A newly developed OSL dosimeter based on Beryllium Oxide: BeO:Na,Dy,Er

V. Altunal[a], V. Guckan[a], Y. Yu[b], A. Dicker[b], Z. Yegingil[a]
[a] Cukurova University, Physics Department, Balcalı, 01330 Sarıçam, Adana, Turkey
[b] Thomas Jefferson University, Sidney Kimmel Medical College, Philadelphia, PA, USA

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INTRODUCTION

Optically Stimulated Luminescence (OSL) is the light emission from a previously irradiated material (semiconductor and insulator) stimulated by the absorption of optical energy. The intensity of the OSL signal is proportional to the dose of absorbed radiation. OSL technique is being developed and has found use in several dosimetry applications, including personal, environmental, medical, and retrospective dosimetry. The earlier reports have described the OSL properties of several important materials that can be used as synthetic OSL dosimeters: Al_2O_3:C (1), halides (2), sulphides (3), and oxides (4,5).

The introduction of BeO to the OSL literature was realized with the study on the light sensitivity property provided an advantage to BeO and the material was suggested as an OSL phosphor (4). After BeO (Thermalox 995 chip) was presented using the OSL technique in detail (6), the material has gained popularity for OSL dosimetry.

BeO Thermalox 995 chips are not produced specifically for dosimetric purposes and contain many impurity elements of Si, Mg, Fe, Al, B, and Ca, making it difficult to understand and control the luminescence properties. Therefore, the luminescence properties of the BeO based materials as a synthesized material have been investigated in this study. This work includes to advance the material synthesis method that made possible to produce the OSL material with desired dosimetric and luminescence properties..We successfully synthesized BeO by doping with La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Er lanthanides and Mg, Al, Ca, Li, Na transition metal ions in different concentrations and combinations using the precipitation synthesis method. Further development of BeO samples and their characterization by doping Na^+, Dy^{3+} and Er^{3+} provided the highest luminescence efficiency.

AIM

Because no detector with suitable dosimetry properties was obtained so far, there is a need for another investigation in this material. The aim of this study was to develop a new OSL material with tissue equivalent Z_{eff} value (Z_{eff} = 7.31) and having high sensitivity to ionizing radiation and fast luminescence lifetime for dosimetry applications.

METHOD

The material structure was confirmed by performing X-ray diffraction (XRD), Scanning Electron Microscope (SEM) and Energy Dispersive X-ray (EDS) analyses. Thermoluminescence (TL), and OSL techniques were used for the investigation of the luminescence properties.

RESULTS

In Figure 1, the X-ray diffraction spectrum was found to be well-matched with the main data of the BeO phase reported in the ICDD-PDF-card no 98-016-3468. The average crystallite size of the BeO:Na,Dy,Er sintered at 1600 ºC was found as (325 ± 7) nm.

Micrograph of a BeO-ceramic sample with additives 5% Na, 0.1%Dy and 0.05%Er is shown in Figure 2a. The high-resolution SEM indicates the presence of no porosity (see Fig. 2a). The SEM photomicrograph of pure BeO is shown in Figure 2b. The microstructure shows an average grain size of ~ 3 µm, besides, some of the grains grew up to ~ 10 µm (data not given). It was found that the rate of grain growth for the BeO sample containing Na, Dy and Er was qualitatively larger with less porosity than that of the pure BeO sample. The luminescence intensity of BeO:Na,Dy,Er ceramics sintered at 1600 ºC were found to be higher than those obtained for pure BeO sintered at the same temperature.

The EDS analysis was performed to investigate the existence of elemental impurities. The presence of Oxygen (O), Sodium (Na), Dysprosium (Dy) and Erbium (Er) in the host structure was confirmed by EDS (see Fig. 3). As seen from the Figure 3, except for the peaks of Carbon (C), Platinum (Pt) and Gold (Au) coating elements, no impurity peaks were found in the EDS spectrum.

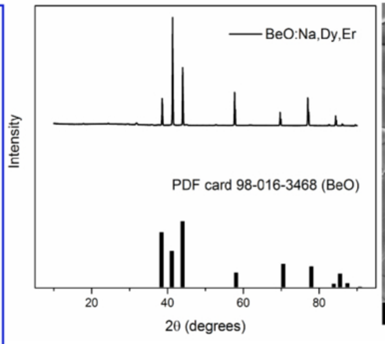

Figure 1. XRD patterns of BeO:Na,Dy,Er pellet with reference BeO (PDF card no 98-016-3468).

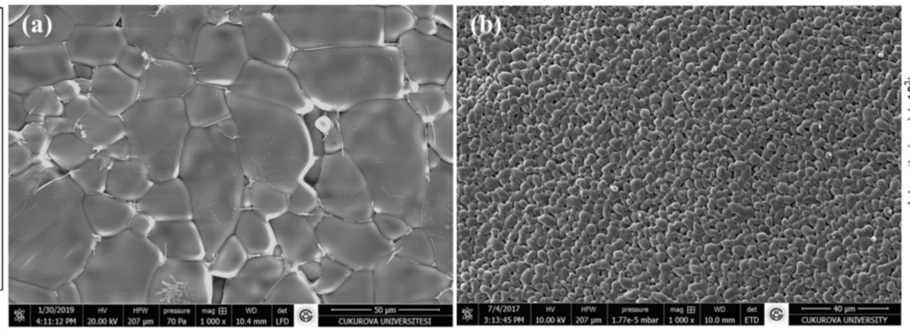

Figure 2. a) SEM micrograph of BeO:Na,Dy,Er pellet, **b)** SEM micrograph of pure BeO pellet

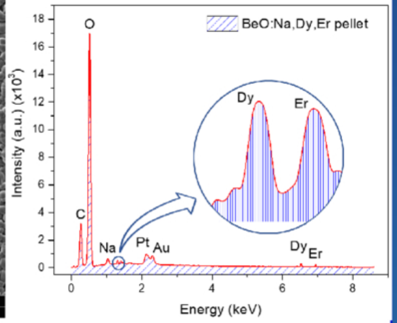

Figure 3. EDS spectrum of the BeO:Na,Dy,Er pellet

In Figure 4a, the OSL intensity from BeO:Na,Dy,Er is almost the same as that of BeO chip and higher than that of previously studied undoped BeO pellet. The data presented in Figure 4b shows that the TL intensity of the BeO:Na,Dy,Er pellet is more sensitive to radiation exposure than that of the other two samples, Thermalox 995 BeO chip and undoped pellet. The OSL and TL sensitivities of BeO:Na,Dy,Er material after exposure to ionizing radiation are found to be high and sufficient for dosimetry applications.

In Figure 5a, the 1st peak located at ~170 °C in the TL glow curve of BeO:Na,Dy,Er pellet was affected by optical stimulation whereas the 2nd and 3rd TL peaks located at ~350 and ~470 °C, respectively were not. This effect of light exposure on TL signals provides evidence that the origin of the OSL signal might be related to the 170 °C TL peak. The inset of Figure 5a is for better viewing of the 2nd and 3rd peaks due to low TL signal intensities. In Figure 5b, OSL signals of both undoped and BeO:Na,Dy,Er pellets started to decrease after 130 °C corresponding to emptying of the 170 °C TL peak. With increasing preheating temperature, the OSL signals of undoped BeO reaches background level whereas that of BeO:Na,Dy,Er sample were constant up to 350 °C. After the 2nd reduction in OSL signals, with the discharge of the 350 °C TL peak, the OSL signals reached the background level. These results confirm that the OSL signals of BeO:Na,Dy,Er pellets might be originated both from the 170 and 350 °C TL peaks, whereas only 170 °C TL peak of the undoped sample contributes the OSL signals.

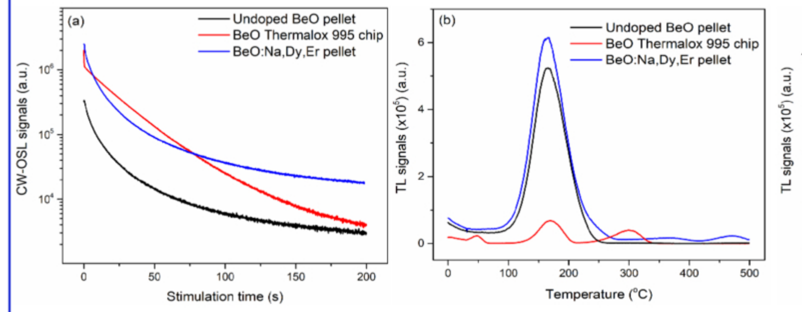

Figure 4. a) OSL and **b)** TL signals from BeO:Na5%,$Dy_{0.1\%}Er_{0.05\%}$ pellet, compared to the OSL/TL from commercial used BeO (Thermalox 995) chip and previously studied undoped BeO pellet. All measurements were done with Hoya U-340 filters. Each curve is the average of three pellets or chips. The heating rate was 1 °C/s.

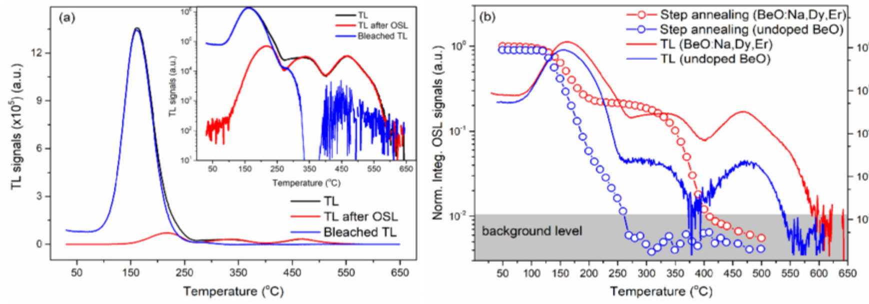

Figure 5. (a) TL glow curve (direct TL), TL glow curve (residual TL) obtained after OSL measurement and Bleached TL curve from the 0.5 Gy irradiated pellets, **(b)** Step annealing curves of OSL signals from BeO:Na,Dy,Er pellets.

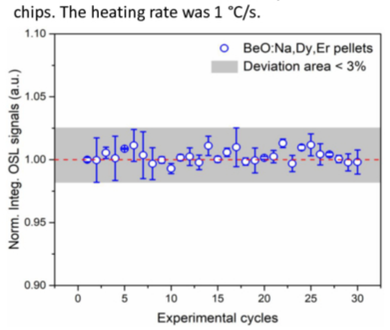

Figure 6. The reusability characteristics of OSL signals of BeO:Na,Dy,Er ceramic pellets. After 0.5 Gy beta test dose and 110 °C for 60 s preheating, OSL signals were recorded during 200 s optical stimulations. Each data point represents the mean of integrated (the total OSL signal counts from 0 to 200 s) and normalized (according to first readout) OSL signals. The error bars represent the experimental standard deviations of mean values obtained from three pellets in each cycle.

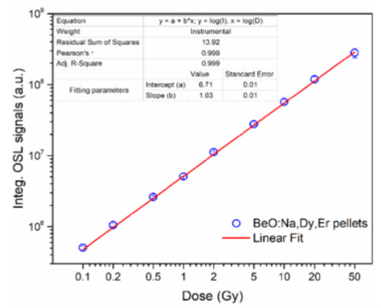

Figure 7. Dose-response curve of the integrated whole OSL signals from three BeO:Na,Dy,Er ceramic pellets in the dose range between 0.1 and 50 Gy. Inset: Linear fitting parameters was obtained by equation of y = a + bx, where refers to y = log(I), x = log(D), a is intercept, b is slope, (I) represents Integrated OSL signals, and D is dose value. The data points on the plot represent the average of the integrated OSL signals (the total OSL signal counts from 0 to 200 s) of three pellets used and the error bars are the standard deviations (1σ).

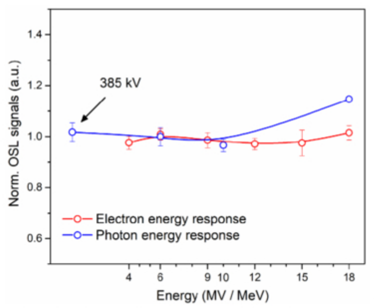

Figure 8. Energy dependence of OSL signals from the BeO:Na,Dy,Er ceramic pellets. Each data point represents the mean of integrated (the total OSL signal counts from 0 to 200 s) and normalized (according to the readout for 385 kV photon energy) OSL signals. The error bars are the experimental standard deviations of mean values obtained from three pellets in each measurement.

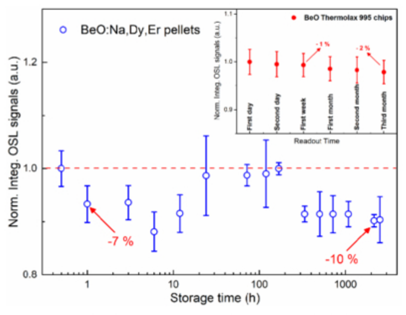

Figure 9. Fading characteristics of the OSL signals from the BeO:Na,Dy,Er ceramic pellets as a function of storage time up to three months and 15 days after 0.5 Gy beta dose initial exposure. The data points on plot represents the average of integrated (the total OSL signal counts from 0 to 200 s) and normalized (according to first readout) OSL signals. The error bars represent the experimental standard deviations of mean values obtained from three pellets in each measurement.

In Figure 6, OSL signals have very good reusability over thirty cycles. The deviation from the first readout value was evaluated as a maximum of ~3 %. Dose-response behaviors of the BeO:Na,Dy,Er ceramic pellets were found to be slightly linear with the 1.03 slope value in the dose range between 0.1 and 50 Gy (see Fig. 7). The energy-response results show that the OSL signals of BeO:Na,Dy,Er ceramic pellets did not change with different energy values (see Fig. 8). In order to gain more understanding of the energy response behavior of BeO:Na,Dy,Er ceramic pellets should be studied in detail at low energies. In fading experiments, we used three well-known BeO Thermalox995 chips as reference material of the readout sensitivity. As is seen from the inset of Figure 9 that integrated OSL signals obtained at third month were decreased by 2 %. After fluctuations in the short-term, the OSL signals remained almost the same until 1-week storage time. Following this stabilization, it was noted that a 10 % reduction occurred in OSL signals and this level of reduction continued almost unchanged by the last storage time (15 weeks).

CONCLUSIONS

In this work, characterization, and the relevant dosimetric and luminescent properties of the newly produced OSL/TL material (Z_{eff}=7.31) based on triply doped BeO:Na,Dy,Er ceramic pellets were reported and discussed. In XRD, SEM and EDS analyses, it was shown that triply doped BeO:Na,Dy,Er samples were successfully synthesized using the precipitation method.

With the triple doping of BeO, it was observed that most of the properties desired in a new OSL dosimeter for radiation dosimetry applications are met by the developed material. In summary, the OSL signal was found to be thermally stable up to 150 °C, reusable under carefully controlled laboratory conditions, and sensitive to radiation dose with a slightly linear dose range from 0.1 to 50 Gy. Except for instability in short storage times, 10% long-term fading was observed for up to three months under ambient laboratory conditions. Reusable, and thermally stable OSL signals were found to be very encouraging and convenient for personal and medical dosimetry applications. More investigation is required to characterize the luminescence mechanism of this promising luminescent ceramic.

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CONTACT INFORMATION

E-mail: valtunal@cu.edu.tr (V. Altunal)