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OSL dosimetric properties of synthetic topaz

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A B S T R A C T

The optically stimulated luminescence (OSL) properties under beta radiation of synthetic topazes produced from three different reactants are reported for the first time. Topazes were synthesized by chemical vapor deposition using sodium hexafluorosilicate (Na_2SiF_6) compacts as solid precursor and either aluminum oxide, aluminum hydroxide or kaolinite compacts as reactants. The OSL dosimetric characteristics of the most promising composition, namely, topaz synthesized using aluminum oxide, were determined and analyzed. The alumina-derived topaz exhibited a linear response in the dose range from 0.2 up to 20 Gy, a satisfactory repeatability and a fading of approximately 30% in the first hours, after which the OSL response remained constant. These characteristics, together with a minimum detectable dose (MDD) of 0.01 Gy – corresponding to a 3σ background signal – suggest the potential of synthesized topaz as an OSL dosimeter. The OSL mechanism might be explained by at least two trap types, possibly related to topaz shallow traps. A decreasing behavior – featuring a single exponential decrease –, similar to that of OSL signal was observed in ultraviolet and visible light bleaching measurements.

1. Introduction

Optically stimulated luminescence (OSL) is a good alternative to thermoluminescence (TL) for applications in geological dating as well as personal dosimetry due to several advantages. One of these advantages is that the stimulation method is completely optical, which makes it unnecessary to use a heating system for stimulating irradiated samples. For the same reason no thermal quenching occurs and more robust plastics encased OSL dosimeters can be easily manufactured. Moreover, high sensitivity of OSL allows multiple readings because it is no necessary to stimulate all of trapped charges and the readout process can be made very fast by increasing the stimulating light intensity (McKeever, 2001).

At present, only a few materials to be applied in OSL dosimetry have been developed and commercialized. The first one, which could be considered as the standard material for OSL in practical dosimetry, is the C-doped alumina (Al_2O_3) (Perks et al., 2007) and the other one is the BeO, which has advantage of having high efficiency and a nearly tissue equivalence (Sommer et al., 2008). Nevertheless, there is a permanent interest in searching for new materials with improved OSL dosimetric properties.

On account of previous investigations where it was shown the potential application of synthetic topaz in thermoluminescence dosimetry (Trujillo-Vázquez et al., 2016), the aim of this work is to study the effect of reactant compact (either aluminum oxide (Al_2O_3), aluminum hydroxide ($Al(OH)_3$) or kaolinite ($Al_2Si_2O_5(OH)_4$)) and processing conditions (temperature, time, atmosphere and angle position of the compact with respect to the gas flow direction) on topaz formation and its OSL properties. Finally, the dosimetric characteristics of the most efficient composition, namely topaz synthetized using Al_2O_3 as reactant, have been analyzed and the feasibility of use this compound as OSL dosimeter has been evaluated.

2. Experimental procedure

Samples were synthesized by chemical vapor deposition (CVD) using sodium hexafluorosilicate (Na_2SiF_6) compacts as solid precursor and aluminum oxide (Al_2O_3), aluminum hydroxide ($Al(OH)_3$) and kaolinite ($Al_2Si_2O_5(OH)_4$) compacts as reactant. Samples were ground in an agate mortar and sieved to-100 mesh. Details on synthesis procedure and characteristics of the topazes synthesized using the different reactants can be found in references Trujillo-Vázquez et al. (2016) and Trujillo-Vázquez and Pech-Canul (2017).

Samples were placed at 1 cm from a 10 mCi ophthalmic Sr-90 beta-source and irradiated at room temperature. The Sr-90 beta-source rendering a dose rate of 0.022 Gy/min at the sample position. For optical stimulation a Luxeon V Star green LED with maximum emissions at 530 nm, a Luxeon V Star blue LED with maximum emissions at 470 nm

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and a Luxeon III Star red LED whit maximum emission at 627 nm, were used. LEDs were driven at 500 mA with a Laser Diode Driver model 525B of Newport rendering an effective luminous flux of 128, 38 and 56 lm at the sample position for the green, blue and red LEDs, respectively. In each case the LED light was filtered by means of two 3 mm thick Schott long-pass filters before reaching the sample, namely, OG570, OG530 and GG420 long-pass filters by red, green and blue stimulation, respectively. Each long-pass filter features a maximum transmission of about 0.9 for wavelengths higher than the cutoff wavelength (570, 530 and 420 nm, respectively) and a transmission less than 10^{-6} at shorter wavelengths. In order to get rid of the stimulation light, two 3 mm thick Hoya B-390 or two 3 mm thick Hoya U-340 band-pass filters were interposed between the sample and the light detector. The B-390 filter has non-zero transmission between 320 and 500 nm and maximum transmission (0.77) at 390 nm and the U-340 filter has non-zero transmission between 250 and 390 nm and maximum transmission (0.80) at 340 nm. OSL was measured by means of an Electron Tube P25PC-02 photon counting head having sensitivity between 180 and 630 nm and maximum response at 350 nm. For all measurements both irradiation and stimulation were applied to the same face of the sample from which the emitted light was detected.

UV and visible bleaching of the samples were carried out by using either a NICHIA chip type UV LED model NCSU033A (T) with maximum emissions at 365 nm, or a Luxeon V Star green LED with maximum emissions at 530 nm, respectively. In both cases, LEDs were placed at 50 cm of the sample and they were driven at 50 mA with the same Laser Diode Driver model 525B.

3. Result and discussion

3.1. Filters and LEDs

In order to determine the optimal combination of filters to maximize the collection of the light emitted by the stimulated samples, a study of the emission spectra of topazes is necessary. Since the light emitted during OSL is not stationary, obtaining its spectrum is not easy without resorting to multichannel highly sensitive detector. Instead, it is possible to obtain the radioluminescence (RL) spectrum, i.e., the spectrum of the light emitted during irradiation, which generally is the same to the OSL spectrum because it is expected that the luminescence center involved in both OSL and RL is the same.

In this context, we use the RL spectra obtained and published and a previously work (Trujillo-Vázquez and Pech-Canul, 2017). In Fig. 6 of reference Trujillo-Vázquez and Pech-Canul (2017) it is possible to see that three samples, namely Al_2O_3, $Al(OH)_3$ and $Al_2Si_2O_5(OH)_4$ compacts as reactant, show a broad band between 250 and 560 nm and centered at 380 nm. These spectra are similar to those measured by Yukihara et al. (1999) and Souza et al. (2006), for Brazilian natural topazes. Yukihara et al. found that the emission spectra of different topazes have a very broad and similar band ranging from 300 to 560 nm whereas Souza et al. reported in 2006 various emission spectra in the range between 350 and 550 nm for several natural topazes.

From these spectra, two configurations of filters (emission filters) were selected to interpose between the sample and the light detector, i.e., two Hoya B-390 and two Hoya U-340 band-pass filters with transmission between 320 and 500 nm and, 250 and 390 nm, respectively. Regarding the stimulation light, three light sources were selected, namely, in the red, green and blue region, respectively, as it was detailed in the Experimental Procedures Section.

When the samples were stimulated with red and green light, both configurations of emission filters, namely Hoya B-390 and Hoya U-340 band-pass filters were evaluated, whereas when they were stimulated with blue light, only the configuration with the Hoya U-340 filters was investigated because of the overlapping of the wavelength.

Of all the investigated configurations, only the last one – i.e., blue stimulation and Hoya U-340 band-pass as emission filters – showed OSL response, irrespective of the studied topaz. In this context, results shown hereafter were obtained with the last mentioned configuration.

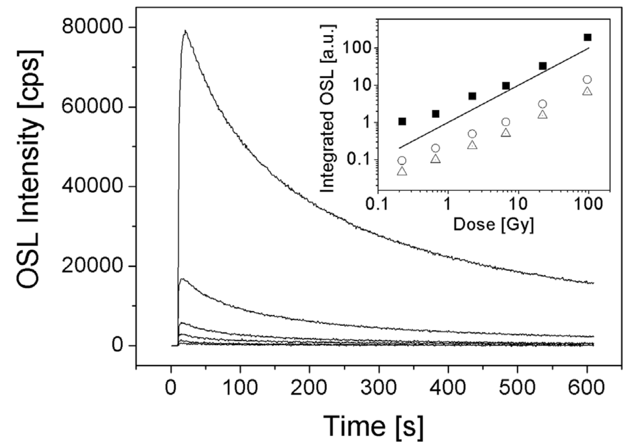

Fig. 1. OSL curves from topaz synthesized using Al_2O_3 compacts as reactant for different irradiation doses, ranging from 0.22 up to 100 Gy from bottom to top one after another. In the inset: dose response when it is integrated the first 10 (dot center triangles), 20 (hollow circles) and 600 (filled squares) seconds, respectively. Error bars are smaller than the symbol size. A solid line with the 1:1 linear behavior has been included for eye-guiding purposes.

3.2. OSL response as a function of reactant

Of the studied topazes, it was found that the topaz synthesized using aluminum oxide as reactant show the highest OSL response, whilst samples processed from aluminum hydroxide and kaolinite exhibit responses that are two orders of magnitude lower than that of the former. This is in accordance with a previous work (Trujillo-Vázquez et al., 2016) where the maximum TL response was obtained for samples synthesized with the same procedure. Hereafter, this work will focus on the characterization of the dosimetric properties of topaz with the highest OSL response, i.e., topaz synthesized using Al_2O_3 as reactant. The F/OH ratio results in synthetic topaz with the stoichiometry, $Al_2F_{1.44}(OH)_{0.56}SiO_4$.

3.3. Dose response

Fig. 1 shows the OSL curves from topaz synthesized using aluminum oxide compacts as reactant. As it can be seen from the figure, a good linearity is observed when the sample is irradiated with different doses of beta radiation, namely 0.22, 0.66, 2.2, 6.6, 22 and 100 Gy, from bottom to top one after another. In the inset of the figure, the dose response when it is integrated the first 10, 20 and 600 s of the OSL curve is presented. A good linearity in the dose range of 0.22–22 Gy and a supralinear behavior in the last dose is observed. In this context, when a linear regression is performed on the experimental data, a regression coefficient equal to 0.999 is found for the cases where it was integrated the first 10 and 20 s of the OSL curve, whereas if the whole OSL curve is integrated, a value of 0.996 is found. In the latter case, it is possible that the regression coefficient was lower than that of the others because while for low doses the OSL curves reached zero, for high doses this was not the case. It is possible to improve the regression coefficient when the highest dose is removed of the regression and the dose range of 0.22–22 Gy is analyzed.

3.4. Repeatability and fading of the OSL signal

In order to assess the feasibility of using this compound as OSL dosimeter, other OSL dosimetric properties such as repeatability and fading of the OSL signal and the minimum detectable dose were determined. Fig. 2 (a) shows the repeatability of the OSL signal when it is