Field:
Material/Biomaterial Science

Session Topic:
New Concept in Photovoltaic Energy (storage technique)

Speaker:
Takuya MATSUI, National Institute of Advanced Industrial Science and Technology

1. Introduction

Facing increasing demands for safe, clean and sustainable energy resources, development of renewable energy is an important subject assigned to the recent science and technology. Among a variety of energy-conversion technologies in progress, photovoltaic (PV) energy conversion becomes one of the most promising ways of meeting the future energy demands.

Currently, solar cells based on crystalline silicon wafers dominate more than 80 percent of the total PV market. Since the material cost of silicon wafer (~200 μm) accounts for nearly half of the manufacturing cost of solar cell device, the amount of silicon consumed must be reduced for further cost reduction. A less expensive alternative is the thin-film silicon solar cells (0.3~3 μm) which can be formed by the direct deposition on a cheap substrate over large area. Therefore, thin film silicon approach offers potential advantages over wafer-based silicon solar cells in terms of cost and material saving. Nevertheless, the conversion efficiency of the industrial thin-film silicon solar cell modules lies between 7 and 10%, which is about half that of crystalline silicon solar cells. To expand the PV market, power generation costs must be lowered through improvements of efficiency and manufacturing processes.

2. Present technologies

In thin-film silicon solar cells, a tandem device structure that combines different two light-absorbing materials is widely used [1]. The top cell consists of wide band-gap (E_g, 1.7 eV) hydrogenated amorphous silicon (a-Si:H) which absorbs the visible part of the sunlight. For bottom cell, a narrow band-gap (E_g, 1.1 eV) hydrogenated microcrystalline silicon (μc-Si:H) is generally used, absorbing the infrared light that passes through the top cell. Because the top and bottom cells are electrically connected in series, the output voltage is equivalent to the sum of the voltages of the individual component cells, leading to the increased output power (efficiency). The plasma-enhanced chemical vapor deposition method is widely used to grow these materials at low temperatures (~200 ^{o}C) on inexpensive substrates such as glass and plastics.

3. Remaining issues and challenges

Several technological issues remain in the conventional a-Si:H/μc-Si:H tandem solar cells. One is the light-induced degradation in a-Si:H top cell, and the other is the throughput of μc-Si:H bottom cell. We have conducted fundamental research and development to attain highly-stable a-Si:H solar cells and high-deposition-rate μc-Si:H solar cells. For a-Si:H solar cells, the light soaking stability has been improved by reducing the higher-order hydride bond density in a-Si:H network by using a remote-plasma deposition technique [2], leading to a high stabilized efficiency of 9.4%. For μc-Si:H bottom cells, we have developed a novel high-rate plasma deposition process which effectively enhance the plasma decomposition of source gases (SiH_4 and H_2) and reduce the plasma-induced damage of the μc-Si:H. This technique allows growing μc-Si:H at high rates (> 2 nm/s) while preserving excellent film qualities in terms of denser microstructure and less post-oxidation behavior [3]. The deposition technique has been successfully incorporated into the industrial plants for large-area and high throughput PV module production [4].

Despite the successful material combination of a-Si:H and μc-Si:H, the stabilized efficiency of the a-Si:H/μc-Si:H tandem solar cells is still limited as low as ~12%. The one of the biggest drawbacks of thin-film silicon solar cells is the low optical absorption because the light-absorbing layers are too thin to attain high sensitivity in the infrared region. To extend the spectral sensitivities of solar cells into longer wavelengths, we have developed hydrogenated microcrystalline silicon-germanium alloys (μc-$Si_{1-x}Ge_x$:H) [5] as a narrower-gap material that can be applied in multijunction structures such as a-Si:H/μc-$Si_{1-x}Ge_x$:H and a-Si:H/μc-Si:H/μc-$Si_{1-x}Ge_x$:H. So far, we have demonstrated efficient (~7-8%) μc-$Si_{1-x}Ge_x$:H (x~0.1-0.17) single junction solar cells exhibiting markedly higher short-circuit current densities than for μc-Si:H (x=0) solar cells due to enhanced infrared absorption.

4. Conclusions and perspectives

We have developed novel processes and materials for various Si-based thin film light-absorbing layers for realizing high-efficiency and cost-effective multijunction solar cells. To make breakthrough in the PV market, further improvement of solar cell performance is necessary in order to achieve our target efficiency of 15%. We will conduct further research and development to create innovative technologies that resolve technological issues, e.g., complete suppression of light-induced degradation in a-Si:H, advanced light management for the efficient light absorption in thinner devices, transparent electrodes with lower optical absorption over the wide spectral range, and μc-$Si_{1-x}Ge_x$:H bottom cells with even higher infrared sensitivity.

References

[1] J. Meier *et al.*, Solar Energy Material and Solar Cells, **66**, 73 (2001).
[2] S. Shimizu *et al.*, J. Appl. Phys. **97**, 033522 (2005).
[3] T. Matsui *et al.*, Jpn. J. Appl. Phys. Part 2, **42**, L901 (2003).
[4] H. Takatsuka *et al.*, Solar Energy, **77**, 951 (2004).
[5] T. Matsui *et al.*, Appl. Phys. Lett., **89**, 142115 (2006).