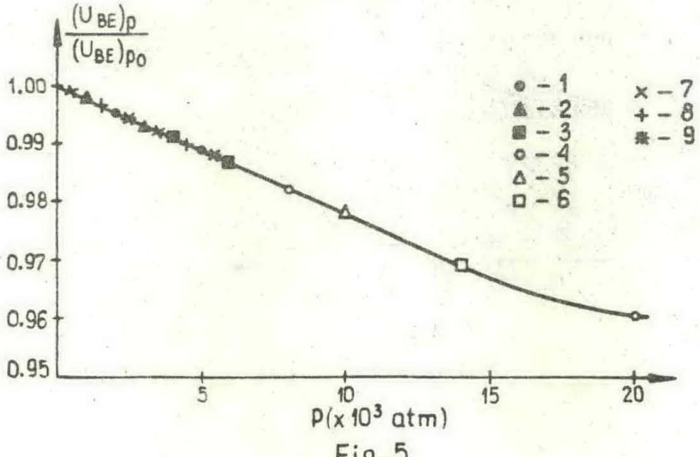


Fig. 3



J_c(mA)
3
2
1
1
2
3
4
5
U_c(V)
● – 1
○ – 2
□ – 3
△ – 4
× – 5
■ – 6
▲ – 7

Fig. 4



$\frac{(U_{BE})_p}{(U_{BE})_{p0}}$
1.00
0.99
0.98
0.97
0.96
0.95
5
10
15
20
P(x 10^3 atm)
● – 1
▲ – 2
■ – 3
○ – 4
△ – 5
□ – 6
× – 7
+ – 8
* – 9

Fig. 5

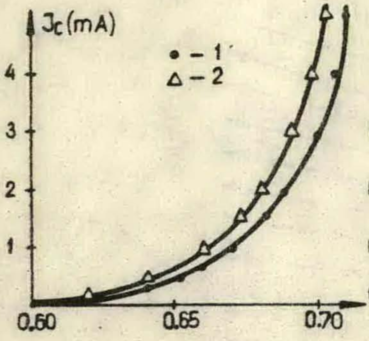


Fig.6

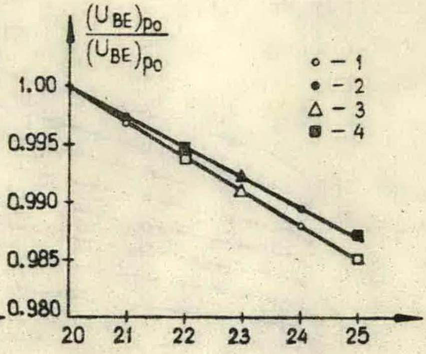


Fig.7

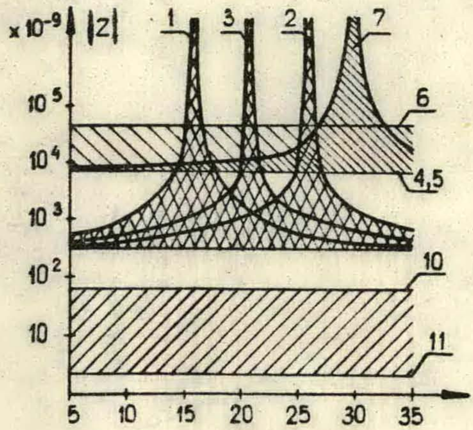


Fig.8

Printed MTESZ, BUDAPEST - 1259