Nuclear Instruments and Methods in Physics Research B 375 (2016) 32–39

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research B

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

Evaluation of trapping parameters of annealed natural quartz

Rui Zhou [a,b], Ming-Jian Wei [a,*], Bo Song [a,c], Yan Zhang [a,d], Qiu-Yue Zhao [e], Bao-Lin Pan [a], Teng-Fei Li [a]

[a] College of Resources, Environment & Tourism, Capital Normal University, 100048 Beijing, People's Republic of China
[b] Shisanling Seismic Station, Institute of Earthquake Science, CEA, 102200 Beijing, People's Republic of China
[c] Beijing Jing Yuan School, 100040 Beijing, People's Republic of China
[d] School of TaiPingqiao, Nan Lu of West Railway Station, 100073 Beijing, People's Republic of China
[e] Key Laboratory of Tourism and Resources Environment in Universities of Shandong, Taishan University, 271000 Tai'an, People's Republic of China

ARTICLE INFO

Article history:
Received 28 November 2015
Received in revised form 23 February 2016
Accepted 29 February 2016
Available online 24 March 2016

Keywords:
Natural quartz
Thermoluminescence
Trap
Parameter

ABSTRACT

The thermoluminescence (TL) trapping parameters of annealed quartz have been investigated. The apparent TL peaks observed at temperatures of 133 °C, 211 °C, 266 °C and 405 °C, respectively, were named Peak I, Peak II, Peak III and Peak IV. The $T_m - T_{stop}$ method is applied to investigate the number of peaks and their positions, and to obtain the trap distributions in the quartz. Peak shape (PS), Hoogenstraaten method (Various Heating Rates Method, VHR), and Computerized Glow Curve Deconvolution (CGCD) are used to evaluate the trapping parameters of the annealed quartz. The glow curve can be considered as a superposition of at least nine overlapping peaks. These peaks show up at 133 °C, 211 °C, 266 °C, 308 °C, 333 °C, 384 °C, 441 °C, 466 °C and 484 °C. The PS method can be only used in evaluating the parameters for Peaks I. The VHR method can be used in evaluating the trapping parameters for the first three peaks. CGCD method is complementary to obtaining parameters for the sub-peaks, and the thermal quenching correction with the Urbach's method is necessary. The Urbach's coefficient for the quartz is 30.03 kT_m.

1. Introduction

The natural quartz plays an important role in retrospective dosimetry, in particular for the dating of Quaternary sediments and archaeological materials. Extensive work on natural quartz, as a result, has been done on different aspects, such as electron spin resonance (ESR), optically stimulated luminescence (OSL) and thermoluminescence (TL) [1]. For thermoluminescence, the TL peaks in alpha-quartz is observed at 110 (150), 220, 325 and 375 °C at a heating of 20 °C·s^{-1}. In some literatures, the peak at 110 °C was found to occur between 90 °C and 130 °C, the peak supposedly at 250 °C is observed at 220 °C [2]. The glow curves show a variety of shapes depending on the nature and origin of quartz. Different glow curves result in the diversities of trap types in different types of quartz. However, widely different values of the trap parameters have been reported in the literature, because of the differences in the origin of the quartz, thermal treatment, impurity content and methods used to evaluate the parameters [3–7]. These parameters are the basis of retrospective dosimetry and luminescence dating. One of the critical assumptions in thermoluminescence dating is that the trapped electrons used for dating are stable over the age being dated. Thus, it is significant to study the trapping parameters of thermoluminescence traps in quartz for thermoluminescence dating. In fact, the differences between the trapping parameters of different quartz should be more extensively studied. As far as the study nowadays concerned, the trapping parameters of different genetic quartz, or the quartz originated from different geological environments need to be cautiously treated, the trapping parameters and glow curves of these different quartz seem different because of its minimal distinction and is still not enough to be used in thermoluminescence dating based on previous studies, the research on trapping parameters of different types of natural quartz still need more work to do. In the case for quartz, the first-order kinetics has been supported by a majority of literatures, while some other authors believe that some types of quartz exhibiting non-first-order behavior is because of complex overlapping peaks [8]. The presence of the overlapping peaks is the difficulty in determining trapping parameters [9].

Therefore, there is neither an agreement on the published values of the kinetic parameters obtained from different types of quartz nor consistent progression [7–9]. The purpose of this investigation is to determine the trapping parameter of annealed high purity quartz obtained by various methods. The main TL

* Corresponding author.
E-mail addresses: weimj@cnu.edu.cn, weimj@yahoo.com (M.-J. Wei).

http://dx.doi.org/10.1016/j.nimb.2016.02.067

peaks are isolated from others, and their properties are revealed. Three methods are used to deduce the trapping parameters from glow curves. The most significant issue here is to separate the overlapping peaks from the glow curve. Whenever the peaks are clearly separated from each other, the traditional methods are suitable for obtaining these parameters.

The number of peaks existing in the glow curve and their positions are identified with the $T_m - T_{stop}$ method. Peak shape (PS), Hoogenstraaten method (Various Heating Rates Method, VHR), and Computerized Glow Curve Deconvolution (CGCD) are used to determine the kinetic parameters of the quartz. The activation energy is a very important parameter for the luminescence dating and retrospective dosimetry. The above-mentioned methods are used to evaluate the peaks in different temperatures of the quartz.

2. Materials and methods

2.1. Sample preparation

The sample used in this experiment is a piece of natural quartz which has been manually ground and sieved to 74–100 μm grain size in a dark room. As shown in Table 1, X-ray fluorescence (XRF) spectrometry was used to determine the chemical composition. The measurements were completed in Analysis and Test center of Peking University, Beijing.

The powdery sample was put in a crucible gradually heated up to 460 °C for an hour in a furnace. The previously accumulated luminescence was erased before the next irradiation. The powder was placed on several aluminum discs (9.7 mm in diameter), and was fixed with silicon grease. The grains covered about 100% of the disc area. They were irradiated with a calibrated $^{90}Sr/^{90}Y$ beta source with a dose rate of 8 Gy·min^{-1} for quartz samples on discs.

2.2. Measurements

The measurements were all made in a flowing nitrogen atmosphere by a RGD-3B manual reader manufactured by DML. The RGD-3B reader had been interfaced with a personal computer [10–12]. The treatments and measurements of the sample were made under red light to avoid the release of the trapped electrons from the semi-stable sites into hole centers (including luminescence centers) due to light sensitivity. A data extraction module based on Excel VBA function was developed to extract the data from RGD-3B TL reader. The lowest heating rate supported by the reader is 2 °C·s^{-1}. Without special description, all the measurements were performed with a linear heating rate of 5 °C·s^{-1}. After the irradiation, the measurements were carried on at once.

3. Experimental

3.1. Glow curve and dose response curve

The glow curves of quartz were obtained after being exposed to various beta radiation doses in a range of 16–1024 Gy, measured at a heating rate of 5 °C·s^{-1}. The apparent luminescence peak may be only one genuine peak or consist of several peaks at different temperatures, and can be read directly from the glow-curve. The photon counts of the first apparent peak (Peak I) were overflowed when the discs were irradiated with 512 Gy or 1024 Gy beta doses, respectively. In order to get the dose response curves, five parallel aliquots were all read out.

Table 1
Results of X-ray fluorescence (XRF) analysis (Wt%).

SiO_2 (%)	CaO (%)	Al_2O_3 (%)	Fe_2O_3 (%)	Norm. (%)
99.900 0	0.072 9	0.036 1	0.022 1	100.000 0

As is shown in Fig. 1, the glow curves exhibit four apparent thermoluminescence peaks in the temperature range between room temperature to 500 °C. The four apparent peaks clearly emerged at temperatures close to 133 °C, 211 °C, 266 °C and 405 °C (hereafter as Peak I, Peak II, Peak III and Peak IV) are observed in the above-mentioned temperature scanning region. The reason for no apparent peak observed below 100 °C is that the luminescence signal is weak in thermal stability, and the TL signal has completely attenuated before the measurements.

To understand the dose response characteristics of apparent Peak III, the baseline is taken into consideration. The thermoluminescence intensity between 250 °C and 270 °C was recorded. The luminescence intensity change with the dose was plotted in Fig. 2(a). The sensitivity for the dose response of each aliquot is quite different, maybe due to the grinding. In the same way as for apparent Peak IV, the luminescence intensity in the range from 400 °C to 420 °C was recorded and plotted in Fig. 2(b). But for highest dose in the figure, the dose of 1024 Gy, the sum of luminescence intensity exceeded the upper limit of statistical software designed by the TL reader, and only three out of five aliquots intensity sums can be recorded in Fig. 2(a) and four aliquots are recorded in Fig. 2(b). The thermoluminescence intensity increases with the rise of doses irradiated with. It has been found that the thermoluminescence signal of this quartz has the requisite TL properties for radiation dosimetry and can be potentially used for geological dating.

3.2. $T_m - T_{stop}$ plot

The peak identification means examining the number of peaks from the glow curve. The $T_m - T_{stop}$ method was applied to investigate the number of the peaks and their positions, and was used to obtain the trap distributions in the quartz [13].

All discs prepared for this experiment were annealed in a FJ-427A2 dosimeter (CNNC Beijing Nuclear Instrument Factory), heated from room temperature to 500 °C, followed by irradiation with 120 Gy $^{90}Sr/^{90}Y$ beta particles.

First, a disc was heated to the stop temperature which began with the temperature of 100 °C. Then, the next disc was started from room temperature and ended in a selected stop temperature which was in a small increment of about 5 °C. The thermoluminescence intensity of each disc was recorded. After that, the same disc was measured again with the same heating rate in a temperature range from room temperature to 500 °C, and was sustained at 500 °C for 20 s. The position of the first maximum in the second turn was recorded as T_m. As the measurement processes repeated, some different stop temperatures (T_{stop}) were emerged, and T_m versus T_{stop} can be plotted as Fig. 3.

The peaks illustrated in Fig. 3 are real peaks which only can be read after peak identification. In the paper, we called it peak or sub-peak of the glow-curve. The peak identification indicates that there are at least nine peaks in the glow curve. These peaks are at 133 °C, 211 °C, 266 °C, 308 °C, 333 °C, 384 °C, 441 °C, 466 °C and 484 °C, respectively. The first three apparent peaks are single peaks at 133, 211, 266 °C. And the last apparent peak (Peak IV, at 405 °C) is a composite peak, consists of six peaks, which are at 308 °C, 333 °C, 384 °C, 441 °C, 466 °C and 484 °C, respectively.

Quartz extracted from archaeological and geological materials exhibits either or both of two common TL peaks, the "325 °C" peak (Rapidly Bleaching Peak, RBP) and the "375 °C" peak, (Slowly Bleaching Peak, SBP). These peaks are shown in quotes because they apply only to a heating rate of 20 °C·s^{-1}. For a lower heating rate, the peaks occur at lower temperatures [14].