Research Letter

The Charge Transport Properties of a HWCVD a-Si:H Thin Film under Bending Pressure

M. Boshta,¹ V. Morchshakov,² K. Bärner,² and R. Braunstein³

¹ Solid State Physics Department, National Research Center (NRC), Dokki, 12332 Cairo, Egypt

² IV. Physics Institute, University of Göttingen, Friedrich-Hund Platz 1, 37077 Göttingen, Germany

³ Department of Physics and Astronomy, University of California, Los Angeles, CA 90024, USA

Correspondence should be addressed to M. Boshta, boshta2000@yahoo.com

Received 15 August 2007; Accepted 21 January 2008

Recommended by Jeffrey T. Glass

The transient thermoelectric effects (TTEs) method is used to measure the ambipolar space charge built up in a low-pressure hot wire chemical vapor deposition (HWCVDs) technique a-Si:H layer deposited on a glass substrate. The stage 2 TTE-transients yield the trap state density difference with and without bending pressure up to 9 bars. The a-Si:H sample shows a reduction of the negative storage peaks at 0.045 eV and 0.026 eV with increasing pressure, while the positive (hole trap) peak and the zero crossing practically do not change with the pressure. At the maximum bending pressure, the negative peaks are almost zero and shifted into the band gap or toward the conduction band. Our result shows that it is necessary to produce and mount hydrogenated thin film solar cell stress-free.

Copyright © 2008 M. Boshta et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

1. INTRODUCTION

Amorphous (a-Si:H) and microcrystalline silicon (μ c-Si:H) thin films are already widely used in microelectronics and solar cell technology. Their application in thin film solar cells promises considerable cost reduction as a result of low material consumption and low-temperature process as well as the possibility of a monolithic series connection of cells [1, 2]. The low consumption of the raw material and the low-temperature process during the production result also in low energy consumption during the production of the thin film solar cells. Among the materials used for thin film solar cells, amorphous silicon is the most important material in the commercial production [1]. Microcrystalline silicon combines the advantages of the a-Si:H technology and the extended absorption of crystalline silicon at long wavelengths. Thin film tandem cell structures comprising amorphous a-Si:H and microcrystalline silicon absorber layers promise conversion efficiencies as high as those achieved with a-Si:H technology alone. In the case of silicon thin film technology, the reduction of interfacial and mechanical strains in the substrate, due to mounting of the solar panels, has become an important research topic.

This work deals with the controlled variation of the mechanical strains in the substrate/thin film structure. Assuming a strong cohesion between thin film and substrate, we can create expansion or compression via concave or convex bending of the substrate. Only few such experiments have been reported [3, 4], and even these results are somewhat inconclusive. Nevertheless, the current accepted knowledge is that uniaxial strains mainly change the bond angles, while bending pressure mainly affects the bond distances. The bond distance changes in turn are supposed to strongly influence the activation and mobility of the H-atoms. They are expected to partially reposition under bending pressure. Another, but completely irreversible, effect is the collapse of microvoids under pressure [4]. As such internal surfaces are considered to be defect sources, this way the defect density can be reduced too. In this work, we combine the TTE-flash method with the application of bending pressure.

2. EXPERIMENTAL

The sample is manufactured using a low-pressure hot wire chemical vapor deposition technique (HWCVD) [5–7]. Here, silane (SiH_4) decomposes at the hot surface of a

meandering tungsten wire whereupon the Si deposits on a nearby substrate [8, 9]. The sample THD84 was prepared on a glass (1737Corning) substrate at a substrate temperature of 535 K. The sample thickness is $2.16 \mu\text{m}$, and the hydrogen content is between 12 and 14 at. %.

The time-resolved thermoelectric power (TTE) has been proposed as a transient method for determining carrier lifetime, carrier diffusivity, carrier mobility, and trap levels in crystalline and amorphous semiconductors, but it also allows to determine the Seebeck voltage $S(T)$ and the heat diffusivity $D(T)$.

A light pulse which is limited in space and time falls on the one end of a rectangular sample. Voltages appear at the end faces and decay with time. These voltage transients sometimes overlap and are empirically described using a superposition of exponentials,

$$V(t) = V_\infty + \sum a_i \exp\left(\frac{-t}{\tau_i}\right). \quad (1)$$

Here, $a_i = V(0)_i - V(\infty)_i$ is the relaxation amplitude of i th relaxation process or the i th carrier type in case of a multi-carrier system.

Specifically, the observed TTE decay curves consist of three stages, each with a characteristic relaxation time τ_i .

- (1) Stage 1 (photodiffusion decay Dember effect): it is related to the recombination of electron hole pairs generated by the light and diffusing into the dark zone of the sample.
- (2) Stage 2 (transient Seebeck effect): it is due to the diffusion of thermally generated carriers in pair, that is, electron-hole pair from higher- to lower-temperature regions of the material. In doped or defect containing semiconductors, Stages 1 and 2 can build up an ambipolar space charge.
- (3) Stage 3 (quasistatic Seebeck effect): it is due to the phonon diffusion from the hot point (illuminated section) to the cold point of the material.

Figure 1 shows the design of the bending pressure arrangement that has been used in this experiment. It basically consists of two fixed points (edges of the sample) and a mechanical force which is applied at the center of the sample. The a-Si:H film and the glass substrate have thicknesses of h_f and h_s and Young's moduli of Y_f and Y_s , respectively. When an external force is applied, it causes the substrate to bend elastically. The bending curvature depends on the thickness and Young's modulus of the substrate. We assume that the substrate is elastically isotropic in the plane. Under a specific tensile or compressional force, a film-substrate couple bends with a constant curvature R . The bending momentum elongates the substrate in the upper section of the film-substrate couple and compresses the substrate in the lower section. This bending produces a torque or bending moment, M_f , about the y axis which passes through the center of the substrate for convenience. Thus,

$$M_f = F_f z = \sigma_f h_f \left(\frac{h_s}{2}\right). \quad (2)$$

FIGURE 1: The bending pressure set-up.

This moment must be balanced by the moment generated by the substrate bending force. Regardless of the prevailing stress distribution, maintenance of mechanical equilibrium requires that the net force (F) and the bending moment be eliminated in the film-substrate couple. Thus, the condition that required for analysis is

$$M_s + M_f = 0. \quad (3)$$

From these requirements, the stress (σ_f) of the film is expressed as

$$\sigma_f = \left[\frac{Y}{1 - \nu} \right] \frac{R h_s^2}{6 h_f}, \quad (4)$$

where $R(m^{-1})$ is the curvature, being positive on a convex film face and negative on a concave one. ν is Poisson's ratio, which for most materials lies around $\nu = 0.3 \pm 0.1$.

The curvature R can be measured by the change in the angle of a reflected laser beam as it is scanned across the substrate. In this case, the beam is acting as an optical lever. Alternatively, optical interference fringes against a reference flat can be measured, in which case also any variation in R over the substrate is readily detected [10].

3. RESULTS

The transient thermoelectric voltages have been recorded at pressures between 0 and 9 bar for the HWCVD a-Si:H sample on glass substrate. The correction of the rough transient voltage data were done according to the procedure described in [11]. We observe some structures in the stage 2 transient voltage versus temperature curve $V_{20}(T)$, that is, the TTE-voltage curve versus temperature does not have an exponential trend but changes at certain temperature values. This implies that there is a significant structure of the trap density of states at these temperature values when one moves deeper into the optical gap, starting from the conduction (or valence) band edge. Since this is not observed in nonhydrogenated a-Si thin films [11], it suggests that the high H-content is responsible for most of the trap state density in some way.

Simultaneously, we measure the relaxation time τ_{20} of the a-Si:H sample. There is a significant structure also in the relaxation time. However, usually we calculate the trap state density difference from the derivative of the corrected voltage with respect to the temperature and not from the correlated relaxation time [11]. It has been shown in [12] that the derivative of the corrected transient voltage is approximately proportional to the difference trap density of states,

FIGURE 2: Temperature derivative dV_{02}/dT versus energy ($\epsilon = 2kT$) and T (upper scale) showing the difference density of trap states as they evolve into the gap under various bending pressures.

FIGURE 3: The slope of the negative peak of difference trap state density of a-Si:H sample versus bending pressure.

($N_{T-} - N_{T+}$), that is, the proportionality constant, g , is a weakly temperature dependent function,

$$dV_{02}/dT = g(N_{T-} - N_{T+}). \quad (5)$$

According to (5), the space charges originating from the hole and electron traps can compensate each other. This behavior is found very often with intrinsic or compensated material [7].

Figure 2 shows the trap state density of a-Si:H sample under different bending pressures as a function of energy.

4. DISCUSSION

With increasing pressure, the sharp negative (doping) peaks (at 45 meV and 26 meV) are reduced while the positive (hole trap) peak and the zero crossing practically do not change position. However, both negative peaks shift inside the energy gap toward the valence band. At the maximum bending pressure (9 bars), the negative peaks have almost disappeared.

The slope of the negative peak decreases with the increase of the bending pressure as shown in Figure 3. This means that the peak width and position change with increasing bending pressure. In contrast, the positive peak intensity and shape show virtually no change with the bending pressure. The strong shift in the negative defect density of state peaks suggests a pressure-induced repositioning of the H-atom related trap states, by shifting them either toward the middle of the band gap or very close to the conduction band edge. In both positions, the electron trap levels contribute less to the negative space charge build up and decay. We propose that the high photoconductivity found in this sample (THD 84) has to do with that negative “doping” peak. Obviously, it is just positioned right in energy for an intermediate storage of the photogenerated excess electrons, which would enhance the overall lifetime. As the application of pressure is expected to shift these energetic positions out of their optimum, this concept would also explain the high-pressure sensitivity of that peak. It also tells us that mechanical stresses are to be avoided if the carrier lifetime in thin films is optimized through critically positioned trap states. The data are obtained from a-Si:H sample. However, the results could be applied also to poly-Si:H thin films, since the transport properties of poly-Si:H thin films are mainly governed by their interface amorphous phases—which are usually left to optimize the light absorption.

ACKNOWLEDGMENTS

The authors thank the Deutsche Forschungsgemeinschaft (DFG 445 AGY-112/1/05) and the NATO Science Commission (NATO Linkage Grant CBP.MD.CLG 981238) for supporting this work. Also, the authors would like to thank Professor Brent P. Nelson’s group, at the National Renewable Energy Laboratory, Golden, USA, for providing the samples.

REFERENCES

- [1] W. Hoffmann, in *Pv solar electricity: one among the new millennium industries in Proceedings of the 17th European Photovoltaic Solar Energy Conference (EPVSEC '01)*, B. McNellis, W. Palz, 4A. Ossenbrink, and P. Helm, Eds., p. 851, WIP, Munich, Germany, October 2001.
- [2] B. Rech and H. Wagner, “Potential of amorphous silicon for solar cells,” *Applied Physics A*, vol. 69, no. 2, pp. 155–167, 1999.
- [3] S. Minomura, “Pressure effects on the local atomic structure,” in *Semiconductor and Semimetals*, J. I. Pankove, Ed., vol. 21A, p. 273, Academic Press, New York, NY, USA, 1984.
- [4] Y. Okayasu, K. Asai, H. Yamamoto, K. Fukui, and S. Minomura, “Light-induced change of a-Si:H under hydrostatic pressure,” in *AIP Conference, Proceedings of the International Conference on Stability of Amorphous Silicon Alloy Materials and Devices*, vol. 157, p. 271, Palo Alto, Calif, USA, January 1987.
- [5] J. Doyle, R. Robertson, G. H. Lin, M. Z. He, and A. Gallagher, “Production of high-quality amorphous silicon films by evaporative silane surface decomposition,” *Journal of Applied Physics*, vol. 64, no. 6, pp. 3215–3223, 1988.

- [6] H. Wiesmann, A. K. Ghosh, T. McMahon, and M. Strongin, "a-Si: H produced by high-temperature thermal decomposition of silane," *Journal of Applied Physics*, vol. 50, no. 5, pp. 3752–3754, 1979.
- [7] J. Liebe, K. Heinmann, K. Bärner, et al., "Transient ambipolar charge distributions in amorphous and crystalline semiconductors," *Materials Science and Engineering B*, vol. 47, no. 3, pp. 244–251, 1997.
- [8] A. R. Middya, J. Guillert, R. Brenot, J. Perrin, J. E. Bouree, and C. Longeaud, "Electronic properties and device applications of hot-wire CVD polycrystalline silicon films," in *Proceedings of Amorphous Silicon Technology Symposium*, S. Wagner, M. Hack, E. A. Schiff, and R. Schropp, Eds., vol. 467, p. 271, MRS, Pittsburgh, Pa, USA, March-April 1997.
- [9] R. A. Street, R. L. Weisfield, R. B. Apte, et al., "Amorphous silicon sensor arrays for X-ray and document imaging," *Thin Solid Films*, vol. 296, no. 1-2, pp. 172–176, 1997.
- [10] D. L. Smith, *Thin-Film Deposition: Principles and Practice*, chapter 5, McGraw-Hill, New York, NY, USA, 1995.
- [11] W. Hahn, M. Boshta, K. Bärner, and R. Braunstein, "The charge transport properties of a-Si:H thin films under hydrostatic pressure," *Materials Science and Engineering B*, vol. 130, no. 1–3, pp. 184–188, 2006.
- [12] J. Liebe, A. Kattwinkel, K. Bärner, G. Sun, S. Dong, and R. Braunstein, "Determination of the gap state density differences in hydrogenated amorphous silicon and Si/Ge," *Materials Science and Engineering A*, vol. 282, no. 1-2, pp. 158–163, 2000.