Extended Abstracts of the 2006 International Conference on Solid State Devices and Materials, Yokohama, 2006, pp. 732-733

P-9-9

Local Characterization of Photovoltage on Polycrystalline Silicon Solar Cells by KFM with Piezo-resistive Cantilever

Masaki Takihara[1], Takatoshi Igarashi[1], Toru Ujihara[2] and Takuji Takahashi[1]

[1]Institute of Industrial Science, University of Tokyo
4-6-1, Komaba, Meguro-ku, Tokyo 153-8505, Japan
Phone: +81-3-5452-6270 E-mail: takihara@iis.u-tokyo.ac.jp
[2]Department of Crystalline Materials Science, Nagoya University
Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan

1. Introduction

Polycrystalline silicon solar cells have a great advantage in fabrication cost compared with single crystal silicon solar cells, but have some disadvantage in the conversion efficiency. For improving the conversion efficiency of the polycrystalline silicon solar cells, influences of grains and their boundaries in polycrystalline silicon solar cells should be carefully investigated. To investigate such influences locally, electron-beam-induced current (EBIC) and laser-beam-induced current (LBIC) measurements are widely performed[1-4]. In these methods, the photocurrent of the solar cell, that is, the short-circuit current is mainly evaluated. On the other hand, there have been very few attempts to locally evaluate the photovoltage, namely the open-circuit voltage which is another important parameter in the solar cell. In this study, therefore, we aimed at characterizing the local photovoltage of the polycrystalline silicon solar cells. For such a purpose, a local potential measurement by Kelvin probe force microscopy (KFM)[5-8] is helpful. In KFM, cantilever deflection due to electrostatic force is used for potential determination, and conventionally an optical beam deflection method is applied to sense the cantilever deflection. However, this method may disturb accurate potential measurements on solar cells due to laser illumination for cantilever deflection sensor. Thus, we adopted a piezo-resistive cantilever for KFM[9], which does not require any laser light for tip height control. Moreover, we improved feedback algorithm for potential determination by suppressing a modulation current signal appearing in the deflection sensor output from the cantilever. In this paper, we report on the local potential measurements on solar cells by KFM to discuss the photovoltage distribution on their surface.

2. Experimental

The polycrystalline silicon solar cell we used was fabricated on a p-type substrate with a phosphorus doped surface n-layer of approximately 500 nm in thickness. In order to investigate an original characteristic of polycrystalline silicon solar cell, we did not carry out any other surface processing such as electrode fabrication, surface texturing and surface coating with antireflective films.

To evaluate the photovoltage of this sample, potential measurements were performed by KFM with piezo-resistive cantilever. This cantilever allows us to avoid unintentional light illumination, which is necessary on conventional optical beam deflection method, on solar cells during potential measurements. Therefore accurate potential measurements on solar cells are expectable. For the potential determination in the KFM, on the other hand, we have to apply ac modulation bias between sample and tip, and this ac modulation bias brings undesirable ac signal derived from displacement current on the cantilever deflection sensor output due to capacitive coupling between the sample and the piezo-resistive sensor part, which consequently disturbs accurate potential determination. To suppress such an influence of signal derived from displacement current, we generated an imitating ac displacement current signal by function generator, and put it into a differential input of a lock-in amplifier. We also applied the special feedback algorithm, by which the surface potential can be determined nearly independent of the displacement current signal. Thus, stable and reliable potential determination became possible even under the light illumination.

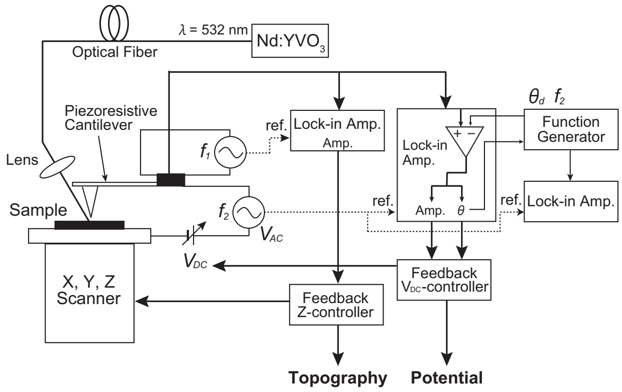

Fig. 1 Experimental setup of our KFM system. An imitating ac signal of the modulation signal was generated by function generator and put into a differential input of a lock-in amplifier.

Figure 1 shows our experimental setup of KFM under light illumination. In this measurement, green laser (Verdi V-10, Coherent Inc.) light at a wavelength of 532 nm was guided by an optical fiber and focused on the sample surface just under the AFM tip. We used a commercial AFM system (SPI4000/SPA300HV, SII NanoTechnology Inc., Japan) with a piezo-resistive cantilever (PRC400, SII NanoTechnology Inc., Japan). The topography and potential images were measured in the tapping mode operation. The typical values of a spring constant of this cantilever and vibration frequency f_1 for tip height control were 3 N/m and 56 kHz, respectively, and the tip was coated with platinum thin film. An amplitude and a

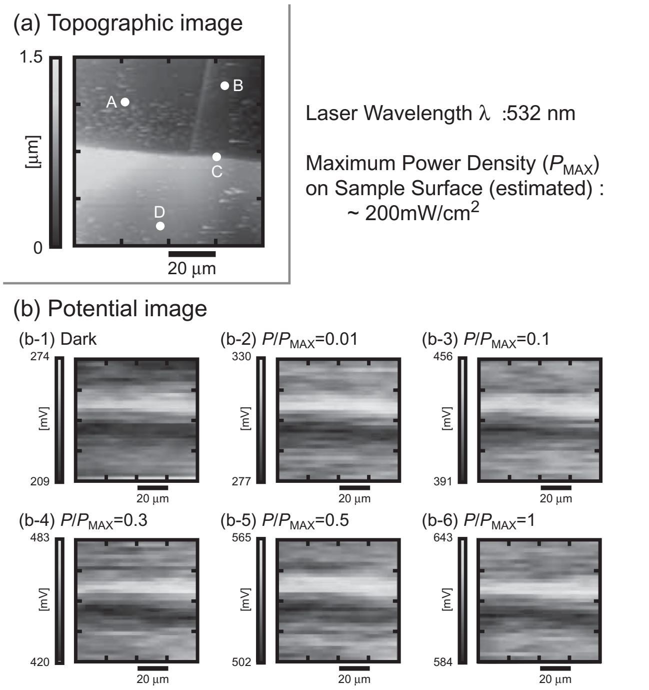

Fig. 2 (a) Topographic and (b) potential images of polycrystalline silicon solar cell. Potential images taken (b-1) in dark condition and (b-2)-(b-6) under light illumination with various light intensities. The contrast in each potential image does not change so much, but the potential value itself gradually changes according to the increase of the light intensity.

frequency f_2 of the ac modulation bias voltage for potential measurements were 2 $V_{peak\text{-}to\text{-}peak}$ and 58 kHz, respectively. This AFM system was operated in a high vacuum (typically, 10^{-7} Torr) and all measurements were done at room temperature.

3. Results and Discussion

Figure 2(a) shows a topographic image of the solar cell, in which some grains and their boundaries are identified. Figures 2(b-1)-(b-6) show corresponding potential images under the dark or various light intensities. Here, the line number of raster scanning for the potential images was reduced to save a time for measurement. The potential in dark condition means an intrinsic surface potential and a change in potential under light illumination shown in Fig. 2(b-2)-(b-6) from Fig. 2(b-1) corresponds to the photovoltage. Although the contrast does not seem to differ so much among all potential images as shown in this figure, the potential value itself gradually changes according to the increase of the light intensity.

Figure 3 shows the evaluated photovoltage at Points A-D as indicated in Fig. 2(a) by subtracting the potential value in the dark condition from those at various light intensities. The solid circles show the photovoltage at Point A and the other symbols show the differences in the photovoltage at Points B, C, and D from that at Point A. Firstly, we can recognize the photovoltage saturation according to an increase of the light intensity which is a basic feature of photovoltage in the solar cell. This result clearly proves the validity of our photovoltage measurements based on KFM. Secondly, we found site de-

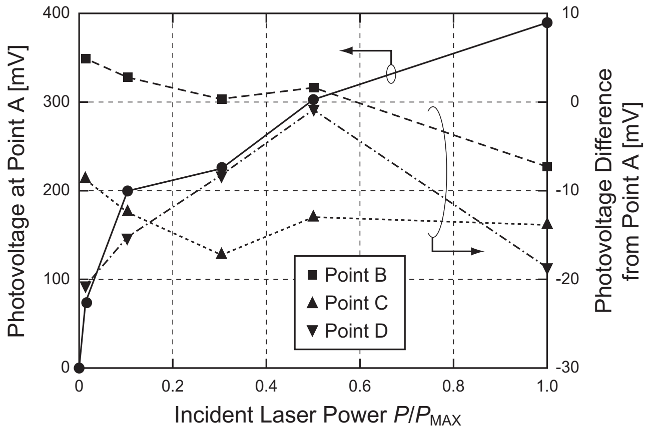

Fig. 3 Photovoltages calculated from the potential images at Points A-D as indicated in Fig.2(a). Solid circles indicate the photovoltage at Point A and other symbols indicate the differences in the photovoltage at Points B, C, and D from that at Point A.

pendence of photovoltage, indicating that photovoltage differs among the grains and their boundary. This kind of photovoltage fluctuation may lead to degradation of solar cell properties fabricated on the polycrystalline silicon materials.

4. Conclusions

We have introduced both the differential input method and the new feedback algorithm for the potential determination in KFM to suppress the influence of the ac modulation signal. Consequently the local photovoltage measurements on the solar cell was realized and the photovoltage distribution on the polycrystalline silicon solar cell was observed.

Acknowledgments

This work was partly supported by a Grant-in-Aid from the Ministry of Education, Culture, Sports, Science and Technology (MEXT), by the Focused Research and Development Project for the Realization of the World's Most Advanced IT Nation, IT Program, MEXT, and by the New Energy and Industrial Technology Development Organization (NEDO).

References

[1] T. Daud, K. M. Koliwad and F. G. Allen, Appl. Phys. Lett. **33**, 1009 (1978).
[2] O. von Roos, Solid-State Electron. **21**, 1063 (1978).
[3] S. A. McHugo, A. C. Thompson, I. Perichaud and S. Martinuzzi, Appl. Phys. Lett. **72**, 3482 (1998).
[4] P. C. Hjemas, O. Lohne, A. Wandera and H. S. Tathgar, Solid State Phenom. **95-96**, 217 (2004).
[5] M. Nonnenmacher, M. P. O'Boyle and H. K. Wickramasinghe, Appl. Phys. Lett. **58**, 2921 (1991).
[6] T. Takahashi, T. Kawamukai, S. Ono, T. Noda and H. Sakaki, Jpn. J. Appl. Phys. **39**, 3721 (2000).
[7] S. Ono, M. Takeuchi and T. Takahashi, Appl. Phys. Lett. **78**, 1086 (2001)
[8] S. Ono, M. Takeuchi, T. Noda and T. Takahashi, Jpn. J. Appl. Phys. **42**, 4869 (2003).
[9] T. Igarashi, T. Ujihara and T. Takahashi, Jpn. J. Appl. Phys. **45**, 2128 (2006).