A NEW OPTICAL TECHNIQUE FOR THE MEASUREMENT OF TEMPERATURE IN RF AND MICROWAVE FIELDS

Kenneth A. Wickersheim and Ronald V. Alves
Luxtron Corporation
1060 Terra Bella Avenue
Mountain View, CA 94043

ABSTRACT

Fluoroptic™ Thermometry will be compared with other optical temperature measurement techniques, the scientific basis of Fluoroptic Thermometry will be presented, and performance characteristics and applications of the first commercial instrument based on this RF-immune technology will be discussed.

Introduction

There is a steadily growing need for an accurate, reliable and non-perturbing technique for the measurement of temperatures in electrically hostile environments. Known applications for which such a technology is needed include (1) diagnostic measurements in high voltage power generation and distribution equipment; (2) measurements for control of industrial heating by RF or microwave fields; (3) measurements during studies of the biological effects of RF and microwave fields; (4) measurements and control of RF-induced heating during medical hyperthermia for cancer therapy. Other possible applications include: operational testing of electronics of all kinds, measurements of temperature during RF-plasma etching of silicon devices and measurements in potentially explosive or flammable environments where the accidental conduction of a spark of static electricity via electrical leads could product serious consequences.

Optical Temperature Measurement Technologies

A number of optical techniques for temperature measurement have been conceived to provide such electrical isolation. Infrared radiometry provides one such approach. This technique also has the virtue of being a totally non-contact technique. However, since radiometers measure radiated energy rather than temperature directly, infrared measurements are always subject to errors resulting from unknown variations in the emissivity of the radiating surface. In addition, the best applications for infrared techniques are those where line-of-sight access to the region of interest is possible - this because of the dearth of longwave infrared transmitting materials.

With the advent of optical fibers, an extension of infrared techniques has been made wherein the short wavelength infrared radiation transmitted by such fibers is utilized. This allows access to points not addressable by direct line of sight. The drawbacks of the infrared/optical fiber approach (in addition to those mentioned above) is that the majority of the infrared energy from an object at low to moderate temperatures is in the long wavelength infrared and is not transmitted by the fiber. Hence sensitivity of such a system is poor at the lower end of the temperature scale - e.g., below about 300°C.

Recently a variety of other techniques utilizing optical fibers have been devised and implemented. The earliest of these utilized a liquid crystal sensor. The amount of light of a given wavelength reflected by the liquid crystal layer is a strong function of temperature. While this device proved the feasibility of optical sensing and indicated the sensitivity that could be achieved, the chemical instability of the liquid crystal materials themselves made it impossible to provide sensors with a well defined, permanent calibration.

Since then, a variety of other optical sensors have been conceived. The most promising to date are those involving temperature-dependent optical properties of solid materials - more specifically index of refraction changes of certain birefringent crystals, band edge absorption changes of semiconductors and fluorescent intensity changes. Of these, the birefringent crystal technology is extremely sensitive, but limited in range. A system based on the band edge shift in gallium arsenide is particularly convenient. In this device the light source is a gallium arsenide LED, the emission from which ideally matches in wavelength both the band edge absorption of the sensing crystal and the optimum transmission of the optical fiber. However, the band edge absorption and birefringent crystal devices both suffer from the difficulty of fabricating identical small sensor crystals, and hence of manufacturing closely reproducible and standardizable sensors. Since both devices operate by detecting total signal intensity changes, there is also the difficulty of separating changes due to temperature effects from those produced by other nonthermal optical signal variations.

Techniques Utilizing Fluorescence

Some proposed fluorescent devices are based on the change in fluorescent decay times under pulsed excitation. The Fluoroptic temperature sensor, developed by the authors of this paper, differs from these pulsed fluorescent techniques principally in that, like the crystalline sensors mentioned earlier, it utilizes steady-state intensity measurements. Because of the particular combination of properties of the rare earth phosphors utilized in the Fluoroptic sensor, it is possible to provide local self-referencing of the sensor so that only temperature-induced effects are interpreted in terms of temperature changes. In particular, source instabilities are eliminated as a source of measurement error. The particular materials characteristics and systems design features which make this possible will be presented and discussed. In addition, sensor fabrication techniques are much simpler for the Fluoroptic sensor than for the crystalline sensors. Because of these fabrication advantages, mass sensor production, lower sensor cost and ultimate sensor standardization are much more likely to be achieved in the near future. Characteristics of the optical fiber and sensor materials used in present generation probe fabrication will be discussed.

0149-645X/81/0000-0468$00.75

The range of the Fluoroptic sensor is much greater than that of the majority of optical sensors developed or proposed to date. Excitation of the phosphor sensor is achieved by ultraviolet radiation transmitted down the fiber optic probe from the instrument. The resultant fluorescence is transmitted back to the instrument for analysis by means of the same optical fiber. The phosphor currently used is europium-activated gadolinium oxysulfide. The fluorescence from this material consists of a number of sharp lines in the visible range. The change of intensity with temperature of certain of these lines is different from that of other lines. Lines of interest can be readily isolated by interference filters.

The self-referencing feature mentioned earlier is achieved by the ratioing of the intensities of two emission lines whose temperature dependences are markedly different. The change of the intensity ratio with temperature varies continuously and in a single-valued manner over the range of operation of the instrument, namely from -50°C to +250°C. The non-linear calibration curve is stored in a PROM within the instrument and the corresponding temperature is determined by a microprocessor which compares the measured ratio with the table values stored in the PROM.

Performance Features and Technology Extensions

In addition to providing RF immunity and electrical isolation during temperature measurements in electrically hostile environments, the fiber optic sensor also exhibits certain other advantages relative to conventional electrical sensors. Chief among these is the lack of significant perturbation of the temperature at the point of interest by the probe. The phosphor has very little thermal mass and the optical fiber is a very poor conductor of heat. Hence very little heat is conducted away from the point of interest in the process of warming the sensor tip. The result is a more accurate measurement, particularly for measurements of very small objects or of the surfaces of poor conductors.

The fact that the data are transmitted optically is another advantage in that data can be transmitted across gaps in the optical train. This opens up the possibilities of non-contact sensing, disposable sensors, measurements on moving objects and so on. These are directions for major downstream extensions of the technology.

The first instrument using the Fluoroptic technology has now been developed by Luxtron for general laboratory use. Design feature and performance characteristics of this instrument will be presented. Sensitivity and precision are sufficiently great to allow the achievement of a precision of 0.1°C over the range of the instrument with a one second signal integration time and a fiber optic probe having a 0.4 mm diameter core.

Specific applications, including those industrial and biomedical uses mentioned earlier, involving RF and microwave fields will be discussed.