ARTICLE IN PRESS

Solar Energy Materials and Solar Cells xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Solar Energy Materials and Solar Cells

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

Accessing externally induced spatially-resolved strain in GaAs thin-film solar cells by electroluminescence imaging

Xiaobo Hu[1], Liangqing Zhu[1], Guoen Weng, Shaoqiang Chen*

MoE Key Laboratory of Polar Materials and Devices, Department of Electronic Engineering, East China Normal University, 500 Dongchuan Road, Shanghai 200241, China

ARTICLE INFO

Keywords:
Strain effect
GaAs thin-film solar cell
Electroluminescence imaging

ABSTRACT

Externally induced strain effect was investigated in GaAs thin-film solar cells by electroluminescence (EL) imaging method. The strained regions demonstrated not only enhancement of local EL intensity but also redshift of the EL emission peaks. The observations were explained well by a gradient quantum-well (GQW) model correlated with tensile strain in the GaAs thin films. External biaxial strain was considered in this model which was accordingly obtained from the energy shift of the EL spectra. Finally, the spatially resolved strain in GaAs thin-film solar cells was obtained from the EL images by relating the EL emission intensity to the shift of the EL spectra. This work provides a potential standard method for diagnosis of externally induced strain in thin-film solar cells by EL measurements.

1. Introduction

Thin-film solar cells have become one of the most important branches in the area of solar cells [1]. One attractive merit of thin-film solar cells is that the devices could be fabricated on plastic or metallic foils such as organic polymers and stainless steel, other than the traditional rigid glass plate substrate [2,3], which leads to thin and light-weight products and also provides new functionality such as flexing and non-planar shaping [4]. However, the new functionality brings a new issue for thin-film solar cell that since the device application may require intentional bending, stretching, or shaping after the fabrication, these externally applied stress may influence the mechanical stability [5]. For solar cells, mechanical stability could usually be influenced by external factors such as mechanical force and temperature variations [6,7]. For example, with temperature changing, the difference in the thermal expansion coefficients between the films and the substrate could induce thermal stress [6], which may induce the appearance of defects in the films that could deteriorate their electrical properties. Mechanical stability is usually characterized by the strains in the thin films [5]. It has been reported that thin-film solar cells may be shaped by plastic deformation without serious consequences on solar cell performance [8], as long as the mechanical strain was kept below certain values. However, it was reported that once the strain exceeded a certain value, the performance of thin-film amorphous silicon solar cells started to deteriorate due to the formation of cracks [4,8]. Thus, it is necessary to monitor the degree of the strains in thin-film solar cells to make sure the devices could work normally. Raman spectroscopy, profilometer measurements and X-ray diffraction (XRD) were common methods used to measure local mechanical strain in semiconductor films and devices [9–12], however, these methods are either with complicated system or time-consuming when measuring large areas. Other methods such as laser beam reflection methods or capacitive methods can provide information on film strain with a high sensitivity while measuring the wafer curvature [13,14], however, they could only provide information on average strain but not local strain in or surrounding devices. It has been generally known that strain in semiconductor devices such as GeSi/Si and III–V compound semiconductors would change the band structures such as the band edges and so influence the band-gap energy [15]. Optical methods such as luminescence measurements were useful ways to obtain the externally induced strain in semiconductor devices from the variation of the band-gap energy with and without external stress.

In this work, a potentially simple method for diagnosis of externally induced strain in GaAs thin-film solar cells by using electroluminescence (EL) measurements was developed, and the measurement of spatially resolved strain in GaAs thin-film solar cells was developed from EL imaging measurements.

2. Experimental

Fig. 1(a) shows the schematic diagram of the EL measurement setup. A GaAs thin-film solar cell with size of $4 \times 2\ cm^2$ is set on a Cu plate,

* Corresponding author.
E-mail address: sqchen@ee.ecnu.edu.cn (S. Chen).
[1] These authors contributed equally to this study and share first authorship.

https://doi.org/10.1016/j.solmat.2017.12.019
Received 24 September 2017; Received in revised form 16 November 2017; Accepted 14 December 2017
0927-0248/ © 2017 Published by Elsevier B.V.

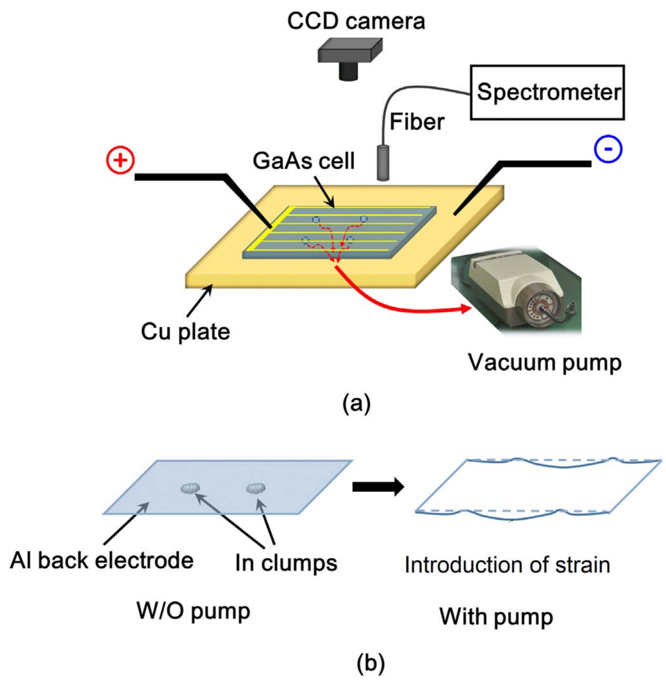

Fig. 1. (a) Schematic diagram of the EL measurement setup; (b) Schematic diagram illustrating the introduction of strain due to the uneven back of the solar cell because of the indium (In) clumps and externally applied vacuum pumping force. W/O pump: the pump is not operating; With pump: the pump is working.

there are four holes through the Cu plate for vacuum pumping (pump type: FV-10, Tokyo. Fluoro Mechanic Co., Ltd.) to make the cell contact tightly with the Cu plate. The back side of the solar cell is Al electrode with two indium (In) clumps below it. A CCD camera was fixed above the cell to capture the EL images of the solar cell when injecting forward current into the solar cell. The EL spectra was measured by a fiber probe connected to a spectrometer which is composed of a monochromator and a cooled silicon charge-coupled device (CCD). The I-V properties of the GaAs solar cell was measured under AM1.5 G, 1-sun illumination condition using a solar simulator at room temperature. The short-circuit current density (J_{sc}) was 25.3 mA/cm^2, the open-circuit voltage (V_{oc}) was 0.996 V, and the energy conversion efficiency (η) was 19.4%. Fig. 1(b) shows the schematic diagram illustrating the introduction of strain due to the uneven back of the solar cell because of the In clumps and externally applied vacuum pumping force. However, it should be noted that the deformation of the thin-film cell due to the strain is slight which could not be observed by eye directly.

3. Results and discussion

Fig. 2(a) and (b) show the EL images under the condition of forward injection current density of 20 mA/cm^2 at 25 °C with the vacuum pump operating and vacuum pump not operating, respectively. Fig. 2(c) shows the image demonstrating the difference between (a) and (b), or (a) minus (b). Three bright spots could be seen in Fig. 2(c) which means in the three spot regions, there is an increase of EL intensity after the vacuum pump operating. This could be attributed to the effect of tensile strain in the GaAs thin-film solar cell which will be detailed illustrated in the following parts.

Fig. 3(a) shows the profiles of EL emission intensity (integration over the y-axis) along the x axis as shown in the inset with variation injection current density from 2.5 to 37.5 mA/cm^2. Fig. 3(b) shows the integrated EL intensity of the three main spots (designated by spot 1, 2, 3 in Fig. 3(a)) along the spatial distribution dependent on the injection current density. It could be seen that the EL intensity of all the spots show the same dependence on the injection current density which first

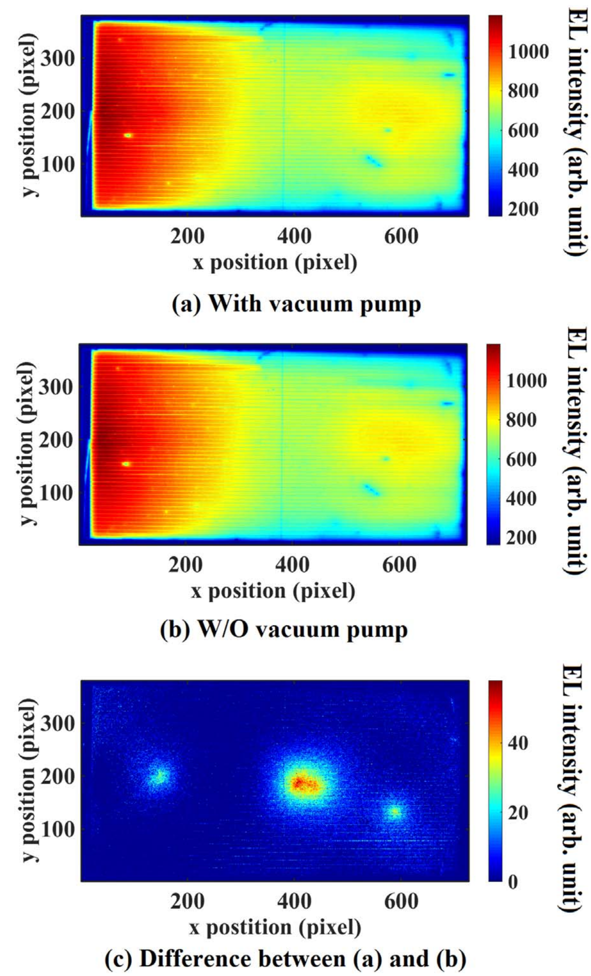

Fig. 2. EL images under the condition of forward injection current density of 20 mA/cm^2 at 25 °C (a) with the vacuum pump operating; (b) without (W/O) vacuum pumping; (c) the difference between (a) and (b), that is, (a) minus (b).

increase at low current density and then gradually saturated at high current density. The inset in Fig. 3(b) shows the bias voltage corresponding to each current density used for the EL measurements

Fig. 4(a) shows the EL spectra measured at spot 2 using a fiber probe connecting to a spectrometer with vacuum pumping and without pumping under forward injection current density of 10 mA/cm^2 and 20 mA/cm^2, respectively. After operating vacuum pump, the EL intensity could be seen increased which is the same as the results in Fig. 3, and also, the peak position is found to shift to longer wavelength (redshift) or to lower energy. Fig. 4(b) shows the quantity of the energy shift due to the vacuum pumping under various forward injection current density. It is found that the energy shift quantity keep almost constant at 2.5–3 meV with varying current density.

The observed phenomena in Fig. 3 and Fig. 4 could be attributed by the generation of strain in the thin-film solar cell due to the external vacuum pumping. And the results could be well explained by a model named gradient quantum-well (QW) which is induced by tensile strain as Fig. 5 shows. The effect of strain mainly reflects on valence and conduction band structure for III–V semiconductors [15,16]. Here we mainly consider biaxial external strain effect on the structure of the valence and conduction band which has been illustrated by a tetragonal distortion model [15]. Biaxial strain has two parts: a hydrostatic part and a shear component. Hydrostatic strain changes the distance between the conduction band and the center of gravity or the weighted average of the three uppermost valence bands (the heavy hole, light hole and spin–orbit split-off bands. The spin–orbit split-off band is not

Download English Version:

https://daneshyari.com/en/article/6534303

Download Persian Version:

https://daneshyari.com/article/6534303

Daneshyari.com