Extended Abstracts of the 2013 International Conference on Solid State Devices and Materials, Fukuoka, 2013, pp1170-1171

Evaluation of the Junction Interface of the Crystalline Germanium Hetero-junction Solar Cells

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Abstract

The junction interface of the crystalline germanium(c-Ge) hetero-junction solar cells has been evaluated. We observed the hetero-epitaxial growth at the interface between the hydrogenated amorphous silicon and the c-Ge substrate. The degree of the epitaxial growth depends on the crystalline orientation of the c-Ge substrate. Besides we confirmed the hetero-junction interface treatment using PH_3 affected the conduction type of the c-Ge substrate near the interface. These interface properties have quite large impact on solar cell performance and conversion efficiency of 6.54% was obtained by optimizing the interface properties.

1. Introduction

Germanium based materials such as crystalline germanium (c-Ge) and crystalline silicon germanium were expected as the infrared light absorber to increase the conversion efficiency of multi-junction solar cells and thermo photovoltaic cells [1-4]. Nevertheless, the open circuit voltage (V_{OC}) of the solar cells using narrow band gap materials decreases drastically under the high temperature condition due to their large reverse saturation current. Accordingly, hetero-junction with hydrogenated amorphous silicon (a-Si:H) that is the proven technique in the case of the crystalline silicon solar cell so-called HIT cell[5-7] can be considered to be the solution to overcome this disadvantage.

We have developed the device fabrication procedure of a-Si:H/c-Ge hetero-junction solar cells and demonstrated that the hetero-junction interface treatment using PH_3 improved solar cell performance dramatically [8]. In this work, we carried out the several evaluations focused on the hetero-junction interface properties.

2. Experiments

We deposited intrinsic a-Si:H (a-Si:H(i)) layer and n-type a-Si:H (a-Si:H(n)) layer using multi-chamber very high frequency plasma-enhanced chemical vapor deposition (VHF-PECVD) system on the p-type c-Ge (c-Ge(p)) substrate that surface was exposed by PH_3 and H_2 mixture gas after cleaning procedure [8]. The crystalline orientation of the c-Ge substrates were Ge(100) and Ge(111), the front side electrode was consisted of ITO and Ag grid. We employed single side hetero-junction structure, so the back side was consisted of only Al electrode.

To evaluate interface properties, we used transmission electron microscopy (TEM), secondary ion mass spectroscopy (SIMS) and scanning capacitance microscopy (SCM).

3. Results and Discussion

Figure 1 shows the cross-sectional TEM images of the a-Si:H(i)/c-Ge(p) interface. It can be seen that hetero-epitaxial growth occurs on Ge(100) substrate clearly. On the other hand, in the case of Ge(111) substrate, epitaxial growth occurs only few atomic layers. The properties of the solar cell, especially V_{OC}, using Ge(111) substrate is much better than that of Ge(100) substrate. Thus, it can be estimated that the existence of the epitaxial growth layer has great influence for solar cell performance as same as the case of c-Si hetero-junction solar cell [9].

Next, we have investigated about the PH_3 exposure treatment. Quantification of the residual phosphorus at the interface after solar cell processing was carried out using SIMS. We employed a-Ge(i)/c-Ge(p) structure to preventing the matrix effect and back side SIMS to evaluate the phosphorus diffusion into the c-Ge substrate. As a result, diffused phosphorus in the c-Ge substrate is not observed. The residual phosphorus density is able to be controlled by the exposure conditions and the solar cell performance depends on the residual phosphorus density.

The conduction type of the c-Ge(p) near the interface with or without PH_3 exposure treatment were investigated using SCM. Figure 2 shows the SCM images of the c-Ge(p)

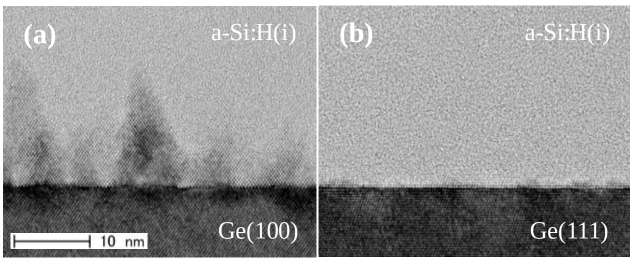

Fig. 1 Cross-sectional TEM images of the a-Si:H(i)/c-Ge(p) interface. (a) Ge(100) substrate, (b) Ge(111) substrate.

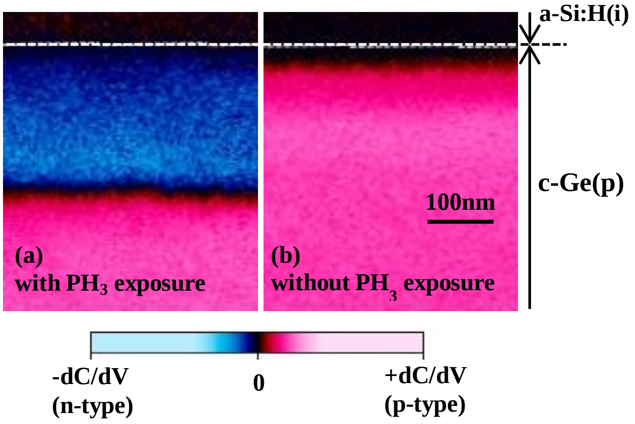

Fig. 2 SCM images of the c-Ge(p) substrate near the interface. (a) with PH_3 exposure, (b) without PH_3 exposure.

substrate near the interface. It can be seen that the carrier density gradient was clearly different. This results suggest that phosphorus adsorbed c-Ge(p) surface act as the donor and play the role of compensation for c-Ge dangling bonds act as the acceptor[10]. In addition, the n-type inversion layer is formed near the interface. It can be estimated that the inversion layer suppresses interface recombination and the solar cell performance is improved.

Based on the above rusults, we optimized the substrate specifications and the device fabrication procedure. Consequently, we obtained the solar cell efficiency of 6.54%. The photocurrent–voltage characteristic is shown in figure 3.

4. Conclusions

We have evaluated the junction properties of c-Ge hetero-junction solar cells using TEM, SIMS and SCM. The hetero-epitaxial growth occurs on c-Ge substrate. We demonstrated that the degree of the epitaxial growth depends on the crystalline orientation of the c-Ge substrate and has great influence for solar cell performance. The residual phosphorus density is able to be controlled by the

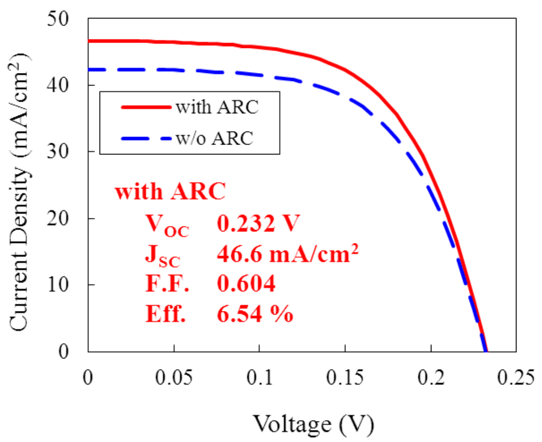

Fig. 3 Photocurrent-voltage characteristics of optimized solar cell with and without anti reflection coating (ARC)

PH_3 exposure conditions. The phosphorus act as the donor and form the n-type inversion layer near the interface of c-Ge substrate. It can be estimated that the inversion layer suppresses interface recombination and the solar cell performance is improved. The conversion efficiency of the hetero-junction solar cell was up to 6.54% by reflecting the results of the evaluation.

Acknowledgements

This work was supported by the New Energy and Industrial Technology Development Organization (NEDO), Japan.

References

[1] N.E. Posthuma, J. van der Heide, G. Flamand, J. Poortmans, IEEE Trans. Electron Devices **54** (2007) 1210–1215.
[2] T. Kaneko, M. Kondo, Jpn. J. Appl. Phys. **50** (2011) 120204.
[3] R. Oshima, Y. Watanabe, M. Yamanaka, H. Kawanami, I. Sakamoto, K. Matsubara, I. Sakata, J. Crystal Growth (In Press)
[4] J. van der Heide, N.E. Posthuma, G. Flamand, W. Geens, J. Poortmans, Sol. Energy Mater. Sol. Cells **93** (2009) 1810–1816.
[5] M. Tanaka, M. Taguchi, T. Matsuyama, T. Sawada, S. Tsuda, S. Nakano, H. Hanafusa, Y. Kuwano, Jpn. J. Appl. Phys. 31 (1992) 3518–3522.
[6] M. Taguchi, A. Terakawa, E. Maruyama, M. Tanaka, Prog. Photovoltaics Res. Appl. **13** (2005) 481–488.
[7] Panasonic Co. News Release, Feb 12 2013.
[8] S. Nakano, Y. Takeuchi, T. Kaneko, M. Kondo, J. Non-Cryst. Solids **358** (2012) 2249–2252.
[9] H. Fujiwara, M. Kondo, Appl. Phys. Lett. **90** (2007) 013503.
[10] J.R. Weber, A. Janotti, P. Rinke, C.G. Van de Walle, Appl. Phys. Lett. **91** (2007) 142101.