

Thick Film Platinum Resistance Temperature Detectors

THE DEVELOPMENT AND MANUFACTURE OF ADVANCED TYPES FOR INDUSTRIAL AND DOMESTIC APPLICATIONS

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The development of a range of thick film platinum resistance temperature detectors is described and the method of manufacture of a cylindrical version by a highly automated route is outlined. These novel detectors comprise a film of platinum bonded to an inert ceramic substrate and protected from the environment by a ceramic glaze and the advanced version of this series shows stability in sealed probes to maximum rated temperatures as well as improved thermal stability relative to previous versions.

The platinum resistance thermometer is a key instrument in the definition of the International Practical Temperature Scale. Its simplicity of operation has resulted in its widespread application in scientific research and its use as a working standard in many calibration establishments. Furthermore, the ready availability of high quality detectors manufactured to internationally recognised standards such as BS1904 and DIN43760 has resulted in the widespread industrial use of platinum resistance temperature detectors, or R.T.D.s.

Wire Wound Detectors

The history of the development of the platinum wire wound resistance thermometer was recently reviewed in this journal by Hunt (1). The pioneering work of Callendar and Griffiths established the critical importance of both the purity of the fine platinum resistance wire, typically 0.001 inch in diameter or less and of the construction of the detector in preventing strain either during manufacture or service or contamination from either processing, the materials of construction or the working

environment. The availability of a large variety of wire wound detectors is a tribute to the painstaking investigations of many workers in this field. A range of wire wound detectors has been developed to satisfy the temperature intervals required and the nature of the many applications. The most common involves a coil of fine platinum wire supported within, and attached to, the bores of a ceramic tube by means of a glass. The whole unit is coated with an insulating material through which electrical connections are made by means of stout platinum leads.

The materials used in the manufacture of wire wound platinum R.T.D.s are necessarily expensive. In addition, construction is skill-intensive, laborious, and demanding of quality assurance. There exists only modest scope for automation, and accordingly unit costs are relatively high and likely to increase. In consequence, although wire wound R.T.D.s offer numerous technical advantages over other electronic detectors, such as thermocouples and thermistors, their wider application is constrained by considerations of cost. Clearly removal of this cost constraint would not only

offer the possibility of securing a share of the current wire wound R.T.D. market, estimated at several million a year, but would also offer the possibility of expanding the overall portion of the temperature sensor market taken by R.T.D.s.

The Early Development of Thick Film Devices

Initial work reported by Iles and Tindall (2) indicated that thick film technology offered considerable potential for the production of platinum resistance thermometers. Other methods of platinum deposition without exception suffered serious technical or economic disadvantages. By careful control of process variables it was demonstrated that devices conforming in all respects to the requirements of BS1904 could be produced by the screen printing method. The monolithic construction of these devices confirmed particular advantages in terms of response time, resistance to vibration and mechanical durability, and they were marketed under the trade name Thermafilm®. Subsequently this technology was extended to enable manufacture of small flat devices and yet further developed to allow fabrication of a cylindrical device compatible with the popular 4 mm probe. In the case of the cylindrical R.T.D. the ceramic substrate was first evenly coated with platinum ink which was then formed into a spiral resistance track by an abrasive wheel.

Development of this basic range of devices enabled small scale production to be established and trial marketing to be undertaken. These activities provided vital feedback, and strong interest in the market place confirmed the viability of the basic concept of mass produced precision components. The principle conclusions drawn from this preliminary phase of the development were:

- (a) Although there exists a substantial market for flat devices the main interest is centred on devices compatible with the popular 4 mm probe.
- (b) A key requirement not met by the initial development was the ability to maintain

stability in sealed stainless steel probes at temperatures above 400°C.

- (c) Both manufacture and quality control still involved a high degree of skilled manual work.

Advanced Development of Thick Film Devices

The initial phases of development indicated that the basic problems were to resolve the materials problems inherent in meeting the basic performance criteria of BS1904, especially when sealed in steel tubes and used at maximum operating temperatures, and then to establish a production facility capable of manufacturing high quality devices in the number required, and at an acceptable price.

Many of these problems are interlinked, thus design features of the ceramic support can radically simplify or complicate the mechanical handling part of machine design, while the requirement for robust terminations may require development of novel materials compatible with the established electrical performance and stability criteria for R.T.D.s.

Basic research revealed the mechanism of degradation of electrical properties during ageing. Modifications to proprietary materials and processing subsequently resolved the durability deficiencies of early devices. The improvement in performance is illustrated in Table I. Parallel work resulted in the development of inks having improved platinum dispersion and stability characteristics and with rheology tailored to the dipping method of film formation.

Following these advances in materials technology an extensive evaluation of potential production processes was undertaken. Such diverse processes as laser scribing, screen printing and air abrasion were evaluated for resistance track definition. Ultimately laser scribing was selected as the most flexible method of achieving the resistance tolerances required. Evaluation of commercial techniques for wire bonding failed to identify a satisfactory method for providing terminations, however this difficulty was finally overcome by the

development of a proprietary wire bonding and reinforcement technique that provides terminations of outstanding strength. The bond strength in tension is comparable to that of the termination wire itself.

Automated Manufacture of Film Devices

The final version of the manufacturing process involves six major stages operated on a

continuous batch basis. This mode of operation offers many advantages including batch identification, creation of buffer stocks to maintain smooth flow of production, and institution of rigorous quality control checks at each process stage. Most of these manufacturing stages are undertaken on unique machines. They incorporate precision engineering and, in certain instances, on-line computer control to ensure maximum flexibility and the minimum

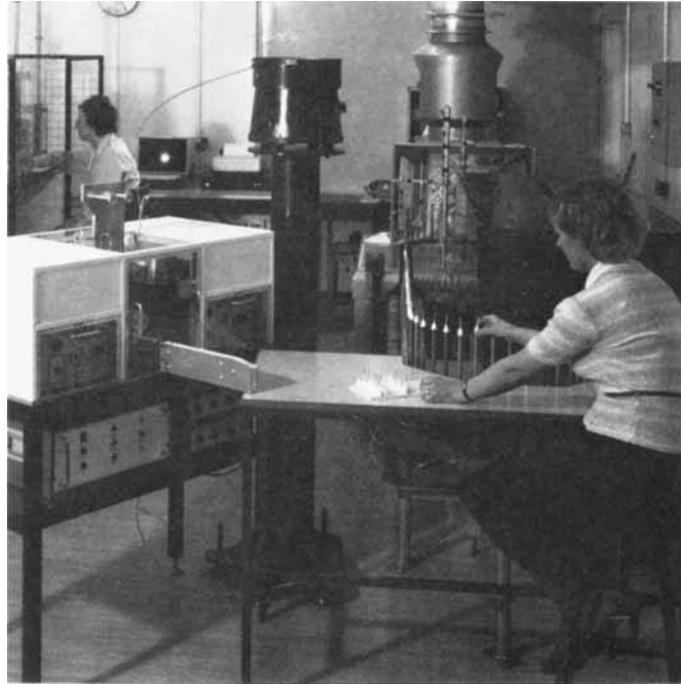


Fig. 1 Ceramic substrates are delivered by a vibratory feed system to an endless chain conveyor that carries them through both the dipping stage, where the platinum film is deposited, and the subsequent drying operation. Next, the coated substrates are automatically loaded on to refractory kiln furniture ready for firing



Fig. 2 The resistance path is defined by a pattern of lines burnt through the platinum film by a high intensity laser beam. This is controlled by an on-line computer to provide the requisite accuracy. The whole operation can be observed by a close circuit television system

Fig. 3 Part-finished units with the required resistance value have the terminal wires attached automatically, the bond strength developed being comparable to that of the wire itself. Subsequently the insulating glaze is applied and the units fired



of operative intervention. The main process stages are as follows:

Film Formation

The equipment shown in Figure 1 produces coated substrates. These are delivered to the equipment by vibratory feed and carried to the coating zone by conveyor system. The conducting film is applied by dipping in a platinum based ink of precisely defined rheological characteristic. After drying the coated ceramic is fired to eliminate organic components, to densify the platinum film and to bond it securely to the substrate.

Pattern Definition and Trimming

The coated substrate is converted into high precision resistors using the equipment shown in Figure 2. The basic resistance track is defined by a complex pattern of lines burnt through the conductive platinum film using a prefocused, high intensity laser beam. The whole operation is monitored by a high speed automatic resistance bridge coupled to an on-line com-

puter that controls the operating sequence of the laser system.

Immediately following main pattern definition the resistor is laser trimmed, again under resistance bridge control, to the very narrow target resistance tolerances demanded by BS1904. The detailed mechanism of adjustment is proprietary but is generally based upon methods commonly applied in the thick film electronics industry.

Devices outside the narrow acceptance band are automatically rejected. The laser system is extremely flexible in operation, having the capability of handling many shapes and sizes. It is readily programmed to enable scribing to a wide range of target resistances and tolerances.

Finishing

Following adjustment to resistance value the part-finished units pass to the finishing section where the wire leadouts and proprietary reinforcement are applied in a fully automatic unit, shown in Figure 3. A coating of insulating glaze is then applied and the units fired.

Table I
The Influence of the Materials and Processing on Device Performance in Terms of Per Cent Change in Ice Point Resistance as a Function of Time at Test Temperature

Detector type	Test type	Test temperature °C	Elapsed time, hours		
			200	500	1000
100R30 Initial production device (a)	Air	450	+0.003	+0.004	—
	Air	600	-0.028	-0.028	+0.014
	Sealed tube	450	+0.65	—	—
Wire wound	Sealed tube	450	+0.023	+0.023	—
100R30* (Improved version of 100R30)	Sealed tube	500	+0.022	-0.012	-0.013
	Air	500	+0.015	+0.017	+0.042
100P30 Current production version	Air	600	-0.013	-0.013	-0.033
	Sealed tube	600	-0.030	-0.030	—

(a) Stable in air but not in a sealed tube above 400°C.

Quality Control

Following completion of the production cycle the devices are subject to a comprehensive quality assurance programme. Quality evaluation is undertaken at various levels and frequency, ranging from 100 per cent inspection for visual defects and key electrical properties to a statistically based sampling plan for durability and other parameters. The key electrical properties are measured and the product graded to BS 1904 limits on the fully automatic microprocessor controlled unit shown in Figure 4. The R.T.D.s are immersed sequentially in ice and steam baths in which their resistances are measured relative to standards by high precision automatic bridges. Resistance ratio values are recorded and the data processed by specially developed algorithms by the computer. Individual device values are compared with the limit values for the BS1904 grades, the information is relayed to a grading station and the devices are automatically sorted. Key information, values of ice point resistance, alpha value and grade are retained in the computer memory and con-

tinuously displayed on an individual basis. Batch statistical information is also developed by the computer and displayed on demand in both numeric and histogram form for each of the key property values. Grading level limits are capable of almost infinite variations by simple programming. Again, the equipment is capable of accepting products of a wide variety of shape, size and resistance value.

Product Performance

The internationally recognised criteria for the performance of platinum resistance thermometers are defined in BS1904 and DIN43760. Thermafilm 100P30 conforms to all the requirements of BS1904 Grade II and in addition is available to a broader resistance tolerance standard of ± 0.25 ohm for applications not requiring the highest precision.

The materials technology developed for the cylindrical device has also been extended to include flat detectors produced by the screen printed route outlined by Iles and Tindall (2). These sensors are available to the tolerances of Grades I and II of BS1904 and also the Grade



Fig. 4 Key electrical properties are determined as the devices are compared with standards separately in ice and steam baths. The resulting data is processed by an on-line computer which grades the devices, and displays and records the key property values

III standard of ± 0.25 ohm at the ice point. Such flat devices are of considerable utility in specialist applications involving surface temperature measurement where the plane sur-

faces and the high thermal conductivity of the alumina substrate enables intimate thermal contact and rapid response.

The standard range of devices is shown on

Fig. 5 By inspecting the tolerance versus temperature graph the grade of Thermofilm® necessary to give the required accuracy can be identified; thus an accuracy of $\pm 2.5^\circ\text{C}$ at 500°C requires the use of Thermofilm® Grade II. A four-terminal measuring system and measuring circuits of commensurate accuracy must be employed if the indicated tolerances are to be achieved

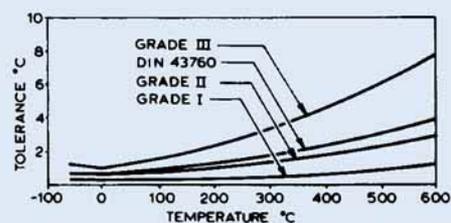


Fig. 6 Thermal response curves, determined according to BS 1904, show Thermofilm® temperature detectors to be superior to conventional 3 mm diameter wire wound devices

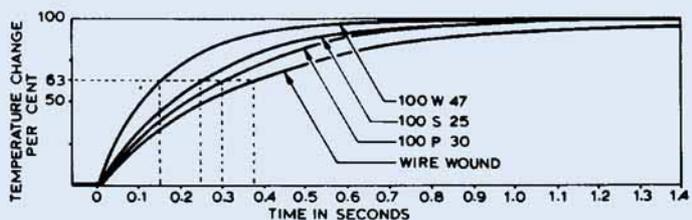


Table II			
Selected Technical Data for ThermoFilm® Platinum Resistance Detectors			
Device	100S25	100W47	100P30
Configuration	Flat, square	Flat, rectangular	Rod shaped
Fundamental interval (Nominal), Ω	38.5	38.5	38.5
Ice point resistance R_0 , Ω			
Grade I	100 ± 0.075	100 ± 0.075	—
Grade II	100 ± 0.1	100 ± 0.1	100 ± 0.1
Grade III	100 ± 0.25	100 ± 0.25	100 ± 0.25
Self heating, * $^{\circ}\text{C}/\text{mW}$	<0.005	<0.005	<0.01
Surface insulation	10 M Ω at room temperature and 240V, or 1 M Ω at 500 $^{\circ}\text{C}$ and 50V		
Thermal response, ** seconds	<0.25	<0.15	<0.3
Stability after temperature cycling, *** per cent	< ± 0.05	< ± 0.05	< ± 0.05
Capacitance (at 1 kHz), pF	<25	<15	<10
Inductance, μH	—	—	<1
Temperature range, $^{\circ}\text{C}$	-70 to +600	-70 to +600	-70 to +600

*When immersed in well-stirred water at the ice point. **Time to reach 63 per cent of ultimate temperature (as BS 1904 test).

***After 10 cycles between minimum and maximum rated temperatures.

page 9 and selected technical data are summarised in Table II. Additional data are presented in the form of approximate temperature tolerances for the various grades in Figure 5, and thermal response curves in Figure 6. Alternative shapes and resistance values for specialist applications are possible, and two-, three- or four-wire termination forms are available for each type. These devices show excellent durability at elevated temperatures in either a free air atmosphere or in sealed stainless steel probes. Selected durability data are shown in Table I.

The Future of Thick Film Devices

The significant role of the platinum R.T.D. in industrial temperature sensing and control will continue and grow for the foreseeable future (3). Undoubtedly film type R.T.D.s will become increasingly competitive particularly

for applications where a standard sensor such as the 6 mm probe is utilised in large numbers, and the benefits of mass production can be fully exploited. In addition the film device is expected to be utilised in many new applications where its characteristics offer technical advantages over conventional types, for example in medical applications and food processing where unusual shapes are required.

Such applications clearly involve high-precision devices conforming to BS1904. However, recent developments in integrated circuits offer the possibility for the first time of cost effective electronic control for domestic applications. This will create a vast new market for compatible sensors to replace electro-mechanical systems. Probable uses range from air thermostats through to domestic appliances such as cookers and washing machines which are often fitted with control devices designed

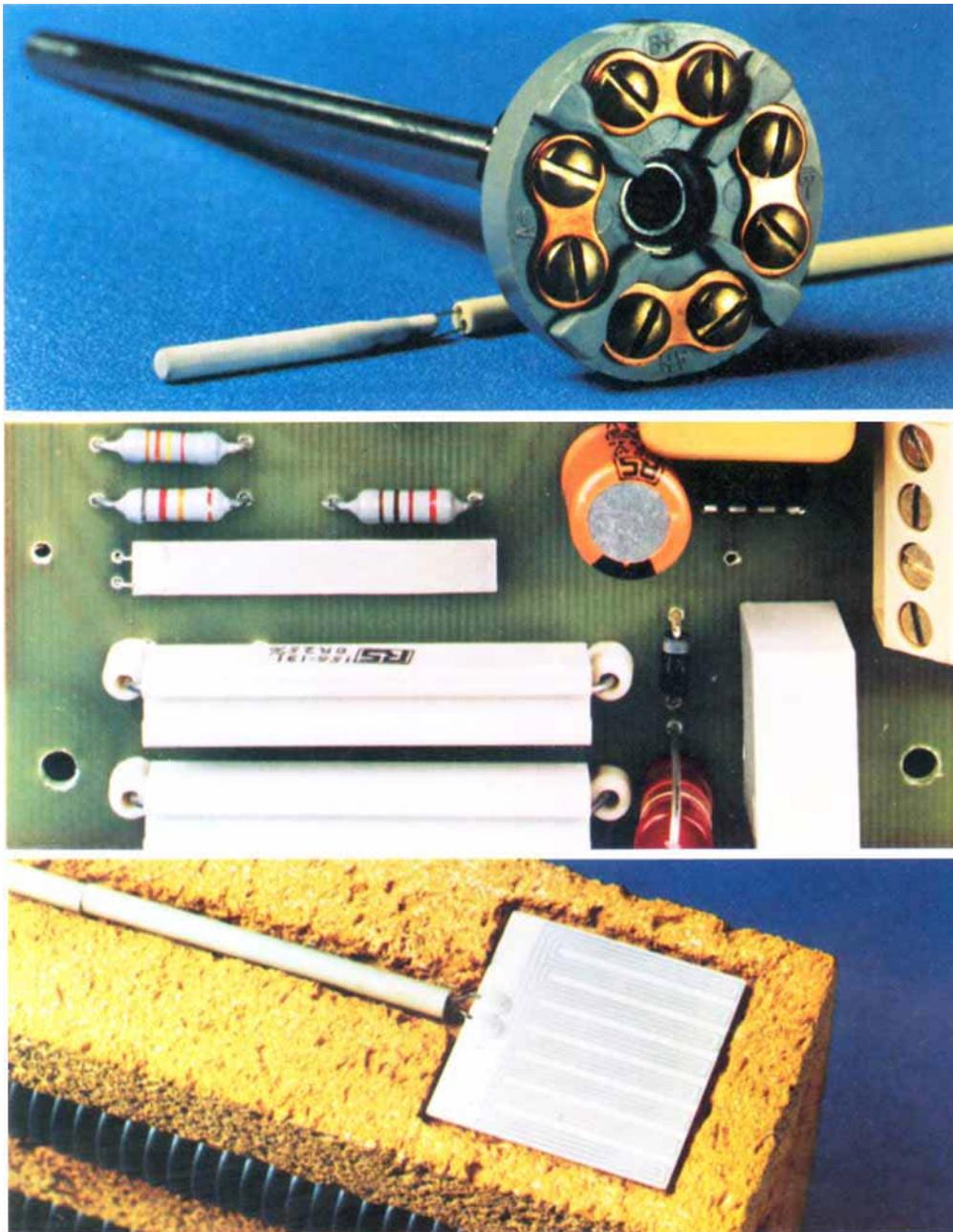


Fig. 7 Matthey Thermoform[®] platinum resistance thermometers, consisting of a thick film of platinum supported on an inert ceramic substrate and protected from the atmosphere by an insulating ceramic glaze, are being used for an increasing number of applications where high accuracy and low cost are required. Many configurations are being developed and evaluated, while the current production range comprises a 3 mm diameter cylindrical unit (100P30), a flat rectangular unit measuring 4.7 × 32 × 0.8 mm (100W47) and a flat 25 mm square unit (100S25). The cylindrical type is shown above (top) in the form of a probe insert, alongside a typical stainless steel sheath. The rectangular 100W47 (middle) is here attached to a printed circuit board where it serves as a spot temperature monitor. On the square device (100S25), (bottom), used as a surface temperature monitor, the platinum resistance track is clearly visible beneath the insulating ceramic glaze

Table III Approximate Temperature Tolerances for Thermafilm GP	
True temperature, °C	0 250 500 700*
Tolerance, ±°C	2 6 10 13

*Maximum recommended service temperature for retention of calibration.

for regulation by the user rather than for exact temperature control. The incorporation of new temperature-sensitive materials such as glass ceramic cooker hobs (4, 5) is making actual temperature control essential. Clearly durability, reproducibility and cost are primary attributes in this market sector, which offers substantial opportunities for film type R.T.D.s. The technical requirements for such applications are normally less demanding than for industrial ones, and a resistance tolerance of 1 per cent ($\pm 15^\circ\text{C}$ at 700°C) is considered to be adequate for such a device.

Ceramic top cooker hob units present some unique control and indication problems that are at present partly resolved by energy regulators and electromechanical temperature limiters. The principal problem derives from a surface temperature limitation of the glass ceramic, above which progressive deterioration can be expected to occur.

That temperature must limit the rate of heat transfer and, therefore, of cooking. Electromechanical limiters are over-temperature protection devices which operate by interrupting the current supply at a preset temperature. However, they suffer from a number of disadvantages which include irreproducibility, non-rugged construction and poor aesthetic

appearance in the cooker. Neither the electro-mechanical limiter nor the electromechanical energy regulator used for heat control can provide an indication that the hob surface is still hot after cooking is completed. With current models hot hob indication is provided by a time based system rather than by true temperature measurement.

Figure 8 shows a comparison between the performance of an electromechanical system and a Thermafilm GP/Plessey SL 443 electronic system fitted to a commercially available domestic hob unit. Thermafilm GP is a specially developed thick film R.T.D. with properties comparable in most respects to the BS1904 Grade of Thermafilm® but with an ice point resistance of 200 ohm to a manufacturing tolerance of ± 1 per cent. Table III shows the temperature tolerance band as a function of temperature, and Table IV shows that the durability is outstanding at the maximum peak service temperature of 700°C .

In the case of the ceramic top cooker, Thermafilm GP in conjunction with electronic control offers many advantages over electromechanical control systems. These include:

- (i) Fastest possible temperature rise is permitted.
- (ii) Accurate temperature control, with narrow control band, allows the closest approach to the highest temperature suitable for the glass ceramic.
- (iii) Outstanding durability enables maximum exploitation of (ii) and virtually eliminates field service problems due to sensor failure.
- (iv) Any field service problems are simplified by the reproducibility of the systems. A replacement heater plus sensor unit can be fitted without any need for recalibration.

Table IV Durability Data for Thermafilm GP Showing Measured Drift During Life Test at 700°C in Air						
Time, hours	200	500	1000	2000	4000	6000
Drift, °C	-0.5	-0.9	-1.1	-0.75	-0.75	-0.75

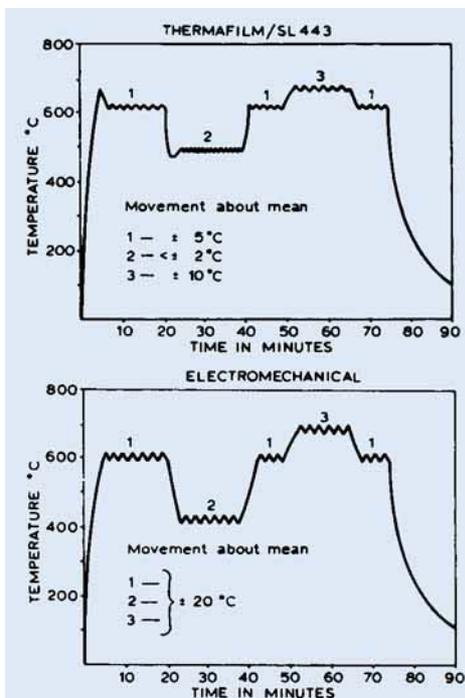


Fig. 8 A comparison between the performance of an electronic and an electro-mechanical system illustrates the advantages of the former. The temperature indicated is that measured on the surface of a glass ceramic top cooker panel by a standard measuring system. The conditions were: 1 Free radiation, 2 Aluminium pan with a ground base 15 cm diameter containing one litre of water, and placed centrally on the hot area of the cooker, 3 Empty milk pan 11 cm diameter, concave base placed centrally

- (v) True hot hob indication is given by temperature measurement.
- (vi) Potential capability for domestic pan watcher and simmerstat control.

Conclusion

The platinum resistance thermometer, a long established scientific tool, is finding increasing use for a wide variety of industrial applications. Accurate measurement and control of temperature can make a significant contribution to the conservation and efficient use of thermal energy both in the workplace and the home; ThermoFilm[®]—a low cost, high accuracy, durable thick film platinum resistance detector, provides an efficient method of achieving this. Devices of many configurations are being evaluated at present for a number of both existing and new applications.

References

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- 2 G. S. Iles and R. F. Tindall, *Platinum Metals Rev.*, 1975, **19**, (2), 42
- 3 Industrial Temperature Control Markets in Europe, Marketing Report No. E341, Frost and Sullivan Inc. New York, 1980
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The Conversion and Storage of Solar Energy

The belief that solar energy harnessed by photochemical processes may be able, in the future, to make a worthwhile contribution to the energy requirements of the world is supported by many of the results being reported by a growing number of workers in this rapidly expanding field of research.

The present interest in the production of hydrogen and oxygen by the visible-light photolysis of water was highlighted in a recent review of The Third International Conference on Photochemical Conversion and Storage of Solar Energy, by Professor Sir George Porter,

F.R.S. whose group at The Royal Institution, London, is actively engaged in this area (*Nature (London)*, 1980, **288**, (5789), 320–321).

Platinum and ruthenium dioxide are known to be electrolytically active for the evolution of hydrogen and oxygen, respectively, and Professor Michael Grätzel and colleagues at the Institute of Physical Chemistry, Lausanne reported the decomposition of water using these two catalysts, together with ruthenium trisbipyridyl as the light sensitiser and methyl viologen as the carrier, in a single system without sacrificial electron donors or acceptors.