THERMALLY EXCITED LUMINESCENCE FROM RARE-EARTH DOPED SiO_2 FOR FIBER-OPTIC THERMOMETER

T. Katsumata, K. Morita, A. Okabe, H. Aizawa, S. Komuro, T. Morikawa

Sensor Photonics Research Center, Toyo University,
Kujirai Nakanodai, Kawagoe, Saitama 350-8585, Japan, katsumat@eng.toyo.ac.jp

Abstract: Thermally excited luminescence from rare-earth element doped SiO_2 fibers were studied for the fiber-optic thermometer application in high temperature. Thermal radiation similar to the black body radiation was observed in visible light region from the SiO_2 fibers doped with Y, La, Ce, Pr, Eu, Tb and Lu. Visible light radiation peaks due to f-f transitions of rare-earth ions were clearly observed in the Nd, Dy, Er, Ho, Tm and Yb doped SiO_2 fibers. Intensity ratio of thermal radiation at different wavelength is suitable for the highly sensitive temperature measurement. The hybridization of fluorescent thermometry and thermal radiation thermometry is suggested to extend the temperature range and increase the temperature resolution.

Keywords: fiber-fptic thermometer, thermal radiation, rare-earth metals.

1. INTRODUCTION

Fiber-optic thermometer based on the fluorescence decay and thermal black body radiation have been reported for the temperature measurements in the extraordinary conditions [1-5]. The fiber-optic thermometer based on the fluorescence decay is not so convenient at high temperature region because of decreasing PL intensity due to thermal quenching and decreasing the PL lifetime [1-5]. On the other hand, the fiber-optic thermometer using the thermal black body radiation, which is suitable for the high temperature measurement, requires infrared (IR) transparent Sapphire fiber. The hybridization of fluorescent thermometry and thermal radiation thermometry is extremely powerful tool because it is suggested to extend the temperature range and increase the temperature resolution [6-8].

In order to develop high temperature sensor, the authors have reported thermally excited luminescence from rare-earth doped SiO_2 sensor used in fluorescence thermometer. In this paper, thermal radiation from rare-earth elements doped SiO_2 fibers are reported for highly sensitive fluorescence thermometer sensor in high temperature measurement.

2. EXPERIMENTAL

Rare-earth doped SiO_2 fibers were prepared using 4N SiO_2, Al_2O_3 and Ln_2O_3 powders (Ln means rare-earth elements). Powders were mixed with 5% polyvinyl alcohol (PVA) solution. Quartz rods with 6, 3 and 1.5 mm diameter

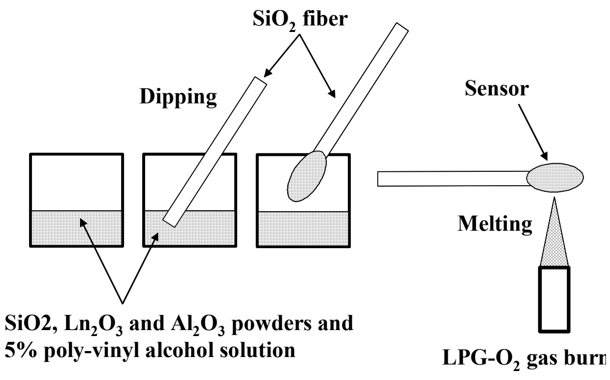

Fig. 1. Schematic illustration for the preparation of rare-earth doped SiO_2 sensor material. SiO_2 fiber is dipped into the mixed solution of SiO_2, Ln_2O_3 and Al_2O_2 with 5% polyvinyl alcohol. Fibers are, then, dried and melted using liquid propane gas (LPG) and O_2 gas burner.

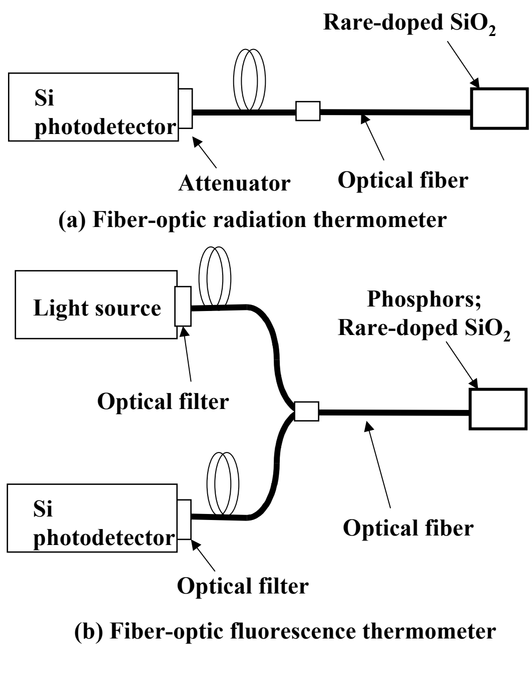

Fig. 2. Schematic illustration of a fiber-optic fluorescence thermometer and a thermal radiation thermometer equipment using Er doped SiO_2 as a sensor materials.

Fig. 3. Er doped SiO_2 fibers fabricated using a process shown in Fig. 1. Various Er concentrations from 500 to 50000 ppm are shown in the figure.

and 0.125 mm diameter SiO_2 optical fiber are dipped into the solution, then, dried, sintered and melted in a flame as shown in Fig. 1.

Figure 2 shows a fiber-optic thermometer based on thermal radiation of rare-earth doped SiO_2. In the thermometer equipment, sensor material is set inside of the quartz tube with a Pt-Rh thermocouple. Thermal radiation spectra from 350 nm to 1100 nm are measured at various temperatures from RT to 1673 K. Peak intensities of the thermal radiation is measured using the spectra at various temperature. Peak intensity ratio of the thermal radiation peaks is also calculated from peak intensities of the thermal radiation spectra.

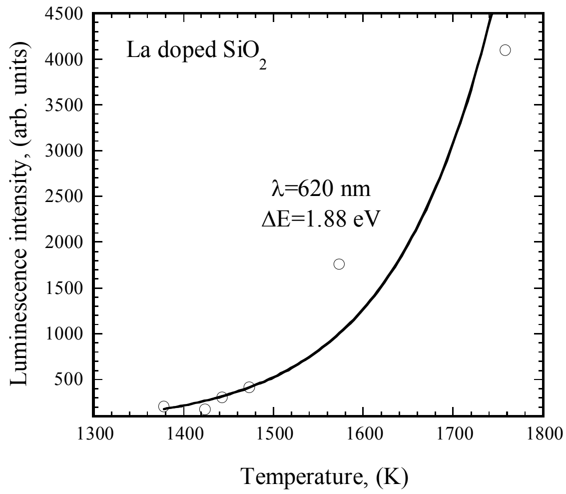

Fig. 5. Temperature dependence of thermally excited luminescence intensity from La doped SiO_2.

3. RESULTS AND DISCUSSION

Figure 3 shows Er doped SiO_2 fiber sensor fabricated using the process shown in Fig. 1. Fiber sensors with various Er concentrations from 500 to 50000 ppm are shown in the figure. Er is only doped at the tip of the fibers.

Thermal radiation spectra similar to the black body

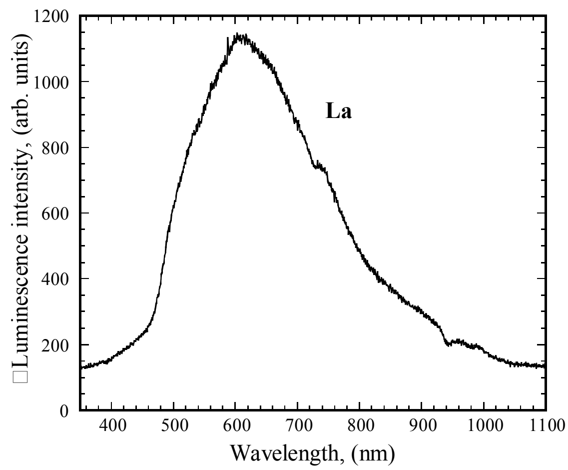

Fig. 4. Thermally excited luminescence spectra from La doped SiO_2.

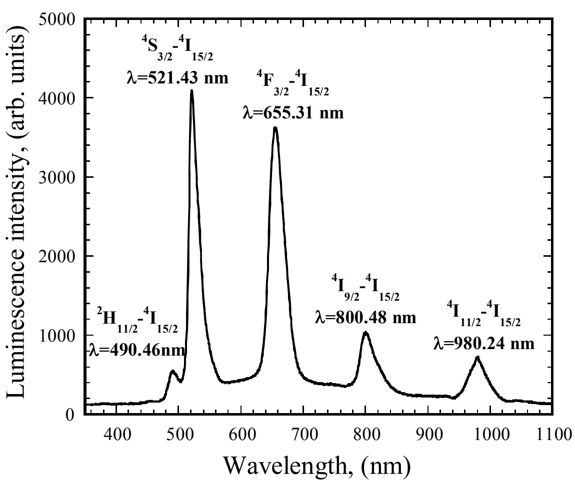

Fig. 6. Thermally excited luminescence spectra from Er doped SiO_2.

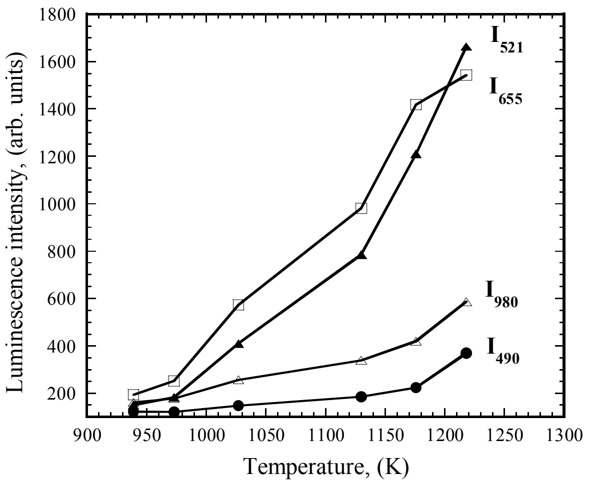

Fig. 7. Temperature dependence of thermally excited luminescence intensity from Er doped SiO_2.

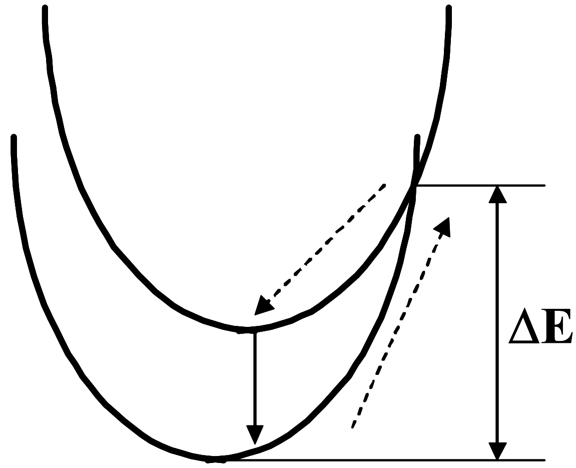

Fig. 9. Schematic illustration of an emission by thermal excitation of f-electrons. This process occurs in the thermal radiation thermometer using rare-earth doped SiO_2 as a sensor materials.

radiation are seen in La doped specimen as shown in Fig. 4. In the thermal radiation spectrum from La doped SiO_2, broad peak at λ=600 nm is observed above 900 K. Peak intensity of thermal radiation increases with temperature. Radiation peak shifts to the short wavelength with temperature.

Figure 5 shows radiation intensity at peak wavelength from La doped SiO_2 fiber at various temperatures. Radiation intensity at peak wavelength increases with temperature. In the La doped SiO_2 fiber, temperature can be measured using intensity or intensity ratio of the thermal radiation. Thermal activation energy for the radiation intensity from La doped SiO_2 fiber is estimated to be ΔE=1.88 eV.

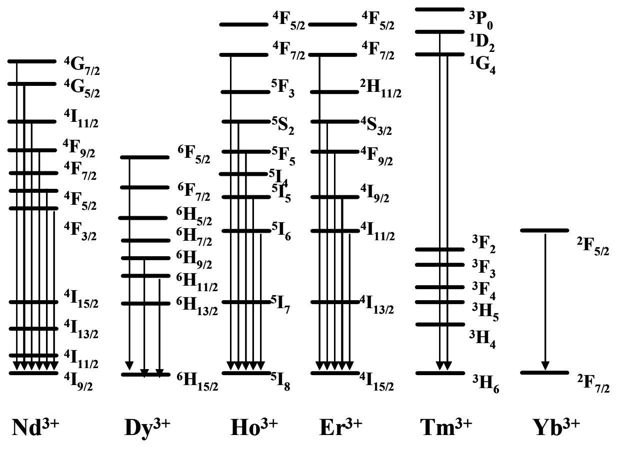

Fig. 8. Energy diagram for rare-earth ions, Nd, Dy, Ho, Er, Tm and Yb. Transitions for thermally excited luminescence is shown in the figure [9]. Diagrams are reported for photoluminescence from rare-earth ions by G. H. Dieke and H. M. Crosswhite.

Typical thermally excited luminescence spectra due to f-f transitions in Er doped SiO_2 is shown in Fig. 6. In the Er doped SiO_2 specimens, thermally excited f-f emissions are clearly observed in the visible light region. These radiation peaks are assigned with the f-f transitions of rare-earth ions [9].

Intensities of these visible light radiation increase with temperature especially at high temperature as shown in Fig. 7. Thermally excited luminescence intensities of peaks at λ=490, 521, 655, 800 and 980 nm increase similarly with temperature. The intensity ratio, $I_{656/980}$, between 656 nm and 980 nm and $I_{521/980}$, between 521 nm and 980 nm are the most suitable for the temperature measurement because of high sensitivity.

Figure 8 shows energy diagram [9] for thermally excited luminescence from rare-earth ions in rare-earth doped SiO_2 fiber sensors. In Nd, Dy, Ho, Er, Tm and Yb doped SiO2 fibers, visible light luminescence due to f-f transitions is clearly observed at high temperature above 900 K. Luminescence peaks can be assigned perfectly with f-f transitions in Fig. 8.

Tentative mechanism for the thermally excited luminescence from rare-earth doped SiO_2 fiber sensors is illustrated in Fig. 9. Electrons at the ground state are excited thermally against thermal activation energy, ΔE, to an exciting state. Thermally excited luminescence is observed due to the radiative transition of these excited electrons.

Fig. 10. Measured points in a flame for two dimensional temperature distribution measurement using Er doped SiO_2 fiber sensor.

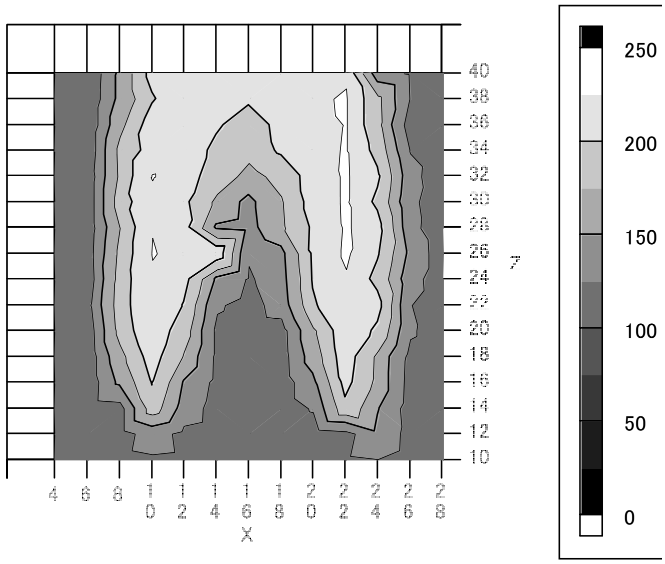

Fig. 11. Two dimensional temperature distribution in a flame measured using Er doped SiO_2 fiber sensor.

Next two dimensional (2-D) distribution of thermally excited luminescence intensity is measured using Er doped SiO_2 fiber sensor fabricated. Figure 10 shows a flame of a propane-O_2 gas burner which is used for 2-D distribution measurement. Grid drawn in the figure shows measured points.

Figure 11 shows 2-D distribution of thermally excited luminescence intensity in the flame using Er doped SiO_2 fiber sensor. 2-D distribution of thermally excited luminescence intensity agrees with shape of flame and 2-D temperature distribution measured by thermocouple. Thermally excited luminescence from rare-earth doped SiO_2 fiber sensor is potentially useful for the temperature measurement at high temperature. Temperature dependences of peak intensity and peak intensity ratio are suggested to be applicable to the fiber-optic thermometer.

4. CONCLUSION

Thermally excited luminescence from the rare-earth end-doped SiO_2 fiber is effective for the temperature measurement at high temperature. Thermal radiation similar to the black body seen in the Y doped SiO_2 and f-f transition seen in the Er doped SiO_2 can be used for the temperature measurement. In some rare-earth elements, hybridization of fluorescent thermometry and thermal radiation thermometry can be realized with the same sensor material.

ACKNOWLEDGMENTS

The study was supported as "High-Tech Research Center" Project for Private Universities: matching fund subsidy from MEXT (Ministry of Education Culture, Sports, science and Technology), 2004-2008.

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