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Research and technical note

Response of a new ceramic–oxynitride (Cernox) resistance temperature sensor in high magnetic fields

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The resistance of a commercial Cernox (ceramic-oxynitride) thermometer has been measured from 4.2 to 30 K in magnetic fields up to 15 T and compared to that of a carbon–glass thermometer. Throughout this field and temperature range, the maximum magnetic field-induced change in the zero-field calibration of the Cernox thermometer is less than 200 mK. This is a factor of two lower than that of the carbon–glass thermometer. Furthermore, its sensitivity at room temperature is a factor of two higher.

Keywords: thermometry; high magnetic fields

Temperature control in high magnetic fields has always been a difficult challenge. For high precision cryogenic thermometry between 2 K and room temperature, the traditional choice has been a rhodium–iron resistance thermometer since its sensitivity is sufficiently high and its calibration is stable to better than 10 mK year^{-1} [1–3]. For measurements in magnetic fields, an additional capacitance thermometer is included. This has poor stability when thermally cycled but has a field-independent response. Typically, the resistance thermometer is used to set the temperature in zero field while the capacitance thermometer holds the temperature stable in high magnetic fields[4].

There has been a continuous effort to fabricate a magnetic field-independent thermometer with good stability and sensitivity. The carbon–glass resistance thermometer is most often used for in-field measurements. Above 50 K, the magnetic response is almost negligible. Below 50 K, the thermometer has a small, and therefore correctable magnetic field-induced temperature error of up to 400 mK in magnetic fields up to 15 T[5]. Its stability is not ideal, approximately 2, 100 and 500 mK year^{-1} at 4.2 K, 77 K and room temperature, respectively[1–3].

Recently a new family of thermometers has emerged which offers the possibility of very low magnetic field-induced temperature errors. In this paper, results are presented for the magnetic field-induced temperature error of a new thin-film Cernox thermometer. Its resistance–temperature characteristics, sensitivity and field-induced temperature errors are compared with those of a traditional carbon–glass thermometer.

Experimental

Rhodium–iron, carbon–glass, and capacitance thermometers were mounted together with the Cernox thermometer in a variable temperature insert (all four thermometers were supplied by Lakeshore Cryotronics Ltd). Both the rhodium–iron and carbon–glass thermometers had been calibrated in zero field by the manufacturer. A Lakeshore DRC 91C temperature controller was used to record the zero-field temperature using the rhodium–iron thermometer and to control the temperature in-field using the capacitance thermometer. The resistance of the carbon–glass and the Cernox thermometers were recorded using a constant current source and digital voltmeter. Measurements were made with an Oxford Instruments 15/17 T (4.2/2 K) superconducting magnet system with the field applied parallel to the long axis of the thermometer canisters.

The rhodium–iron thermometer was used to set the temperature in zero field. The capacitance thermometer kept the temperature constant as the magnetic field was increased. The resistances of all four thermometers were recorded at integer field values up to 15 T. Before beginning a different temperature, the superconducting magnet was demagnetized by taking it through positive and negative field cycles of decreasing size. The error in the temperature values is less than 50 mK.

Results and discussion

Figure 1 shows the zero-field resistance *versus* temperature characteristics and sensitivity of the carbon–glass and Cernox thermometers from 4.2 to 300 K. For comparison, data for a rhodium–iron thermometer are included. Multiplying the sensitivity by 100 gives the percentage change in resistance per kelvin. Both the carbon–glass and the Cernox thermometers have a monatomic, negative temperature coefficient. At low temperatures, they have sufficiently high sensitivity for detection of millikelvin variations. Above 50 K, the Cernox thermometer has significantly higher sensitivity, reaching twice that of the carbon–glass thermometer at room temperature.

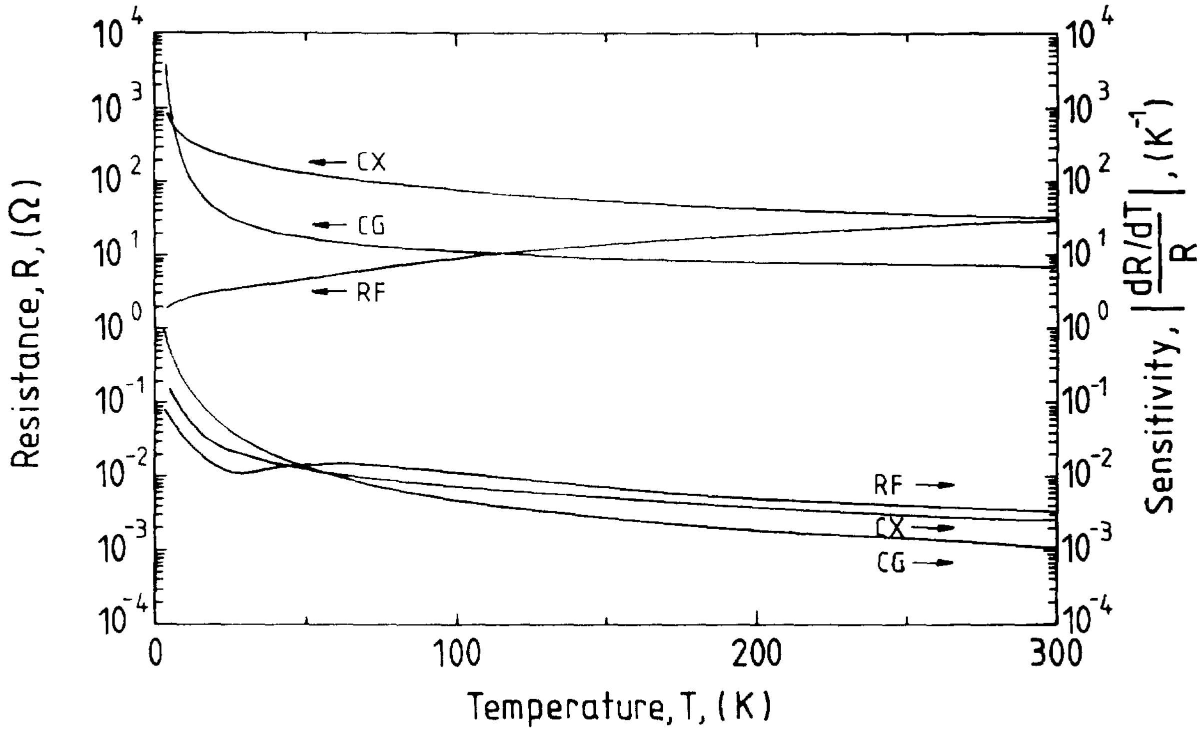

Figure 1 Zero-field resistance *versus* temperature characteristics and sensitivity of carbon–glass (CG), rhodium–iron (RF) and Cernox (CX) resistance thermometers

In *Figure 2*, the magnetic field-induced temperature error for the carbon–glass thermometer is shown from 4.2 to 30 K. The graph shows a small error of less than 400 mK up to 15 T, which is in agreement with the literature value[6].

Figure 3 shows the magnetic field-induced temperature error for the Cernox thermometer from 4.2 to 30 K. This has a maximum of approximately 200 mK, a factor of two less than that of the carbon–glass thermometer.

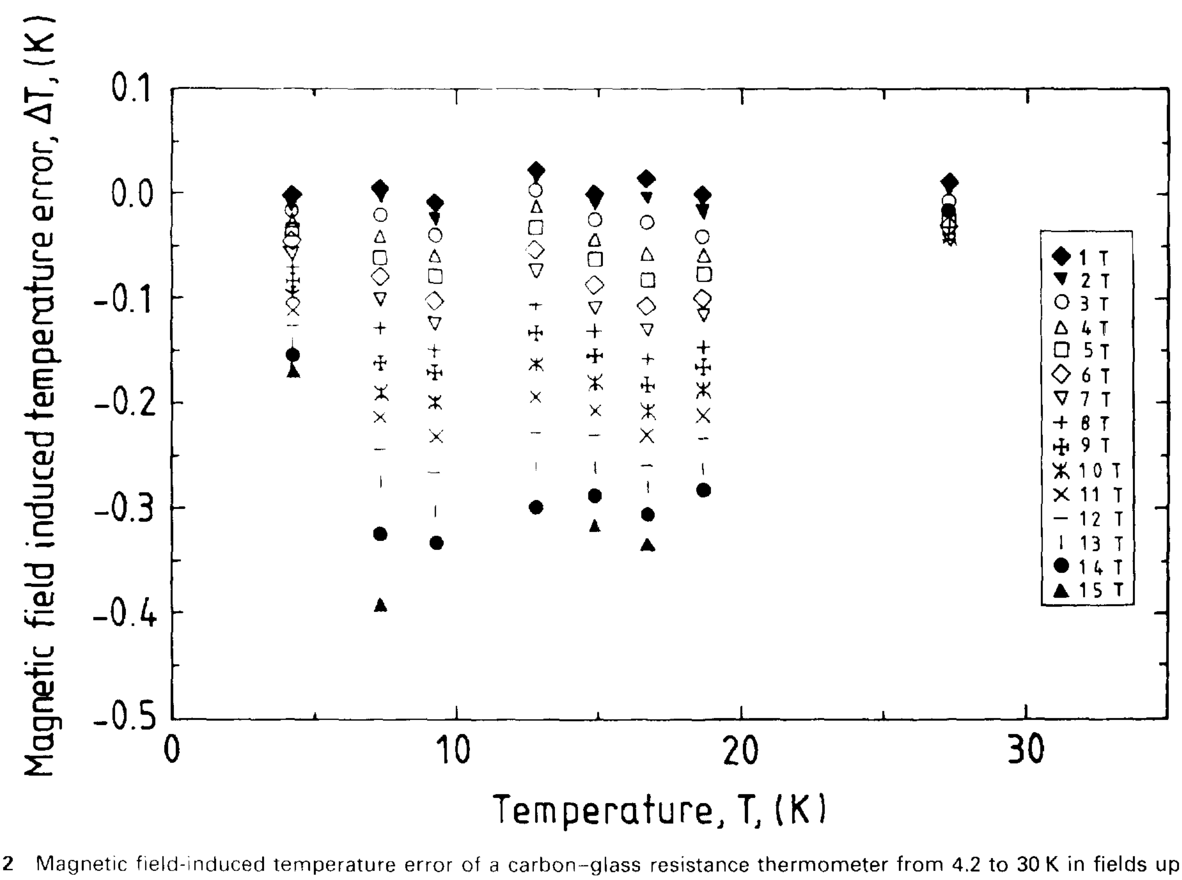

Figure 2 Magnetic field-induced temperature error of a carbon–glass resistance thermometer from 4.2 to 30 K in fields up to 15 T

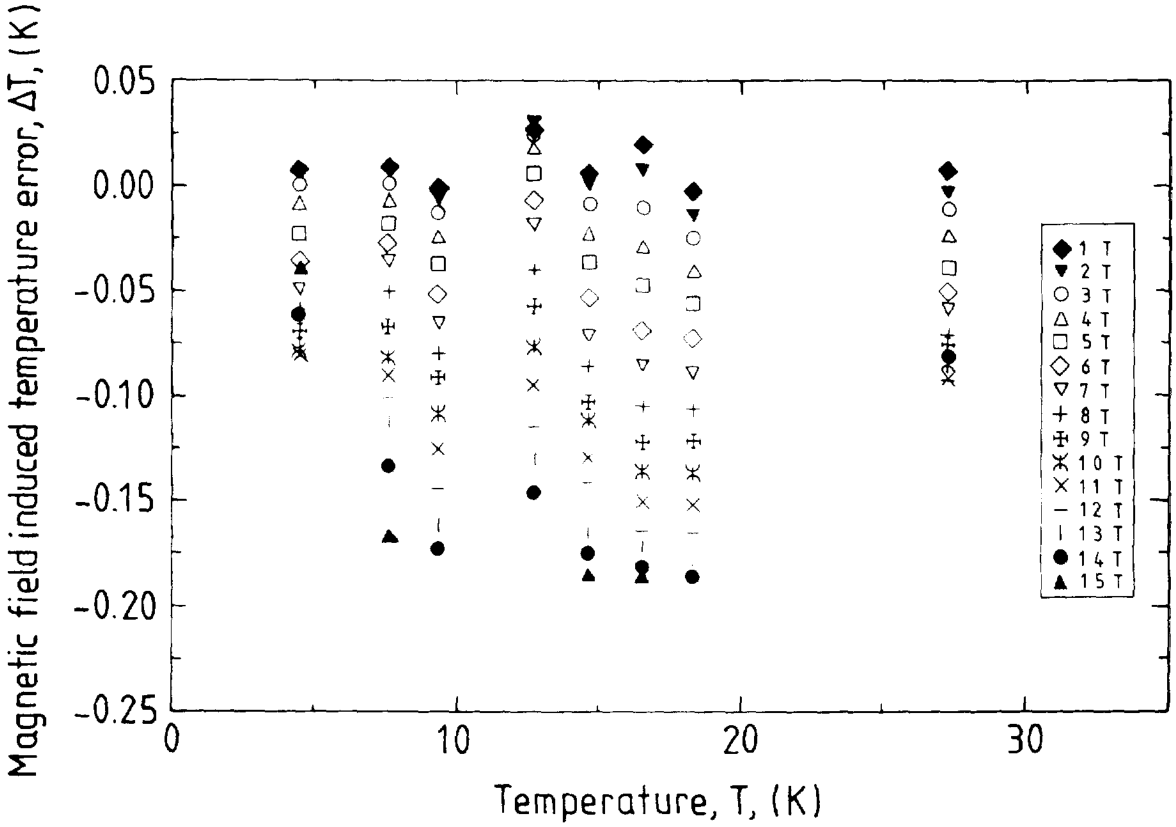

Figure 3 Magnetic field-induced temperature error of a Cernox resistance thermometer from 4.2 to 30 K in fields up to 15 T

The Cernox thermometers are thin-film resistance temperature sensors mounted on a sapphire substrate with gold contact pads. They are sufficiently robust to allow samples to be attached directly to the substrate. This minimises any temperature gradients between the sample and thermometer. Their low weight, less than 3 mg, makes them ideal for in-field specific heat measurements where very small thermometers are required. Unencapsulated carbon glass thermometers are available but the bonded gold leads are very susceptible to damage. Both thermometers can be encapsulated in a copper canister which makes them more robust.

Conclusions

Both carbon–glass and Cernox thermometers can be used from 2 K up to room temperature in high magnetic fields. The Cernox thermometer has a sensitivity which is a factor of two higher, at room temperature, than the carbon–glass thermometer. Its maximum field-induced temperature error is a factor of two lower, up to 15 T.

It remains to be seen whether the long-term stability of the Cernox thermometer is sufficiently good to make them the preferred choice for a field-independent thermometer for use from 2 K up to room temperature.

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