Journal of Luminescence 148 (2014) 89–93

Contents lists available at ScienceDirect

Journal of Luminescence

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

Influence of organic solvent treatment on elasticoluminescent property of europium-doped strontium aluminates

Yuki Fujio [a,*], Chao-Nan Xu [a,b,*], Nao Terasaki [a], Naohiro Ueno [a,1]

[a] Measurement Solution Research Center, National Institute of Advanced Industrial Science and Technology (AIST), Saga 841-0052, Japan
[b] International Institute for Carbon-Neutral Energy Research (WPI-I^{2}CNER), Kyushu University, Fukuoka 819-0395, Japan

ARTICLE INFO

Article history:
Received 6 October 2013
Received in revised form
17 November 2013
Accepted 24 November 2013
Available online 10 December 2013

Keywords:
Mechanoluminescence
$SrAl_2O_4$:Eu
Strain measurement

ABSTRACT

The influence of an organic solvent treatment on elasticoluminescent (ELS) characteristics of mechanoluminescent (ML) sensor using the composite film consisting of an ELS material and epoxy resin was investigated. We used strontium aluminate doped with a small amount of europium ($SrAl_2O_4$:Eu, SAOE) as an ELS material in this study. After evaluating the ELS characteristics of the fabricated ML sensors using SAOE treated with/without various organic solvents, SAOE treated with methanol and ethanol showed lower ELS intensities than that of untreated SAOE. In contrast, the ELS response curves against strain for the ML sensors using SAOE treated with acetone and toluene, overlapped with that of untreated SAOE. From the characterization of SAOE treated with alcohols, such as methanol and ethanol, we can hypothesize that poor ELS characteristics is due to the degradation of the SAOE grain surfaces by the hydrolyze reaction of SAOE with hydroxyl group of alcohol. Thus, on the basis of the obtained results, we can conclude that the selection of organic solvent used in the preparation of SAOE film is of considerable importance in the development of ML sensor with a highly-reliable ELS characteristic.

1. Introduction

Recently the structural health monitoring of various constructions, such as bridge, building, chemical plant, and social infrastructure, is a very important issue. Actually, there have been a lot of accidents caused by age-related degradation all over the world, for instance, the collapses of the Mississippi river bridge in Minneapolis, USA (August 1, 2007) and Sasago tunnel in Yamanashi, Japan (December 2, 2012). In order to ensure the safety in the social life, a development of a highly-reliable structural health monitoring technique is an urgent and crucible concern.

So far, there have been numerous reports in regard to the sensing technology, such as an ultrasonic wave method [1], electrical strain gage [2], fiber optic sensor [3,4], and so on, aiming at a structural health monitoring application. Quite recently, we have reported that the mechanoluminescent (ML) sensor using a composite film consisting of an ML material and organic compounds can be useful technique for not only a dynamic visualization of the strain (or stress) distribution in complicated structure of metal substrate [5] but also a health monitoring of an aged bridge [6]. The ML is the phenomenon of luminescence induced by mechanical actions, such as compression, tension, friction, or torsion. In the ML sensor, an elasticoluminescence (ELS) is used as a sensing signal for the reason of a reversible luminescence in the elastic deformation and its proportionality to the strain (or stress). The detail of ELS definition was mentioned in a paper [7]. Among various reports about the ELS materials aiming at strong luminescence and various emission colors (wavelength), for example, ZnS:Mn [8,9], $CaAl_2Si_2O_8$:Eu [10], $BaTiO_3$–$CaTiO_3$:Pr [11,12] and $Sr_{n+1}Sn_nO_{3n+1}$:Sm [13], strontium aluminates doped with a small amount of europium ($SrAl_2O_4$:Eu, SAOE) is one of the promising ELS material owing to the strongest visible light emission [14–21]. From the application point of ELS material to the ML sensor which consists of ELS material and organic compounds [22–25], it is vital to choose the appropriate organic compounds, which are polymeric materials and organic solvents, to the ELS material, keeping or enhancing the original ELS characteristics. However, the effect of organic compounds on the ELS characteristics has been still unclear, although a selection of the combination of an ELS material and organic materials is the most important for achieving a high performance ELS characteristics.

In this study, we fabricated ML sensors using composite films of SAOE powder treated with/without organic solvents and epoxy resin, and investigated their ELS characteristics. As an organic solvent, we examined four kinds of solvents with

* Corresponding author. Tel.: +81 942 81 4011; fax: +81 942 81 3696.
E-mail addresses: yuki-fujio@aist.go.jp (Y. Fujio), cn-xu@aist.go.jp (C.-N. Xu).
[1] Present address: Graduate School of Science and Engineering, Saga University, Saga 840–8502, Japan.

0022-2313/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.jlumin.2013.11.084

different polarities, such as methanol, ethanol, acetone, and toluene. After evaluating the ELS characteristics of the prepared SAOE films, other optical and structural characteristics were also examined.

2. Experimental

2.1. Preparation of SAOE and SAOE treated with organic solvent

The SAOE powder was synthesized through a conventional solid-state reaction method. The commercial $SrCO_3$ (Kanto Chemical Co., Inc., Japan), α-Al_2O_3, and Eu_2O_3 (Kojundo Chemical Laboratory Co., Ltd., Japan) were weighed precisely to the molar ratios of $Sr_{0.97}Al_2O_4$:$Eu_{0.03}$, and mixed together by means of ball-milling method using zirconia balls (5 mm in diameter) in ethanol solution at 100 rpm for 20 h. The resulting suspension was dried to vaporize an ethanol on an electrical hot plate, stirring continually, and pre-calcined at 800 °C for 1 h in air. The solidified product was ground in a mortar and sintered again at 1350 °C for 4 h in 5% H_2/Ar atmosphere. The final SAOE powder was obtained by thoroughly pulverizing the sintered powder in a mortar.

The synthesized SAOE powder (3.0 g) was vigorously stirred for 24 h in each of four kinds of organic solvent (100 ml each). The obtained suspensions were dried to obtain SAOE treated with an organic solvent. The each of SAOE powders treated with methanol, ethanol, acetone, and toluene, denoted by SAOE-Mt, SAOE-Et, SAOE-Ac, and SAOE-To, respectively.

2.2. Evaluation of ELS characteristics

The SAOE films were fabricated by means of screen printing technique using a mixture of an SAOE powder and epoxy resin. In all cases, the thicknesses of the prepared SAOE films were approximately 60 μm. The fabricated SAOE films adhered to the front side of SUS631 substrate with a commercial adhesive. The commercial strain gage was also applied on the back side of the SUS631 substrate. The ELS characteristics of the prepared SAOE films were evaluated under an ELS evaluation system in a dark room at room temperature. This system was built up with four parts; (1) a metal substrate (SUS631, $250 \times 20 \times 0.5^t$ mm) attached with the SAOE film (10×10 mm) and a commercial strain gage (Kyowa Electronic Instruments Co., Ltd., Japan), to record ELS images and strain simultaneously, (2) material testing machine (MTS 810, MTS Systems Co., US), to apply a mechanical load to the metal substrate attached with the SAOE film and strain gage, (3) a CCD camera to take ELS images, and (4) a computer, to control a material testing machine and record ELS images and strains, as has already been reported elsewhere [5,26]. For reproducible and quantitative ELS measurement, the ML sensor applied on the SUS substrate was once irradiated by ultraviolet light (UV, 365 nm, 0.7 mW/cm^2) for 1 min and keep under dark condition for 1 min. The ELS intensities corresponding to strain were estimated from the obtained ELS images and strain gage.

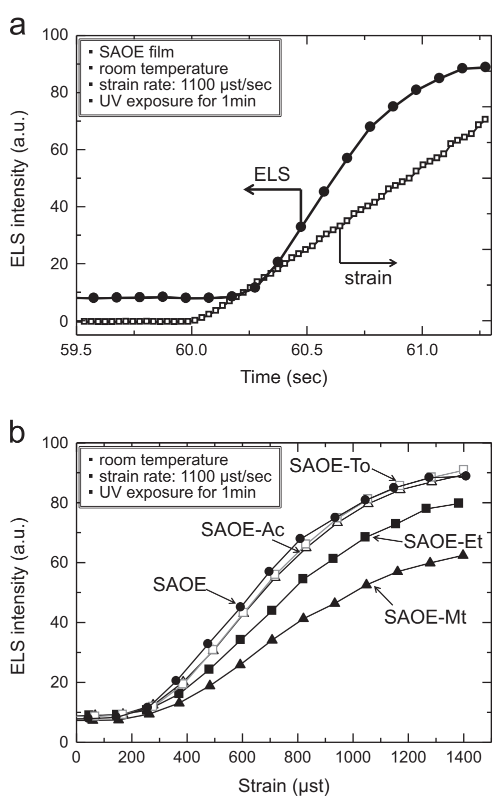

Fig. 1. (a) ELS response curve of ML sensor using untreated SAOE film and strain curve of strain gage after UV light exposure for 1 min and wait for 1 min; (b) comparison of strain dependency of ELS intensities for ML sensors using SAOE, SAOE-Mt, SAOE-Et, SAOE-Ac, and SAOE-To films.

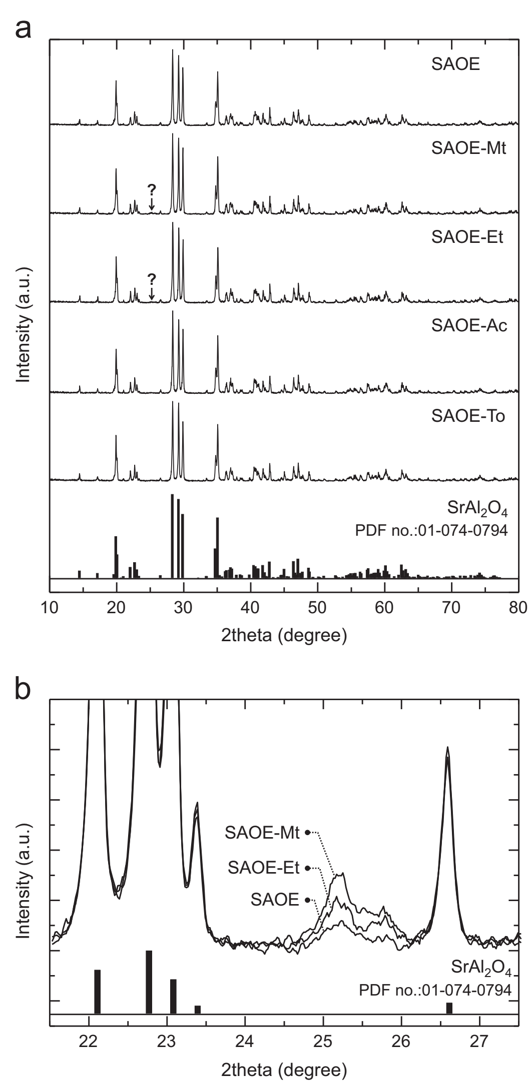

Fig. 2. (a) XRD patterns of SAOE, SAOE-Mt, SAOE-Et, SAOE-Ac, and SAOE-To powders as well as standard PDF data for $SrAl_2O_4$ (01-074-0794), and (b) magnified XRD patterns of SAOE, SAOE-Mt, and SAOE-Et powders.