Title	Effect of a silicon nitride film on the potential-induced degradation of n-type front-emitter crystalline silicon photovoltaic modules
Author(s)	Suzuki, Tomoyasu; Masuda, Atsushi; Ohdaira, Keisuke
Citation	Japanese Journal of Applied Physics, 59(10): 104002-1-104002-5
Issue Date	2020-08-28
Type	Journal Article
Text version	author
URL	http://hdl.handle.net/10119/18016
Rights	This is the author's version of the work. It is posted here by permission of The Japan Society of Applied Physics. Copyright (C) 2020 The Japan Society of Applied Physics. Tomoyasu Suzuki, Atsushi Masuda, Keisuke Ohdaira, Japanese Journal of Applied Physics, 59(10), 2020, 104002. https://doi.org/10.35848/1347-4065/abb39e
Description	

Effect of a silicon nitride film on the potential-induced degradation of n-type front-emitter crystalline silicon photovoltaic modules

Tomoyasu Suzuki[a], Atsushi Masuda[b,c,†], Keisuke Ohdaira[a,*]

[a]*Japan Advanced Institute of Science and Technology, Nomi, Ishikawa 923-1292, Japan*

[b]*National Institute of Advanced Industrial Science and Technology, Tsukuba, Ibaraki 305-8568, Japan*

[c]*Graduate School of Schence and Technology, Niigata University, Niigata 950-2181, Japan*

*E-mail: ohdaira@jaist.ac.jp

[†]Present affiliation: *Niigata University, Niigata 950-2181, Japan*

We investigate the effect of silicon nitride (SiN_x) films in n-type front-emitter (n-FE) crystalline Si (c-Si) solar cells on the potential-induced degradation (PID) of n-FE photovoltaic (PV) modules. A negative-bias PID test for a few min does not degrade the performance of PV modules with n-FE cells without SiN_x/silicon dioxide (SiO_2) stacks, unlike in the case of PV modules with cells with SiN_x/SiO_2. This is because of the absence of polarization-type PID. After a longer PID test, the PV modules with n-FE cells without SiN_x/SiO_2 show a slower decrease in fill factor (FF), originating from Na introduction into the depletion layer of a p–n junction, than the modules with cells with SiN_x/SiO_2.

The mitigation of PID by eliminating SiN_x is partly consistent with the results of PV modules with p-type conventional cells without SiN_x in which no PID occurs. SiN_x thus has a function of enhancing Na introduction into c-Si.

1. Introduction

In recent years, large-scale photovoltaic (PV) power plants have been constructed all over the world. Such large-scale PV power plants generally have a high system voltage of 1000 V or more, leading to the smaller number of system components and a reduction in the cost of electricity. This high voltage, however, can cause a performance loss of PV modules referred to as potential-induced degradation (PID).[1–4] PID is a phenomenon in which the performance of PV modules degrades due to a potential difference between an aluminum (Al) frame and cells. PID has been recognized as one of the most important reliability issues for PV modules, because it can take place in a short duration — from a few months to a few years. The behaviors and mechanisms of the PID of PV modules are known to be different depending of the structure of cells in the modules.

n-type crystalline silicon (c-Si) solar cells generally have higher conversion efficiency than p-type ones, because holes, minority carriers in n-type c-Si, have a smaller capture cross section for many impurities than electrons, minority carriers in p-type c-Si.[5,6] In addition, p-type c-Si cells can suffer from light-induced degradation due to the formation of the boron (B)–oxygen (O) complexes, which increases the recombination rate of minority carriers.[7,8] For these reasons, PV modules consisting of n-type c-Si solar cells are expected to have more share in the PV market in the near future.[6] On the other hand, unlike in the case of the PV modules with p-type c-Si solar cells,[1–4, 9–15] for which much research on PID has been conducted, there is less sufficient knowledge about the PID of the PV modules consisting of n-type c-Si cells.[16–31] It is therefore necessary to perform more detailed research on PID for the n-type c-Si PV modules.

n-type front-emitter (n-FE) c-Si PV modules have been reported to exhibit three-stage degradations.[28–30] In this paper, we refer to these degradations as PID-1, PID-2, and

PID-3, in the order corresponding to their emergences. PID-1 is characterized by simultaneous decreases in short-circuit current density (J_{sc}) and open-circuit voltage (V_{oc}), due to the enhancement of surface recombination by the accumulation of positive charges in a front-side Si nitride (SiN_x) antireflection film. We have proposed that the origin of the positive charges is positively-charged K centers in SiN_x, dangling bonds backbonded to three nitrogen atoms.[26,29] PID-2 is characterized by a decrease in fill factor (FF). This degradation may be caused by the introduction of sodium (Na) atoms into the depletion layer of the p–n junction through the SiN_x and/or from cell edges.[28] PID-3 is characterized by additional reductions in V_{oc} and FF, triggered by further introduction of Na and resulting formation of Na-based dome-like protrusions composed mainly of Na on the top of pyramids on the cell surface.[30]

Although the behaviors and mechanisms of the PID of n-FE PV modules have been clarified to some extent, they can be influenced by the structure of the cells, which is important to understand the degradation mechanisms in more detail and to establish measures for the suppression of the PID. For example, PV modules with n-FE cells without SiO_2 between SiN_x and c-Si do not exhibit PID-1, whereas they show more rapid and serious PID-2 and PID-3 than the modules with the cells with SiO_2.[31] These results indicate that SiO_2 acts as a barrier to prevent the charge exchange between SiN_x and c-Si and delays the introduction of Na into c-Si in the PID of n-FE modules.

The surface SiN_x may also affect the PID of n-FE PV modules. Surprisingly and interestingly, it has been reported that PID does not occur in PV modules with p-type cells from which SiN_x is removed.[15] The similar effect can be seen in PID-2 and PID-3 of n-FE PV modules, since the PID of conventional p-type c-Si PV modules also originates from Na introduction into c-Si. In this study, we investigate the PID of n-FE PV modules

with n-FE cells without SiN_x and clarify how the PID behaviors are different from the modules with n-FE cells with SiN_x. The results also give us valuable knowledge for the commonalities and differences between the PID of the PV modules with p-type and n-type cells.

2. Experiment methods

We used commercial n-type bifacial cells with SiN_x/SiO_2 stacks on both sides, from which the SiN_x/SiO_2 stack on the p^+ emitter side was removed. The cells originally had a size of 156×156 mm^2, which were cleaved to a few centimeter small pieces. As the first step for the removal of SiN_x/SiO_2, 1-methoxy-2-propyl acetate (photoresist solution) was coated on the n^+ layer side of the cells as a protective film. The SiN_x/SiO_2 stack on the p^+ layer side was then removed using 55% hydrofluoric acid (HF) solution. Ag electrodes on the p^+ emitter side were also removed during this process. The coated photoresist films were removed in acetone after the removal of SiN_x/SiO_2. Since it is difficult to completely remove the photoresist, a slight amount of the photoresist remains on the back side of the cells. Ag electrodes were then formed by evaporation through a hard mask. Part of the back-side SiN_x/SiO_2 was unintentionally etched off during the HF treatment, due to imperfect protection by the photoresist. The cells were thus finally cleaved to a small size so that the cells do not contain the remaining photoresist and the back-side of the cells are fully covered with SiN_x/SiO_2. We also used normal n-FE cells from which SiN_x/SiO_2 was not removed for comparison.

We then fabricated PV modules composed of conventional cover glass/ethylene vinyl acetate copolymer (EVA)/cell/EVA/polyvinyl fluoride (PVF)/polyethylene terephthalate (PET)/PVF backsheet. One module contained only one n-FE cell, and the

area of the modules was 45×45 mm^2. The PV modules received a PID test based on the Al-plate method.[32] PID tests were performed on the modules by applying a negative bias of −1000 V to shorted interconnector ribbons of the modules with respect to a grounded Al plate placed on the cover glass surface using TOS7210S (Kikusui Electronics Corp.) at a temperature of 85 °C and a relative humidity of <2%.

To evaluate the degradation of the PV modules, we performed dark and one-sun-illuminated current density–voltage (J–V), and external quantum efficiency (EQE) measurements on the PV modules before and after the PID tests. The measured dark J–V data before and after the PID tests were analyzed using the two-diode model[33] to obtain the saturation current densities of the first (J_{01}) and second (J_{02}) diodes, respectively, the ideality factor of the second diodes (n_2), the shunt resistance (R_{sh}), and the series resistance (R_s). In this study, the ideality factor of the first diode was fixed to n_1=1. In order to confirm the initial condition of the cells, electroluminescence (EL) observation was also performed using PVX100 (ITES Co., Ltd.).

3. Results

Fig. 1 shows the initial one-sun-illuminated J–V characteristics of the PV modules with n-FE cells with and without SiN$_x$/SiO$_2$. The PV module with the n-FE cell without SiN$_x$/SiO$_2$ shows smaller J_{sc} and V_{oc} than the module with the cell with SiN$_x$/SiO$_2$. This result is quite reasonable because the films functioning as anti-reflection and surface passivation are missing. Nevertheless, the n-FE modules with n-FE cells without SiN$_x$/SiO$_2$ can be utilized for the PID experiment, because severe decreases in FF due to changes in R_{sh} and R_s are not seen. This also indicates that the evaporated Ag electrodes have a sufficiently low contact resistance with a bare p$^+$ emitter. The EL image of the

module with the n-FE cell without SiN_x/SiO_2 is shown in the inset of Fig. 1. One can see no cracks or defects which can be formed during the SiN_x removal and module fabrication processes.

Fig. 2 shows the normalized J_{sc}, V_{oc}, FF, and maximum output power (P_{max}) of the modules with n-FE cells with and without SiN_x/SiO_2 as a function of PID-stress duration. We see no PID-1, characterized by decreases in J_{sc} and V_{oc} due to positive charge accumulation in SiN_x, in the modules with cells without SiN_x/SiO_2. This is reasonable because of the absence of SiN_x serving as a charge storage layer and of SiO_2 having the function of barriers for charge exchange.[31] PID-2, characterized by a decrease in FF alone due to Na introduction into the depletion layer of the p–n junction and resulting carrier recombination there, is seen in the modules with cells without SiN_x/SiO_2 in a longer-duration PID test, like in the case of the modules with cells with SiN_x/SiO_2. Note that the emergence of the FF reduction is delayed in the modules with cells without SiN_x/SiO_2 compared to the modules with cells with SiN_x/SiO_2. FF values continue to decrease with increase in the PID-stress duration in both types of modules, and are then saturated. The saturated FF is almost constant independent of the presence or absence of SiN_x/SiO_2 in the cells. Further increase in the PID-stress duration results in an increase in FF. The reason for the increase in FF is unclear at present. One possible explanation is that Na-based dome-like structures start to be formed on the surface of the cells and Na in a depletion region is sucked out into the Na domes.[30] The formation of the dome-like structures can induce further decreases in V_{oc} and FF due to the destruction of SiN_x and p-n junction — PID-3 in this paper.[30] Although PID-3 is seen in the modules with n-FE cells with SiN_x/SiO_2, the modules with cells without SiN_x/SiO_2 show almost no further V_{oc} and FF reductions even after a significantly long-duration (>100 h) PID test. This is

also a clear indication of the delay of Na-related PID by the removal of SiN_x. Note that, although SiO_2 is also removed in this experiment, the removal of SiO_2 is not the reason for the delays of PID-2 and PID-3, because we have previously confirmed that the modules with n-FE cells with SiN_x alone show rather acceleration of Na-derived PID.[31]

Fig. 3 shows the dark J–V curves of the n-FE c-Si PV module with a cell without SiN_x/SiO_2 before and after the PID test. Fig. 4 shows the results of two-diode fitting for the dark J–V curves shown in Fig. 3. Increases in n_2 and J_{02} are seen at a PID-test duration for 3–6 h. This corresponds to the emergence and progression of the decrease in FF shown in Fig. 2. These tendencies are similar to the results of our previous work,[28] whereas the onset of the increases in n_2 and J_{02} is delayed. Note that, although R_{sh} obtained by the two-diode fitting decreases, no noticeable shunting is confirmed near the origin of the dark J–V characteristics, as shown in the inset of Fig. 3(b). We therefore consider that the main reason for the decreases in FF and R_{sh} is not the formation of shunting path but the enhancement of recombination current.

4. Discussion

As described above, PID-2 is associated with the introduction of Na into the depletion layer of the p–n junction. Hence, the fact that the removal of SiN_x from n-FE cells leads to the delay of PID-2 means that SiN_x has a function of accelerating Na-derived PID. This is partially consistent with the previous result about the PID of modules with p-type c-Si cells without SiN_x, in which their PID is completely suppressed.[15] It is seemingly mysterious that the removal of SiN_x, known as a good diffusion barrier against Na ions,[34] leads to the mitigation of Na-derived PID. Although Na ions can drift through SiN_x with the assistance of a strong electric field,[35] the voltage drop in SiN_x results in a

smaller electric field in glass and encapsulant (EVA). Hence, the Si surface of the n-FE cells without SiN_x/SiO_2 must receive more Na ions than that of the cells with SiN_x/SiO_2 in the same PID-test duration, which conflicts the obtained experimental results. The removal of SiN_x thus rather affects the process of Na introduction into c-Si, and SiN_x may act to squeeze Na into Si. Since the diffusion coefficient of Na in Si at temperatures of <100 °C is quite small,[36] Na atoms cannot invade c-Si through the simple diffusion process, and an effective driving force for the introduction of Na into Si must be provided from SiN_x. One possible mechanism for the Na introduction into c-Si is the assist of positive charges in SiN_x. SiN_x generally has positive charges if it is on c-Si, and positively-charged Na ions can be repelled and pushed into c-Si. The second possible effect of SiN_x is the strong accumulation of Na between SiN_x and c-Si. As described above, SiN_x has a high barrier property against Na, and the Na ions that have penetrated through the SiN_x must be highly localized underneath the SiN_x. The heavy accumulation of Na at a SiN_x/c-Si interface has been actually observed in p-type c-Si cells.[12] The heavy accumulation of Na might be related to the introduction of Na into c-Si. In the case of the cells without SiN_x, Na ions may be concentrated less heavily in the vicinity of the c-Si surface, which might mitigate the invasion of Na into c-Si. The third possible mechanism is the influence of SiN_x on the formation of Na-decorated stacking faults (SFs).[12,13] Naumann et al. have experimentally confirmed the introduction of Na into c-Si through the formation of Na-decorated SFs. The formation of Na-decorated SFs might be triggered by SiN_x, and the properties of SiN_x, such as stress, density, and thickness, perhaps influence the formation of Na-decorated SFs. Actually, the PID of PV modules with conventional p-type cells can be suppressed by the usage of modified SiN_x.[37] If this hypothesis is true, Na atoms on the cell without SiN_x are completely free from the trigger for the formation of Na-decorated

9

SFs, and Na introduction into c-Si can be suppressed. Further detailed work is needed for the clarification of the mechanism for the mitigation of Na-derived PID by the removal of SiN_x.

Another interesting fact in the PID of PV modules with cells without SiN_x is the difference of PID behaviors between p-type cells and n-type cells. The modules with p-type cells without SiN_x show no degradation at all,[15] whereas the modules with n-FE cells without SiN_x show an FF reduction induced by Na introduction after a sufficiently long PID test. This difference may originate from the polarity of the emitter into which Na is introduced. As mentioned above, Na introduction into c-Si is believed to proceed through the formation of Na-decorated SFs.[12,13] Na-decorated SFs are more stable in p-type c-Si than in n-type c-Si.[38] Based on these facts, Na introduction into p-type c-Si, the emitter for n-FE cells, can proceed more preferentially than Na introduction into n-type c-Si, the emitter for p-type cells, and Na ions are introduced into c-Si to some extent even without the help of SiN_x only in the case of n-FE modules.

In reality, the removal of SiN_x from n-FE cells cannot be measures for the suppression of PID because of the poor initial characteristics of the cells without SiN_x. However, further investigations on the mechanism of Na introduction into c-Si will lead to the establishment of ways for preventing Na introduction into c-Si and resulting Na-derived PID by, e.g., interface engineering and/or the control of SiN_x properties.

5. Conclusion

We have investigated the effect of SiN_x on the PID of n-FE c-Si PV modules. The removal of SiN_x from n-FE cells results in the disappearance of PID-1, characterized by reductions in J_{sc} and V_{oc} due to positive charge accumulation, which is reasonable because

the positive charges are stored in SiN_x. PID-2, an FF reduction due to the introduction of Na into Si, and PID-3, reductions in FF and V_{oc} by the formation of Na-based dome-like structures, are delayed and mitigated by the usage of n-FE cells without SiN_x/SiO_2 in PV modules. Also considering the fact that the PID of p-type c-Si PV modules with cells without SiN_x is completely suppressed, SiN_x has a function of introducing Na ions into c-Si. The incomplete suppression of Na-derived PID in n-FE PV modules by the removal of SiN_x may be due to the difference of the polarity of the emitter layer, n^+ c-Si in p-type cells and p^+ c-Si in n-FE cells, into which Na is introduced.

Acknowledgment

Reference

1) W. Luo, Y. S. Khoo, P. Hacke, V. Naumann, D. Lausch, S. P. Harvey, J. P. Singh, J. Chai, Y. Wang, A. G. Aberle, and S. Ramakrishna, Energy Environ. Sci. **10**, 43 (2017).

2) S. Pingel, O. Frank, M. Winkler, S. Daryan, T. Geipel, H, Hoehne, and J. Berghold, Proc. 35th IEEE Photovoltaic Specialists Conf., 2010, p. 2817.

3) J. Berghold, O. Frank, H. Hoehne, S. Pingel, B. Richardson, and M. Winkler, Proc. 25th European Photovoltaic Solar Energy Conf. Exhib./5th World Conf. Photovoltaic Energy Conversion, 2010, p. 3753.

4) P. Hacke, M. Kempe, K. Terwilliger, S. Glick, N. Call, S. Johnston, S. Kurtz, I. Bennett, and M. Kloos, Proc. 25th European Photovoltaic Soler Energy Conf. Exhib./5th World Conf. Photovoltaic Energy Conversion, 2010, p. 3760.

5) D. Macdonald and L. J. Geerligs, Appl. Phys. Lett. **85**, 4061 (2004).

6) A. ur Rehman and S. H. Lee, Sci. World J. **2013**, 470347 (2013).

7) M. Vaqueiro-Contreras, V. P. Markevich, J. Coutinho, P. Santos, I. F. Crowe, M. P. Halsall, I. Hawkins, S. B. Lastovskii, L. I. Murin, and A. R. Peaker, J. Appl. Phys. **125**, 185704 (2019).

8) A. Herguth, G. Schubert, M. Kaes, and G. Hahn, Prog. Photovolt.: Res. Appl. **16**, 135 (2008).

9) J. Bauer, V. Naumann, S. Großer, C. Hagendorf, M. Schütze, and O. Breitenstein, Phys. Status Solidi: Rapid Res. Lett. **6**, 331 (2012).

10) V. Naumann, C. Hagendorf, S. Grosser, M. Werner, and J. Bagdahn, Energy Procedia **27**, 1 (2012).

11) V. Naumann, D. Lausch, and C. Hagendorf, Energy Procedia **77**, 397 (2015).

12) V. Naumann, D. Lausch, A. Hähnel, J. Bauer, O. Breitenstein, A. Graff, M. Werner,

S. Swatek, S. Großer, J. Bagdahn, and C. Hagendorf, Sol. Energy Mater. Sol. Cells **120**, 383 (2014).

13) V. Naumann, C. Brzuska, M. Werner, S. Großer, and C. Hagendorf, Energy Procedia **92**, 569 (2016).

14) H. Nagel, A. Metz, and K. Wangemann, Proc. 26th European Photovoltaic Solar Energy Conf. Exhib., 2011, p. 3107.

15) S. Jonai, Y. Tachibana, K. Nakamura, Y. Ishikawa, Y. Uraoka, and A. Masuda, Proc. 46th IEEE Photovoltaic Specialists Conf., 2019, p. 1969.

16) R. Swanson, M. Cudzinovic, D. DeCeuster, V. Desai, J. Jürgens, N. Kaminar, W. Mulligan, L. Rodrigues-Barbosa, D. Rose, D. Smith, A. Terao, and K. Wilson, Technical Digest of 15th International Photovoltaic Science and Engineering Conf., 2005, p. 410.

17) V. Naumann, T. Geppert, S. Großer, D. Wichmann, H.-J. Krokoszinski, M. Werner, and C. Hagendorf, Energy Procedia **55**, 498 (2014).

18) A. Halm, A. Schneider, V. D. Mihailetchi, L. J. Koduvelikulathu, L. M. Popescu, G. Galbiati, H. Chu, and R. Kopecek, Energy Procedia **77**, 356 (2015).

19) K. Hara, S. Jonai, and A. Masuda, Sol. Energy Mater. Sol. Cells **140**, 361 (2015).

20) S. Yamaguchi, A. Masuda, and K. Ohdaira, Sol. Energy Mater. Sol. Cells **151**, 113 (2016).

21) S. Bae, W. Oh, K. D. Lee, S. Kim, H. Kim, N. Park, S. I. Chan, S. Park, Y. Kang, H. -S. Lee, and D. Kim, Energy Sci. Eng. **5**, 30 (2017).

22) M. Barbato, A. Barbato, M. Meneghini, G. Tavernaro, M. Rossetto, and G. Meneghesso, Sol. Energy Mater. Sol. Cells **168**, 51 (2017).

23) K. Hara, K. Ogawa, Y. Okabayashi, H. Matsuzaki, and A. Masuda, Sol. Energy Mater.

Sol. Cells **166**, 132 (2017).

24) S. Yamaguchi, C. Yamamoto, K. Ohdaira, and A. Masuda, Sol. Energy Mater. Sol. Cells **161**, 439 (2017).

25) N. Nishikawa, S. Yamaguchi, and K. Ohdaira, Microelectron. Reliab. **79**, 91 (2017).

26) S. Yamaguchi, A. Masuda, and K. Ohdaira, Appl. Phys. Express **9**, 112301 (2016).

27) S. Yamaguchi, C. Yamamoto, K. Ohdaira, and A. Masuda, Prog. Photovolt.: Res. Appl. **26**, 697 (2018).

28) Y. Komatsu, S. Yamaguchi, A. Masuda, and K. Ohdaira, Microelectron. Reliab. **84**, 127 (2018).

29) S. Yamaguchi, K. Nakamura, A. Masuda, and K. Ohdaira, Jpn. J. Appl. Phys. **57**, 122301 (2018).

30) K. Ohdaira, Y. Komatsu, T. Suzuki, S. Yamaguchi, and A. Masuda, Appl. Phys. Express **12**, 064004 (2019).

31) T. Suzuki, S. Yamaguchi, K. Nakamura, A. Masuda, and K. Ohdaira, Jpn. J. Appl. Phys. **59**, SCCD02 (2020).

32) K. Hara, H. Ichinose, T. N. Murakami, and A. Masuda, RSC Adv. **4**, 44291 (2014).

33) M. Wolf, G. T. Noel, and R. J. Stirn, IEEE Trans. Electron. Dev. **24**, 419 (1977).

34) J. V. Dalton and J. Drobek, J. Electrochem. Soc. **115**, 865 (1968).

35) M. Wilson, A. Savtchouk, P. Edelman, D. Marinskiy, and J. Lagowski, Sol. Energy Mater. Sol. Cells **142**, 102 (2015).

36) A. V. Zastavnoi and V. M. Korol', Tech. Phys. Lett. **42**, 415 (2016).

37) K. Mishina, A. Ogishi, K. Ueno, T. Doi, K. Hara, N. Ikeno, D. Imai, T. Saruwatari, M. Shinohara, T. Yamazaki, A. Ogura, Y. Ohshita, and A. Masuda, Jpn. J. Appl. Phys. **53**, 03CE01 (2014).

38) Y. Ohno, H. Morito, K. Kutsukake, I. Yonenaga, T. Yokoi, A. Nakamura, and K. Matsunaga, Appl. Phys. Express **11**, 061303 (2018).

Figure captions

Fig. 1 Initial one-sun-illuminated J–V characteristics of PV modules with n-FE cells with and without SiN_x/SiO_2. The EL image of the module with a cell without SiN_x/SiO_2 is also shown in the inset.

Fig. 2 J_{sc}, V_{oc}, FF, and P_{max}, normalized by their initial values, of the n-type FE c-Si PV modules with cells with and without SiN_x/SiO_2 as a function of PID-stress duration. Each data point shows the mean value for three modules, and each error bar corresponds to the standard deviation of the mean.

Fig. 3 Dark J–V characteristic of the n-FE c-Si PV module with a cell without SiN_x/SiO_2 before and after the PID test plotted in (a) log scale and (b) linear scale.

Fig. 4 J_{01}, J_{02}, R_{sh}, and n_2 of the n-FE c-Si PV module with a cell without SiN_x/SiO_2 obtained from dark J–V characteristics as a function of PID-stress duration.
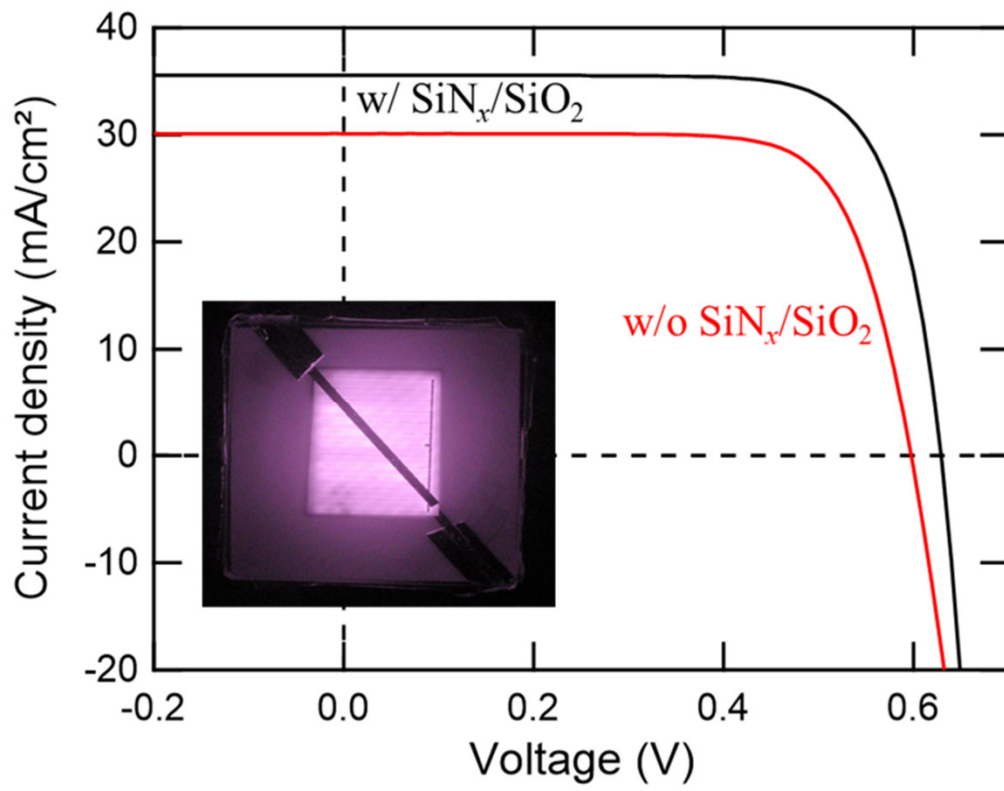
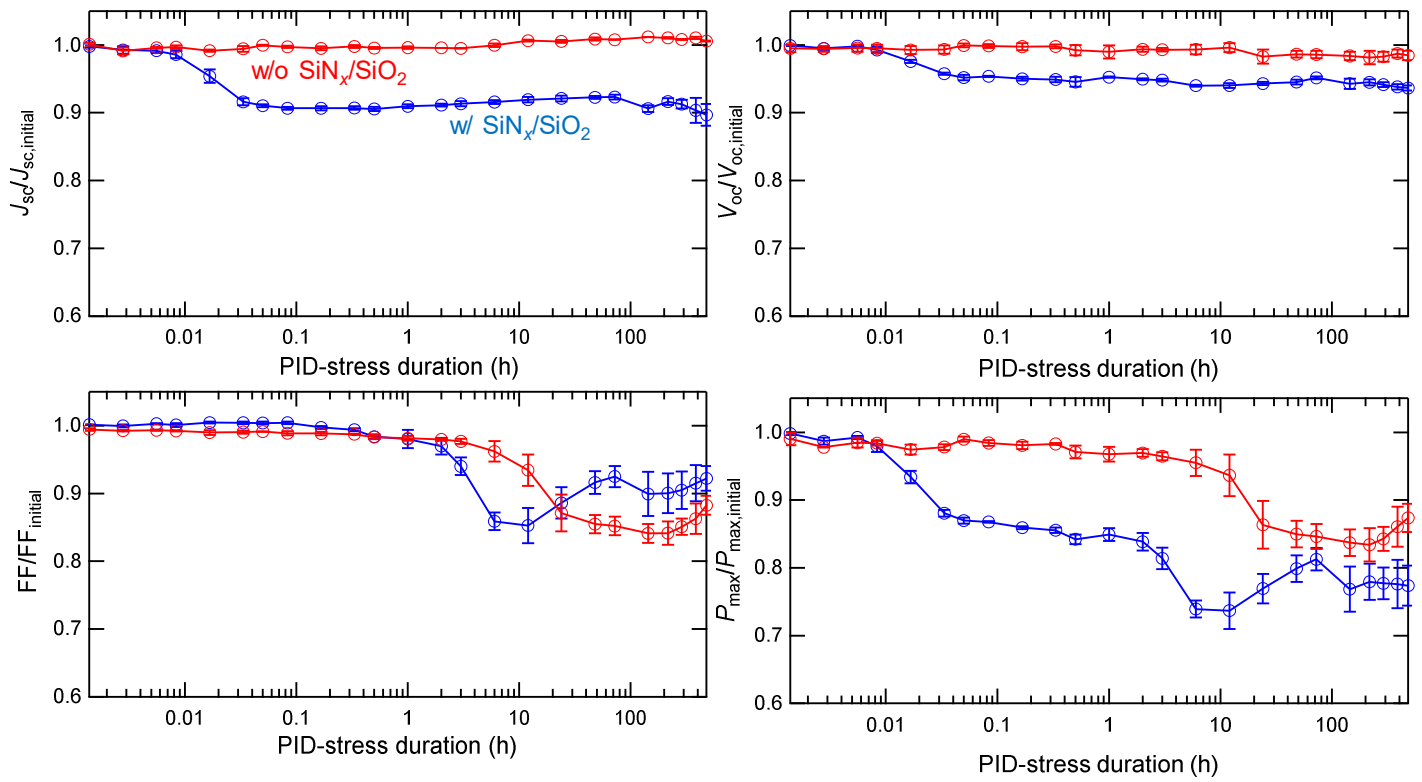Fig. 1. (Color online) T. Suzuki et al.,
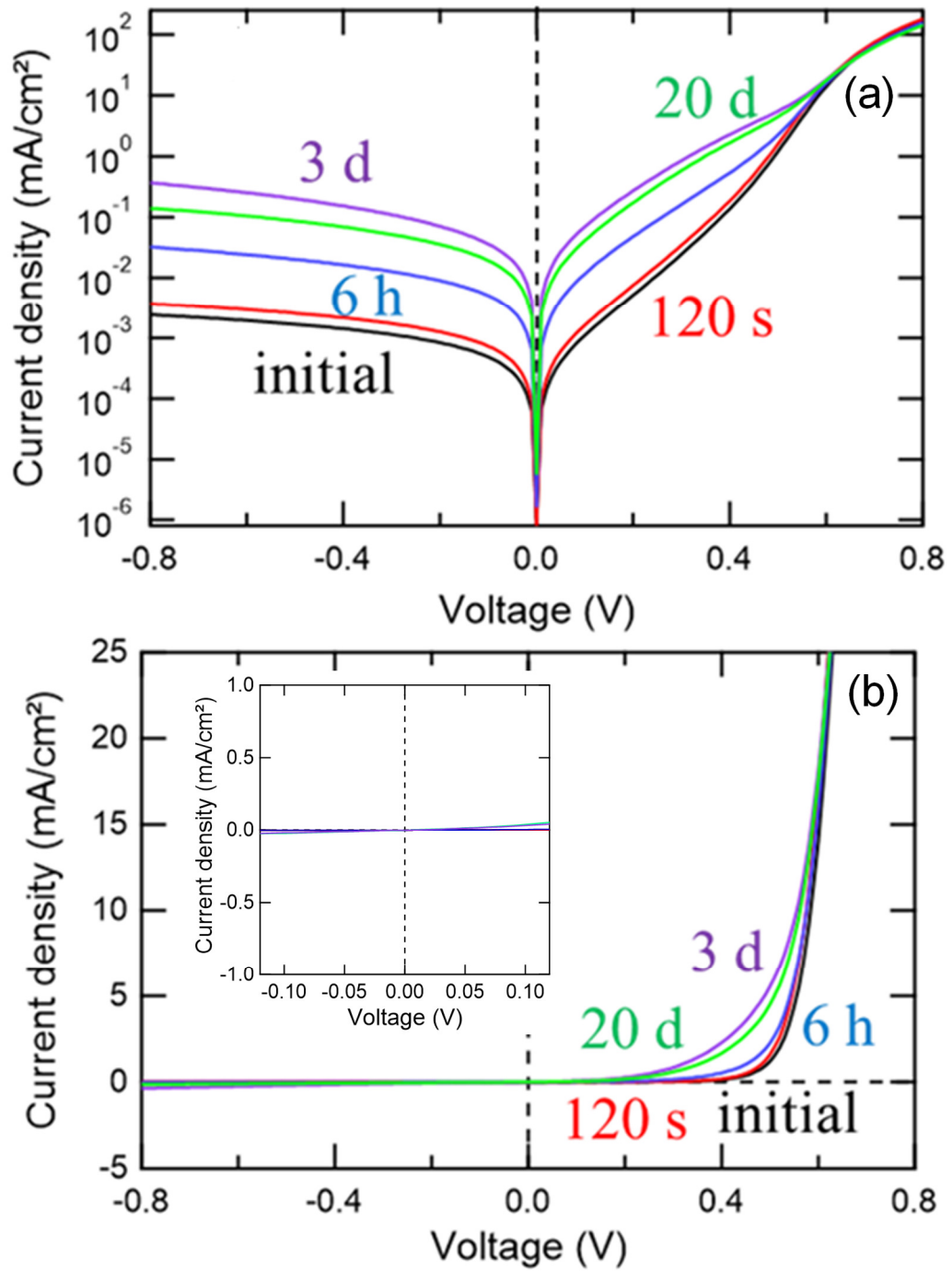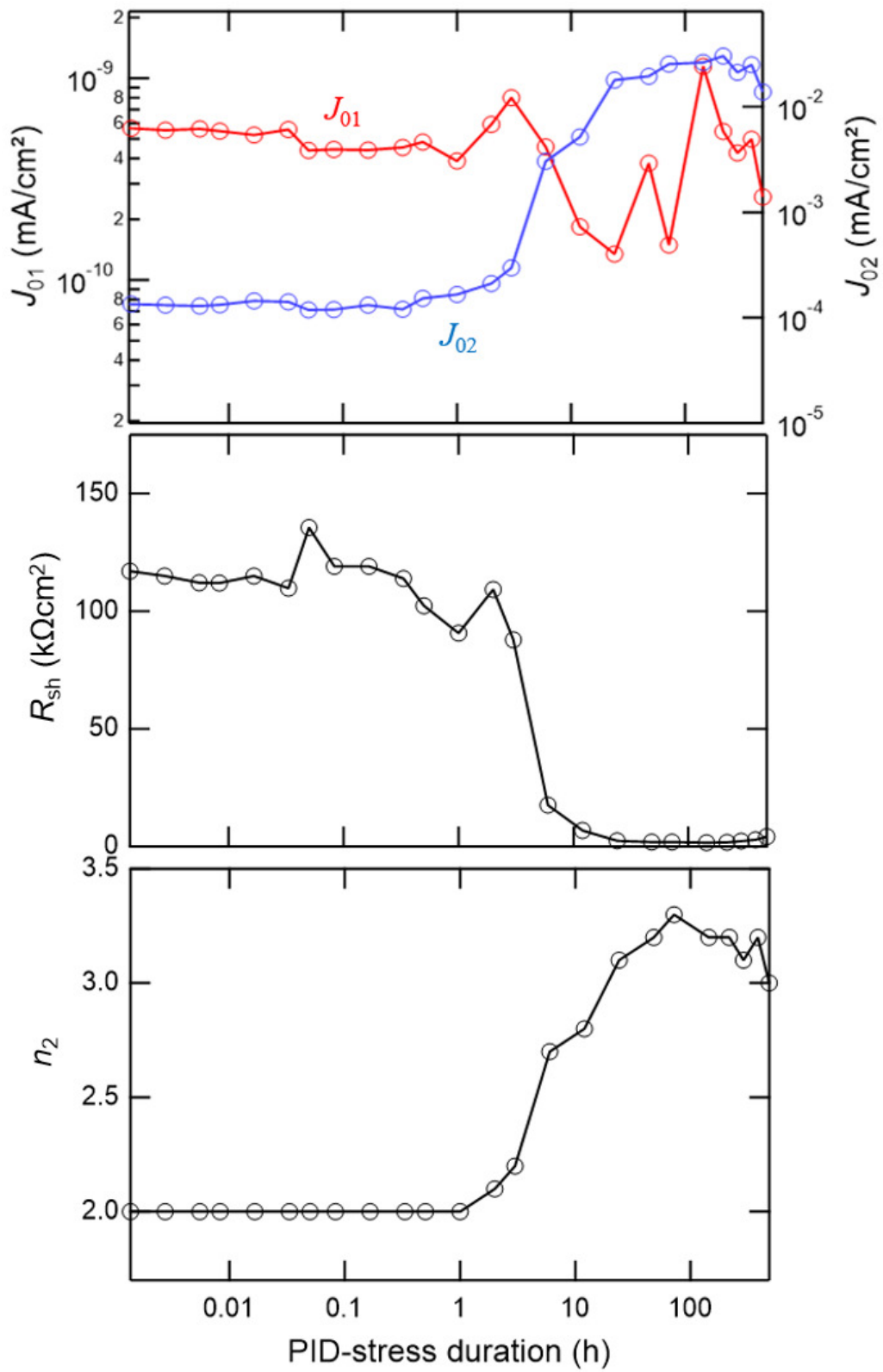
Fig. 2. (Color online) T. Suzuki et al.,

Fig. 3. (Color online) T. Suzuki et al.,

Fig. 4. (Color online) T. Suzuki et al.,