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Preparation and mechanoluminescent properties of $SrAl_2O_4$: Eu film grown on silicon substrate using double buffer layers

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ABSTRACT

In this paper, we utilized double layer method to prepare $SrAl_2O_4$:Eu (SAOE) film on silicon substrate (400). The Al_2O_3 layer (about 200 nm) was used as a hetero-buffer layer to eliminate the large difference of crystal lattice and thermal mismatch between the SAOE and silicon substrate. Thin SAOE layer (about 600 nm) was grown on Al_2O_3 layer as homo-buffer layer to reduce internal stress during film growth process. On double buffer layers, continuous sputtering formed about 1.5 μm SAOE film. The resulting thick SAOE/Al_2O_3/Si film possessed both excellent photoluminescence (PL) and mechanoluminescence (ML) properties. The similarity of PL and ML spectra suggested that PL and ML both originated from same emitting center of Eu^{2+}. The strong ML intensity showed that the as-prepared SAOE film can be regarded as an indicator to detect stress distribution of an object. The thermoluminescent (ThL) results indicated that a large amount of trapped electrons existing in the resulting film answered for the strong ML intensity.

1. Introduction

Europium doped strontium aluminate films ($SrAl_2O_4$:Eu) have attracted much attention because of their wide applications in traffic signs, emergency signage, watches and clocks, textile printing, and so on [1]. In particular, in recent years, $SrAl_2O_4$:Eu phosphors have been found to possess mechanoluminescence (ML) property. Mechanoluminescence is an interesting luminescence phenomenon, which is a light emission caused by mechanical stimuli such as grinding, cutting, collision, striking, friction and so on [2,3]. ML sensors employed to detect environmental stress by means of emitting light are expected to find their wide applications such as indicating earthquakes, damage detection for airplanes or cars, and the study of human diseases [4–6]. Compared to other ML materials, SAOE possesses the strongest ML intensity, thereby which has widely applied to probe mechanical stress distribution in various fields, including bridge, steel, etc.

Thin ML films show several advantages, such as good thermal stability and adhesion to the solid surface, compared to their powder counterparts. The preparation of SAOE films with good quality is important for fabricating high sensitive ML devices. SAOE films on various substrates, including quartz glass substrate [7], inconel substrate [8], Al_2O_3 substrate [9,10] and so on, have been reported. However, except Al_2O_3 and inconel substrates, it is difficult to obtain SAOE films growing on other substrate, such as quartz glass and silicon substrates, due to large difference of the crystal lattice and thermal mismatch between the SAOE and substrate. Buffer layers were introduced to eliminate these effects to obtain good SAOE film. Fu and Yamada have reported that SAOE films on quartz glass could be prepared using a homo-buffer method. This synthesis method was effective to prepare thin SAOE film (usually less than 1 μm). However, if the thickness of the SAOE film was more than 1 μm, the gradual increase of internal stress would induce the serious peel of thicker SAOE films from the substrate [7]. While usually the ML intensity was dependent on the film thickness. Thus, developing a synthesis route to obtain thick SAOE films was of importance for preparing ML sensors.

In this paper, we reported the preparation of a thick SAOE film (about 2 μm) on a silicon substrate featured by not only good adhesion but also high ML intensity. In the synthesis process, two kinds of buffer layer were employed to eliminate the internal stress. Firstly, a hetero-buffer layer, Al_2O_3 was introduced to eliminate the large difference of crystal lattice and thermal mismatch between the SAOE and silicon substrate. Then, a thin SAOE film was grown on Al_2O_3/Si as a homo-buffer layer to reduce the internal stress. Finally, the continued sputtering formed thick SAOE film. The present results are expected to promote the development of SAOE materials.

2. Experiment

Samples were grown on silicon substrate by means of a conventional RF (13.56 MHz) sputter setup. Two source targets with 4 in in diameter were fabricated by employing Al_2O_3 and $Sr_{0.995}Eu_{0.005}Al_2O_4$

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powder, respectively. The substrate was cleaned in sequence by UV light, acetone, ethanol and distilled water, before it was loaded into chamber. Before deposition, the target was pre-sputtered for 20 min with the shutter closed. Firstly, the Al_2O_3 film was deposited for 20 min as hetero-buffer layer under conditions of RF power about 2.5 W/cm^2, an Ar atmosphere at pressure of 0.1 Pa, and substrate temperature of 100 °C. Then the SAOE film was deposited for 1 h under similar conditions, only substrate temperature was changed to 600 °C. In order to prepare compact buffer layer, the SAOE/Al_2O_3/Si buffer layer samples were calcined at 950 °C for 2 h in tube furnace with reduced atmosphere Ar/H_2 (95%/5%).

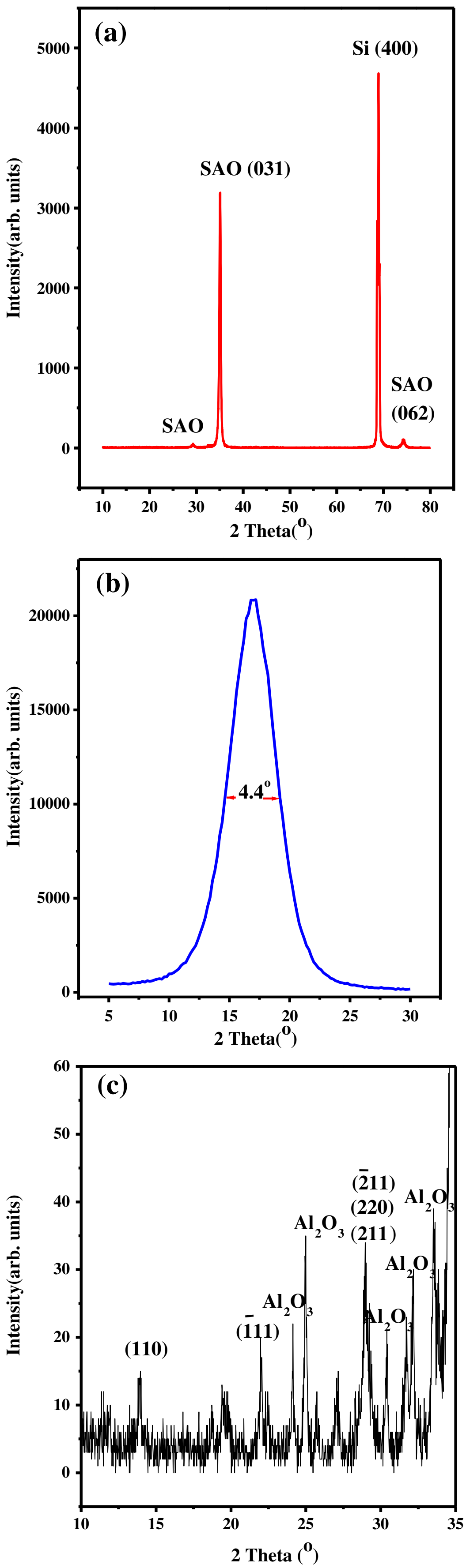

Fig. 1. (a) XRD pattern of SAOE/Al_2O_3/Si films. (b) Rocking curves of SAOE/Al_2O_3/Si films. (c) Enlarged XRD pattern between 10 and 35°.

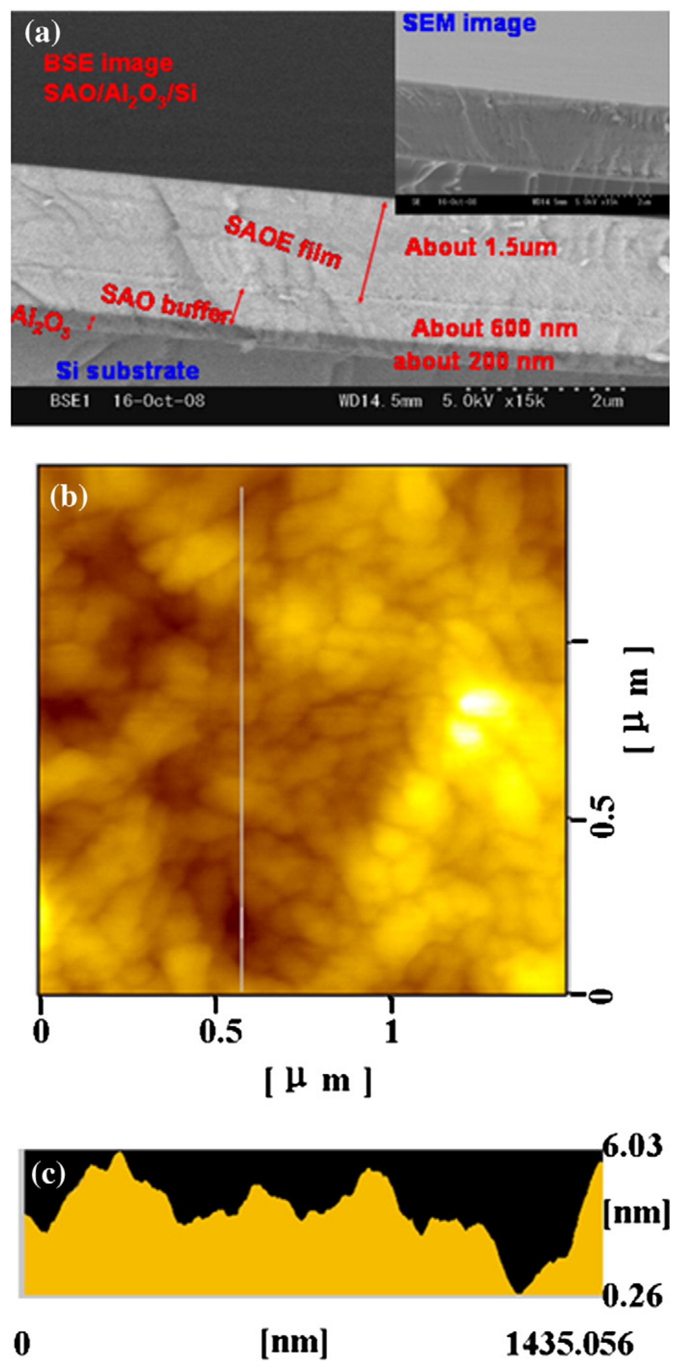

Fig. 2. (a) BSE images of SAOE/Al_2O_3/Si films and the inset is the corresponding SEM image. (b) AFM images of SAOE/Al_2O_3/Si films. (c) The longitudinal surface roughness of SAOE/Al_2O_3/Si films.