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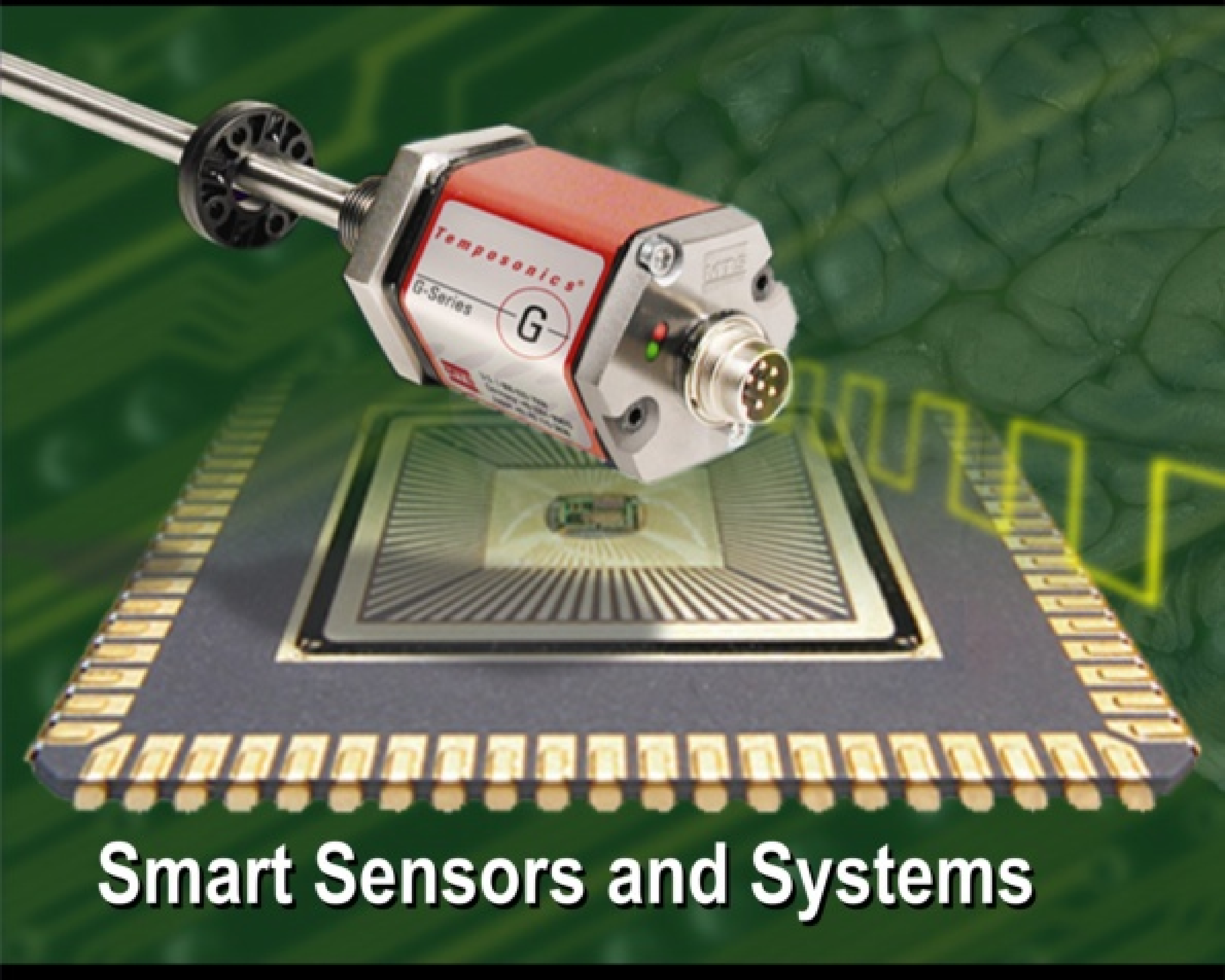

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Lifetime Based Temperature Sensing

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Abstract: The most promising lifetime based temperature sensing technique involving measurements of Fluorescence Lifetime has been reviewed. The experimental measurements for Eu^{3+} doped tellurite glass are found to be compatible with the theoretical requirements having a specific energy gap between the two close lying energy levels. *Copyright © 2007 IFSA.*

Keywords: Fluorescence Lifetime, Energy gap, Tellurite glass, Electromagnetic field

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1. Introduction

Significant advances in the field of optical fiber sensors have resulted in the development of different types of sensors and are of special interest in conditions where the conventional techniques fail, for example, where electromagnetic interferences exists such as in monitoring the temperature of electrical transformers at power stations where the electromagnetic field prevents the use of conventional sensors. Much optical fiber temperature sensors are strain conventional sensors. Many optical fiber temperature sensors are strain sensitive and therefore must be utilized with utmost care. To avoid the problems of this type of cross sensitivity fluorescence from glass materials or fibers doped with rare earth ions is employed for this purpose [1, 2]. Often in rare earth doped glass there are two close lying levels. For example, $^5D_1$ and $^5D_0$ in triply ionized europium with separation of the order of ~1725cm^{-1} which are useful for this application [3, 4]. Kusama et al. [5] reported temperature sensing properties of Y_2OS: Eu phosphor using FIR technique with a temperature resolution of ~10-15^{0}C in the range -173 to 27^{0}C. Temperature sensors using fluorescence from europium doped Lanthanum and Gadolinium oxysulphide phosphors for use within -100 to 290^{0}C have been developed by Alves and coworkers [6, 7] with an accuracy of ~±0.1^{0}C. The effect of temperature on the fluorescence intensity emitted from $^5D_1$ and $^5D_0$ levels of Eu^{3+} doped in an optical fiber 1.84m in length after excitation with 465nm line from an Ar$^+$ laser have been investigated by Wade et al. [8]. Temperature sensing behavior of Eu^{3+} doped tellurite and calibo glasses based on the Fluorescence Intensity Ratio (FIR) technique has been recently reported [9].

The theme of the present work is to employ the technique based on the fluorescence lifetime in Eu^{3+} doped tellurite glass and to test the relative merits in a wide range of temperature (300-600K).

2. Experimental Procedure

The methods used for preparation of the Eu^{3+} doped tellurite glass are described in our earlier work [9]. Fluorescence was excited by 476.5 nm line of an Ar$^+$ laser and was dispersed with a 0.5 m Spex monochromator fitted with S-20 photomultiplier tube. The lifetime of the excited level was measured using a pulsed laser.

3. Results and Discussion

Fig 1 shows the typical energy level diagram for the fluorescent Eu^{3+} ion. Both the upper levels radiatively decay to the lowest level.

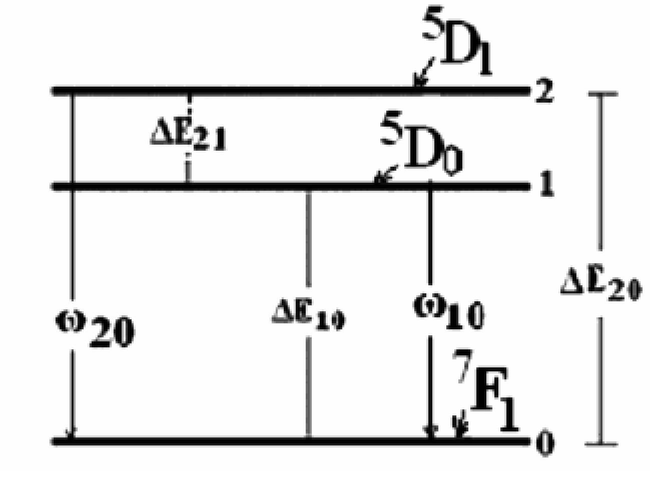

Fig. 1. Typical energy level diagram of Eu^{3+} ion.

Assuming the rate of relaxation between the two levels 1 and 2 very small due to rapid thermalization, the resultant fluorescence lifetime may be given by [2] as,

$$\tau = \left(\frac{1+b_{21}}{A_{10}+A_{20}b_{21}}\right), \tag{1}$$

where A_{10} and A_{20} are the spontaneous transition rates corresponding to the two levels 1 and 2. $b_{21} = (g_2/g_1)\exp(-\Delta E_{21}/kT)$, is the ratio of the population in levels 1 and 2 at equilibrium. g_1 and g_2 are their respective degeneracies, k the Boltzmann's constant and T is the Kelvin temperature.

For the fluorescence lifetime (FL) based temperature sensing technique, the temperature dependent fluorescence decay from the excited levels is monitored using pulsed excitation. The radiative lifetime (τ_2 and τ_1) of the $^5D_1$ and $^5D_0$ levels of Eu^{3+} (separation between the two levels is ~1725cm^{-1}) is 0.17ms and 0.51ms respectively [11]. The resultant fluorescence lifetime at lower temperatures is noted to be approximately the same as the lifetime of the lower level ($^5D_0$ level). In the present case the resultant fluorescence lifetime at room temperature is calculated by equation (1) and the value thus obtained is ~0.52ms. The resultant fluorescence lifetime (τ) at higher temperatures either increase or decrease, depending upon the intrinsic lifetime ratio of the two levels [2],

1. For $\tau_2/\tau_1 < 1$, the resultant lifetime decreases with increasing the temperature.
2. For $\tau_2/\tau_1 > 1$, the resultant lifetime increases with increasing the temperature.

In the present case (i.e. Eu^{3+} doped tellurite glass) the intrinsic lifetime ratio $\tau_2/\tau_1 = 0.33 < 1$ and the lifetime should decrease with increasing temperature. We have determined the lifetime of one (D_0) of the excited levels at different temperatures and found that they decrease with increase in temperature Fig 2.

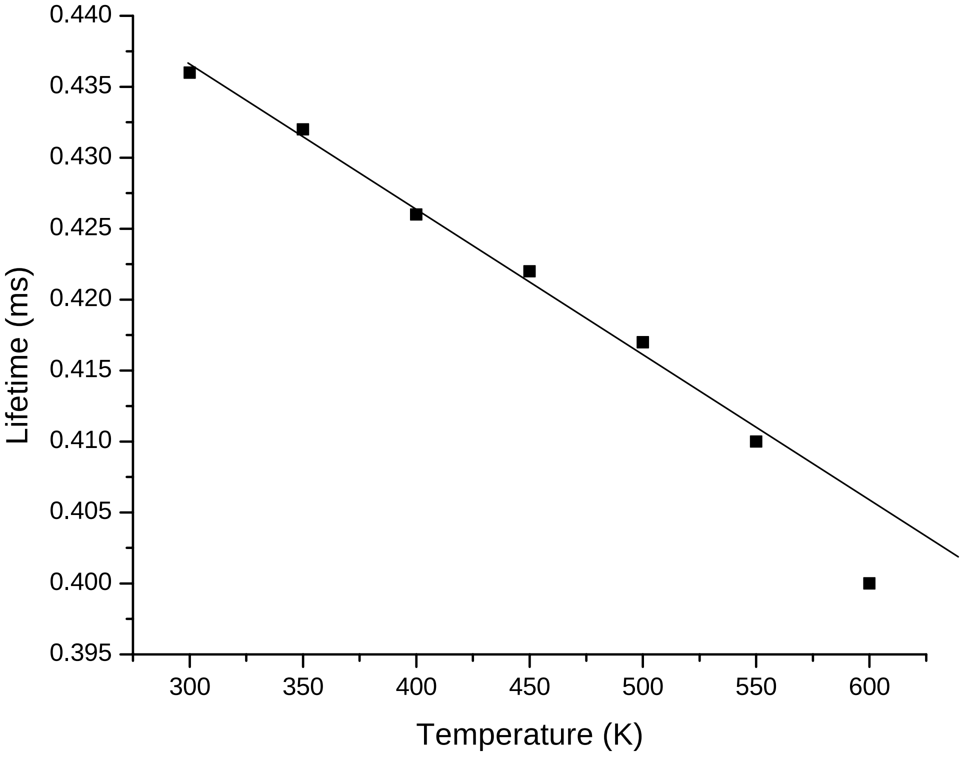

Fig. 2. Variation of the lifetime of $^5D_0$ level in Eu^{3+} doped tellurite glass with temperature.

In the Fluorescence lifetime method, one considers 'τ / τ_1' {the ratio of the thermalized lifetime 'τ' from equation (1) to the lifetime (τ_1) of the lower ($^5D_0$) level} and plot of the same i.e. τ / τ_1 versus temperature is shown in Fig 3.

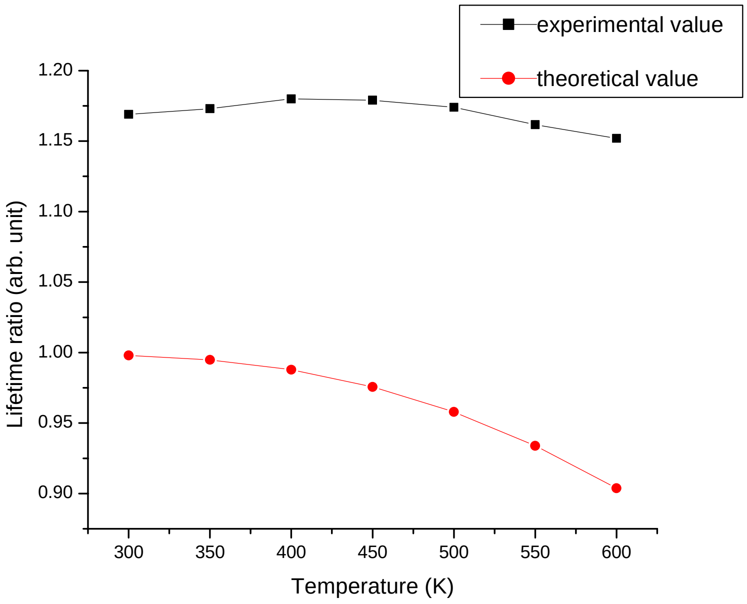

Fig. 3. Ratio of the thermalized lifetime to the lower $^5D_0$ level lifetime with temperature in Eu^{3-} doped tellurite glass.

It is seen that the theoretical and the experimental values differ by nearly ~22% and therefore one would be able to monitor the temperature upto ~550 K within this error.

The sensitivity of the fluorescence lifetime may be given as,

$$S_s = \frac{1}{\tau}\frac{\partial \tau}{\partial T} = \left(1 - \frac{1}{1+b_{21}}\right)\left(\frac{1 - \frac{A_{20}}{A_{10}}}{1 + \frac{A_{20}}{A_{10}} b_{21}}\right)\frac{\Delta E_{21}}{kT^2} \tag{2}$$

From equation 2 the sensitivity of the technique has been calculated and is noted to be ~0.63%/K. The above discussions indicate that the lifetime based temperature sensing technique may be used to monitor the temperature upto 550 K region with in the error limit ~22%.

Acknowledgements

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Sensors & Transducers Journal (ISSN 1726- 5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In additional, some special sponsored and conference issues published annually.

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