5 Silicon Temperature Sensors

5.1 Introduction

The KTY temperature sensor developed by **Siemens** is based on the principle of the Spreading Resistance.

The expression “Spreading Resistance” derives from a method, called the “one-point-method” (**figure 18**) used to measure the specific resistivity of semiconductor wafers.

The resistance R is given by:

$$R = \frac{\rho}{\pi \times d}$$

where:

R Sensor resistance (Ω)
ρ Specific resistivity of bulk Silicon ($\Omega \times$ cm)
d Diameter of measuring point (cm)

This measurement is independent of the thickness, “D” and the diameter of the wafer, as long as the contact point diameter “d” is negligibly small in comparison.

In addition, the contact resistance between semiconductor and metal is also measured.

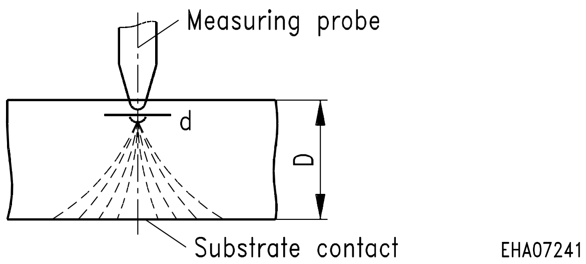

Figure 18
Measuring the Specific Resistance of Semiconductors Using the “One-point Method”

In a conventional temperature sensor based on the principle of spreading resistance, a contact hole in the oxide mask serves as the measuring point (**figure 19**). In order to comply with the measuring principle, the hole diameter must be negligibly small compared to the chip dimensions.

An essential feature of the spreading resistance sensor is that it contains no p/n junction.

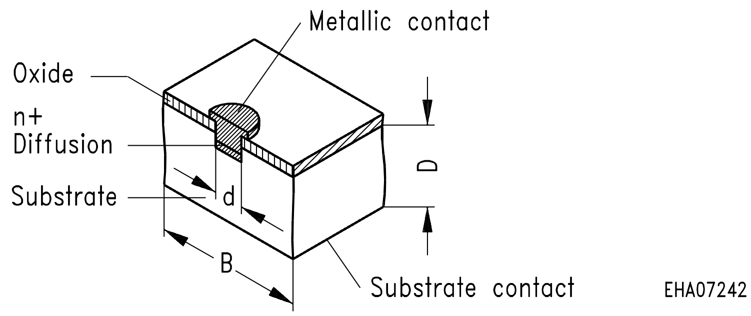

Figure 19
Conventional Spreading Resistance Temperature Sensor

The basic conduction mechanism can be explained by looking at a single Si-crystal. At normal temperatures all crystal locations are ionised, so an increase in temperature does not lead to an increase in the number of charge carriers. However, the increased lattice energy associated with a rise in temperature leads to an increase in the phonon scatter within the crystal and thereby increases the resistance. A Si-temperature sensor based on the spreading resistance principle therefore has a positive temperature coefficient (**figure 20**).

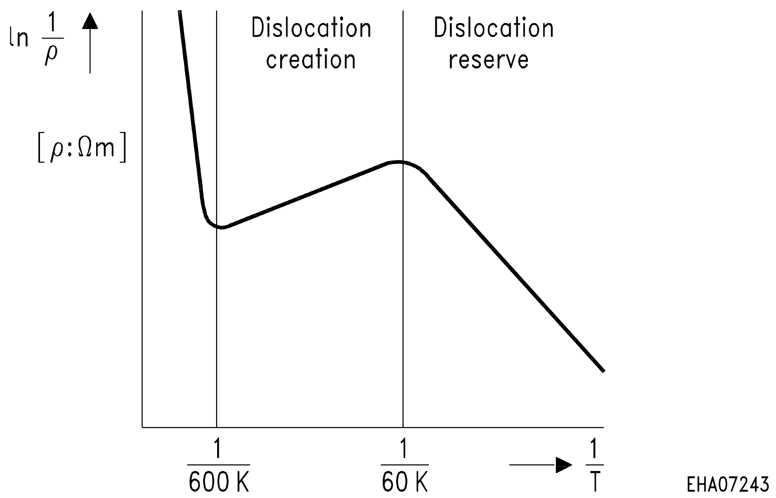

Figure 20
Change in the Specific Conductivity of Silicon with the Reciprical Temperature 1/*T*

The temperature range of dislocation creation is limited by the intrinsic conductivity process at higher temperatures and by the dislocation reserves at low temperatures. This gives a natural boundary on the measurement range of a Spreading resistance sensor, it is dependent on the crystal doping. A specific resistance of about 7 Ωcm results in a TC factor (100 °C/25 °C) of 1.70. With a hole diameter of 22 µm this gives a resistance value of 1000 Ω.

In a conventional spreading resistance temperature sensor the current flow spreads from the contact hole in the oxide mask on the chip surface through to to the rearside of the chip (**figure 18**).This construction is assymmetric and, due to the non-ohmic contact between the metalisation and the silicon, produces to a resistor which is dependent on current direction.

To overcome this, a symmetric construction was selected for the KTY temperature sensor (**figure 21**). Here, two spreading-resistance sensors are put in series with one another, the current through the sensor then flows through two identical contact holes in the oxide mask. With this arrangement the sensor is low in capacitance; this means that the sensor has to be protected against high voltages.

With the optimised values of 7 Ωcm and 22 µm hole diameter the sensor resistance is defined at (2 × 1000) Ω = 2000 Ω.

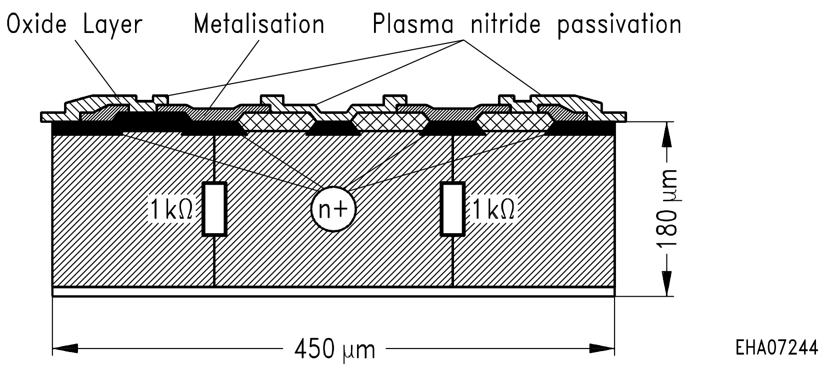

Figure 21
Schematic Cross Section through the Temperature Sensor KTY Chip

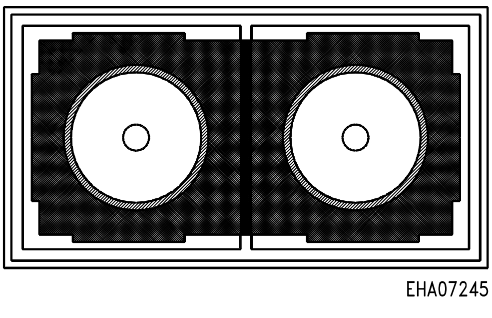

Figure 22
View on the KTY Sensor Chip

5.2 Technology of the KTY Temperature Sensor

Photolithography with image definitions in the sub micron range are used to produce the KTY temperature sensor. A double layer of Oxide and Nitride on the chip surface serves as an insulation film. After deposition of the contact areas, this is again covered with plasma nitride, only that over the contact point being etched away to allow bonding. The chip produced in this process is thereby fully passivated against environmental influences.

In order to increase the yield of chips per wafer which fall into the tightest possible tolerance band, neutron activated material is used in the production of the KTY sensors. In this doping method the silicon wafer is implanted with neutrons in a nuclear reactor which change Si-atoms into P-atoms. This method allows not only a precise doping level (to 0,1%), but also gives exceptionally high homogeneity (1% Tolerance on doping level instead of 15% with normal material).

The quality of the contact of the back of the Silicon chip to the metal lead frame is a further factor influencing the resistance value of a conventional spreading resistor sensor. With the KTY sensor the chip rear side is coated with Gold and alloyed to the lead frame. In comparison to the conventionally used adhesive solution this leads to a higher stability of the bonding between the sensor chip and the lead frame.

The restrictions placed on the contact holes are decisive for the reproducibility and the long term stability. In the KTY sensor a multi-layer metalisation is employed as opposed to the conventional Al-Metalisation. This multi-layer metalisation of Ti-Pt-Au, was developed for industrial microwave components which normally have very high current densities and which place strong demands on reliability. This together with Au-thermo-compression bondwire contacting assures high reliability in the KTY sensor. **Figure 23** shows results of long-term high temperature steady state operation.

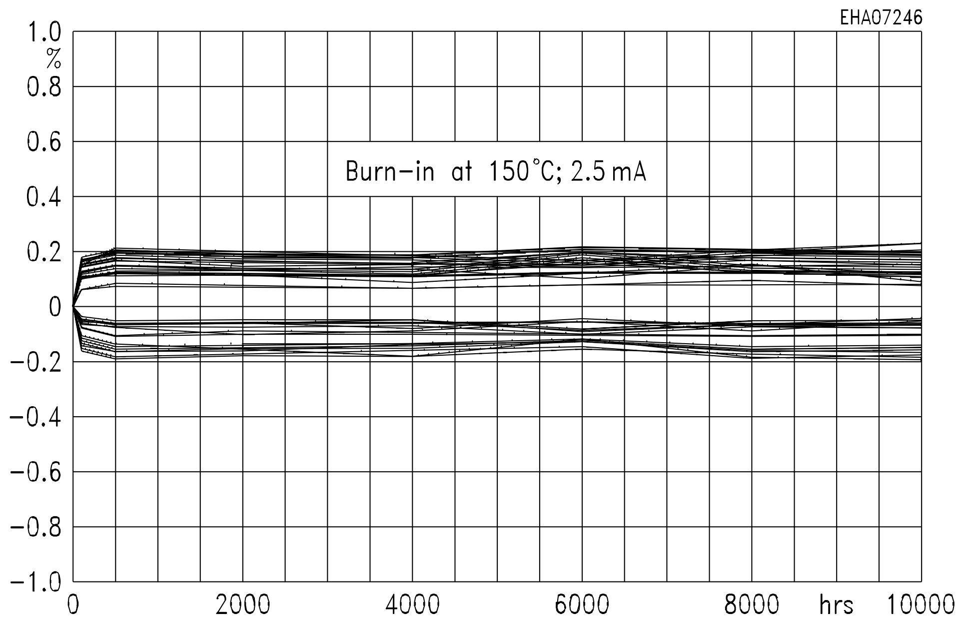

Figure 23
Drift of the Resistance *R* with Long-term High Temperature Steady State Operation

Spread of Resistance Value and Corresponding Temperature Error

Table 8

T °C	**Resistance Band** Ω		**Temperature Deviation** °C
	KTY 10-6/11-6/13-6[1)]	**KTY 21-6/23-6**[2)]	
– 50	1002.2 … 1070.5	501.1 … 535.2	± 3.43
– 45	1053.0 … 1121.0	526.5 … 560.5	± 3.29
– 40	1105.9 … 1173.3	553.0 … 586.7	± 3.15
– 35	1160.9 … 1227.5	580.4 … 613.7	± 3.00
– 30	1217.9 … 1283.5	608.9 … 641.7	± 2.86
– 25	1276.9 … 1341.3	638.4 … 670.7	± 2.71
– 20	1338.0 … 1401.0	669.0 … 700.5	± 2.57
– 15	1401.1 … 1462.4	700.6 … 731.2	± 2.43
– 10	1466.3 … 1525.7	733.1 … 762.9	± 2.28
– 5	1533.5 … 1590.9	766.8 … 795.4	± 2.14
0	1602.8 … 1657.8	801.4 … 828.9	± 1.99
5	1674.2 … 1726.6	837.1 … 863.3	± 1.85
10	1747.5 … 1797.2	873.8 … 898.6	± 1.71

Table 8 (cont'd)

T °C	Resistance Band Ω KTY 10-6/11-6/13-6[1)]	Resistance Band Ω KTY 21-6/23-6[2)]	Temperature Deviation °C
15	1823.0 … 1869.6	911.5 … 934.8	± 1.56
20	1900.5 … 1943.9	950.2 … 972.0	± 1.42
25	1980.0 … 2020.0	990.0 … 1010.0	± 1.27
30	2057.0 … 2102.6	1028.5 … 1051.3	± 1.41
35	2135.8 … 2187.3	1067.9 … 1093.6	± 1.56
40	2216.4 … 2274.0	1108.2 … 1137.0	± 1.71
45	2298.8 … 2362.7	1149.4 … 1181.4	± 1.85
50	2383.1 … 2453.5	1191.5 … 1226.8	± 1.99
55	2469.2 … 2546.4	1234.6 … 1273.2	± 2.14
60	2557.1 … 2641.3	1278.6 … 1320.6	± 2.28
65	2646.9 … 2738.2	1323.4 … 1369.1	± 2.43
70	2738.5 … 2837.2	1369.2 … 1418.6	± 2.57
75	2831.9 … 2938.3	1415.9 … 1469.1	± 2.71
80	2927.1 … 3041.4	1463.6 … 1520.7	± 2.86
85	3024.2 … 3146.5	1512.1 … 1573.3	± 3.00
90	3123.1 … 3253.7	1561.5 … 1626.9	± 3.15
95	3223.8 … 3363.0	1611.9 … 1681.5	± 3.29
100	3326.3 … 3474.3	1663.2 … 1737.2	± 3.43
105	3430.7 … 3587.7	1715.3 … 1793.8	± 3.58
110	3536.9 … 3703.1	1768.4 … 1851.5	± 3.72
115	3644.9 … 3820.5	1822.5 … 1910.3	± 3.87
120	3754.8 … 3940.0	1877.4 … 1970.0	± 4.01
125	3866.4 … 4061.6	1933.2 … 2030.8	± 4.15
130	3979.9 … 4185.2	1990.0 … 2092.6	± 4.30
135	4043.5 … 4256.3	2021.7 … 2128.2	± 4.44
140	4145.0 … 4367.5	2072.5 … 2183.8	± 4.59
145	4246.6 … 4478.9	2123.3 … 2239.4	± 4.73
150	4348.1 … 4590.2	2174.0 … 2295.1	± 4.87

1) R_{25} = 1980 … 2020 Ω
2) R_{25} = 990 … 1010 Ω