Lawrence Berkeley National Laboratory
Recent Work

Title
Improved Electrical and Transport Characteristics of Amorphous Silicon Enriching with Microcrystalline Silicon

Permalink
https://escholarship.org/uc/item/6sh3p8n4

Authors
Mireshghi, A.
Hong, W.S.
Drewery, J.
et al.

Publication Date
1994-04-01

eScholarship.org Powered by the California Digital Library
University of California

LBL-35435
UC-414

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

Physics Division

Presented at the Spring Meeting of Material Research Society, San Francisco, CA, April 4-8, 1994, and to be published in the Proceedings

Improved Electrical and Transport Characteristics of Amorphous Silicon by Enriching with Microcrystalline Silicon

A. Mireshghi, W.S. Hong, J. Drewery, T. Jing, S.N. Kaplan, H.K. Lee, and V. Perez-Mendez

April 1994

LOAN COPY | Circulates | for 4 weeks | Bldg. 50 Library.
Copy 2
LBL-35435

Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

LBL-35435

IMPROVED ELECTRICAL AND TRANSPORT CHARACTERISTICS OF AMORPHOUS SILICON BY ENRICHING WITH MICROCRYSTALLINE SILICON

A. Mireshghi, W.S. Hong, J. Drewery, T. Jing, S.N. Kaplan, H.K. Lee, and V. Perez-Mendez

Physics Division
Lawrence Berkeley Laboratory*
University of California
Berkeley, CA 94720

APRIL 1994

----

*This work was supported by the Director, Office of Energy Research, Office of High Energy Nuclear Physics, High Energy Physics Division of U.S. Department of Energy under Contract Number DE-AC03-76SF00098

Presented at Spring Meeting of Material Research Society, April 1994, San Francisco, CA

IMPROVED ELECTRICAL AND TRANSPORT CHARACTERISTICS OF AMORPHOUS SILICON BY ENRICHING WITH MICROCRYSTALLINE SILICON

A. Mireshghi, W.S. Hong, J. Drewery, T. Jing, S.N. Kaplan, H.K. Lee, and V. Perez-Mendez,
Lawrence Berkeley Laboratory, University of California, Berkeley, CA 94720

ABSTRACT

We have deposited n-i-p diodes with microcrystalline intrinsic layers for radiation detection applications. The diodes show interesting electrical characteristics which have not been reported before. From TOF measurement for our best samples we obtained μ_e values which are about 3 times larger than our standard a-Si:H. for $\mu\tau$ values approximately a factor of 2 improvement was observed. The N_D^* values derived from hole-onset measurements show lower ionized dangling bond density than normal a-Si:H material. We have proposed a simple model which can very well explain the experimental results.

INTRODUCTION

Since its first preparation through chemical transport technique by Veprek *et al.* in 1968 [1], microcrystalline silicon (μc-Si) has been the subject of extensive research. Due to its low optical absorption and high electrical conductivity compared to hydrogenated amorphous silicon (a-Si:H), p-doped μc-Si has been considered as window layers of solar cells [2-4]. Among different deposition techniques, the plasma CVD of H_2 diluted SiH_4 has been used more often. By PECVD it is possible to deposit microcrystalline material embedded in a-Si:H material with various degrees of crystallinity. A variety of deposition conditions have been studied by different groups for their effects on deposition rate, volume fraction of crystallinity, and crystalline grain size [5]. Although there are many reports on electronic properties of doped μc-Si films, they deal mostly with dark and photo conductivity and bandgap measurement [6-8]. On electronic transport properties such as carrier mobility and lifetime, especially for undoped μc-Si layers, direct measurement results are not available.

We are considering PECVD deposited μc-Si -a-Si:H material (hereafter , just μc-Si:H) for radiation detection applications. Our group, as well as others, have successfully used a-Si:H in the form of nip diode structures to detect charged particles, X-rays, gamma rays, and neutrons [9-10]. For these applications an important characteristic is the mobility lifetime product ($\mu\tau$) value, which determines the mean free path of charge carriers ($d= \mu\tau E$) within the intrinsic layer, that in turn controls the charge collection efficiency of the detector. In this paper we will present the measurement results on both material and electronic properties of our PECVD deposited μc-Si:H samples.

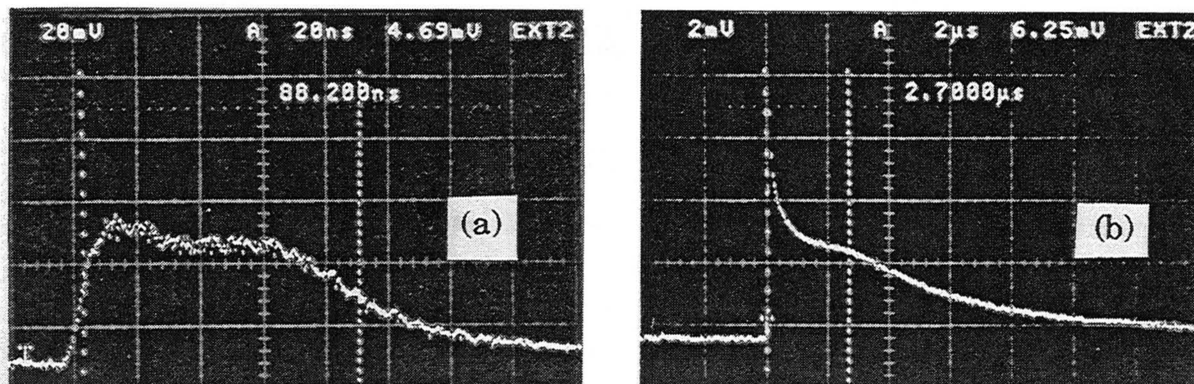


Fig. 1 Typical transient photocurrent signals from the TOF measurement of: (a) electrons; (b) holes

EXPERIMENTAL

The samples we have measured were 5-8 µm thick nip diodes, deposited in our plasma enhanced CVD machine at an RF frequency of 85 MHz. For substrates we used Corning 7095 glass, and the top and bottom contacts were sputtered transparent Cr layers. The 300 nm thick n and p doped layers were deposited under our standard a-Si:H deposition conditions. We used hydrogen dilution only for the intrinsic layers. The deposition conditions for these layers are given in Table I. The sum of H_2 and SiH_4 flow rates were kept constant at 100 Sccm, while the flow rate ratios were varied for different samples. All samples were deposited at the pressure of 1Torr. The electron and hole mobilities were measured using the standard time of flight technique(TOF), by shining the p and n sides respectively. In our TOF experimental setup, we used a 3 ns (FWHM) N2_Dye laser to produce 510 nm light (MPF~.2 µm in a-Si:H). Typical electron and hole photo-current pulses are shown in Fig. 1.

For $\mu\tau$ measurement, we used the same experimental setup and measured the collected charges for a set of reversed bias values. The data were then fitted to the Hecht equation [11] in order to derive the $\mu\tau$ values.

The density of ionized dangling bonds (N_D^*) was determined by hole-onset measurement. In this measurement, laser light entered through the n sides of the samples and the signal amplitudes were measured by varying the reversed biases applied to the diodes. The onset voltage found in this manner was assumed to correspond to the full depletion of the device, and was used to calculate N_D^* from the appropriate equation.

RESULTS

The Microcrystalline structure of our samples was revealed by TEM images and micro diffraction patterns and was also confirmed by XRD spectra. Both TEM images and micro diffraction patterns showed Si microcrystals embedded in a-Si:H tissue (Fig.2). The degree of

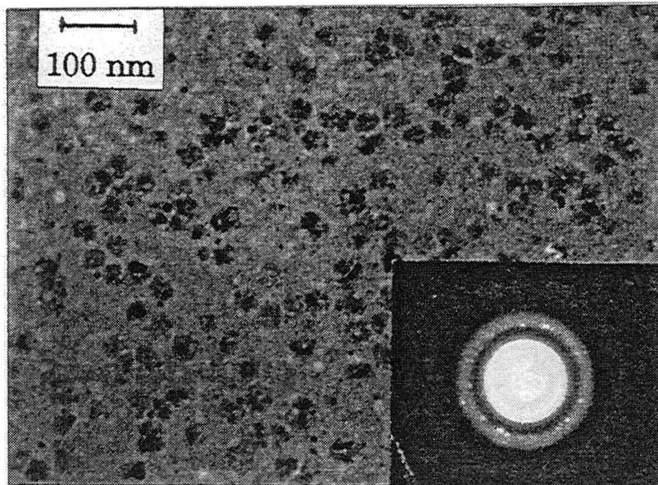


Fig.2 A TEM micrograph and the associated SAD for a μc-Si:H sample deposited at: H_2/SiH_4 =25, Ts=190°C, and P = 60 mW/cm^2

crystallinity and the grain size depends on the deposition conditions. The grain sizes and crystallinity values are consistent with Ref. 5. In the XRD spectra of our various samples, a prominent peak at 2θ = 47.3 degrees shows that the materials are highly textured with a predominant (220) orientation (see Fig. 3). The same strong (220) orientation has also been reported in Ref.12, for the μc-Si:H films deposited by layer-by-layer technique. Table II gives the results of electron and hole μ and μτ, as well as Nd* for our various samples for which the deposition conditions are listed in table I. The last row gives the parameters of our standard a-Si:H material.

The measured electron and hole mobility values for these hydrogenated samples , as seen from table II, depend on the deposition condition. For hydrogen to silane ratio of 15, sample MC361 shows to have an electron and hole mobility value of about 3 times larger than our standard a-Si:H. For the same sample the μτ values for holes and electrons have improved approximately, by a factor of 2, compared to our normal a-Si:H values. These improvements either decreased or disappeared when higher temperature or higher power was used. At a hydrogen to silane ratio of 20, the sample produced at 190°C and 60 mW/cm^2 had improved overall characteristics for

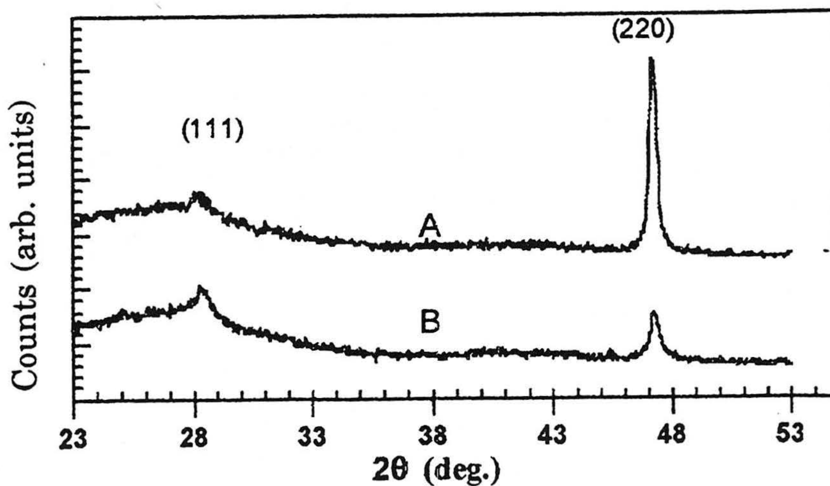


Fig.3 X-ray diffraction patterns showing an strong (220) peak for two samples produced at : T_s=190°C, P= 60 mW/cm^2 For A the hydrogen to silane ratio is ~25 and for B the the ratio is ~20.

Table I. Deposition conditions for the intrinsic layers of various Samples

Sample	[H2] /[SiH4]	Subs. Temp. (o C)	Power Density (mW /cm ^{2})	Dep. Rate (A^o/sec)
MC361	15	190	60	4
MC362	15	190	90	4.3
MC363	15	250	60	3
MC292	20	190	60	2.2
MC370	20	190	90	2.1
MC354	20	250	60	2.2
Std. A-Si:H	0	250	50	7

Table II Measured electron and hole transport parameters and stress values

Sample	μ_e ($cm^2/V/s$)	$(\mu\tau)_e$ (cm^2/V)	μ_h ($cm^2/V/s$)	$(\mu\tau)_h$ (cm^2/V)	N_D^* (cm^{-3})	Stress (MPa)
MC361	4.2	2.2E-07	0.013	6.0E-08	2E+13	652
MC362	2.7	1.1E-07	0.009	3.4E-08	9E+13	677
MC363	1.2	1.2E-07	0.006	1.7E-08	3E+13	607
MC292	2.5	3.0E-07	0.011	1.7E-08	1.6E+14	650
MC370	1	1.4E-07	0.009	2.0E-08	1.4E+14	580
MC354	1.1	1.5E-07	0.003	2.0E-08	1.3E+14	717
Std. A-Si:H	1.2	1.2E-07	0.004	2.6E-08	7E+14	350

electrons, while for holes, only the mobility increased. The hole mobility for all samples deposited at lower temperature of 190°C showed an improvement by a factor of 2 to 3 over the standard a-Si:H values.

The N_D^* values derived from hole onset measurement are in general lower than our standard a-Si:H samples. For samples MC361 and MC363, the hole onset occurs at ~ 0 volts and the N_D^* values are estimated based on an assumed built-in potential of 0.9 volts.

In table II, we have also presented the results of our stress measurements. The stress values for the new samples are in general higher by a factor of 2-3 than standard a-Si:H.

DISCUSSION

Based on the measured data presented in table II, our μc-Si:H samples deposited at optimum RF power and substrate temperature have electron and hole mobilities 2-4 times larger than our

standard a-Si:H. The improvement in hole mobilities have also been reported by the Dundee group [8] for their microcrystalline samples deposited by microwave decomposition of H_2 diluted SiF_4. The fact that the increase in crystallinity by adding more hydrogen from the H_2/SiH_4 level of 15, or by using higher temperatures or powers did not result in any further enhancement in mobilities, but rather caused decrease in their values, leads us to believe that the higher mobilities are not the result of microcrystalline formations. But instead, it is the improvement in the quality of the amorphous material which is responsible for this favorable change. The hydrogen role can then be viewed as diffusing into the growing layers and breaking loose Si-Si bonds and therefore, enhancing the long range order in the amorphous material. This would imply narrower band tails, both at the conduction and valence mobility edges, resulting in higher drift mobilities for both electrons and holes. Using a simple geometrical model shows that, for the range of volume fraction of crystallinity that we are dealing with (<25%), a very small fraction of carriers would pass through microcrystallites. Thus, carrier mobilities are predominantly governed by the mobilities within the amorphous material (μ_a). Therefore, assuming that μ_a has improved, the increase in measured mobilities of the samples is well explained. We have also used a similar concept in order to simulate the effect of grain boundaries on the carrier lifetimes. Calculation of life time in the grain boundaries (τ_b) from this model, for both electrons and holes shows that as long as the ratio of grain size to volume fraction of crystallinity is less than 60, neither electron nor hole lifetime are appreciably affected by grain boundary captures. The increase in the measured $\mu\tau$ values of our best samples are in good agreement with the higher μ values and the model prediction of negligible or no adverse effect from grain boundaries on the overall carrier lifetime. For the overall defect density, due to the presence of grain boundaries, our model predicts a value about 10 times higher than the defect density of the amorphous part, while our measured values of ionized defect densities (N_D^*) are better by a factor of 5-30 than that of normal amorphous silicon samples. The ionized dangling bond density, N_D^* from amorphous silicon samples is one third of the ESR measured N_D value. Therefore, the lower values of N_D^* for our new samples may mean that, either the defect density in the amorphous part has improved by a large factor, or, for the new material, the relation between the N_D^* as measured by hole-onset method and the total defect density N_D is different from the one established for standard amorphous silicon [13]. The former may be true, if we assume that the extra hydrogen also plays a role in passivating further some of the dangling bonds in the amorphous part. This is consistent with our stress measurement results which show about 2 times higher stress values for our new samples, and the empirically known inverse relation between the internal stress and the dangling bond density [14].

CONCLUSION

We have measured electron and hole μ and $\mu\tau$ for the new μc-Si:H samples deposited in our PECVD with high hydrogen dilution of silane. For the optimum deposition condition, we

measured mobility values ~3 times and $\mu\tau$ values approximately 2 times those of standard a-Si:H. The N_D^* values have also improved. Stress measurements also show higher stress values. We have developed a simple model, the results of which are consistent with our measurements. We have suggested that these improvements might have come from the hydrogen dilution by suggesting the following roles for the extra hydrogen: a) it causes narrowing the band tails by breaking loose Si-Si bonds and therefore bringing about more long range order; b) passivating some more of the dangling bonds in the amorphous material.\

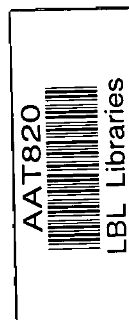
ACKNOWLEDGMENT

This work was supported by High Energy Physics Division of U.S. Department of Energy under Contract Number DE-AC03-76SF00098

REFERENCES

1. S. Veprek and V. Maracek, Solid State Electronics **11**, 683 (1968).
2. Yushiyuki Uchida, Takeshige Ichimura, Masakazu Ueno and Hiromu Heruki, J.J. Appl. Phys. **21**, L586 (1982).
3. Y. Matsumoto, G. Hirata, H. Tkakura, H. Okamoto, and Y. Hamakawa, J. Appl. Phys. **67**, 6536 (1990).
4. L. Yang, L. Chen, S. Wiedeman and A. Catalano, MRS Symp. Proc. **283**, 463 (1993).
5. A. Matsuda, in Amorphous Semiconductor Technologies and Devices, Y. Hamakawa (ed.) JARECT **22** (OHMSHA and North Holand, 1987)pp.111-119.
6. Y. Mishima, S. Miyazaki, M. Hirose and Y. Osaka, Philos. Mag. B, **46**, 31 (1982).
7. K.P. Chik , P. H. Chan, B. Y. Tong, S. K. Wong and P. K. John, Philos. Mag. B, **61**, 377 (1990).
8. A.C. Hourd, D. L. Melville and W. E. Spear, Philos. Mag. B, **64**, 533 (1991).
9. V. Perez-Mendez, in Amorphous and Microcrystalline Semiconductor Devices, edited by J. Kanicki (Artech House, Boston, 1991) pp. 297-330.
10. A. Mireshghi, G. Cho, J. Drewery, T. Jing, S. N. Kaplan, V. Perez-Mendez and D. Wildermuth, IEEE Trans. Nuc. Sci. **NS-39**, 635 (1992).
11. R. A. Street, Phys. Rev. B, **27**, 4924 (1983).
12. S. Ishihari,D. He, T. Akasaka, Y. Araki, M. Nakata, and I. Shimizu, Mat. Res. Soc. Symp. Proc. **283**, 489 (1993).
13. S. Qureshi, V. Perez-Mendez, S.N. Kaplan, I. Fujieda, G. Cho, and R.A. Street, IEEE Trans. Nucl. Sci. **NS-36,** 194 (1989).
14. W.E. Spear and M. Heintze, Philos. Mag. B, **54**, 343 (1986).

LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
TECHNICAL INFORMATION DEPARTMENT
BERKELEY, CALIFORNIA 94720


AAT820
LBL Libraries