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PASSIVE (SELF-POWERED) FIBER OPTIC SENSORS

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Abstract

Oak Ridge National Laboratory (ORNL) is developing a new group of fiber-optic sensors for characterizing physical aspects such as ambient temperature. These sensors exploit the inherent property of thermographic materials that the lifetime and/or intensity of the emitted fluorescence decreases with increasing temperature. Unlike current fluorescent temperature sensors that use a light source for excitation, these sensors are totally passive (self-powered) and use either an embedded or external radiation source.

A proof-of-principle temperature sensor was developed, based on this concept, using a well-known thermographic material, magnesium fluorogermanate. Our experimental results showed that the radiation-induced fluorescence resulted in an intensity change but no significant decay rate change with increasing temperature.

I. INTRODUCTION

Monitoring temperature by measuring change in a photoluminescence sensor's intensity or decay time has been successfully demonstrated by several authors[1,2,3,4,5]. In each measurement, the authors attach an optical fiber, either directly or remotely, to a thermographic material and illuminate the material with a pulsed external light source. A fluorescence signal, characteristic of the thermographic material's temperature, is transmitted back through the optical fiber, or a separate fiber, and detected by a photodetector. Previous excitation schemes used to determine the temperature dependent luminescent characteristics of thermographic materials have included short pulse flashlamps, continuous tungsten sources[4], LEDs and laser diode emitting devices[1,6], and UV lasers[5]. The use of such devices normally requires an excitation source for each temperature sensor and extreme care to separate or cancel the source signal from the fluorescence signal.

A new method for measuring the temperature dependent characteristics of thermographic materials is being developed at ORNL. Instead of relying on an external light source for exciting the thermographic material, a low-activity radiation source is embedded within the material (Fig. 1). The radiation source continuously excites the thermographic material and transmits a fluorescence signal to a photodetector for characterization. This passive method of self-excitation provides freedom from expensive external light sources and eliminates problems encountered with canceling source signal.

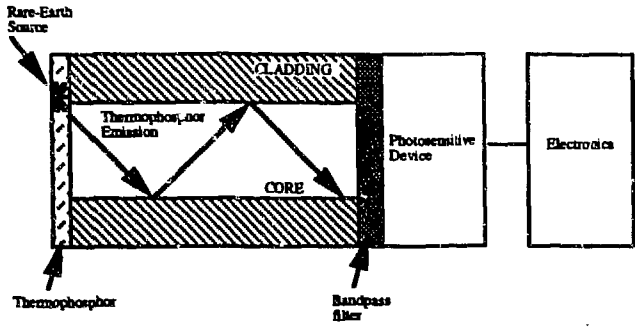

Fig. 1 ORNL passive temperature sensor with embedded radiation source.

II. CHARACTERISTICS OF THERMOGRAPHIC MATERIAL FOR PASSIVE SENSOR

To test the passive temperature sensor concept, a near room-temperature thermographic material was chosen to easily demonstrate a change in fluorescence with existing laboratory equipment. Wickersheim, et al.[3] successfully marketed a Xenon flash lamp fluoroptic thermometry system based on magnesium fluorogermanate activated with tetravalent manganese [$Mg_4FGeO_6(Mn)$]. They reported that the red-emitting $Mg_4FGeO_6(Mn)$ had a highly reproducible variation of fluorescent decay time between room-temperature and 450°C and was thermally stable, relatively inert, benign, and insensitive to chemicals and radiation damage. The measured decay time[7] for $Mg_4FGeO_6(Mn)$ as a function of temperature is shown in Fig. 2. Using the flash lamp excitation source, the room-temperature decay time is shown to be approximately 3.5 ms. When elevated to a temperature of 200°C, the decay time shortens to approximately 2.5 ms. Similar results have been shown using a remote uv laser[8].

These decay times were not observed with the passive sensor which uses a low-activity, thorium source (alpha energy ~ 4.0 MeV) for excitation. Oscilloscope traces of alpha-induced fluorescence in $Mg_4FGeO_6(Mn)$ consistently showed average decay times of approximately 100 μs. Assuming that the previously reported 3.0 ms decay time still exists within the 100 μs average decay curve observed under

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alpha-induced fluorescence, the average decay can be deconvoluted into it's separate decay constants. Using this reasoning, it was found that the 3.0 ms decay constant constituted less than 5% of the total light output from alpha-induced fluorescence in $Mg_4FGeO_6(Mn)$ and had virtually no effect on the shape of the convoluted decay curve with changing temperature. This made this techniques unacceptable at this point to accurately monitor variance of temperature through decay time differences in this material.

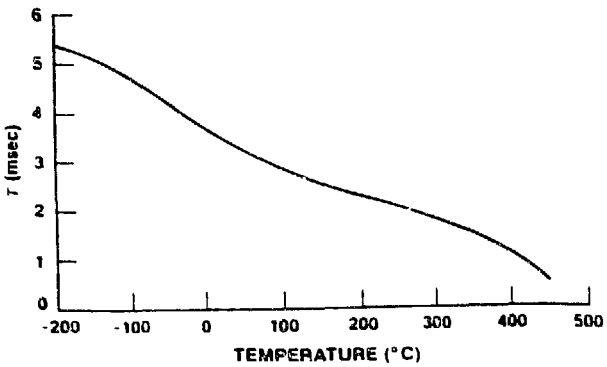

Fig. 2 Measured decay time for $Mg_4FGeO_6(Mn)$ as a function of temperature using a Xenon flash lamp excitation source.

The phenomena of the detailed shape of the decay curve depending on ionization density has been discussed extensively by Birks[8]. Many scintillators show small deviations in a material's decay constant(s) for differing ionization particles. The large variance in decay time observed in alpha-induced fluorescence of $Mg_4FGeO_6(Mn)$ was not expected. Further research into the energy loss mechanism of ionizing particles in thermographic ceramics is required to fully understand the reason for the decay time discrepancy.

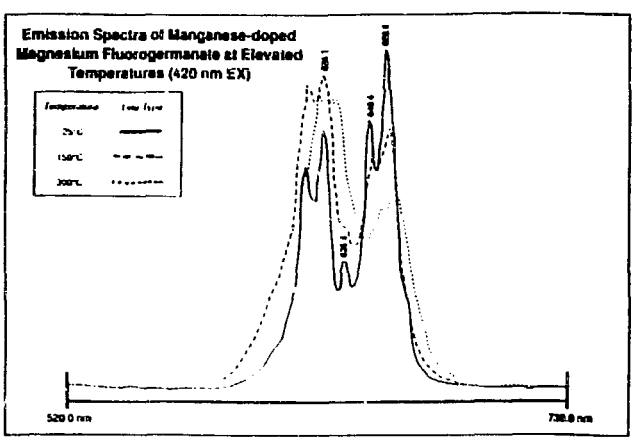

Fig. 3 Emission spectra for uv laser-induced fluorescence in $Mg_4FGeO_6(Mn)$.

According to Bugos[9], the spectra for uv laser-induced emission in $Mg_4FGeO_6(Mn)$ has two peaks centered around 625 nm and 650 nm (Fig. 3). It can be seen that the intensity of the 650 nm peak decreases with increased temperature. This effect is mainly caused by the competition between radiative and nonradiative energy transfer. At the higher temperatures, more uv laser-induced excitation is dissipated through the radiative process than the nonradiative process that leads to the fluorescence at 650 nm. Alpha-induced fluorescence in $Mg_4FGeO_6(Mn)$ also showed a similar intensity decrease in the 650 nm emission peak with increasing temperature.

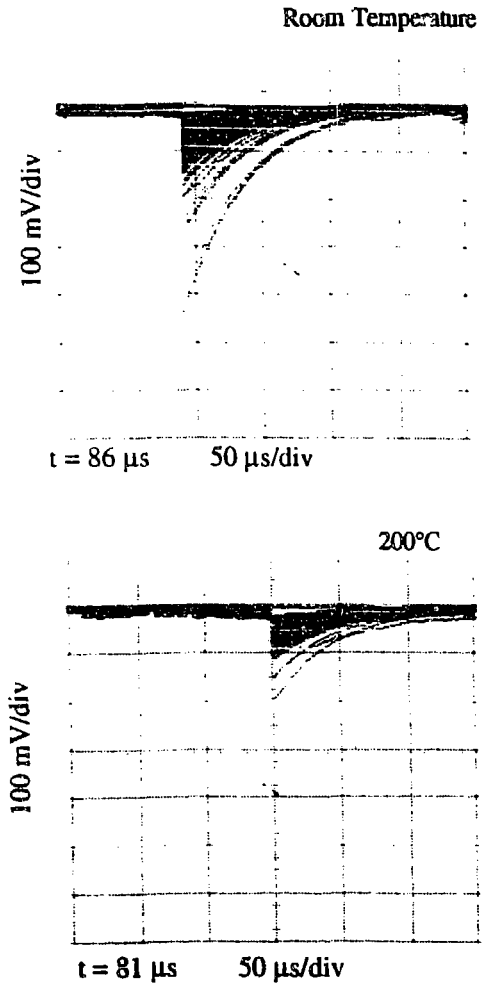

Fig. 4 Experimental results of the intensity of alpha-induced fluorescence in $Mg_4FGeO_6(Mn)$.

The results of data acquired over a 24 hour period at two temperatures are shown in Fig. 4. At room temperature, the average decay time was 86 µs and the pulse heights (intensity) were between 200-400 mV. When the temperature was elevated to 200°C, the decay time was 81 µs and there was a reduction in pulse amplitude. The decay time difference at the two temperatures was thought to be within the statistical noise of the electronics and not caused by an actual change in decay time.

III. EXPERIMENTAL SETUP

The experimental setup for testing the passive temperature sensor concept is shown in Fig. 5. The sensor was fabricated by mixing 25 μm particle size $Mg_4FGeO_6(Mn)$ into an optically-transparent, high temperature epoxy. A small string coated with thorium oxide was placed in the uncured mixture and attached to the end of a 1 mm quartz fiber. A small aluminum cap was placed over the tip of the optical fiber. The one meter long fiber was coupled to a 650 nm bandpass filter (10 nm FWHM bandwidth) and coupled to a Burle C7164R multialkilide photomultiplier tube. The sensor end of the optical fiber was placed inside an environmental chamber for regulating temperature.

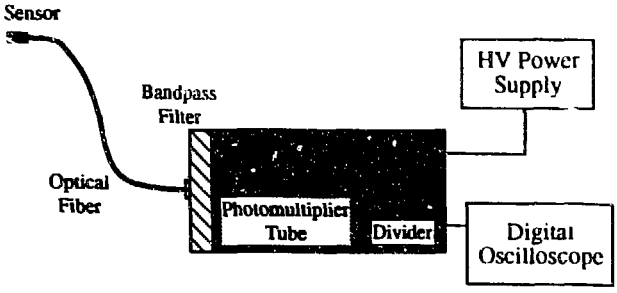

Fig. 5 Experimental setup for testing the passive temperature sensor concept

IV. CONCLUSIONS

The concept of a passive temperature sensor self-activated by an embedded source has been successfully demonstrated. Experimental results showed that for commonly used $Mg_4FGeO_6(Mn)$ alpha-induced fluorescence resulted in an intensity change with temperature. However, no significant change in decay time was detected for the thermographic material. The alpha-induced decay rates were an order of magnitude below the reported flash lamp and uv laser results and may be explained by multiple time constants.

The future use of $Mg_4FGeO_6(Mn)$ for a passive temperature sensor may be limited unless an appropriate method for deconvoluting the decay curve is achieved. The change in intensity with temperature, using an ionizing particle source, will be extremely inaccurate and difficult to calibrate. It will be necessary to determine the deconvoluted decay times of the thermographic materials in order to acquire the ± 2°C accuracy without calibration reported in literature[7]. Other thermographic materials will be investigated in the future for use with ionizing particle sources.

Future passive sensor development efforts at ORNL will focus on alpha-induced fluorescence in different phosphors, characterization of the energy transfer mechanism in ceramic materials and applying the technique to alternate technologies. One example of an alternate device is the neutron flux/temperature sensor for reactor studies. A neutron-sensitive material is mixed with the appropriate thermophosphor and attached to an optical fiber. The count rate represents neutron flux and the characterized decay time determines temperature. This new, combined sensor reduces the number of core penetrations required for separate temperature and flux sensors and will be capable of performing from room temperature to approximately 1500°C.

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