A precise temperature sensor for 600–1600°C

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Abstract A simple, sensitive and reliable thermopile for the temperature range 600–1600°C is described.

There is an increasing demand for high-quality crystals and materials that require more and more stringent control of the temperatures necessary in the fabrication process. In the following we describe a sensitive, reliable and precise temperature sensor that can be used in the range 600–1600°C and for short periods up to 1800°C. Although platinum resistance thermometers are reputed to work up to 1400°C, owing to evaporation and recrystallization of the platinum, they are not reliable above 1000°C. As optical pyrometers are not sufficiently sensitive in the above temperature range, thermocouples are the most widely used sensors. Table 1 summarizes some of the pertinent properties of a few currently used thermocouples.

Table 1 A comparison of the sensitivities and properties of a six-junction Pt/Rh6–Pt/Rh30 thermopile and of some conventional thermocouples

Sensor	Sensitivity (μV °C^{-1})		Maximum working temperature	
	at 25°C	at 1200°C	for hours	~months
Chromel–Alumel	40	36	1100	900
Platinel	32	39	1300	1150
Pt–Pt/Rh10	6	12	1600	1350
Pt/Rh6–Pt/Rh30	<0·07	10·5	1800	1600
Pt/Rh6–Pt/Rh30 thermopile	<0·4	63	1800	1600

Thermocouples such as Pt–Pt/Rh10, Chromel–Alumel (Hoskins Manufacturing Co.) and Platinel (Engelhard Industries Ltd) have sensitivities of only 12–40 μV °C^{-1} at 1200°C and therefore require voltage measurements with an accuracy of 1 μV for a precision of better than 10^{-4}, as is required in several crystal-growth and other fabrication processes, (see, for example, Scheel and Elwell 1972, and Elwell and Scheel 1974). Furthermore, as their sensitivity is essentially independent of temperature, the cold junction must be stabilized in temperature within the precision limits of the high-temperature measurements.

An extremely sensitive temperature-measuring system, based on a computer-controlled infrared television camera, has been developed by Kwap, O'Kane and Gulitz (1971 unpublished). This has a sensitivity of about 4 mV °C^{-1} at 1400°C, but is not universally applicable because of its complexity and need for a vapour-free optical path. Such a path is not available in many systems that have to be sealed, that contain vapours or for which the convection inherent in an optical path would produce significant temperature fluctuations.

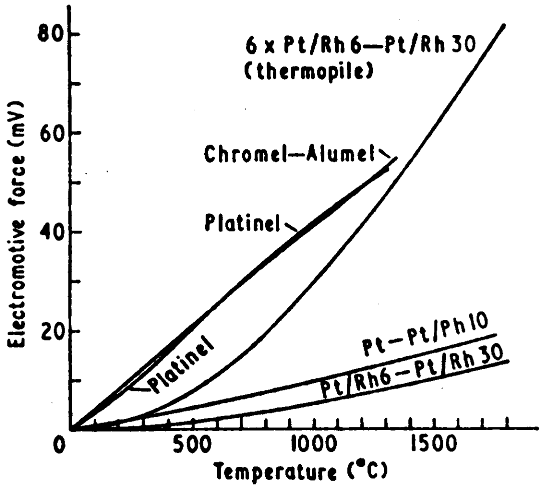

Figure 1 Output as a function of temperature for a six-junction Pt/Rh6–Pt/Rh30 thermopile and some conventional thermocouples

We have developed a thermopile using 94% Pt/6% Rh–70% Pt/30% Rh (available from Engelhard Industries Ltd or from Johnson Matthey Chemicals Ltd) that overcomes the disadvantages of conventional thermocouples and is free from the problems associated with a complex infrared TV system.

The advantages of a Pt/Rh6–Pt/Rh30 thermopile come from its extremely low sensitivity at room temperature relative to that at high temperatures, which for a single junction is comparable to that of the thermocouples mentioned above. This is illustrated in figure 1, which compares the electromotive forces of Platinel, Chromel–Alumel and Pt–Pt/Rh10, three commonly used thermocouples, with those of a single Pt/Rh6–Pt/Rh30 junction and a six-junction thermopile made of the same material. The standard thermocouple materials have high EMF, but as they are essentially linear with temperature, they are equally sensitive to cold and hot junction temperature changes. A single junction of Pt/Rh6–Pt/Rh30 has a smaller EMF, but a six-junction thermopile produces a higher EMF at high temperatures than the sensitive Chromel–Alumel and Platinel thermocouples, with a much smaller sensitivity to cold-junction temperature changes.

Obviously, Chromel–Alumel and Platinel thermopiles could produce a higher EMF, but because of the high sensitivity to cold-junction temperature changes it would be difficult to achieve high precision. Pt/Rh6–Pt/Rh30, on the other hand, is more than 100 times less sensitive to cold-junction temperature changes, so that for a given error of the cold-junction temperature, more precise temperature measurements will be possible.

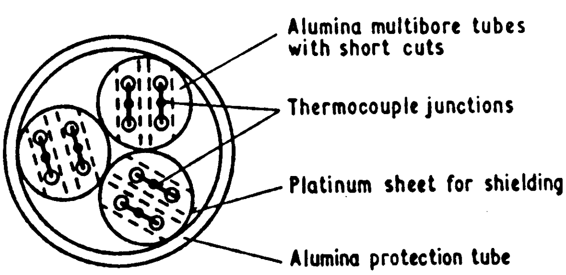

Figure 2 Cross section of the six-junction thermopile

A cross section of the hot end of a thermopile made from six Pt/Rh6–Pt/Rh30 thermocouples is shown in figure 2. The wires of the six thermocouples were insulated by three multibore tubes of 4 mm diameter (with four holes each) of pure Al_2O_3 ceramic (Degussa, Hanau, Germany). Pairs of holes were connected at the hot end by 2 mm deep transverse cuts into which the junctions could be drawn back and thus be separated from each other and from the thin platinum sheet around the alumina tubes, which was earthed. The junctions were made by welding the twisted wire ends in an oxidizing gas–oxygen flame. The wire thickness was 0·1–0·5 mm depending on the required time constant and durability.

The thermocouple extensions to the cold junctions were insulated by Teflon tubing or by silica wool tubing and shielded by a flexible steel sheath. For the cold junctions a similar arrangement with four multibore tubes was chosen, and the connection with the measuring or regulation instruments was achieved by shielded copper wires.

The cold junctions were maintained at a constant temperature in a water–ice mixture or a water–ice–vapour triple-point cell for short periods, and in a Peltier cooling device (regulated at $0 \pm 0{\cdot}01$ °C) for experiments of long duration such as in crystal growth from high-temperature solutions (Scheel and Elwell 1972, Elwell and Scheel 1974, in the latter reference details are also given on the precautions necessary with platinum-based thermocouples). For certain applications, the lack of sensitivity to cold-junction temperature changes would permit the use of a simple enclosure consisting merely of a high thermal capacity material in a well-insulated dewar.

Thermopiles made in this way have a long lifetime at temperatures up to 1600°C and can be used intermittently up to 1800°C. Compared with standard thermocouples, for a modest increase in size and complexity, they offer higher output voltages with a reduced sensitivity to cold-junction temperature changes so that they are more precise temperature sensors. If properly fabricated and calibrated, such thermopiles could be useful standards for the temperature range of 1064·43°C to about 1600°C, for which until now pyrometers had been proposed according to the International Practical Temperature Scale of 1968 (IPTS-1968 1969).

The higher output voltage simplifies the apparatus needed to obtain temperature measurements of a given precision, particularly where it is necessary to multiplex sensors for computer-based temperature control or data-logging systems.

References

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