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Gamma-rays attenuation of zircons from Cambodia and South Africa at different energies: A new technique for identifying the origin of gemstone

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HIGHLIGHTS

- Gamma-rays interaction of zircons from Cambodia and South Africa studied.
- Measured energy is during 223–662 keV.
- Different μ_m between the two zircons observed at gamma-ray energies below 400 keV.
- The origins the two zircons could be successfully identified.

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ABSTRACT

In this work, the gamma-rays interaction properties of zircons from Cambodia and South Africa have been studied. The densities of Cambodian and South African's zircons are 4.6716 ± 0.0040 g/cm^3 and 4.5505 ± 0.0018 g/cm^3, respectively. The mass attenuation coefficient and the effective atomic number of gemstones were measured with the gamma-ray in energies range 223–662 keV using the Compton scattering technique. The mass attenuation coefficients of both zircons decreased with the increasing of gamma-rays energies. The different mass attenuation coefficients between the two zircons observed at gamma-ray energies below 400 keV are attributed to the differences in the photoelectric interaction. The effective atomic number of zircons was decreased with the increasing of gamma-ray energies and showed totally different values between the Cambodia and South Africa sources. The origins of the two zircons could be successfully identified by the method based on gamma-rays interaction with matter with advantage of being a non-destructive testing.

1. Introduction

Zircon is a common accessory mineral in the majority of igneous and metamorphic rocks with Zr as an essential structural constituent. Zircon is also useful because it has a high melting point and is therefore used to make foundry sand, heat-resistant materials and ceramics (Hoshino et al., 2012; Bonewitz, 2008). The zircon stones are found in Sri Lanka, Thailand, Combodia, Myanmar, South Africa, Australia and New Zealand; therefore gemologists often need to identify whether the stones are from natural or artificial origin, as well as the country or region of origin (Bonewitz, 2008). This identification can in many cases be achieved by optical inspection with a light microscope, because color and visible inclusions are often characteristic for gemstones from a certain region. However, these identification schemes do not always gives unambiguous results; therefore alternative identification techniques are desirable (Osipowicz et al., 1995).

The knowledge of major, minor and trace elements present in gemstones and their correlations in geological samples are very important because these factors provide a key to the history of minerals. In geological research, gemstone classification is performed by identifying the presence of major elements such as Na, Mg, Al, Si, P, K, Ca, Ti, Mn and Fe. Similar information on trace elements can be obtained using analytical techniques. Because of their low concentrations, it is difficult to obtain information on trace elements unless a suitable technique is adopted (Venkateswarulu et al., 2012). Hoshino et al. (2012) characterized the trace elements in zircon from granitic pegmatites of Japan (Naegi and Ohro) and Vietnam (Saigon) by using inductively couples plasma mass spectrometry (ICP-MS), electron microprobe analysis (EPMA), X-ray diffraction (XRD) and micro-Raman spectroscopy techniques. Osipowicz et al. (1995) used the particle induced X-ray emission (PIXE) technique to identify the trace elements concentrations for Burmese and Thai rubies. Venkateswarulu et al. (2012) employed the XRD and PIXE

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techniques for obtaining information about elemental concentrations of Indian garnet gemstone. Laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) has been applied to classify the origin of gem corundum (Pornwilard et al., 2011) and gem corundum and zircon(Sutherland et al., 2008; Rubatto, 2002) used the high mass resolution ion microprobes for study the zircon trace elements. Pappalardo et al. (2005) applied portable PIXE-alpha spectrometer and portable XRF spectrometer for characterization of gemstones in museums. Sanchez et al. (1997) analyzed the trace elements concentration of rubies from different locations in Myanmar by micro-PIXE. The LA-ICP-MS was also applied by Peucat et al. (2007) to constrain the geological origin of blue sapphires.

The mass attenuation coefficients, effective atomic number and electron density are basic quantities required for determining the attenuation of X-rays and gamma-rays in matter which are useful for understanding the physical properties of matters. Several authors reported the work related to the mass attenuation coefficients and the effective atomic number of some gemstones as following: Gerward et al. (2001, 2004) introduced the WinXCom program for calculating the mass attenuation coefficients of elements, compounds and mixtures materials. Korkut et al. (2011) studied the mass attenuation coefficients of amethyst ore at different gamma ray energies. Midgley (2005) measured the X-ray linear attenuation coefficients of sapphire, beryl and almandine garnet at energies 32–66 and 140 keV. Ryzhikov et al. (2009) reported the effective atomic number of quartz glass.

Due to the dependence of radiation shielding parameters of material on the concentrations of major, minor and trace elements, it may be possible to develop as a new technique for identify the origin of some gemstones. In this work, we are the first to report on the mass attenuation coefficients and the effective atomic numbers measured with different photon energies of zircons from Cambodia and South Africa. The incident photon energies have been realized by the Compton scattering technique with a Cs-137 (662 keV) source.

2. Mass attenuation coefficient and effective atomic number calculations

The mass attenuation coefficient is written as (Limkitjaroenporn et al., 2011)

$$\mu_m = \frac{\ln\left(\frac{I_0}{I}\right)}{\rho t} \tag{1}$$

where ρ is the density of material (g/cm^3), I_0 and I are the intensities of incident and transmitted beams and t is the thickness of absorber (cm).

The value of mass attenuation coefficients can be used to determine the total atomic cross-section ($\sigma_{t,a}$) by the following relation (Limkitjaroenporn et al., 2011).

$$\sigma_{t,a} = \frac{(\mu_m)_{alloy}}{N_A \sum_i^n (w_i/A_i)} \tag{2}$$

where N_A is Avogadro's number, A_i is atomic weight of constituent element of mixture and w_i is the fraction by weight of the ith atomic constituent. Also the total electronic cross-section ($\sigma_{t,el}$) for the element is expressed by the following formula (Limkitjaroenporn et al., 2011).

$$\sigma_{t,el} = \frac{1}{N_A} \sum_i^n \frac{f_i A_i}{Z_i} (\mu_m)_i \tag{3}$$

where f_i is the number of atoms of element i relative to the total number of atoms of all elements in alloy, Z_i is the atomic number of the ith element in mixture. Total atomic cross-section and total electronic cross-section are related to effective atomic number (Z_{eff}) of the compound through the formula (Limkitjaroenporn et al., 2011).

$$Z_{eff} = \frac{\sigma_{t,a}}{\sigma_{t,el}} \tag{4}$$

The electron density can be defined with number of electrons per unit mass, and it can be mathematically written as Kaewkhao et al. (2008)

$$N_{el} = \frac{\mu_m}{\sigma_{t,el}} \tag{5}$$

3. Experimental setup and procedures

The experimental arrangement of the Compton scattering technique is shown in Fig. 1. The source system was mounted on a composite of adjustable stands. This setup can move in the transverse direction for proper beam alignment. The ^{137}Cs radioactive source of 15 mCi (555 MBq) strength was obtained from the Office of Atom for Peace (OAP), Thailand. The aluminium rod was used as the scattering rod. The Compton scattered γ-rays were measured on a rotatable scintillator detector in the scattering

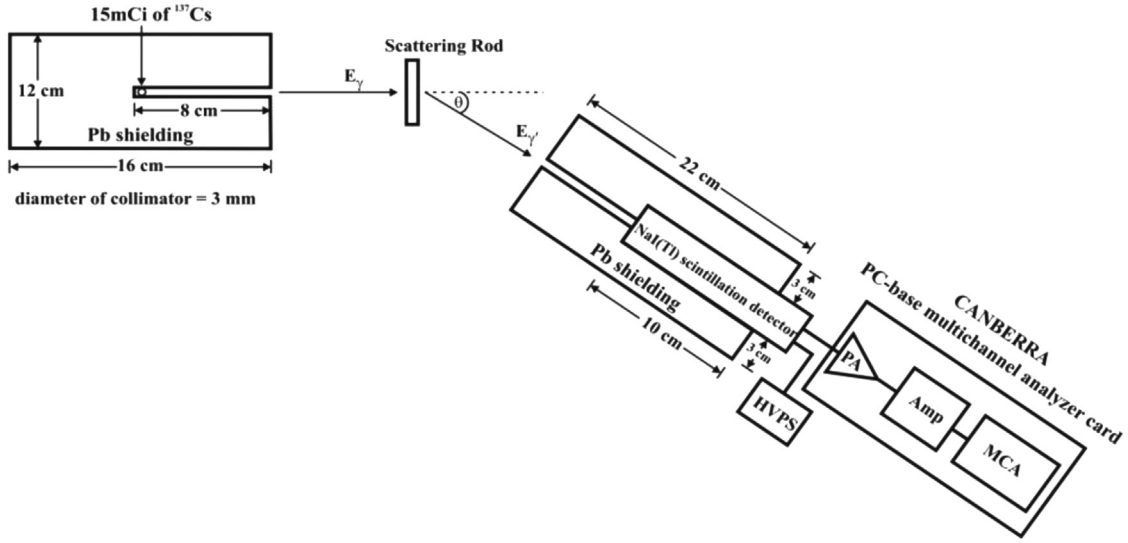

Fig. 1. Schematic of the Compton scattering experiment to realize different gamma rays energies.