Effect of hole accumulation on photodegradation in a-Si:H

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Abstract

An effect of hole accumulation during band gap illumination on degradation is examined in hydrogenated amorphous silicon (rf glow-discharge). It is found that accumulation of holes is more efficient than that of electrons in causing photodegradation, similar to the carrier-induced metastability. We suggest that the self-trapping of holes (STH), which weakens covalent bonds, could affect degradation and the number of STH could increase under hole accumulation.

1. Introduction

Although a number of studies have been made to understand the origin of light-induced metastable defects (LIMDs), how LIMDs are created is still not understood. It is known, by phototerradiation, that holes in the p-type layers induce defects faster than the creation of defects by electrons in the n-type layers in nipi-multilayer structure [1]. Similarly, accumulation of holes is more efficient than that of electrons in causing carrier-induced metastability in hydrogenated amorphous silicon (a-Si:H) [2]. Based on these results we suggest that holes have a major effect on photodegradation in undoped a-Si:H too. It is of interest to examine the effects of holes on photodegradation. Holes can be accumulated near an illuminated surface when a d.c. voltage is applied during illumination. Through examinations of the biasing effects, the effects of holes on photodegradation will be analyzed.

2. Experimental

Undoped a-Si:H films (1 μm) were deposited on indium-tin-oxide (ITO) coated glasses (substrate temperature $T_s = 220^\circ C$) by capacitively coupled rf glow-discharge (13.56 MHz) decomposition of silane diluted by He (10 vol.% of SiH$_4$). Then Al was evaporated as a top electrode (sandwich structure). A high-pressure mercury lamp with an infrared (IR) water filter or Ar-laser was used and the illumination was made on the ITO side to induce photodegradation. During illumination a dc electric field was applied between ITO and Al electrodes. The current as a function of voltage, $I(V)$, was measured.

3. Results

Fig. 1 shows $I(V)$ in dark conditions measured at room temperature. The forward currents are observed when ITO is positively biased and the reverse current is 1/200 times the forward current under the applied voltage (4 V). The $I(V)$ curve is not described by a simple exponential relation, since the resistance of the interior can be larger...
than that of the Schottky barriers which can be formed in both the top (Al) and bottom (ITO) electrodes. Note, from the $I(V)$ curves, that the ‘barrier’ of ITO is expected to be the largest and for this case the band diagram is shown in Fig. 2.

The $I(V)$ curves, for (a) before light soaking, (b) after light soaking (6 h) with applying bias voltage (+2 V) to ITO, and (c) after light soaking (6 h) with applying bias voltage (−2 V) to ITO, are shown in Fig. 3. Each $I(V)$ curve was measured after illumination under biasing (+) to ITO (forward condition) in dark. Note that the illumination was made by a mercury lamp (60 mW/cm$^2$). The curves (b) and (c) almost return to the original annealed state of (a). Similar results produced by Ar-laser illumination (70 mW/cm$^2$) are also shown in Fig. 4. All notations, (a)–(c) are the same as those for irradiation with mercury lamp (Fig. 3). Note that the dashed line in Fig. 4 indicates the $I(V)$ curve after no biasing voltage, which is rather close to curve (b).

Fig. 5 shows the time-dependent changes in the resistance ($V/I$) deduced at the forward applied voltage of 4 V (after the Ar-laser irradiation). The curves, (a) and (b), are those for applying (+) bias voltage to ITO (electron accumulation) and (−) bias voltage to ITO (hole accumulation). The change in resistance for (b) does not saturate in this time range, while that for (a) seems to saturate.

4. Discussion

To confirm the type of effect induced by illumination under dc biasing voltage, the differential
resistances, $R_d$, defined as $dV/dI$, are estimated from the $I(V)$ curves for the irradiation with the Ar-laser in Fig. 4, for example. These are plotted in Fig. 6. $R_d$ should be the sum of the junction resistance and the series resistance. It decreased with increasing forward bias voltage and then became a constant (series resistance). Each curve, (a)–(c), correspond to those indicated in Fig. 4. $R_d$ increased after illumination as shown by curves (b) and (c). Based on the increase of series resistance, we suggest the occurrence of photodegradation, since the dark conductivity is known to be decreased after photoradiation in a-Si:H (the Staebler–Wronski effect) [3]. Note that $R_d$ for (c) is much larger than that for (b). This difference indicates that hole accumulation (practically not accumulation but the number of holes is much greater than electrons) accelerates photodegradation, since more holes than electrons can be collected near the ITO interface during illumination under the biasing condition of (c) (see Fig. 2). Remember that electron accumulation has no effect, since the $I(V)$ curve for no biasing is close to curve (b) as mentioned in the previous section (see Fig. 4).

Next, we discuss why ‘holes’ are the largest effect in photodegradation in a-Si:H. The idea of breaking of weaker Si–Si bonds induced by non-radiative recombination (NRR) of band-tail electrons and holes has been proposed [4,5]. In this model electrons and holes should affect LIMD creation, since the NRR of electron and hole is used for bond breaking, suggest that a hole could not have any particular affect on bond scission. Morigaki [5], however, has suggested that the self-trapping of holes (STH) creates more weaker Si–Si bonds and hence the NRR process occurring at this site (STH) produces bond breaking. We expect the STH to be important.

If the number of holes becomes greater than that of electrons in the illuminated region, the rate for non-geminate recombination (either radiative or non-radiative) between electrons and holes increases, and the STH is induced more easily. A question arises: STH creation should occur at relatively lower temperatures and hence more LIMDs should be observed at lower temperatures, which is not consistent with experimental results [5]. Note, however, that the STH creation is only a triggering process for LIMD creation and some other factors, e.g. bond switching, are also important and the details have been discussed in Ref. [5]. This, we expect hole accumulation during illumination to accelerate LIMD creation.

There is also an alternative model for LIMD creation. A self-trapped exciton (STE) may have an effect in which a greater carrier–lattice interaction is required. The STE model seems to successfully explain the LIMD creation for amorphous SiO$_2$ and chalcogenides [6,7]. A STE can be produced when an electron is bounded by a STH. When the number of STH increases the number of STE could also increase, which may produce more LIMD. The same discussion as for the NRR process can be possible even for the STE model. It is still not known if STEs exist in a-Si:H,
5. Conclusions

The extent of photodegradation depends on polarity of biasing voltage during illumination. Hole accumulation was found to accelerate photodegradation, similar to the carrier-induced metastability. We suggested that the STH which causes weakening covalent bonds could affect degradation and the number of such holes could increase under hole accumulation.

Acknowledgements

We thank K. Morigaki, T. Aoki, A.Ganjoo, and N. Yosida for useful discussions.

References