Journal of Luminescence 159 (2015) 238–245

Contents lists available at ScienceDirect

Journal of Luminescence

journal homepage: www.elsevier.com/locate/jlumin

Further studies on the relationship between IRSL and BLSL at relatively high temperatures for potassium-feldspar from sediments

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ARTICLE INFO

Article history:
Received 7 May 2014
Received in revised form
4 November 2014
Accepted 18 November 2014
Available online 27 November 2014

Keywords:
K-feldspar
IRSL
BLSL
Component

ABSTRACT

In optical dating of potassium-feldspar, the luminescence signals can be stimulated by both infrared (IR) light and blue light (BL). To develop reliable dating methods using different stimulation light sources for feldspars, it is important to understand the sources of the traps associated with the infrared stimulated luminescence (IRSL) and blue light stimulated luminescence (BLSL) and their relationship. In this study, we explored the luminescence characteristics of IRSL and BLSL at different stimulation temperatures (from 60 °C to 200 °C) and their relationship based on five sets of experiments, i.e. post-IR BLSL, post-BL IRSL experiments, pulse annealing test, dose–response test and laboratory fading rate test. Our results suggest that the luminescence characteristics of IRSL and BLSL and their relationship are dependent on stimulation temperature. For IR stimulation at a relatively high temperature of 200 °C, at least two components of IRSL signals are involved in the process. One component of IRSL signals can be easily bleached by BL stimulation at 60 °C, while the other is relatively hard to be bleached by BL stimulation at 60 °C. The two components have different luminescence properties, such as thermal stability, dose–response and laboratory fading rate.

1. Introduction

Both quartz and potassium-rich feldspar (K-feldspar) have been widely used as natural dosimeters for optically stimulated luminescence (OSL) dating [2]. Compared with quartz OSL, the infrared stimulated luminescence (IRSL) signal from K-feldspar [17] has advantages of much brighter luminescence signals and much higher dose saturation level, making feldspar as an attractive candidate for luminescene dating of the natural sedimentary samples. However, the usage of K-feldspar for dating has long been hindered by the anomalous fading of the trapped charges related to the IRSL signals (e.g. [38,18,25,30]).

More recently, progress in understanding anomalous fading in feldspar has raised the prospect of isolating a non-fading component from the IRSL at relatively high temperatures [41,22,19,29]. Correspondingly, a two-step post-IR IRSL (pIRIR) protocol [7,39] and a multi-elevated-temperature post-IR IRSL (MET-pIRIR) protocol [26] have been proposed to overcome anomalous fading for dating K-feldspar from sediments, which offer the promising potential for extending the luminescence dating limit [39,28,23,31]. However, the high temperature pIRIR signal (e.g. >200 °C) is found to be more difficult to bleach than the IRSL signal measured at lower temperatures [26,6,37], and it usually requires up to several hours or even days of exposure to sunlight or a solar simulator to bleach the pIRIR signal down to a stable level (here the term "bleach" means to reduce the luminescence intensity by optical stimulation). For some samples, a significant non-bleachable (or residual) component in the pIRIR signals was left even after a prolonged bleaching period using solar simulator or sunlight [8,36,9,24]. These studies suggest that the IRSL signals recorded at relatively high temperature have different luminescence behaviors compared with the IRSL signals at room temperature.

There have been several studies conducted to explore the relationship between luminescence with IR stimulation and luminescence with visible wavelength light stimulation. It was demonstrated that the majority of green light stimulated luminescence (GLSL) can be bleached by prolonged IR light and an upper limit of ~90% GLSL was depleted as a result of IR bleaching at room temperature [12,14]. Jain and Singhvi [20] concluded that the blue–green (BG) stimulated luminescence measured at 125 °C is associated with at least two trap populations. One trap population is responsive to both IR stimulation and BG stimulation. Another trap population is only responsive to BG stimulation. Gong et al. [15] conducted a study on the relationship between the infrared stimulated luminescence (IRSL) and blue light stimulated luminescence (BLSL) at 60 °C. They observed that most of the IRSL

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http://dx.doi.org/10.1016/j.jlumin.2014.11.033
0022-2313/

signals at 60 °C can be bleached by BL at 60 °C, while the BLSL signals at 60 °C can only be partially bleached by IR at 60 °C. The sources for the IRSL at 60 °C are mainly associated with the fast and medium components of the BLSL at 60 °C.

In this study, in order to better understand the sources of the traps associated with the IRSL and BLSL, we further explore the relationship between IRSL and BLSL using K-feldspar from two eolian sand samples. The luminescence properties, in terms of thermal stability, dose–response and laboratory fading rate, are also examined for the different IRSL components at a relatively high temperature of 200 °C.

2. Samples and equipment

Two eolian sand samples (HSDK-11 and SY) from the Hunshandake desert in northeast China were used in this study. Both samples have been investigated in previous studies [33,16]. The samples are from the same environmental settings of the same region and have similar luminescence behaviors, so the experimental results obtained from them should be comparable. The samples were treated with 10% hydrochloric acid (HCl) and 10% hydrogen peroxide (H_2O_2) to remove carbonate and organic matter, respectively, in subdued red light in the Luminescence Dating Laboratory, The University of Hong Kong. Grains of 150–180 μm in diameter were obtained by dry sieving. The K-feldspar grains were separated with heavy liquids (2.58 g cm^{-3}) and then etched for 40 min with diluted (10%) hydrofluoric acid (HF) to clean the grains. HCl (10%) was used again to dissolve any contaminating fluorides after etching before final rinsing and drying. K-feldspar grains were prepared by mounting the grains in a monolayer, on a 9.8 mm diameter aluminum disc with "Silkospay" silicone oil.

The luminescence measurements of the sample HSDK-11 were carried out with an automated Risø TL-DA-15 reader equipped with an IR LED array (880 nm, FWHM 40 nm) and a blue LED array (470 nm, FWHM 20 nm) in the Luminescence Dating Laboratory, the University of Hong Kong. The IR and BL stimulations deliver ~135 mW cm^{-2} and ~50 mW cm^{-2} at the sample position, respectively [4]. To keep our results comparable with those from Gong et al. [15], 90% of the full power was used for stimulation in this study. Irradiations were carried out within the reader using a ^{90}Sr/^{90}Y beta source which delivered a dose rate of 0.0761 Gy s^{-1} to K-feldspar on aluminum discs. The IRSL and the BLSL signals were both detected after passing through 7.5-mm-thick U-340 filters, which mainly pass light from 290 nm to 370 nm with peak transmission at ~340 nm [32]. The experimental work on the other sample SY was performed in the Luminescence Dating Laboratory, Institute of Geology and Geophysics, Chinese Academy of Sciences. The luminescence measurements of the sample SY were carried out with an automated Risø TL/OSL reader (TL/OSL-DA-15) using the similar equipment setting. The ^{90}Sr/^{90}Y beta source in the equipment delivered a dose rate of 0.0837 Gy s^{-1} to K-feldspar on aluminum discs.

3. Experimental details and results

3.1. The relationship between the IRSL and the BLSL at different stimulation temperatures

Two sets of experiments, namely post-IR BLSL (pIR-BLSL) and post-blue light IRSL (pBL-IRSL), are conducted to investigate the relationship between the IRSL and the BLSL at different stimulation temperatures. For simplification, we describe the stimulation temperatures used in the prior IR and post-IR BLSL as pIR(T_1)-BLSL (T_2), where T_1 is the stimulation temperature used in the prior IR measurement and T_2 is the temperature used in post-IR BLSL measurement.

3.1.1. pIR-BLSL experiments

The pIR-BLSL experiments were carried out using the procedure listed in Table 1. Four aliquots of of K-feldspar grains HSDK-11 were firstly heated to 500 °C and then given a dose of 30.4 Gy. These aliquots were subsequently preheat at 280 °C for 10 s and then bleached using IR stimulation at a temperature of T_1 for different periods ranging from 0 to 5000 s. The pIR-BLSL signal (L_x) was then measured at a temperature of T_2. After that, a test dose of 15.2 Gy was applied and the induced BLSL signal (T_x) was measured following the same preheat to monitor sensitivity change for L_x. The signals for both L_x and T_x were calculated from the integrated photon counts in the first 1 s of stimulation, with subtraction of the instrumental background signal. The experiments are conducted at a set of different temperature combinations, i.e. pIR(60)-BLSL(60), pIR(100)-BLSL(60), pIR(150)-BLSL(60), pIR(200)-BLSL(60) and pIR(200)-BLSL(200), respectively.

The IR bleaching effects on the pIR-BLSL signal for different periods of time are shown in Fig. 1. It is observed that the IR bleaching at higher temperatures can deplete the BLSL at 60 °C at a faster rate than IR stimulation at lower temperatures. The BLSL at 60 °C was bleached to about 5% of the initial intensity after IR bleaching at 200 °C for 5000 s. In comparison, the BLSL at 60 °C was bleached to about 15% of the initial intensity after IR bleaching at 60 °C for 5000 s. If we increase the stimulation temperature in BLSL from 60 to 200 °C, i.e. pIR(200)-BLSL (200), the IR stimulation at 200 °C can bleach the most of the traps associated with the BLSL at 200 °C and only 6% of the initial intensity of the BLSL at 200 °C was remaining after IR bleaching at 200 °C for 5000 s (Fig. 1). The results suggest that both the BLSL measured at 60 °C and the BLSL at 200 °C can only be partially bleached by prolonged (up to 5000 s) IR stimulation even at a relatively high temperature (i.e. 200 °C).

In our previous study [15], it was found that the BLSL signals measured at 60 °C for the K-feldspar from sample HSDK-11 can be

Table 1
Experimental procedures for the pIR(T_1)-BLSL(T_2) and pBL(T_2)-pIRSL(T_1) experiments. T_1 were set at 60, 100, 150, 200 °C respectively, while T_2 were set at 60 and 200 °C.

	pIR(T_1)-BLSL(T_2)		pBL(T_2)-pIRSL(T_1)	
Step	Treatment	Observed	Treatment	Observed
(1)	Cut-heat to 500 °C		Cut-heat to 500 °C	
(2)	Regenerative dose (30.4 Gy)		Regenerative dose (30.4 Gy)	
(3)	Preheat to 280 °C for 10 s		Preheat to 280 °C for 10 s	
(4)	IR bleaching at T_1 for different times (0–5000 s)		BL bleaching at T_2 for different times (0–320 s)	
(5)	BLSL measurement at T_2 for 200 s	$L_{\text{pIR-BLSL}}$	IRSL measurement at T_1 for 160 s	$L_{\text{pBL-IRSL}}$
(6)	Test dose (15.2 Gy)		Test dose (15.2 Gy)	
(7)	Preheat to 280 °C for 10 s		Preheat to 280 °C for 10 s	
(8)	BLSL measurement at T_2 for 200 s	T_{BLSL}	IRSL measurement at T_1 for 160 s	T_{IRSL}
(9)	Return to step 1 and time for bleaching changes		Return to step 1 and time for bleaching changes	