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Study of the relationship between infrared stimulated luminescence and blue light stimulated luminescence for potassium-feldspar from sediments

Abstract

In luminescence measurements of potassium-feldspar (K-feldspar), both infrared (IR) and blue light (BL) can be used as stimulation sources. Component analysis suggests that the blue light stimulated luminescence (BLSL) measured at 60 °C from K-feldspar can be fitted using three components, namely fast, medium and slow. In order to explore the relationship between the origin of the infrared stimulated luminescence (IRSL) signal and the different components of the BLSL, five sets of experiments were conducted, namely post-IR BLSL (pIR-BLSL), post-BL IRSL (pBL-IRSL), pulse annealing tests, dose response and laboratory fading rate tests. It is observed that most of the IRSL signal can be bleached by BL, while the BLSL signal can only be partially bleached by the IR. The sources for IRSL are mainly associated with the fast and medium components of the BLSL signal.

Keywords

between, sediments, feldspar, potassium, light, relationship, blue, study, luminescence, stimulated, infrared, CAS

Disciplines

Medicine and Health Sciences | Social and Behavioral Sciences

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Study of the relationship between infrared stimulated luminescence and blue light stimulated luminescence for potassium-feldspar from sediments

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Abstract:
In luminescence measurements of potassium-feldspar (K-feldspar), both infrared (IR) and blue light (BL) can be used as stimulation sources. Component analysis suggests that the blue light stimulated luminescence (BLSL) measured at 60 °C from K-feldspar can be fitted using three components, namely fast, medium and slow. In order to explore the relationship between the origin of the infrared stimulated luminescence (IRSL) signal and the different components of the BLSL, five sets of experiments were conducted, namely post-IR BLSL (pIR-BLSL), post-BL IRSL (pBL-IRSL), pulse annealing tests, dose response and laboratory fading rate tests. It is observed that most of the IRSL signal measured at 60 °C can be bleached by BL at 60 °C, while the BLSL signal at 60 °C can only be partially bleached by IR at 60 °C. The sources for IRSL at 60 °C are mainly associated with the fast and medium components of the BLSL signal measured at 60 °C.

1. Introduction

For dating sediments, potassium-feldspar (K-feldspar) has the advantage over quartz of having a higher saturation dose as measured by luminescence. Infrared (IR) light, in addition to visible wavelength light, have been used as stimulation sources for luminescence dating (Aitken, 1998; Hütt et al., 1988). During the last two decades, several studies have been carried out to study the relationship between luminescence

with IR stimulation and luminescence with visible wavelength light stimulation. Earlier studies were made to explore the relationship between green light stimulated luminescence (GLSL) and IR bleaching (Duller and Bøtter-Jensen, 1993; Galloway, 1994). The GLSL was stimulated by green wavelengths (515-560 nm) from a 75 W halogen lamp and detected through a filter combination (12 mm of Corning 7-59 and 5 mm Schott BG-39) designed to give maximum sensitivity around 400 nm. It was demonstrated that the majority of the GLSL can be bleached by prolonged IR exposure and an upper limit of ～90% GLSL was depleted as a result of IR bleaching at room temperature (Duller and Bøtter-Jensen, 1993; Galloway, 1994). Jain et al. (2001) further investigated the relationship between infrared stimulated luminescence (IRSL) and blue-green stimulated luminescence (BGSL). The blue-green (BG) stimulation was achieved using a tungsten-halogen lamp filtered through GG-420 and SWP 550 interference filters. Luminescence was measured through a combination of one BG 39 and two U-340 filters. They concluded that BGSL 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 (Jain and Singhvi, 2001). However, it is still not very clear which component of BLSL is mainly associated with the origin of IRSL.

It was observed that the BGSL signals from feldspars can be separated into three components by curve fitting using three first-order components (Bulur, 2000). More recently, blue light emitting diodes (LED) were used as another option for optical stimulation (470 nm, FWHM 20 nm), which deliver ~50 mW/cm^2 at the sample (Botter-Jensen et al., 2003). Blair et al. (2005) studied the blue light stimulated luminescence (BLSL) from K-feldspar using a UV detection window with 7.5 mm U-340 filters, which peaks at 340 nm. It was suggested that there might be a link between IRSL and the fast component of BLSL for their museum feldspar samples. They observed that the oligoclase, albite, and microcline produce bright IRSL signals and have a fast BLSL component. The anorthoclase and andesine produce weak IRSL signals and do not show a significant fast component in the BLSL.

In this paper we further investigate the relationship between the origin of IRSL

and different components of BLSL, based on sets of post-IR BLSL (pIR-BLSL), post-BL IRSL (pBL-IRSL) experiments and characteristic study of luminescence behavior, in terms of bleaching rate, thermal stability, dose response and laboratory fading rate.

2. Samples and equipment

The sample used in this study is an aeolian sand sample (HSDK-11) from the Hunshandake Desert in northeast China. The sample was treated with 10% hydrochloric acid (HCl) and 10% hydrogen peroxide (H_2O_2) to remove carbonate and organic matter in subdued red safe-light conditions. Grains in size range 150-180 μm were obtained by dry sieving. The K-feldspar grains were separated using 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 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). The IR and BL stimulations deliver ~135 mW/cm^2 and ~50 mW/cm^2 at the sample, respectively (Bøtter-Jensen et al., 2003). 90% of their full powers were used for stimulation in this study. Irradiations were carried out within the reader using a ^{90}Sr/^{90}Y beta source which delivers a dose rate of 0.0761 Gy/s to K-feldspar grains on aluminum discs. The IRSL and 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 (Aitken, 1998). Unless specified, all the stimulations for IRSL and BLSL measurements were carried out at 60 °C.

3. Results and discussion

3.1 The Continuous wave OSL (CW-OSL) signals

Five aliquots of K-feldspar grains were firstly heated up to 500 °C to remove all residual signals. These aliquots were given an irradiation dose of 7.6 Gy and preheated at 280 °C for 10 s. BLSL were then measured with blue light for 200 s. A typical BLSL curve measured at 60 °C is shown in Fig. 1(a). Our results suggest that the BLSL curve can be described using three exponential components of first order kinetics, which are termed as fast (F), medium (M) and slow components (S) (note that use of these terms does not necessarily imply physically distinct traps, but merely refers to different decay parts of the OSL curves). The fitted decay rates for fast, medium and slow components are 0.375 ± 0.004 s^{-1}, 0.077 ± 0.002 s^{-1} and 0.0072 ± 0.0002 s^{-1} respectively. These decay rate parameters were then fixed for deconvolution of the BLSL into components in later investigations on the relationship between IRSL and BLSL. Previous studies also suggested that the BGSL from K-feldspar can be described using three components with different decay rates (Bulur, 2000; Hayes et al., 1998).

The relative contributions of the different components to the total signal as a function of illumination time of are shown in Fig. 1(b). It was observed that the initial BLSL signal measured at 60 °C is dominated by the fast and medium components, which contribute ~90% to the total signal from 0 s to 0.4 s. However, the contribution from the fast and medium components decreases to ~50% at 16 s. After 16 s, the slow component begins to dominate.

3.2 The relationship between IRSL and BLSL

3.2.1 pIR-BLSL experiments

The pIR-BLSL experimental procedure is listed in Table 1. Four aliquots of K-feldspar grains were firstly heated up to 500 °C to remove residual signals. They were all given the same irradiation dose of 30.4 Gy. These aliquots were preheated at 280 °C for 10 s. The aliquots were bleached with IR stimulation for different periods

of time from 0 to 5000 s. Finally, a BLSL measurement (L_{BLSL}) was carried out. The BLSL sensitivity (T_{BLSL}) was measured, following a test dose of 15.2 Gy and preheating at 280 °C for 10 s.

All the sensitivity corrected BLSL curves obtained were then fitted using three components. The results of IR bleaching for different periods are shown in Fig. 2. It was observed that the BLSL can only be partially bleached, even after prolonged IR stimulation. About 4% and 9% for the fast and medium component of the BLSL signal remained after IR bleaching for 5000 s. There was 88% of the slow component remaining after IR bleaching for 5000 s. These results indicate that the majority of the sources for IRSL are mainly associated with the fast and medium components of BLSL.

3.2.2 Post-blue IRSL (pBL-IRSL) experiments

The procedure for the pBL-IRSL experiments is listed in Table 1. Four aliquots of K-feldspar grains were firstly heated up to 500 °C to remove residual signals and then given the same irradiation dose of 30.4 Gy. These aliquots were preheated at 280 °C for 10 s. They were then bleached with blue light stimulation for different periods from 0 s to 320 s before IRSL measurement. The IRSL sensitivity (T_{IRSL}) was measured, following a test dose of 15.2 Gy and preheating at 280 °C for 10 s.

The loss of IRSL as a result of blue light bleaching is shown in Fig. 3 (a). It is observed that the IRSL can be bleached to a negligible level (~0.2% of the initial intensity) by blue light stimulation for 320 s. In order to investigate the relation between IRSL and the different components of BLSL, the reduction of IRSL as a result of blue light bleaching for different times was also compared with the decay curve of different components of the BLSL signal (inset of Fig. 3 (a)). The results indicate that the rate of reduction of the IRSL signal under blue light bleaching is slower than the rate of decay of the fast component of the BLSL signal. But it is faster than the decay rates of both the medium and slow components of the BLSL signal. It is interesting to note that the rate of reduction of the IRSL is very similar to the rate of

decay of the sum of the fast and medium components of BLSL under blue light stimulation. Such similar bleaching rates under blue light further indicates that the sources for IRSL were probably mainly associated with the fast and medium components of the BLSL signal, as discussed in the previous section.

Further evidence of the relationship between these signals can be obtained by investigating the relationship between the emitted light counts from different components of the BLSL signal and the corresponding lost counts from the pBL-IRSL as a result of blue light bleaching for different periods. We plotted the emitted counts from the various components of the BLSL, against the lost counts of IRSL as a result of BL bleaching in Fig. 3(b). This is similar to the method applied to study the relation between IRSL and thermal luminescence (TL) by Duller (1995). It is observed that the total emitted light counts of BLSL are significantly larger than the lost counts in pBL-IRSL. These results imply that the BL access more traps than those responding to IRSL. However, the lost counts in pBL-IRSL have a nearly 1:1 relationship with the sum of the emitted light counts of the fast and medium components of BLSL. These results again indicate a close relationship between IRSL and the fast and medium components of BLSL.

In summary, the results from the pIR-BLSL and pBL-IRSL experiments suggest that most of the traps associated with the IRSL signal measured at 60 °C can be bleached by blue light at 60 °C, while the traps associated with the BLSL signal measured at 60 °C can only be partially bleached by IR stimulation at 60 °C. The origin for the IRSL signal is probably mainly associated with the fast and medium components of the BLSL.

3.2.3 Thermal stability studies of IRSL and BLSL

The results from sections 3.2.1 and 3.2.2 indicated that the origin for the majority of the IRSL is probably associated with the fast and medium components of the BLSL. If this is true, the IRSL should have a similar thermal stability to the fast and medium components of the BLSL. The thermal stability studies are carried out using a pulse

annealing test (Table 2) (Li et al., 1997). An aliquot of K-feldspar was firstly heated to 500 °C to remove residual signals and was given a 30.4 Gy dose. It was preheated at 280 °C for 10 s, and then heated to a temperature at T °C before the remaining IRSL ($L_{60°C\ IRSL}$) was measured for 200 s. Any sensitivity change was monitored by measuring the IRSL signal ($T_{60°C\ IRSL}$) from a test dose of 30.4 Gy. The same preheat condition (280 °C for 10 s) was applied for the test dose IRSL measurement. This cycle was repeated by increasing the annealing temperature (T) from 160 °C to 500 °C in steps of 20 °C. A similar pulse annealing test was also conducted for the BLSL, which is listed in Table 2. The sensitivity corrected BLSL signals were then resolved into three first order components. The heating rate for all these pulse annealing experiments is 3 °C/s.

Fig 4 shows the pulse annealing results for the IRSL signal and the various components of the BLSL. In the inset graph of Fig 4, it is observed that the slow component of the BLSL is slightly more stable than both the fast and medium components of the BLSL. It is interesting to note that the pulse annealing curve of the IRSL measured at 60 °C is nearly identical with that of the sum of the fast and medium components of the BLSL measured at 60 °C. These results further imply that the majority of the traps associated with the IRSL signal measured at 60 °C are probably mainly associated with the fast and medium components of the BLSL measured at 60 °C

3.2.4 Dose response curves of IRSL and BLSL

The form of the dose response curve (DRC) can be used as another means of comparing the origin of the luminescence signals. The same group of traps should have a similar dose response curve. Here we compare the dose response curve of IRSL from K-feldspar with that of the sum of the fast and medium components (F+M) of the BLSL signal obtained using deconvolution. Regenerative doses ranging from 0 to 1950 Gy were employed in a single aliquot regeneration (SAR) protocol for IRSL and BLSL. A test dose of 13 Gy was inserted to monitor and correct for sensitivity

change. A recycling dose at 26 Gy was used and recycling values are all within 3% of unity for our sample. The preheat temperature (held for 10 s) was the same for both regeneration and test dose measurements. A cut-heat to 500 °C was used in between SAR cycles to clean the residual signals from the previous cycle. For construction of the dose response curves the total BLSL signal induced by the test dose was used for sensitivity correction for the various BLSL components. Dose response curves of different luminescence signals were obtained and fitted with single saturating exponential functions (Fig. 5). It is observed that the DRC of F+M is nearly identical to that of the IRSL signal, but that they are different from that of the slow component. The characteristic saturation dose (D_0) for the IRSL, the sum of the fast and medium component of the BLSL, and for the slow component of the BLSL are 395.8±32.0 Gy, 379.5±22.9 Gy and 422.1±30.0 Gy, respectively. The results further support the suggestion that sum of the fast and medium components of the BLSL signal and the IRSL signal have the same origin.

3.2.5 Laboratory fading tests of the IRSL and BLSL

Laboratory anomalous fading was observed for both IRSL and BLSL signals in previous studies (Thomsen et al., 2008). It is expected that the signals from a similar origin should have the same fading rate. Thus it is expected that similar laboratory fading rates can be observed for the IRSL measured at 60 °C and the sum of the fast and medium components of the BLSL measured at 60 °C. To check this, anomalous fading tests were conducted for IRSL and BLSL using K-feldspar grains, using a single-aliquot procedure (Auclair et al., 2003). In these experiments, six aliquots were heated to 500 °C to remove any residual signals (similar to a hot-bleach between SAR cycles). Then these aliquots were given 30.4 Gy and immediately preheated at 280 °C for 10 s. The sensitivity corrected signals were then measured after delays of different times. For the test dose, 7.5 Gy was given and the same preheat condition was applied. The IRSL signals $L_{(x)}$ and $T_{(x)}$ were calculated from the integrated photon counts in the first 1 s of stimulation, with subtraction of a background signal derived from the

last 10 s of the 200 s stimulation. Measurement of the fading rate of the BLSL signal was the same as for IRSL, except that the stimulation light is blue light. The first measurement of the IRSL/BLSL signal at 60 °C took place at a time t_c= 400 s after the mid-point of the irradiation time. The sensitivity corrected BLSL curves were then fitted with fast, medium and slow components. The decay of the IRSL signals and the various components of the BLSL after normalization as a function of storage time is shown in Fig 6. The corresponding anomalous fading rates (g-value) were calculated based on the data sets and are also shown in Fig 6. It is observed that the IRSL and the sum of the fast and medium components of the BLSL have similar fading rates (5.3± 0.4 %/decade and 5.5±0.3 %/ decade), while the slow components of the BLSL have a significantly lower fading rate (2.9±0.2 %/decade)). These results again support the idea that the IRSL and the fast and medium components of the BLSL are probably from the same origin. Thomsen et al. (2008) also observed that the pIR-BLSL signal has a lower laboratory fading rate (2.1±0.2 %/decade) than the IR signal (4.7± 0.3 %/decade) both under UV detection for their K-feldspar samples. This can be explained as the pIR-BLSL signal is dominated by the slow components of the BLSL, while the IR signal mainly originates from the fast and medium components of the BLSL. Thus a significant difference can be observed between the laboratory fading rates for the pIR-BLSL signal and IR signal from K-feldspar.

4. Conclusions

From the pIR-BLSL and pBL-IRSL bleaching experiments, it is concluded that most of traps responsible for the IRSL signal measured at 60 °C can be bleached by blue light, while the traps associated with the BLSL signal measured at 60 °C can only be partially bleached by IR stimulation. The fast and medium components of the BLSL are mainly associated with the IRSL. The similar characteristics of their luminescence behaviors, in terms of bleaching rate, thermal stability, dose response curves and laboratory fading rates indicate that they are probably from the same

origin.

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Figure captions

Fig 1: (a) Representative BLSL curves measured at 60 °C from sample HSDK-11. Three exponential components (fast, medium and slow), the fitted total BLSL as well as the experimental BLSL are shown. (b) Relative contributions from different components to the total BLSL are plotted against the stimulation time. F: fast component; M; medium component; S: slow component; F+M: The sum of fast and medium components;F+M+S: The sum of fast, medium and slow components; The acronyms are the same cases for other figures throughout the paper;

Fig 2: Remaining components of the BLSL signal measured at 60 °C after IR bleaching at 60 °C for different times.

Fig 3: (a) Remaining IRSL signal measured at 60 °C after blue light bleaching at 60 °C for different times; the inset shows the rate of reduction of the IRSL signal measured at 60 °C as a result of bleaching using blue light for different times for different components of BLSL. (b) The relationship between emitted counts of components of BLSL at 60 °C and the lost counts of pBL-IRSL as a result of blue light bleaching for different times.

Fig 4: Pulse annealing curve based on the IRSL signal measured at 60 °C, the slow component of the BLSL signal measured at 60 °C, and the sum of the fast and medium components of the BLSL signal measured at 60 °C. The inset graph shows the pulse annealing curves for the fast, medium and slow components of the BLSL signal measured at 60 °C. The heating rate is 3 °C/s.

Fig 5: Dose response curves of the IRSL signal measured at 60 °C, the sum of the fast and medium components of the BLSL signal measured at 60 °C, and the slow components.

Fig 6: Anomalous fading tests for the IRSL signal and different components using six aliquots from sample HSDK-11 as a function of delayed period (t).

Fig 1 (a)

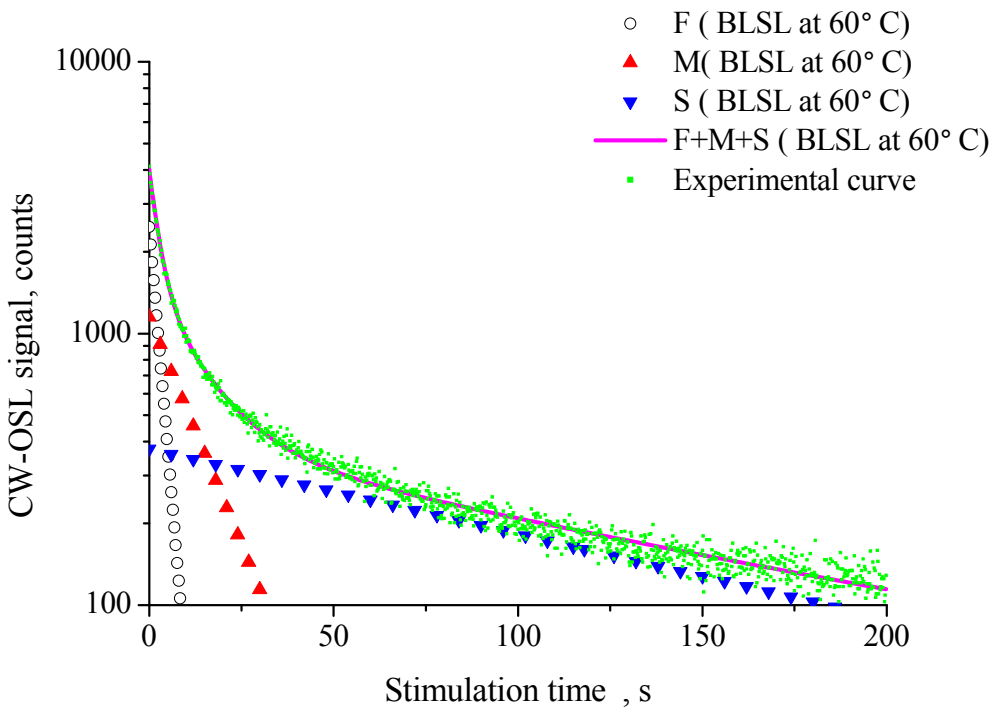
F (BLSL at 60° C)
M(BLSL at 60° C)
S (BLSL at 60° C)
F+M+S (BLSL at 60° C)
Experimental curve
CW-OSL signal, counts
10000
1000
100
0
50
100
150
200
Stimulation time , s

Fig 1 (b)

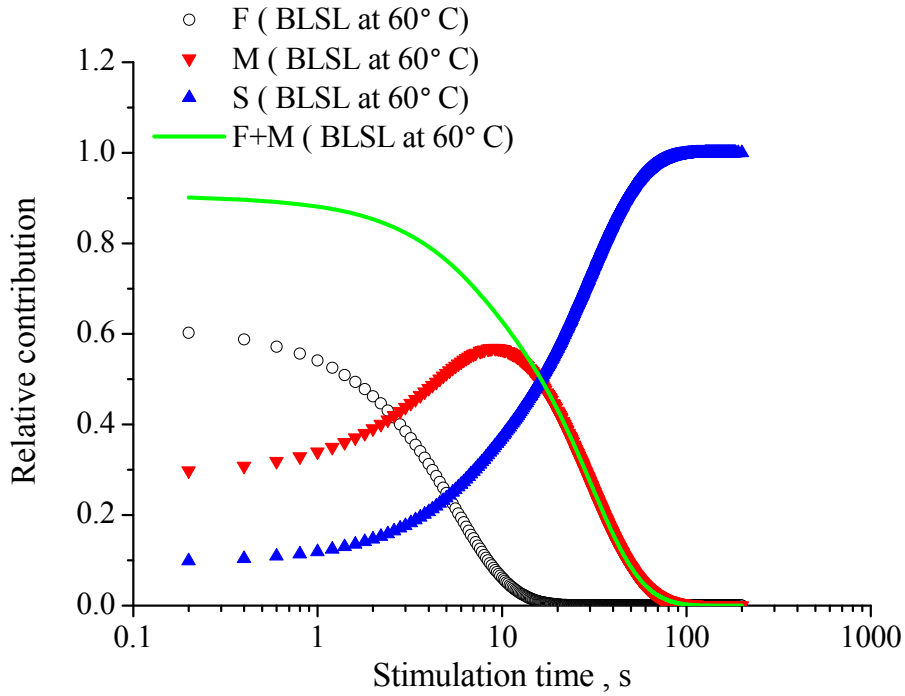
F (BLSL at 60° C)
M (BLSL at 60° C)
S (BLSL at 60° C)
F+M (BLSL at 60° C)
Relative contribution
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.1
1
10
100
1000
Stimulation time , s

Fig 2

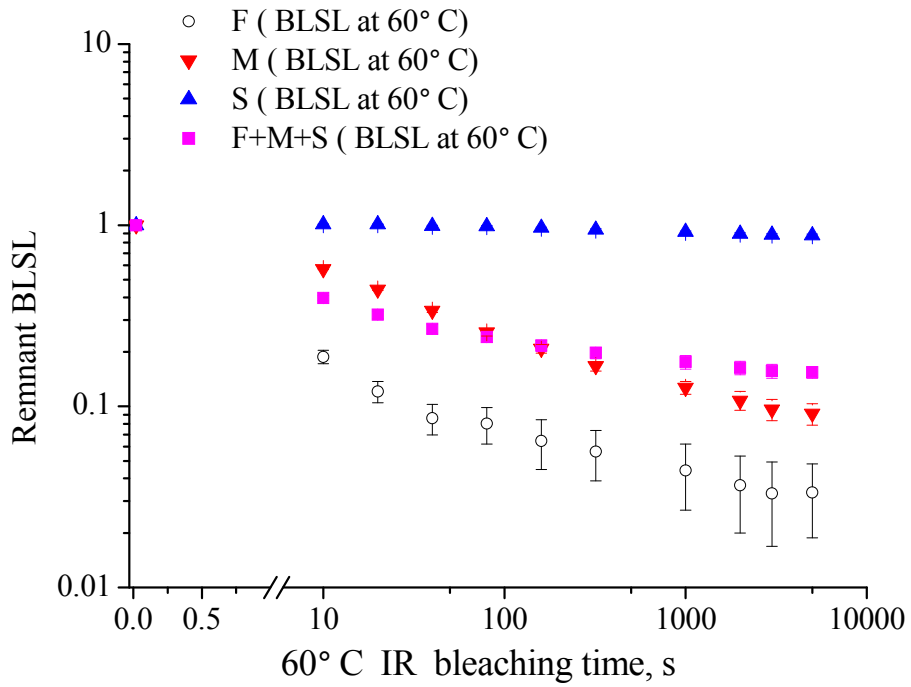
F (BLSL at 60° C)
M (BLSL at 60° C)
S (BLSL at 60° C)
F+M+S (BLSL at 60° C)
Remnant BLSL
10
1
0.1
0.01
0.0
0.5
10
100
1000
10000
60° C IR bleaching time, s

Fig 3 (a)

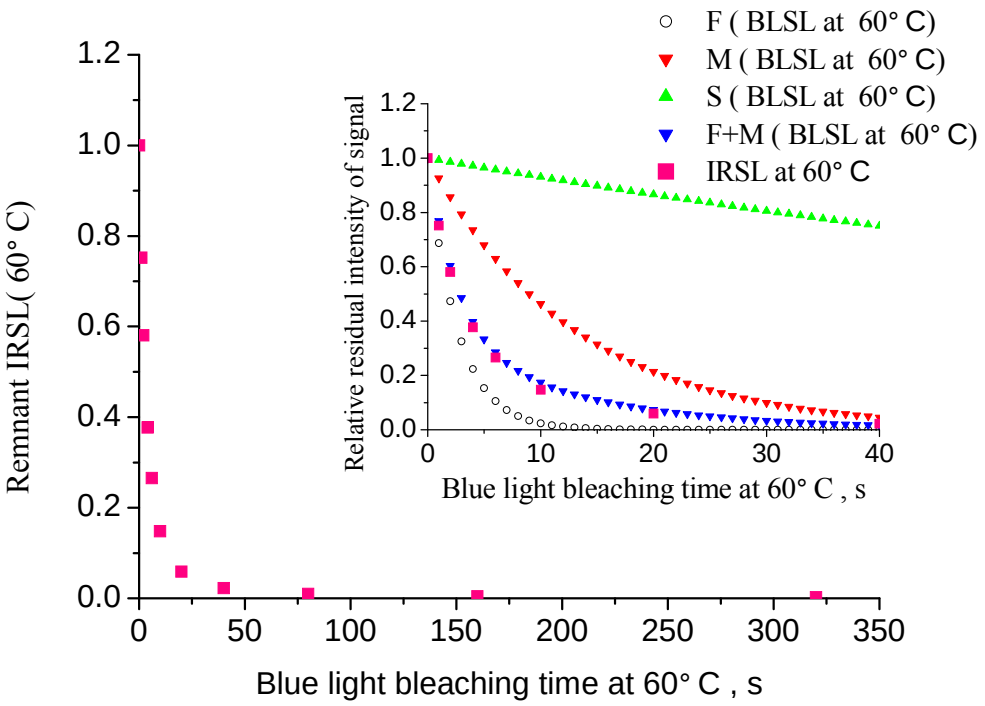
F (BLSL at 60° C)
M (BLSL at 60° C)
S (BLSL at 60° C)
F+M (BLSL at 60° C)
IRSL at 60° C
Remnant IRSL(60° C)
Blue light bleaching time at 60° C , s
Relative residual intensity of signal
Blue light bleaching time at 60° C , s

Fig 3 (b)

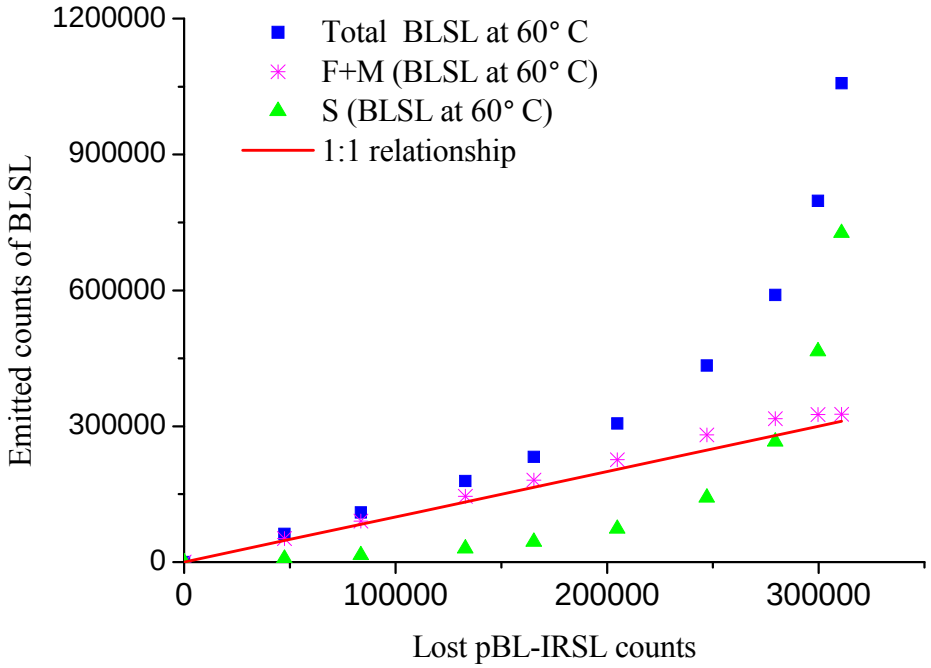
Total BLSL at 60° C
F+M (BLSL at 60° C)
S (BLSL at 60° C)
1:1 relationship
Emitted counts of BLSL
Lost pBL-IRSL counts

Fig 4

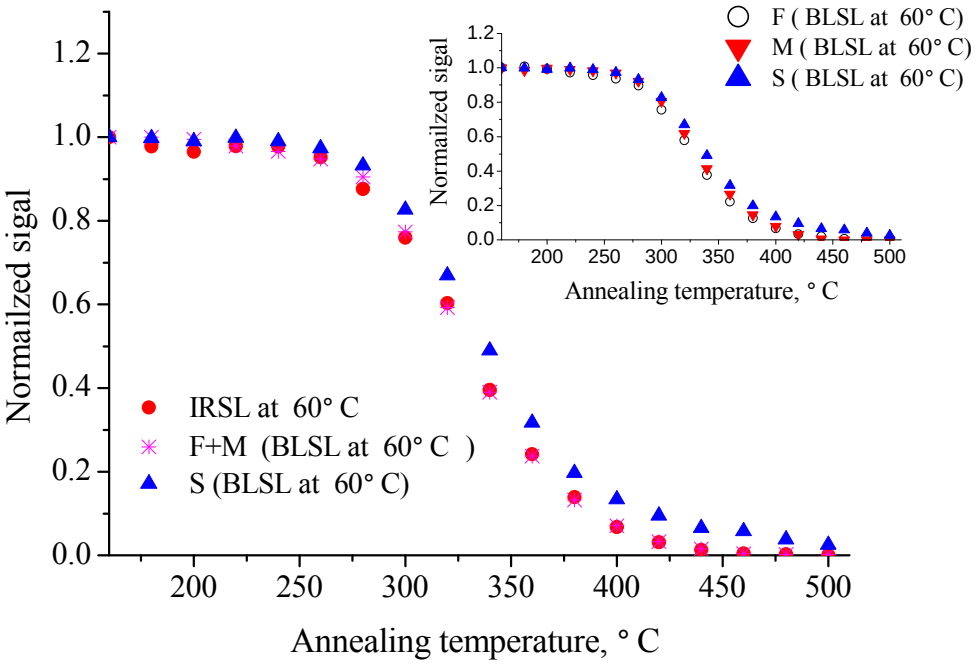
Normailzed sigal
Annealing temperature, ° C
IRSL at 60° C
F+M (BLSL at 60° C)
S (BLSL at 60° C)
F (BLSL at 60° C)
M (BLSL at 60° C)
S (BLSL at 60° C)
Normalized sigal
Annealing temperature, ° C

Fig 5

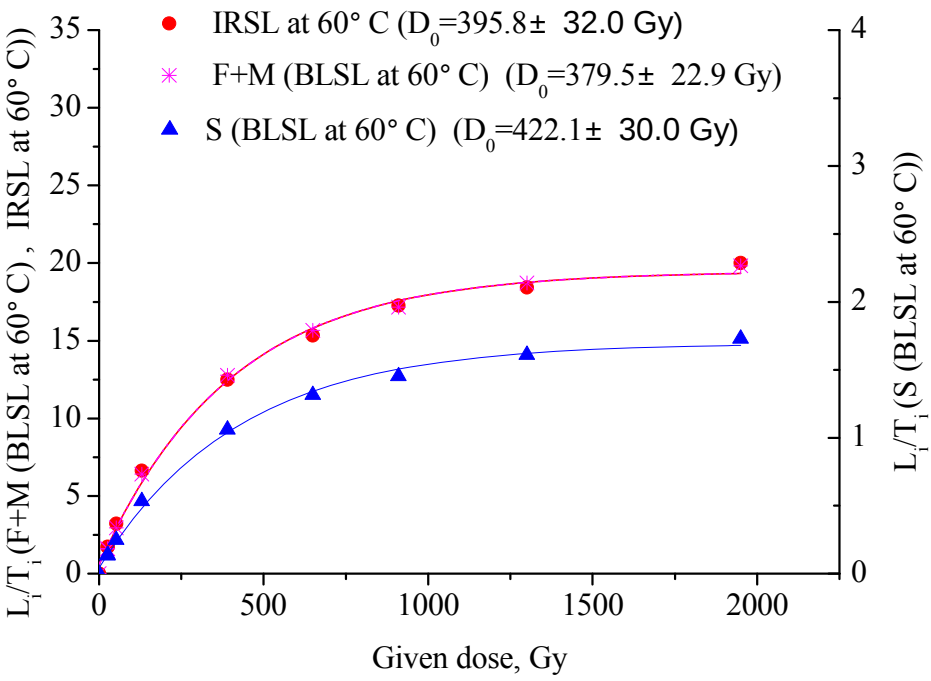
IRSL at 60° C (D0=395.8± 32.0 Gy)
F+M (BLSL at 60° C) (D0=379.5± 22.9 Gy)
S (BLSL at 60° C) (D0=422.1± 30.0 Gy)
Li/Ti (F+M (BLSL at 60° C) , IRSL at 60° C))
Li/Ti (S (BLSL at 60° C))
Given dose, Gy
0
5
10
15
20
25
30
35
0
1
2
3
4
0
500
1000
1500
2000

Fig 6

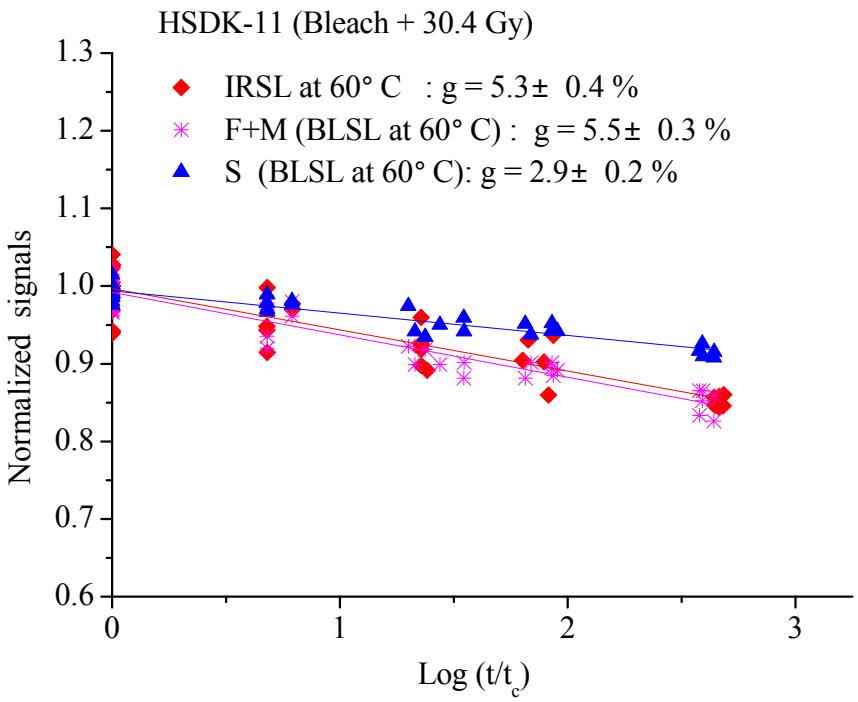
HSDK-11 (Bleach + 30.4 Gy)
IRSL at 60° C : g = 5.3± 0.4 %
F+M (BLSL at 60° C) : g = 5.5± 0.3 %
S (BLSL at 60° C): g = 2.9± 0.2 %
Normalized signals
Log (t/t_c)
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0
1
2
3

Table 1: Experimental procedures for the pIR-BLSL and pBL-pIRSL experiments. Note that the sequence of pIR-BLSL procedure is steps 1, 2, 3 4a, 5a, 6, 7, 8a and 9, and the sequence of pBL-IRSL procedure is steps 1, 2, 3 4b, 5b, 6, 7, 8b and 9.

Step	Treatment	Observed
1	Cut-heat to 500 °C	
2	Regenerative dose (30.4 Gy)	
3	Preheat to 280 °C for 10 s	
4a	IR bleaching at 60 °C for different time (0-5000 s)	$L_{60\ °C\ IRSL}$
4b	Blue light bleaching at 60 °C for different time (0-320 s)	$L_{60\ °C\ BLSL}$
5a	BLSL measurement at 60 °C for 200 s	$L_{60\ °C\ pIR\text{-}BLSL}$
5b	IRSL measurement at 60 °C for 160 s	$L_{60\ °C\ pBL\text{-}IRSL}$
6	Test dose (15.2 Gy)	
7	Preheat to 280 °C for 10s	
8a	BLSL measurement at 60 °C for 200 s	$T_{60\ °C\ BLSL}$
8b	IRSL measurement at 60 °C for 160 s	$T_{60\ °C\ IRSL}$
9	Return to step 1 and time for bleaching time changes	

Table 2: Pulse annealing procedures for IRSL and BLSL. Note that the sequence of IRSL is steps 1, 2, 3 4, 5a, 6, 7, 8a and 9, and the sequence of BLSL is steps 1, 2, 3 4, 5b, 6, 7, 8b and 9.

Step	Treatment	Observed
1	Cut-heat to 500 °C	
2	Regenerative dose (30.4 Gy)	
3	Preheat to 280 °C for 10 s	
4	Cut-heat to T °C (160 °C -500 °C)	
5a	IRSL measurement at 60 °C for 200 s	$L_{60\ °C\ IRSL}$
5b	BLSL measurement at 60 °C for 200 s	$L_{60\ °C\ BLSL}$
6	Test dose (30.4 Gy)	
7	Preheat to 280 °C for 10 s	
8a	IRSL measurement at 60 °C for 200 s	$T_{60\ °C\ IRSL}$
8b	BLSL measurement at 60 °C for 200 s	$T_{60\ °C\ BLSL}$
9	Return to step 1 and T = T +20 °C	