TEMPERATURE DEPENDENCE OF GREEN UPCONVERSION FLUORESCENCE OF FLUOROPHOSPHATE AND TELLURITE-BARIUM GLASSES FOR APPLICATION IN TEMPERATURE SENSORS

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Temperature dependences are studied of green upconversion fluorescence of the five erbium- and ytterbium-doped glasses (three fluorophosphate glasses, one of which is additionally doped with Tm, and two tellurite-baruim ones) in the temperature range from 30°C to 150°C. The ratio of intensities is determined of two fluorescence bands at about 515-525 nm and 540-560 nm versus the specimen temperature. The sensitivity of temperature measurement is found and a comparison of the glasses is performed according to this characteristic.

Introduction

Optical sensors based on the temperature-dependent interaction of optical radiation with solid hosts represent fast-growing branch of science and technology. They can be used for temperature, pressure, electric and magnetic field strength as well as for gas sensing. Temperature-dependent fluorescence of rare-earth doped hosts is widely studied for the purpose of use in optical temperature sensors. The sensing is based on fluorescence lifetime or fluorescence intensity ratio dependence on the temperature of a solid-state sensor head. Fluorescence intensity ratio (FIR) temperature sensors attract great attention due to their wide operating range, stability, independence on pump power variations, relative simplicity and cost-effectiveness [1].

A wide range of rare-earth-doped solids are studied for use in FIR sensors e.g. crystals, glasses and glass-ceramics. The purpose is to increase maximum measurable temperature and temperature measurement sensitivity, enhance fluorescence signal, minimize optical noises and measurement errors, improve stability and reduce cost.

Our previous works deal with some crystals and nano-glass-ceramics where the ratio of intensities of upconversion fluorescence from two closely-spaced temperature-related levels was studied [2].

In this contribution we consider five erbium-doped glasses: three fluorophosphate ones and two tellurite-baruim ones, in view of their use for sensing head of a solid-state optical temperature sensor.

Samples and Experiment

The following erbium-doped glass sampes are studied:

S1. Fluorophosphate glass with dopants ErF_3 - 1% and YbF_3 10%.

S2. Tellurite-barium glass with the composition: Te_2O_3 and BaO in proportion 4:1, Er 1%.

S3. Fluorophosphate glass with dopants ErF_3 – 0.5% and YbF_3 10% (2 times lower Er content compared to the 1st sample).

S4. Fluorophosphate glass with dopants ErF_3 0.8%, Yb 8%, Tm_2O_3 0.1%.

S5. Tellurite-barium glass with Er 0.5% (2 times lower compared to the 2nd sample).

The solid-state samples were pumped by radiation of a laser diode at about 960 nm. The temperature of each sample was varied from 30°C to 150°C by a furnace PV10 («Coversion Ltd», Great Britain) with a temperature controller. Fluorescence radiation was driven into S-100 spectrometer with a fiber input.

Upconversion fluorescence was observed for all the samples, i.e. radiation with a wavelength shorter than a pump radiation one. Though the set of fluorescence bands was different for some samples, two green bands at approximately 515-525 nm and 540-560 nm were observed in all the cases. The two bands are thought to be temperature-related and are frequently considered in FIR thermometry as the ratio of their intensities can be a reliable indicator of a sample temperature [1].

The green upconversion fluorescence bands normalized to unity maximum intensity are shown on the Fig.1.

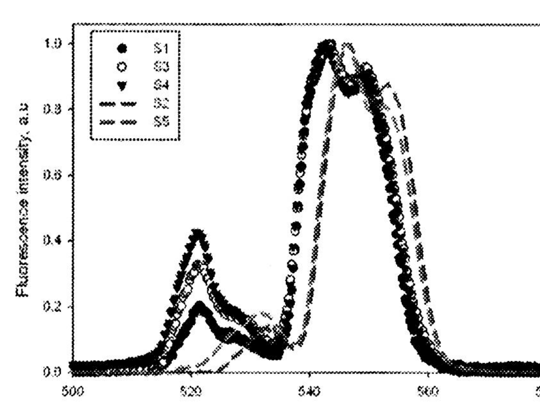

Fig. 1. Normalized green fluorescence bands.

The fluorophosphate glasses spectra are shown by symbols, the tellurite-baruim glasses ones are shown by dashed lines. It can be seen that a host composition effects the bands' spectral position – the spectra in higher-density hosts are slightly long-wavelength shifted.

To calculate the fluorescence intensity ratio the portions of the bands were taken with the intensities higher than 0.1 of a maximum band's intensity at 30°C. The calculated FIR ratios are shown on the Fig. 2.

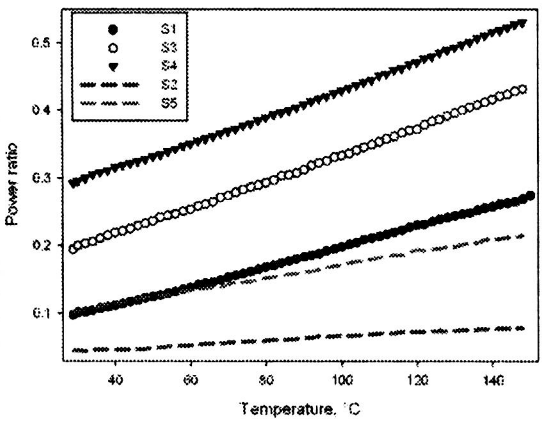

Fig. 2. FIR for green fluorescence bands.

The linear nature of the fluorescence intensity ratio is the most convenient one for the temperature measurement. The FIRs obtained generally meet the requirement for linearity.

On the basis of the FIR the sensitivity of the temperature measurement can be calculated which shows the relative FIR increase per 1°C temperature rise. The higher sensitivity is needed for a temperature sensor to be suitable for practical applications.

For sensitivity estimation the FIR curves were approximated by 3rd order polynomials. The estimated sensitivity dependencies on the temperature are shown on the Fig. 3.

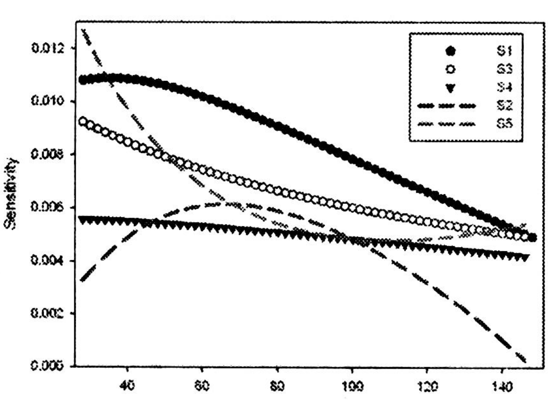

Fig. 3. Estimation of the sensitivity of temperature measurement.

The sensitivity curves are shown by symbols for fluorophosphate glasses and by dashed lines for tellurite-baruim ones. The sensitivities for the former are generally larger and fall in range from 0.004 to 0.011 – the S1 sample has the range ~0.005-0.010 for the sensitivity, the S3 has ~0.005-0.009 range, and the S4 has ~ 0.004-0.006 one. The sensitivities for tellurite-barium glasses vary significantly in the considered temperature range. While the S5 sample with 0.5% Er concentration is competitive with the fluorophosphate glasses and even shows the maximum sensitivity among all samples considered (it takes place at room temperatures), the S2 sample with two times higher Er concentration shows much lower fluorescence intensity due to concentration quenching and it's the poorest sample in view of sensitivity of temperature measurement.

The samples S1 and S3 of fluorophosphate glasses also differ only in Er concentration (two times larger for the first one). The fluorescence intensity for the first one was larger significantly in our experiments, but the Fig. 3 shows that the sensitivity is better for the S3 sample. The third fluorophosphate glass S4 which is additionally doped with Tm exhibited the best luminescent properties with the highest intensity obtained and with the richest set of upconversion luminescence bands. Nevertheless, the estimated sensitivity for this sample is inferior to the other two fluorophosphate glass samples and even to the S5 tellurite-baruim glass sample.

Conclusions

The five samples of Er- and Yb-doped glasses (three fluorophosphate ones and two tellurite-baruim ones) were considered under laser diode radiation at ~960 nm in view of their use as solid-state heads for optical temperature sensors. The green upconversion fluorescence bands intensity ratio was calculated in the temperature range from 30°C to 150°C. The FIR exhibits approximately linear behavior. The estimation of the sensitivity of temperature measurement was performed. The sensitivities for fluorophosphate glasses are generally better than for tellurite-baruim ones and lie in the range from 0.004 to 0.011.

It may be concluded that the optimization of an optical sensor head implies the proper choice both of a glass host and dopants concentrations allowing achieving sufficient fluorescence power, linear behavior of FIR ratio and the highest sensitivity possible.

References

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