JOURNAL OF OPTOELECTRONICS AND ADVANCED MATERIALS Vol. 13, No. 1, January 2011, p. 69 - 71

Temperature sensor based on lifetime measurement of Erbium fluorescence

S. W. HARUN[a,c*], M. YASIN[b,c], A. HAMZAH[c], H. AROF[a], H. AHMAD[c]
[a]*Department of Electrical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia.*
[b]*Department of Physics, Faculty of Science and Technology, Airlangga University, Surabaya 60115, Indonesia.*
[c]*Photonics Research Centre, Department of Physics, Faculty of Science, University of Malaya, 50603 Kuala Lumpur, Malaysia*

A fluorescence based fiber-optic temperature sensor is demonstrated using a modulated pump laser in conjunction with a piece of Erbium-doped fiber (EDF). The remote fiber sensor is based on a lifetime measurement of 90 cm long EDF, which is diode-pumped by a 980 nm laser and can be used to measure temperature in the range of 26^{o}C to 60^{o}C. The sensitivity of the sensor is obtained at 0.009 ms/^{o}C with a linearity of more than 94%. The use of fibers of this type opens up significant possibilities for high temperature sensor probes, which is effective and useful for its high resolution and precision.

(Received November 22, 2010; accepted January 26, 2011)

Keywords: Fiber optic, High temperature and lifetime measurement, Erbium fluorescence

1. Introduction

The need for temperature measurement exists in many applications for various processes. Although there are many kinds of temperature sensors based on thermoelectric effects, fiber-optic sensors offer many advantages over them in certain applications [1-2]. Since signals from the thermoelectric sensors are normally mixed with intrinsic noise and extrinsic interferences, they are imprecise to a certain degree and may contain intolerable errors. Therefore, this type of sensors is inapt for gauging temperature in microfluidic or nano-sized devices, in extreme marine environments, and underground geological sites where long distance measurement or precision is required. For such applications, fiber optical sensors offer a better alternative since the optical signal does not suffer from interference by electromagnetic fields and can be transmitted over extremely long distances without any significant loss [3-6].

A variety of fiber optical sensors have been demonstrated recently for temperature measurement such as the sensors based on Bragg gratings [7], scattering [8], and fluorescence-based techniques [9]. Fiber Bragg gratings are very efficient at temperature sensing and are easy to implement; however, they always need additional techniques to discriminate the Bragg shifts by temperature and by strain/compression. On the contrary, the fluorescence-based techniques are relatively independent of ambient conditions besides temperature. One of the widely used methods is the detection of fluorescence lifetimes [10-11]. This method can be utilized with various rare-earth-doped silica fibers. In principle, fluorescence is induced by pump power at a certain wavelength that is suitable for the doped ions, and only a straightforward detection procedure is needed. An additional advantage of such rare-earth-doped fiber sensors is that they are compatible with a wide range of existing fiber-optic multiplexing schemes that can simultaneously detect multiple physical parameters.

The underlying principle behind the ability of the rare-earth doped materials to be used as temperature sensors [12] is their properties of emission and absorption that are dependent on the temperature. This behavior is due to the homogeneous broadening of the linewidth and the changing population of the energy levels with temperature. In the earlier work, a remote temperature sensor has been proposed using fluorescence intensity-ratio technique [13]. In this paper, a new temperature sensor is demonstrated based on fluorescence decay time in Erbium-doped silica fiber. This technique has the advantage of incorporating a time based encoding system, which is less sensitive to system losses such as those associated with optical cables and connectors.

2. Experimental

Fig. 1 shows the schematic diagram of the experimental set-up. The 980nm laser pump beam is launched into a piece of 90 cm long Erbium-doped fiber (EDF) via a wavelength division multiplexing (WDM) coupler. The EDF is placed in a vacuum oven which allows us to vary the fiber temperature within 25 to 200^{o}C interval. The fluorescence signal from the forward pumped EDF is detected by a Ge photo-detector and processed with a digital oscilloscope. The 980 nm pump beam is chopped so as to generate a square-wave modulated signal with pulse width of 2.2 ms, peak power of approximately 124 mW and frequency of 45 Hz. When the erbium-doped fiber is pumped with the photon energy of 980 nm, the $^4I_{11/2}$ erbium level is excited and the $^4I_{13/2}$ metastable level is quasi-instantaneously populated due to the non-radiative transition. The population inversion between $^4I_{13/2}$ and $^4I_{11/2}$ level is responsible for the emission of fluorescence at around 1550 nm. When the EDF is pumped at a fixed rate, the fluorescence variation including a lifetime change can reflect corresponding temperature. The temperature dependent fluorescence lifetimes of the spontaneous emission of the EDF is investigated and studied in this work.

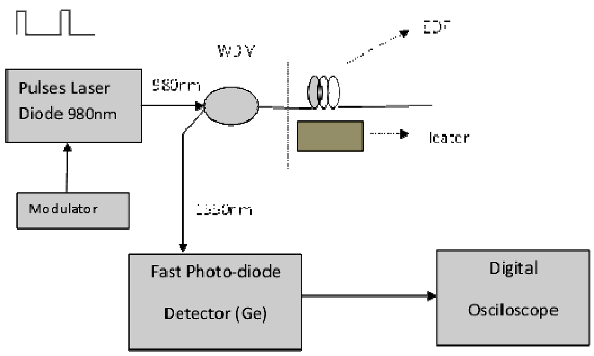

Fig. 1. Experiment setup of fiber optic high temperature sensor.

3. Results and discussion

Fig. 2 shows the output spectrum of the amplified spontaneous emission (ASE) of the forward pumped EDF when the continuous wave pump power is fixed at 31 mW. The ASE spectrum peaks at 1529 nm with the average power of around -58 dBm. The temperature sensing mechanism in this work is based on the temperature dependence of the Erbium fluorescent lifetime decay. The Erbium fluorescence lifetime is measured using a modulated pump laser with power of approximately 2 mW and the results for temperature measurements of 85°C and 130°C are shown in Figs. 3(a) and (b), respectively. Fitting the exponential curve produces lifetimes of 4.85 and 4.75 ms for temperatures of 85°C and 130°C accordingly. The fluorescence lifetime data taken over the range of 25°C to 160°C are presented in Fig. 4. The graph shows the existence of an inverse linear relationship between the Erbium lifetime and the temperature. The fluorescence lifetime data shown in Fig. 4 are mean values of consecutive measurements at corresponding stabilized temperature. The sensitivity of the sensor is obtained at 0.009 ms/°C with a linearity more than 94%. The lifetime reduction is attributed to the quenching of the Erbium luminescence, which results in less efficient excitation. The quenching is mainly due to a decrease in the absorption coefficient of Erbium ion as the temperature is increased.

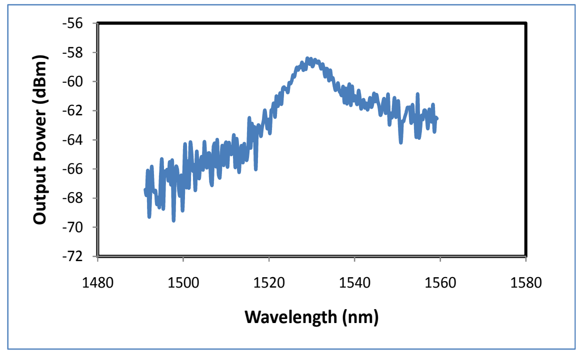

Fig. 2. Output spectrum of the generated ASE with 980 nm pump power of 31mW.

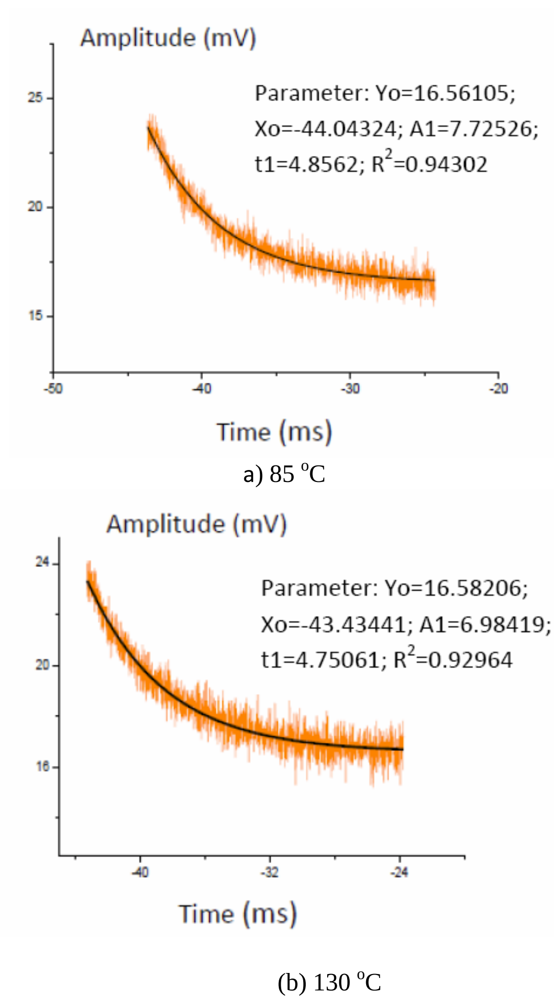

Fig. 3. Fluorescence lifetime decay of EDF at (a) 85 °C and (b) 130 °C from a digital oscilloscope.

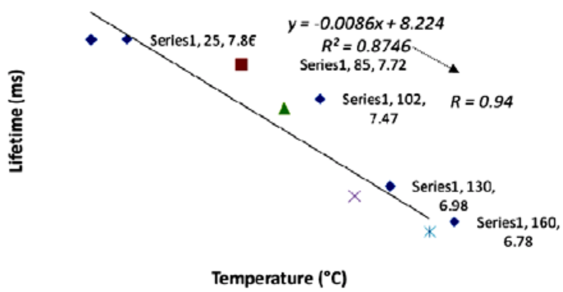

Fig. 4. Lifetime of EDF as function of Temperature.

4. Conclusions

The fluorescence lifetime decay time of EDF as a function of temperature in the 26-60^{o}C range is demonstrated for sensor application. The remote temperature sensor is based on a lifetime measurement of 90 cm long of EDF, which is diode-pumped by a modulated 980 nm laser. The sensitivity of the sensor is obtained at 0.009 ms/^{o}C with a linearity of more than 94%. This temperature sensor is shown to be effective and useful for its high resolution and precision.

References

[1] B. Lee, Opt. Fiber Technol. **9**, 57 (2003).

[2] D. Liu, H. Liu, D. M. Liu, Optoelectron. Adv. Mater. – Rapid Comm.. **4**(6), 795 (2010).

[3] M. Yasin, S. W. Harun, H. Z. Yang, H. Ahmad, Optoelectron. Adv. Mater. – Rapid Comm. **4**(8), 1063 (2010).

[4] L. Li, X. Y. Dong, L. Y. Shao, C. L. Zhao, Y. L. Sun, Optoelectron. Adv. Mater. – Rapid Comm. **4**(7), 943 (2010).

[5] H. Ahmad, W. Y. Chong, K. Thambiratnam, M. Z. Zulklifi, P. Poopalan, M. M. M. Thant, S. W. Harun, IEEE Sensors J., **9**(12), 1654 (2009).

[6] K. S. Lim, S. W. Harun, H. Z. Yang, K. Dimyati, H. Ahmad, J. Modern Optics, **56**(17), 1838 (2009).

[7] K. J. Han, Y. W. Lee, J. Kwon, S. Roh, J. Jung, B. Lee, IEEE Photon. Technol. Lett., **16**, 2114 (2004)

[8] R. Rathod, R. D. Pechstedt, D. A. Jackson, D. J. Webb, Opt. Lett., **19**, 593 (1994).

[9] V. Lopez, G. Paez, M. Strojnik, Infrared Physics & Technology, **46**, 133 (2004).

[10] H. C. Seat, J. H. Sharp, Z. Y. Zhang, K. T. V. Grattan, Sensors and Actuators A, **101**, 24 (2002).

[11] S. Baek, Y. Jeong, J. Nilson, J. K. Sahu, B. Lee, Optical Fiber Technology, **12**, 10 (2006).

[12] M. McSherry, C. Fitzpatrick, E. Lewis, Sensor Review, **25**, 56 (2005).

[13] J. Castrellon-Uribe, Optics and Lasers in Engineering, **43**, 633 (2005).

*Corresponding author: swharun@um.edu.my