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Bias-induced instability in an intrinsic hydrogenated amorphous silicon layer for thin-film solar cells

Youngseok Lee[a], Cheolmin Park[a], Jinjoo Park[b], Donghyun Oh[b], Youn-Jung Lee[b], Junsin Yi[b,*]

[a] Department of Energy Science, SungKyunKwan University, Suwon 440-746, South Korea
[b] College of Information and Communication Engineering, SungKyunKwan University, Suwon 440-746, South Korea

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ABSTRACT

In this article we present a mechanism for creating metastable defects in intrinsic hydrogenated amorphous silicon (a-Si:H) layers by changing the flow-rate ratio of SiH_4 and H_2. This is an important cardinal property that restricts the performance of both solar cells and thin-film transistors (TFT). Light or electrical bias results in generation of metastable dangling bonds. We evaluated the gas flow-rate ratio dependence of current decrease before and after application of electrical bias stress. Furthermore, we produced an a-Si:H TFT for comparison with a single-layer a-Si:H. Intrinsic layers deposited by SiH_4 to H_2 flow-rate ratios of 1:3 exhibited greater resistance to stress. In a-Si:H single layer experiment, we got a similar result, samples with SiH_4 and H_2 flow-rate ratios of 1:3 exhibited less decrease in current after application of electrical bias stress. These results will facilitate fabrication of more-stable a- Si:H thin film p-i-n solar cells.

1. Introduction

Hydrogenated amorphous silicon (s-Si:H) is widely used in thin-film transistors (TFTs) and solar cells. Metastable defects cause degradation of amorphous silicon thin-film applications. Metastable dangling bond defects are formed in an a-Si:H, whenever it is illuminated [1], and charge carriers accumulate [2] or temperature increases [3]. Creation of defects by illumination, known as the Staebler-Wronski effect [1], is a major cause of efficiency limitation in amorphous silicon solar cells. Metastable defects in a-Si:H solar cells can also be generated when the cells are subjected to prolonged forward bias without illumination [4]. With regard to TFTs, electrons are injected into the channel region and break weak Si-Si bonds increasing the density of the dangling bonds in a-Si:H layers, which leads to a threshold voltage shift [5,6].

The instability of a-Si:H layers prevents their use in devices. The generation of metastable defects by illumination [7,8] and temperature changes [9,10] has been investigated extensively. The generation of metastable defects by electrical bias is, however, insufficiently understood. In this paper, we investigate defect creation by electrical bias in intrinsic a-Si:H layers deposited using SiH_4 and H_2 gases with flow-rate ratios of 1:0, 1:1, 1:3 and 1:5.

2. Experimental

a-Si:H films were deposited on Eagle 2000 glasses by VHF (60 MHz) PECVD. The H_2/SiH_4 gas flow-rate ratio was varied from 0 to 5, and the other deposition conditions were kept constant—power at 30 W, temperature at 200 °C and working pressure at 200 mTorr. The film thickness was 200 nm. The a-Si:H films were prepared as finger joint shape of photoconductor as seen in Fig. 1. The a-Si:H photoconductors were annealed at 180 °C for 1 h to ensure identical initial conditions. We measured the spectral response of a-Si:H photoconductors before and after 15 V bias stress at room temperature up to 3600 s.

A series of amorphous silicon TFTs with an inverted-staggered structure was prepared. An amorphous silicon film was deposited to a thickness of 100 nm with various H_2:SiH_4 gas ratios. The gate insulator was 200 nm thick silicon nitride (SiN_x). We measured the bias dependence of the threshold voltage shift as follows. First, the samples were annealed to 180 °C for 1 h to ensure identical initial conditions and to ensure negligible charge injection into the SiNx. Electrical properties were measured using a programmable

* Corresponding author at: 2066, Seobu Ro, Jangan Gu, Suwon Si, Gyeong Gi Do 16419, South Korea.
E-mail address: junsin@skku.edu (J. Yi).

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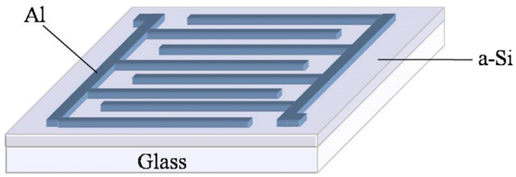

Fig. 1. Schematic of a finger-joint-shape photoconductor.

Keithley 617 electrometer. Bias stress of 15 V was applied to gate (V_G) of the transistor for 3600 s at room temperature (Table 1).

Table 1
Deposition conditions of intrinsic amorphous silicon layers.

Gas Flow			Temp (°C)	Power (W)	Depo. Time	Pressure (mTorr)
SiH4 (sccm)	H2 (sccm)	Ratio				
30	0	1:0	200	30	4 m 30s	200
30	30	1:1			5 m	
30	90	1:3			6 m 30s	
30	150	1:5			8 m 20s	

3. Results and discussion

Typical threshold voltage shifts (ΔV_T) are shown in Fig. 2. The ΔV_T differed according to the SiH_4:H_2 gas ratio.

The ΔV_T in a-Si:H TFTs are due to the charge trapping in SiN_x, mainly through tunneling and the creation of metastable defects in the a-Si:H channel layer near the gate insulator [11–13]. Charge trapping in the gate insulator becomes larger at higher gate biases, while metastable defects are generated at gate biases of 15–20 V [14,15]. Generation of defects in a-Si:H TFTs due to prolonged bias has been reported to be similar to that induced by illumination [7]. In our experiments, ΔV_T differed according to film deposition gas flow rate. The a-Si:H TFT deposited with gas flow-rate ratio of SiH_4 and H_2 of 1:3 exhibited the smallest shift in threshold voltage of 4.45 V (Fig. 2(c)). Since the gate bias of 15 V was applied to each transistor equally, the change in ΔV_T directly denotes the amount of thin film defects generated. In other words, the a-Si:H layer deposited by a SiH_4: H_2 ratio of 1:3 has considerable bias stress durability. In contrast, the a-Si:H TFT deposited by gas flow-rate ratio of SiH_4 and H_2 of 1: 0 exhibited a 5.27 V shift in threshold voltage (Fig. 2(a)) which was the largest. This result indicates that hydrogen likely plays a role in stabilizing the defects, as is generally considered.

Fig. 3 shows ΔV_T versus bias stress time for TFTs at room temperature. During the entire stress time, a-Si:H TFT with gas ratio of 1:3 showed a small ΔV_T value. In contrast, the a-Si:H TFT with gas ratio of 1:0 exhibited a large ΔV_T value during the whole stress time.

The a-Si:H photoconductors produced using four different gas ratio deposition conditions were subjected to 15 V bias stress for 1 h (3,600 s) at room temperature. The spectral response of the a-Si:H photoconductors was measured (Fig. 4). By comparing the photo-currents, we determined which layer shows the least degradation in the presence of bias stress.

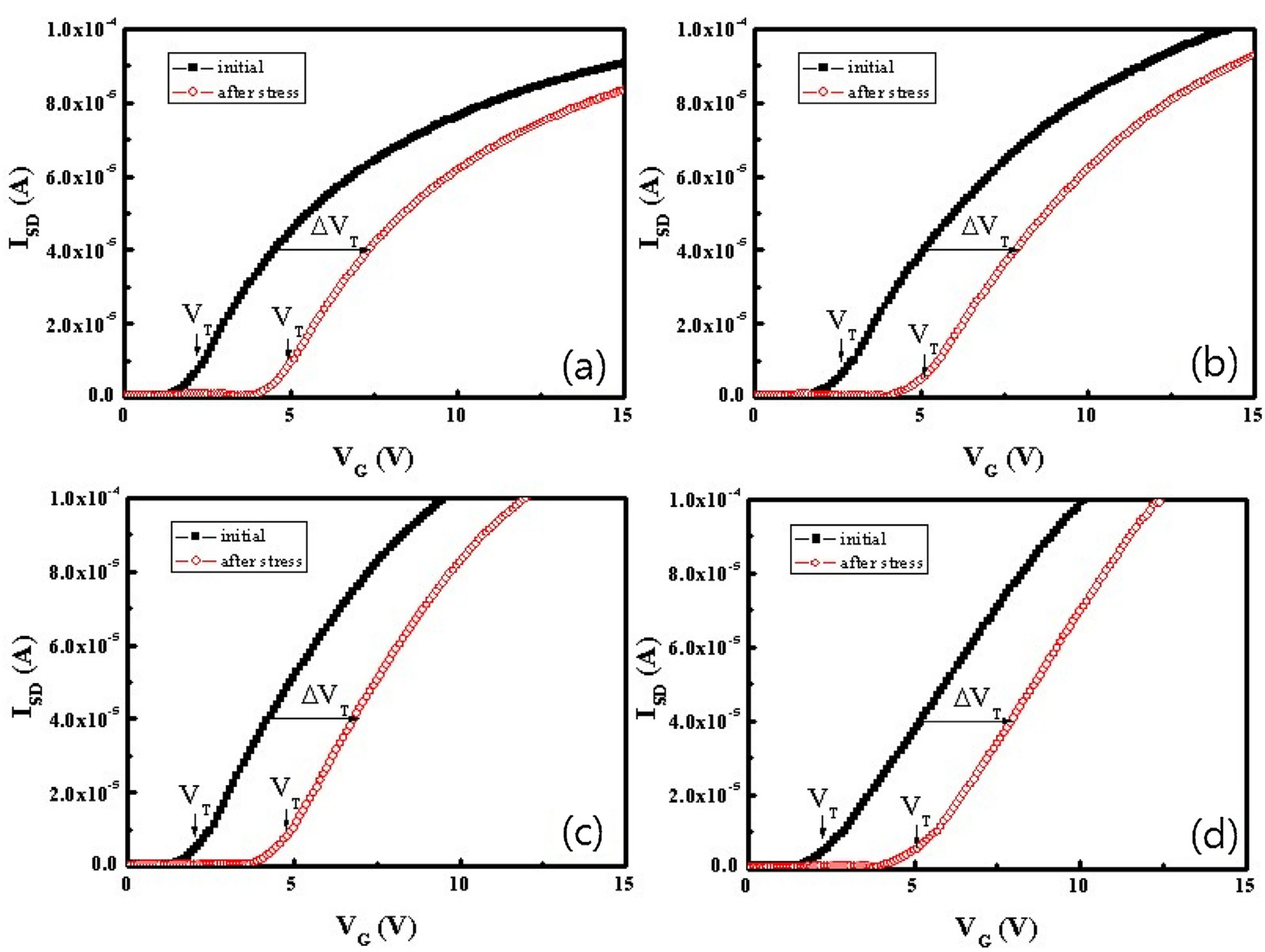

Fig. 2. Threshold voltage shifts due to 15 V gate bias as a function of SiH_4: H_2 gas ratio. (a) SiH_4: H_2 = 1: 0, (b) SiH_4: H_2 = 1: 1, (c) SiH_4: H_2 = 1: 3, and (d) SiH_4: H_2 = 1: 5.

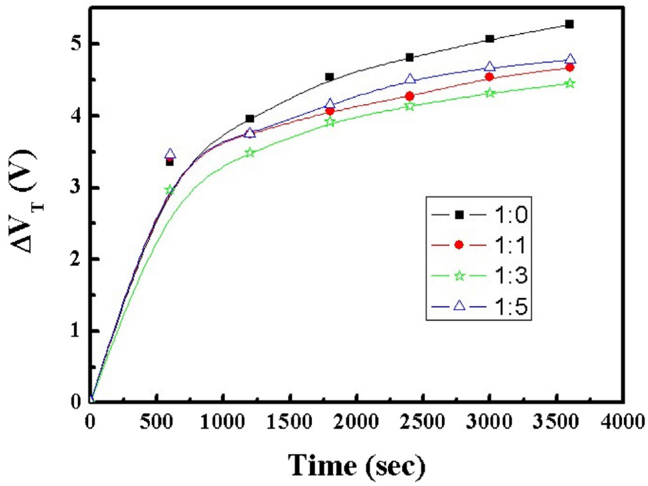

Fig. 3. Threshold voltage shift versus bias stress time for TFTs with four different intrinsic a-Si:H layers every 600 s.

Fig. 4(a) shows the spectral response of the a-Si:H layer deposited with SiH_4: H_2 = 1: 0. The photo-current of this photoconductor decreased over the whole wavelength range after the stress. Furthermore, the current in this layer was too low for use as an absorption layer in thin-film solar cells. The others exhibited good resistance to bias stress (Fig. 4(b), (c), (d)). The layer deposited by SiH_4: H_2 = 1: 3 showed the highest current, suggesting it to have the greatest photosensitivity.

We used spectroscopic ellipsometry (SE) to determine the absorption coefficients of a-Si:H layers. The absorption coefficient (α) was calculated from the extinction coefficient measured by SE using the following equation:

$$\alpha(E) = \frac{4\pi k(E)}{\lambda} \quad (1)$$

The sub-gap optical absorption coefficient is strongly associated with defect density [16]. Therefore, the sub-gap absorption coefficient may increase after application of bias stress which would increase the density of defects. Fig. 5 shows the increase in sub-gap absorption with bias stress. The absorption coefficient of the layer deposited with SiH_4: H_2 = 1: 0 was considerably higher after application of bias stress compared to the initial state. In contrast, the layer deposited with SiH_4: H_2 = 1: 3 shows little difference in absorption coefficient before and after application of bias stress. The change in absorption coefficients of a-Si:H photoconductors was similar to the change in ΔV_T of TFT devices. The least defects were generated in the film with gas ratio of 1:3 after the bias stress and the most defects were generated for the case of gas ratio of 1:0.

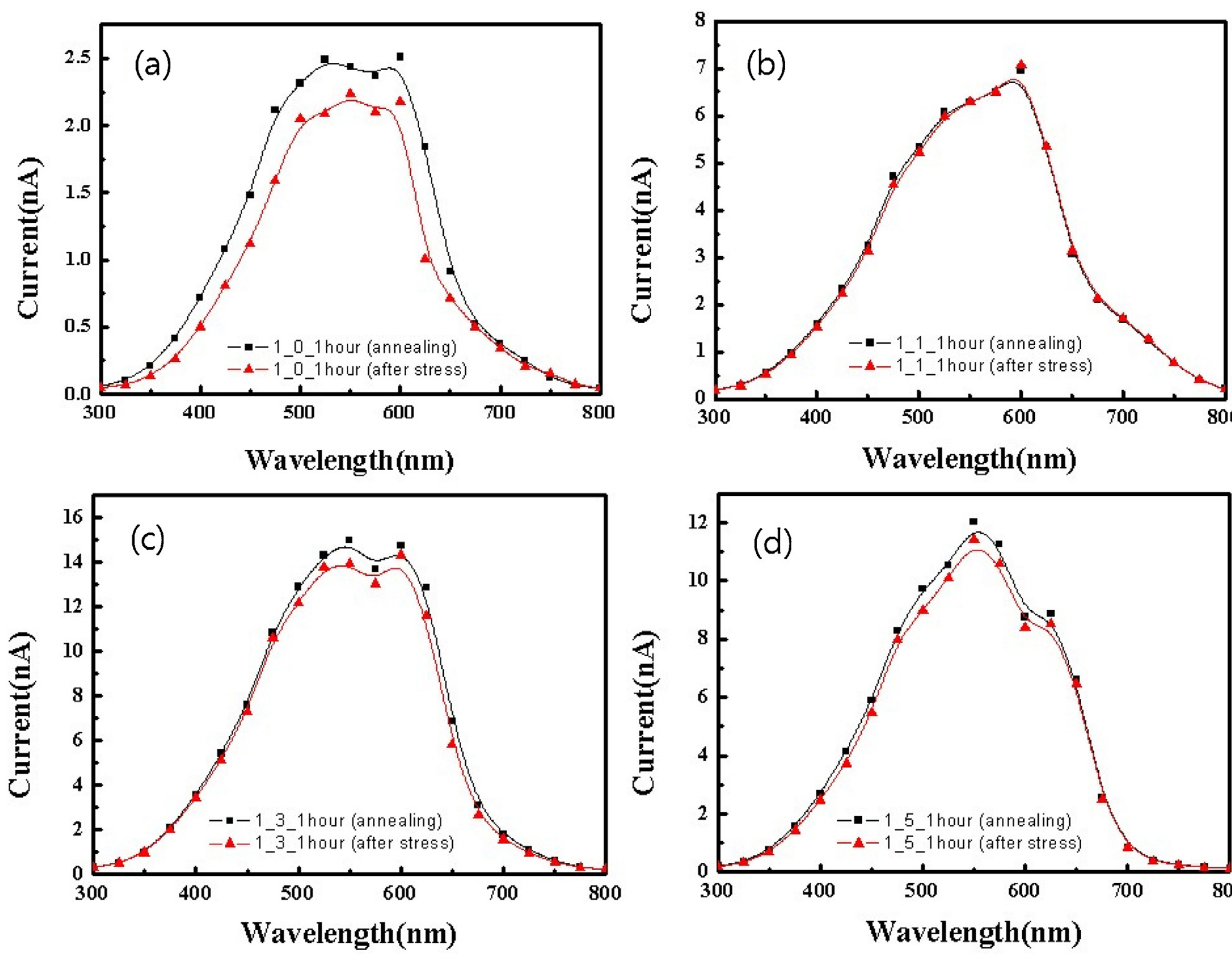

Fig. 4. Spectra response of a-Si:H photoconductors under various gas flow rate deposition conditions, before bias stress (squares) and after bias stress (triangle). (a) SiH_4: H_2 = 1: 0, (b) SiH_4: H_2 = 1: 1, (c) SiH_4: H_2 = 1: 3, and (d) SiH_4: H_2 = 1: 5.

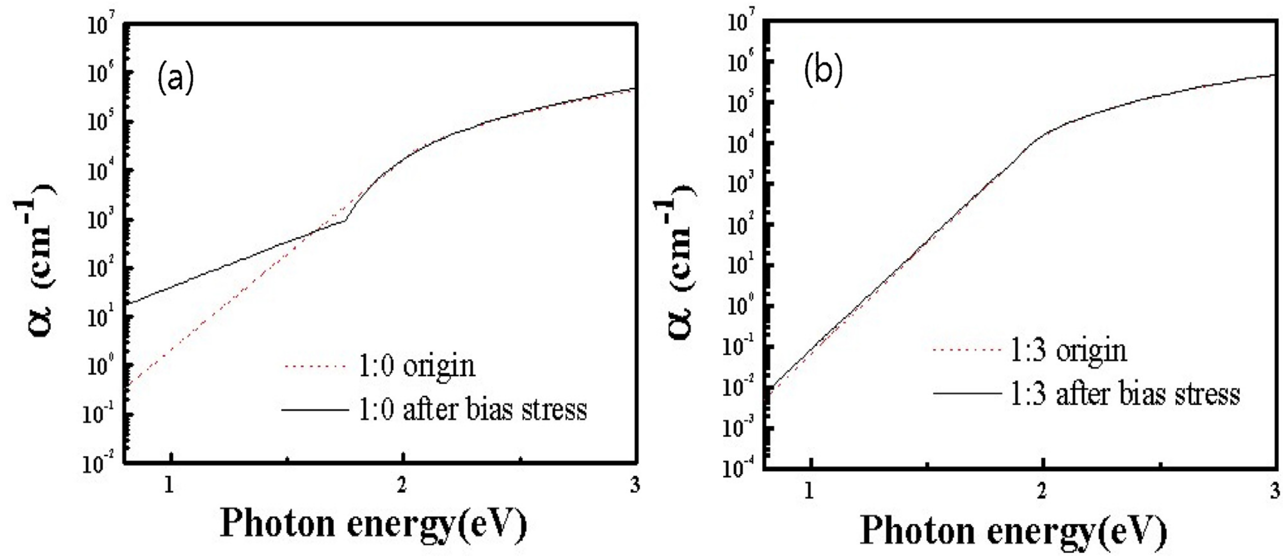

Fig. 5. Subgap optical absorption coefficient (α) of an a-Si:H layer with various SiH_4: H_2 ratios measured by spectroscopic ellipsometry. Dotted line is the initial state and solid line is the after bias-stress state. (a) SiH_4: H_2 = 1: 0, (b) SiH_4: H_2 = 1: 3.

4. Conclusion

In this study, we investigated the electrical bias instabilities of a-Si:H films using TFT and photoconductor structures. Although we did not calculate the hydrogen contents in a-Si:H films or the hydrogen-bonding configuration, our findings indicated that hydrogen likely plays a role in stabilizing defects. If the light degradation and the generation of defects after bias stress follow the same mechanism, degradation experiments could be carried out using bias stress instead of light degradation experiments which take very long time. Our results suggest that the electrical stability in a-Si:H films is adequate for production of more-stable a-Si:H thin film solar cells and for other applications.

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