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16. Abstract

The measurement characteristics of thin-Pt-film temperature sensors fabricated using advanced methods are discussed. The limitations of wound-wire Pt temperature sensors and the history of Pt-film development are outlined, and the commonly used film-deposition, structuring, and trimming methods are presented in a table. The development of a family of sputtered film resistors is described in detail and illustrated with photographs of the different types. The most commonly used tolerances are reported as + or -0.3C + 0.5 percent of the temperature measured.


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PLATINUM THIN FILM RESISTORS AS ACCURATE AND STABLE TEMPERATURE SENSORS

W. Diehl*

## Introduction /89

The temperature more or less influences the electrical resistance of all conducting substances. This is exploited in resistance thermometry for measuring temperature.

The range 200-850°C was, up until a few years ago, only covered by platinum (temperature) measurement resistors using the wound wire technology. Special designs with stress-free "suspended" measurement wire were also used for representation of the international practical temperature scale. But, the mass-produced platinum wire measurement resistors manufactured in great numbers by special firms have achieved a high state of technology. In these elements, characteristics such as mechanical stability, shaking resistance, etc. are most important. These are requirements which calibration thermometers and laboratory thermometers do not satisfy.

The resistance-temperature relationship of industrial temperature measurement resistors is specified in well-known standards, for example, the BS 1904 and the DIN 43760 standards. Progress is being made on an international standard. The tolerances specified in the standards for the electrical values allow temperature measurements within an accuracy of about 0.25-0.5% of the temperature, already using standard platinum resistors, even those which have not been specially calibrated.

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The realization of resistance temperature relationships, for example, according to DIN 43760 requires a platinum scale /90 with 98% of the specific electrical conductivity of the highly pure and compact platinum in the finished resistance element.

Already the manufacture of platinum resistors using wire-wound technology and which have this property requires substantial know-how. In the case of platinum layer resistors, one has to, to begin with, count on additional effects which reduce the conductivity, which are related to the physics of thin layers and the inclusion of impurities when the layer is created. This is probably the reason why the Pt measurement resistors using the layer technology according to the standards only appeared later on commercially. On the other hand, Pt layer resistors have a resistance-temperature variation which deviates from the standards and these hardly can be sold commercially, because it is not possible to exchange them freely with platinum measurement resistors which satisfy the standard. Also, they cannot be used in a straight-forward manner in existing measurement devices.

## Limits of wire-wound platinum measurement resistors

The most demanding and most well-known version of a platinum measurement resistor is the ceramic measurement resistor. The measurement wire is in the form of a coil, which is installed in the longitudinal cavities of a cylindrical ceramic insulated body and is fixed in it.

The practical requirements for smaller and smaller dimensions and higher resistance values led to the use of wires with smaller and smaller diameters. There is a limit on how these can be manipulated and these limits have now been reached.

The production technology includes a number of manual steps which cannot be further rationalized or automated in a rational manner. Therefore, we do not expect a significant reduction in the production costs of conventional platinum measurement resistors which could then lead to an expansion of the possible applications.

<u>The development of platinum temperature measurement resistors using layer technology</u> /91

In the last few years, a few manufacturers have started to introduce new technologies for production: instead of measurement wires, thin platinum layers are used as temperature sensitive elements. The layers are applied to flat or cylindrical ceramic carriers. The layer thickness is always in the range between 1 and 2 $\mu$m, is introduced into a conductor band structure having the shape of a meander, so that the desired resistance values are achieved in the smallest possible dimensions.

Three different methods of layer production are used, that is:

- vacuum,
- deposition-cathode vaporization (sputter),
- burning in of a platinum thick film paste.

Independent of the methods used, substantial research has to be performed in order to produce platinum layers with the desirable electrical characteristics required by the European industry, that is, a temperature coefficient of the electrical resistance of 3.85 $10^{-3}$ deg. which amounts to 98% of the specific electrical conductivity of the purest compact platinum.

There were additional unsolved problems:

- deficient adherence of the layer on the substrate
- meandering and fine trimming of the resistors which depend very greatly on temperature
- methods for attaching connection wires onto the layer

In the meantime, six manufacturers in the world are producing platinum layer measurement resistors according to DIN 43760. Three of these manufacturers use the thick film technology and two additional ones use the vacuum vaporization method.

The platinum layer measurement resistors which are introduced here are produced by cathode vaporization. /92

Table 1 gives a summary on the main production steps when producing platinum layer measurement resistors, which can be obtained commercially.

| Layer Production Method | Production of the Meander Structure | Fine Trimming |
|---|---|---|
| Cathode Vaporization | Laser Processing | Laser Processing |
| Vaporization | Laser Processing | Laser Processing |
| Burning in of a platinum thick film paste | Laser Processing | Laser Processing |
| Burning in of a platinum thick film paste which is printed with a sieve pressure mask in the shape of a meander | | Laser Processing |
| Burning in of a platinum thick film paste which is printed with a sieve pressure mask in the shape of a meander | | By producing a short circuit bridge |

Table 1: Methods for producing platinum layers, the meander structure and the fine trim method when producing the platinum layer measurement resistors from various manufacturers available commercially now.

It is not the purpose here to critically compare the methods discussed in Table 1. However, we can notice that the platinum layer measurement resistors with an ice point resistance of 1kΩ do not yet exist in the marketplace if based on thick film /93 technology.

A type program of sputtered platinum layer measurement resistors

The "natural" form of platinum temperature measurement resistors manufactured according to the layer technology is the flat measurement resistor in the form of a small plate. One can use flat $Al_2O_3$ substrates available commercially for producing such elements. The covering of such substrate plates with a platinum layer of uniform thickness using HF cathode vaporization is one method which can be easily used with the sputter facilities available commercially. However, special processing parameters are required in order to achieve suitable adhesion on the substrate and at the same time to bring about the desired electrical properties of the platinum layer.

Figure 1 shows a cube shape Pt100 basic element. The contact surfaces with the connection wires applied by thermal compression welding techniques are at the end of the chip in contrast to what is usually done. Between the connection surfaces one can see the meander shape conductor paths with a few additional fine trim steps, and these are defined by insulated laser sections. The dimensions of the chip are 0.65 mm (equal substrate thickness) x 5 mm x 1 mm. For special purposes, a substrate thickness of 0.25 mm is also used. The temperature sensitive meander surface is not greater than about 1.5 $mm^2$ as can easily be seen.

In principle, the basic element shown can already be used as a temperature measurement resistor in this form. The adhesion of the platinum layer on the substrate is very good. The adhesion force of the connection wire-welding connection on the platinum layer measured in a 90° pull test is around 300 p. In practice however one finds that if one bends the connection wires upwards several times, the welding joints can become separated due to the notch effect. In other words, additional measures are required to mechanically unload the connection points. Figure 2 gives one possible solution of this problem by welding on a ceramic two-hole disc, in order to relieve the stress.

This unloading of the welding joints was found to be /94 very effective. Any pulling or bending load on the wires does not attack the welding joint, but instead on the ceramic support body. Therefore, the tearing strength of the wires and not the strength of the welding joints determines the mechanical stability of the electrical connections.

All the flat measurement resistors of the type program were equipped with such a stress relief. In other cases, encapsulation provides for the mechanical support of the wires.

The chemical resistance of the platinum as well as the good adhesion properties of the sputtered platinum layers on the substrate would allow using the flat measurement resistor with an unprotected surface. The platinum layer however is very sensitive to mechanical effects (crashes, etc.) which can cause resistance changes, in the soft-annealed state. A glass ceramic insulation layer with a thickness of about 10 $\mu$m is an effective protection. This layer also allows one to produce platinum layer measurement resistors for continuous operation up to 600°C.

The melting on of a mechanical stress relief device for the connection wires leads to a flat measurement resistor according to Figure 2 in conjunction with the glass ceramic covering layer, the simplest encapsulation technology, mentioned above. Of course this can be produced with various dimensions and resistance values. In addition to the version of the flat measurement resistor up to 600°C with a high quality noble metal connection wire alloy, we produced a variation which can be used up to 400°C. By using cheap silver connection wire alloys one can substantially reduce the production costs.

The traditional form of the cylindrical ceramics measurement resistor with connection wires on one side is advantageous when installing them in tubes closed on one end (measurement applications) and therefore still remains attractive. The plate shaped basic elements with connection wires for producing flat measurement resistors are therefore given dimensions to begin with (with some exceptions) so that they can be introduced /95 in cylindrical $Al_2O_3$ tubes in the longitudinal direction. By melting the open ends of the tube with a glazing, which at the same time also melts in the two ends of the chip and the connection wires and attaches them, one obtains a resistance element in this way whose external shape corresponds exactly to the conventional wire-wound ceramic measurement resistors. For example, the basic element shown in Figure 1 can be introduced into a thin wall $Al_2O_3$ tube with an external diameter of 2 mm and a length of 5 mm and the ends of the tube can be melted closed as described above. This can be done by directing one of the connection wires around the bottom side of the chip.

Production cost savings are achieved with the 400°C version by using a cheap silver connection wire alloy.

Figure 3 shows a view of the interior of the opened Pt-100Ω measurement resistor with dimensions 12 mm x 3 mm diameter, obtained by grinding off the upper third of the cylindrical body. As can be seen, the meander area is not in contact with the tube inner wall or with the end connections. The area available on the installed chip is only occupied to a small degree by the meander. Without any changes in the external dimensions, one can produce platinum layer measurement resistors with $R_o$ values of up to 1KΩ without changing the outer dimensions. Even 1KΩ double measurement resistors with dimensions of 12 mm x 3 mm diameter can be produced.

In addition to these models, which are derived from traditional applications and surface measurements, additional encapsulation technologies have been developed for Pt layer measurement resistors which are related to production methods for electronic components. For example, one can use mass-produced housing parts and machines available commercially. Figure 4 in the center shows a Pt100 in a T018 transistor housing. Figure 5 shows this measurement resistor type before welding the cap. /96 There's a 0.65 mm x 2 mm x 2.3 mm Pt 100Ω chip mounted on the transistor socket, which is also the base element of the flat measurement resistor shown in Figure 2. The electrical connection between the chip to the free ends of the gold-plated Kovar wires is produced by "bonded" gold wires (can be seen in the photograph as loops). (The free ends are isolated in the glass and melted into the base plate.)

The platinum thin layer element installed in the metal transistor housing is well suited because of its gas tight encapsulation for direct use; for example, in a human atmosphere and in liquids. Maximum use temperature: 200°C. If one uses a TO39 housing, $R_o$ values of up to 1 kΩ can be produced.

A closed flat housing represents another kind of encapsulation, as is often used in electronic manufacturing for producing highly integrated components such as operational amplifiers, gates, etc. This square shaped housing when delivered consists of two separated, almost equal, halves which have a low melting glazing layer on them along the frame shaped separation surfaces. After laying down the platinum thin layer measurement resistor chips with the connection wires into one of the halves of the housing, the two halves are again brought together by melting the glazing together again. The connection wires which go to the outside are melted into the glazing layer. Figure 5 gives an example of such a sensor. In this type we have realized nominal resistances of up to $R_o$ = 1KΩ. The housing allows continuous operational temperatures of up to 350°C. This means that we have an additional temperature range of the metal transistor housing towards higher temperatures.

At the end of this chapter we would like to discuss a special type developed for a special purpose (ice warning systems for vehicles), which is shown in Figure 5 on the right. This is a chip with dimensions of 4 mm x 5 mm x 0.65 mm with $R_o$ = (1000 ±1)Ω. The meander is protected with a glass ceramic insulation layer. The electrical connections are zinc plated hard copper conductors with a rectangular cross section. /97
The maximum continuous operating temperature is 200°C.

## Conclusion

It was the purpose of this paper to point out the extended application of platinum resistance thermometry, which the new production technology is now making possible. Typical models and possibilities are discussed. The reader is referred to sales literature for a summary of all available dimensions, resistance values, tolerances and data.

At the present time the tolerance asked for the most for the new sensors is ±[0.3°C+0.005 T(°C)] class B according to DIN43760. The lower temperature limit is -50°C in all models. The upper temperature limits are selected so that after repeated cyclical temperature changes between the upper and lower temperature limit and/or a 100 hour continuous test at the upper temperature limit, the $R_o$ change does not exceed 0.06%. In this specification, the platinum thin layer resistor corresponds to the traditional wire wound version. Many versions therefore use the new sensors for precision temperature measurement. In particular, the advantages of the new low-ohm, low-temperature versions are completely exploited with respect to production costs and savings possibilities for measurement equipment. Typical applications include ice warning systems for vehicles, the control of thermal pumps and heat measurements in heating installations.

The range of moderate temperature (up to about 200°C) with large tolerances (a few degrees) is presently covered by NTC resistors. The negative temperature coefficient of the electrical resistance and the characteristic line which is greatly curved without additional circuits, however, is unsuitable for many applications. This tendency (caused by the energy shortage) for higher accuracy of temperature measurement therefore will mean that the cheap platinum sensors will be able to be used in [illegible] applications as well.

There is another group of new applications for the /98
temperature range between 200°C to 600°C with large tolerances. For example, we mean heating and temperature control of soldering irons, temperature measurement in ovens and baking ovens and monitoring of surface temperature of expensive facilities which could overheat.

The range of possible applications of the new family of platinum sensors is still being expanded. Essentially this depends on the imagination of the designer, who must not restrict his imagination to the standard program presented in the sales literature. The flexibility of the production methods and the collected knowhow will allow the new design and prototype fabrication of any new sensor type.

Figure 1: Resistance element Pt100 with dimension 0.65 mm (thickness) x 5 mm x 1 mm.

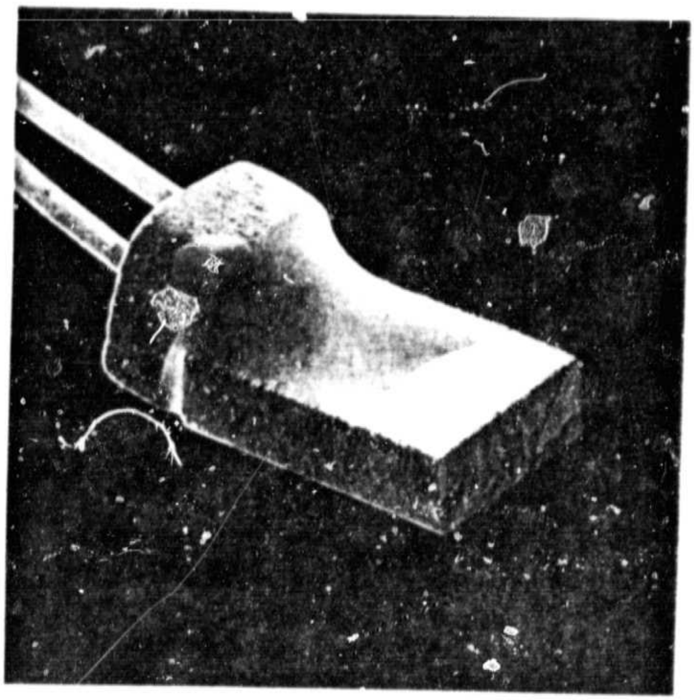

Figure 2: Flat measurement resistor Pt100 with melted on stress relief device for the connection wires. Chip dimension 0.65 mm (thickness) x 2 mm x 2.3 mm.

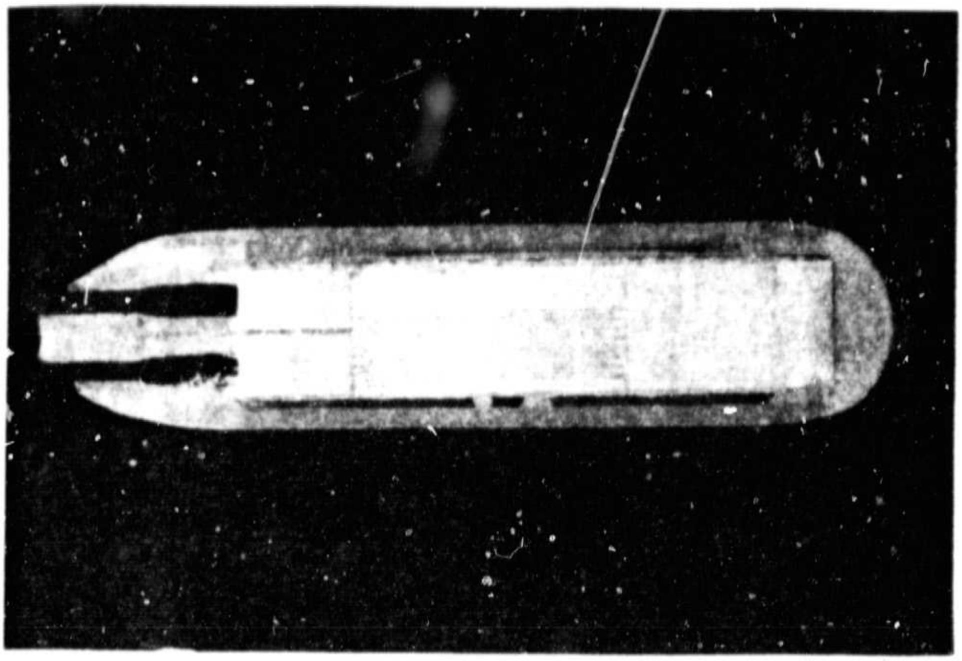

Figure 3: Cylindrical ceramic thin layer measurement resistor 12 mm x 3 mm diameter, $R_o$ = 1000Ω which has been opened by grinding, with installed basic element of dimensions 0.65 mm (thickness) x 2 mm x 10 mm.

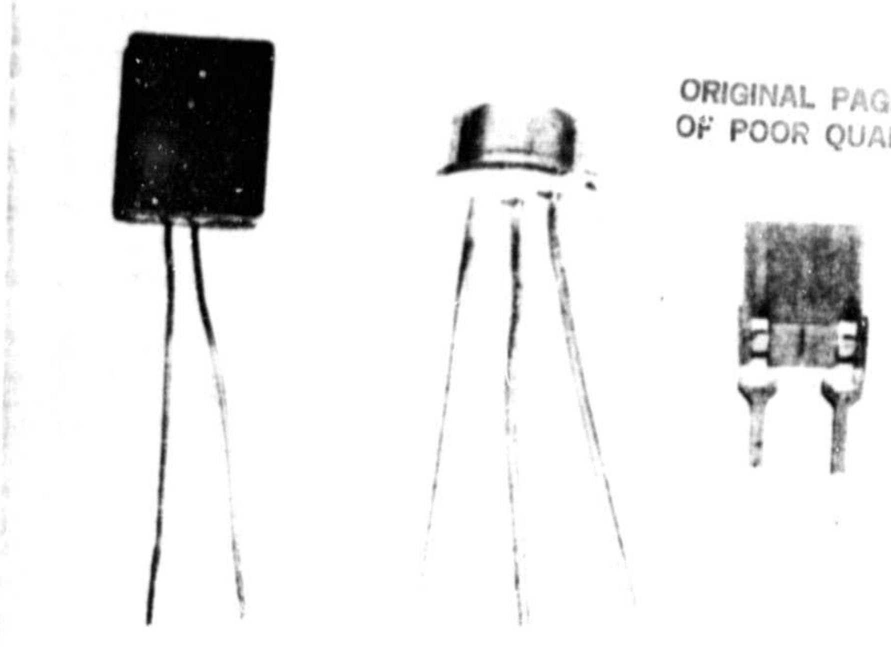

Figure 4: Platinum thin layer measurement resistor in ceramic housing up to 300°C (left), in T018 housing up to 200°C (center), and in the 1000Ω flat version. (Chip dimension 0.65 mm (thickness) x 4 mm x 5 mm) for vehicle ice warning systems with zinc covered hard copper connection terminals.

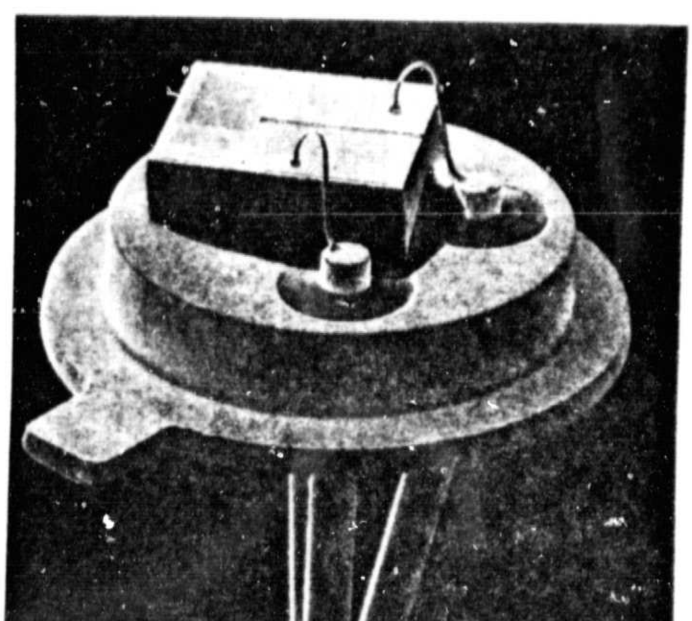

Figure 5: T018 glass penetration for transistors with installed Pt100 chip with dimensions 0.65 mm (thickness) x 2 mm x 2.3 mm.