Journal of Alloys and Compounds 678 (2016) 65–69

Contents lists available at ScienceDirect

Journal of Alloys and Compounds

journal homepage: http://www.elsevier.com/locate/jalcom

Enhanced solar photons harvesting of a-SiC:H solar cells with ZBLA fluoride glasses containing rare earth ions

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ARTICLE INFO

Article history:
Received 4 October 2015
Received in revised form
28 March 2016
Accepted 30 March 2016
Available online 1 April 2016

Keywords:
Rare earth
ZBLA fluoride glass
a-SiC:H
Downshifting
Upconversion
Photoelectric efficiency

ABSTRACT

As encapsulation glasses for a-SiC:H cells, $Yb^{3+}/Ce^{3+}-Er^{3+}$ tri-doped ZBLA fluoride glasses were prepared using the high temperature melt-quenching method and the optical characteristic of the glass were measured. Depending on the nature of rare earth doped ZBLA fluoride glasses, both near infrared (low-energy) and ultraviolet (high-energy) solar photons can be transformed into visible photons. By downshifting the ultraviolet (280–350 nm) light combined with upconverting the near infrared (900–1100 nm) light, the glass can emit strong visible (500–700 nm) light, which matches well with the spectral responsivity of a-SiC:H cells. The conversion of non-absorption photons energies by upconversion and downshifting leads to promote the improvement of a-SiC:H cells performances, and measurement shows relatively increase of 7.6%–0.8% in cell efficiencies.

1. Introduction

Hydrogenated amorphous-silicon carbide (a-SiC:H) solar cells have attracted extensive attention as one of the promising Silicon-based solar cells. However, a-SiC:H cells have a maximum absorption in visible (VIS) light of solar radiation that confines the increase of photoelectric transformation efficiency (PTE) [1,2], as shown in Fig. 1. Some research efforts have been focused on extending solar photons absorption to improve the PTE [4–6]. As is well known that rare earth (RE) ions have been studied to be used in plasma displays, fiber lasers, greenhouse, and solar cells due to the advantage of optical properties for their 4f-4f transitions [7–11]. RE ions doped upconversion (UC) [11,12] combined with downshifting (DS) [12,13] materials is an available approach to compensate for the non-absorbable waveband of a-SiC:H cells via transforming near infrared (NIR) and ultraviolet (UV) solar photons to VIS photons.

For the past years, RE-doped UC/DS materials has been identified in powder phosphors, thin-film phosphors, ceramics, and some approaches have been implemented to films and phosphors with a few applications to some kinds of photovoltaic (PV) cells in device performance [3,6,13,14]. Most studies have been performed on the luminescent film (LF) and luminescent coating (LC), which place on the top-encapsulated glass of cells, while few UC/DS has been researched in glass base-materials for a-SiC:H cells. ZBLA fluoride glasses [15] have emerged as promising candidates for RE-doped UC/DS materials containing a merits of good thermal and chemical stability compared with other kinds of glasses [16–22], low refractive indices for light confinement, high transparency in the optimum SR of a-SiC:H cells. Planar RE-doped ZBLA fluoride glass have dual-function of encapsulation and solar spectral optimization for a-SiC:H cells, which may be appropriate for practical application of a-SiC:H cells. In this paper, the $Yb^{3+}/Ce^{3+}-Er^{3+}$ tri-doped ZBLA fluoride glasses have been synthesized, which can absorb the solar photon from not only UV but also NIR bands. The transparent ZBLA fluoride glass can efficiently emit VIS photons that match well with the SR needed for a-SiC:H cells. The results might be a better approach to raise a-SiC:H cell performance.

2. Experiment section

2.1. Sample preparation

Yb^{3+}, Ce^{3+} and Er^{3+} ions were doped into ZBLA fluoride glasses to form glassy luminescent layers. The samples were prepared by high temperature melting method and subsequent heat treatment with the composition in a mole percentage:

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http://dx.doi.org/10.1016/j.jallcom.2016.03.288
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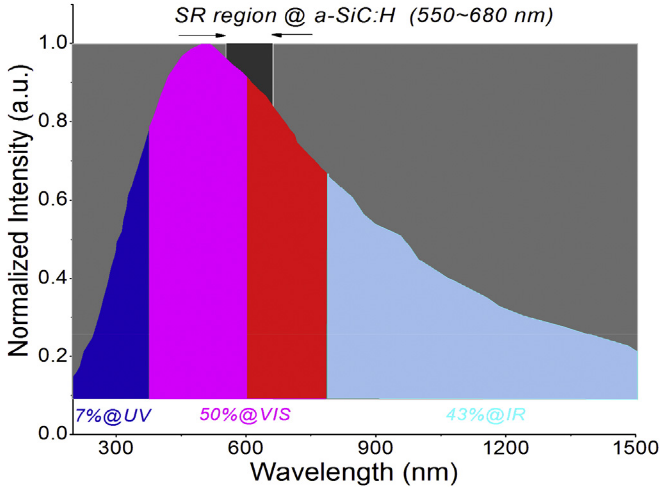

Fig. 1. The normalized AM 1.5G solar radiation [3]. The optimum wavelength of spectral responsivity (SR) of a-SiC:H is around 550–680 nm [1].

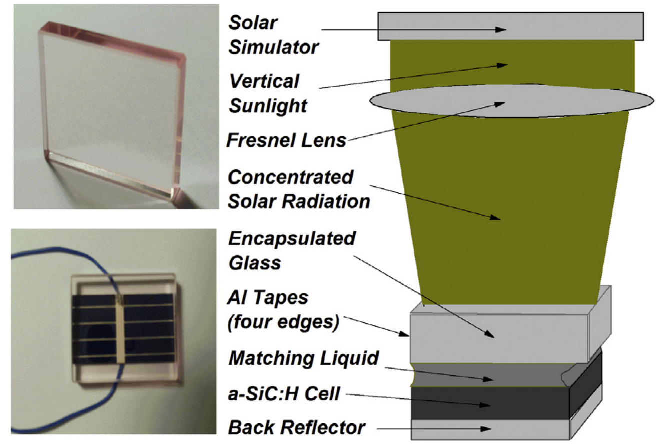

Fig. 2. An illustration of the a-SiC:H cell covered with an encapsulated-glass sample. Cell device equipped with spectral converters, consisting of a bifacial a-SiC:H cell with a ZBLA fluoride glass attached to the top side of the cell, was characterized under the broadband excitation with a Fresnel lens placed in front of the cell device, and the whole system was characterized with a solar simulator.

$(55ZrF_4–36BaF_2–4LaF_3–5AlF_3)$ + $(5Yb_2O_3–0.2CeO_2–0.7Er_2O_3)$. Each batch of 15 g raw materials of ZrF_4, BaF_2, LaF_3, AlF_3, CeO_2, Er_2O_3 and Yb_2O_3 were fully mixed and then heated and achieved a homogeneous melt at 900 °C for 10 min in a covered corundum crucible under helium atmosphere, the melt liquid was then poured into a preheated copper plate at 210 °C in order to process quenching. The samples were heated in an annealing furnace at 200 °C for 60 min to eliminate the stress. The samples were cut in the form of square plates (40 mm × 40 mm × 3 mm) and polished on double sides for optical characterization measurements.

2.2. Sample characterization

The absorption, Photoluminescence (PL), photoluminescence excitation (PLE) and UC/DS emission spectra of glass samples were measured on an Omni-SBP-λ300 fluorescence spectrophotometer (Zolix Instruments, China) under the excitation of an LHX500 xenon arc lamp (Zolix Instruments, China) and 980 nm laser diode (Zolix Instruments, China). The VIS emission was detected by a photomultiplier tube detector. The whole measurements were carried out at 25 °C.

The prepared glass could be a prospective material serving DS and UC dual function of solar radiation transformation for improving the PTE of a-SiC:H cell. The prepared glass was covered onto an a-SiC:H cell, as shown in Fig. 2. The solidified glass was attached to the cell with the index matching liquid immersion oil (Type 300, Nikon) and four aluminum tapes were respectively attached on the edges of the glass to reduce the loss of isotropic radiation [14,23]. Effects of glasses on PTE of a-SiC:H cells and cell characteristics under illumination were measured with an AM 1.5 solar simulator (Keithley, Class-AAA-94023A, 100 mW/cm^2).

The structure of a-SiC:H solar cell is glass/SnO_2/p a-SiC:H/i-n a-Si:H/Al substrate with heteroface type. An film of a-SiC:H can be fabricated by glow discharge decomposition of silane and hydrocarbon gas mixture. The fluctuation of series resistance originating in a transparent electrode in a solar cell was suppressed and the glass/SnO_2/p-i-n/Al structure was employed. A boron doped a-SiC:H layer of 100 Å was deposited on the substrate. Then an undoped a-Si:H of 5000 Å and a phosphorus doped a-Si:H of 500 Å were deposited. An aluminum electrode can be evaporated onto the surface of an n-layer as a back side contact.

3. Results and discussion

3.1. Optical characteristics analysis

The samples are of highly transparency in the VIS range and the VIS sunlight can easily pass through. The absorption in the NIR range (900–1100 nm) and UV (280–390 nm) region derive from Yb^{3+} ($^2F_{7/2}$) → Yb^{3+} ($^2F_{5/2}$) transition, Er^{3+} ($^4I_{15/2}$) → Er^{3+} ($^4I_{11/2}$) transition, and Ce^{3+} (4f) → Ce^{3+} (5d) transition, respectively, as shown in Fig. 3. We focus on the VIS emission which is the main absorption band for a-SiC:H material. The absorption peaks at 380, 486, 520 and 650 nm are respectively assigned to transitions of Er^{3+} ($^4I_{15/2}$) to Er^{3+} ($^4G_{11/2}$), Er^{3+} ($^4F_{7/2}$), Er^{3+} ($^2H_{11/2}$) and Er^{3+} ($^4F_{9/2}$).

Fig. 4 shows the excitation spectrum of the Yb^{3+}/Ce^{3+}-Er^{3+} tri-doped ZBLA fluoride glass monitoring at 668 nm. On one hand, the red-orange emission are excited by the UV (280–390 nm) range: The excitation band of the 280–350 nm derives from the Ce^{3+} (4f) → Ce^{3+} (5d) transition, and the excitation band of 350–390 nm derives from the Er^{3+} ($^4I_{15/2}$) → Er^{3+} ($^4G_{9/2}$) (365 nm peak) and Er^{3+} ($^4I_{15/2}$) → Er^{3+} ($^4G_{11/2}$) (380 nm peak) transitions. On the other hand, the red-orange emission are also excited by the NIR (900–1000 nm) range: Yb^{3+} ($^2F_{7/2}$ → $^2F_{5/2}$) transition.

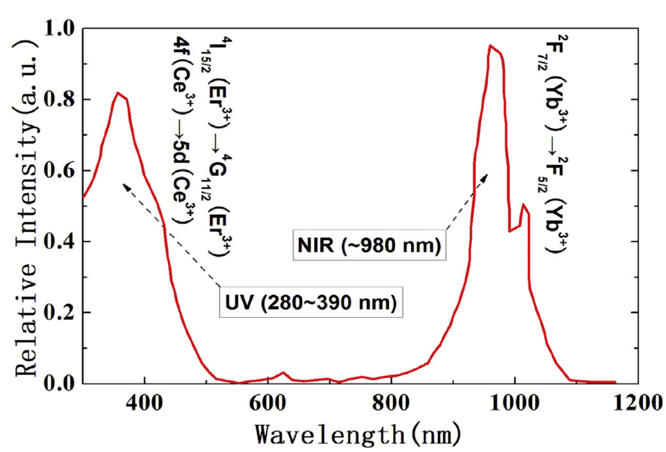

Fig. 3. The absorption spectrum of the Yb^{3+}-Ce^{3+}-Er^{3+} tri-doped ZBLA fluoride glass with 3 mm thickness.