N2

Development of Thin Film Silicon Solar Cells
薄膜シリコン系太陽電池開発

Akihisa Matsuda
松田彰久

Research Institute for Science and Technology, Tokyo University of Science
2641Yamazaki, Noda-shi, Chiba 278-8510, Japan
東京理科大学　総合研究所，〒278-8510　千葉県野田市山崎2641

Recent progress is introduced in the development of thin-film silicon-based solar cell which is one of the most promising candidates for low-cost high-efficiency solar cells in the field of the photovoltaic solar energy conversion in the near future. Importance of the control of optoelectronic properties in thin film silicon materials, amorphous silicon and microcrystalline silicon, during film growth on the basis of microscopic understandings of their growth processes is emphasized.

1. Introduction

Solar energy is highly expected as clean and infinite energy resources, and photovoltaic solar energy conversion is recognized as the most convenient electricity-generation method among many technologies proposed to utilize the solar energy. Therefore, development of low-cost and high-efficiency solar cell is crucial issues to realize the large scale introduction of photovoltaic system and to cover a mass of electricity consumption in the future world.

A variety type of thin-film type solar cells such as hydrogenated amorphous silicon (a-Si:H), hydrogenated microcrystalline silicon (μc-Si:H), cadmium telluride (CdTe), copper indium di-selenide ($CuInSe_2$) etc., have been proposed .to reduce the production cost of solar cells. This is simply because single-crystalline silicon and poly-crystalline silicon solar cells, the most popular solar cells at present, take high cost for their production due to two main reasons. First, light-absorption coefficient in crystalline silicon is so low due to its indirect-optical-transition properties that more than several-ten micron in thickness is required to absorb sufficient sunlight. Second, the production process of crystalline silicon solar cells from source gas (trichloro-silane) takes high-temperature processes more than 1000 C at least three times and also involves slow process (crystal growth from the melt).

2. Thin film silicon solar cell

Thinking of the environmental problem and natural abundance of constituent of solar cells, silicon-based solar cells are considered as the most promising candidate among many candidates mentioned above. From this point of view, hydrogenated amorphous silicon (a-Si:H) has attracted an attention as suitable material for solar cells, since it shows no indirect-optical-transition properties and this material is popularly prepared by so-called low-temperature process of 200 C using plasma enhanced chemical vapor deposition (PECVD) method.

However, a-Si:H solar cell shows photo-induced degradation, in which the initial conversion efficiency of 10% for instance is degraded down to less than 8% by prolonged light irradiation. To overcome this problem, although it is essentially important to control the photo-induced degradation through the control of network structure responsible for this phenomenon in a-Si:H during film growth, tandem-type solar-cell structure has been proposed which consists of thin a-Si:H top cell and microcrystalline silicon (μc-Si:H) bottom cell showing no photo-induced degradation.

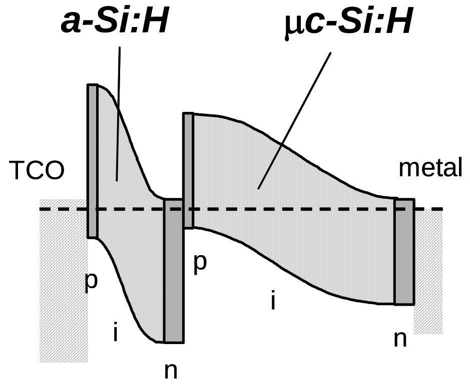

Fig. 1. Band diagram of tandem-type thin-film silicon solar cell and materials used in the cell.

Thin a-Si:H solar cell less than 0.1 microns does not show any photo-induced degradation due to large internal built-in field in p-i-n solar-cell structure by which recombination event of photo-excited electrons and holes in active i layer, being considered as the trigger action for photo-induced degradation, is avoided by efficient carrier correction into p-side and n-side electrodes. Transmitted light (red and infrared light) through thin a-Si:H top cell is well absorbed by the presence of μc-Si:H bottom cell whose optical band gap is narrower than a-Si:H.

More than 18% in conversion efficiency is theoretically predicted in tandem-type thin film silicon solar cells. However there are many material issues to be solved for actualizing low-cost and high-efficiency thin film silicon solar cells.

3. Material issues to be solved

We have to understand the growth process of a-Si:H as well as μc-Si:H from SiH_4-/H_2 reactive glow-discharge plasmas to improve optoelectronic properties of those materials for achieving high conversion efficiency and to increase their growth rates for actualizing low-fabrication cost. These are the materials issues for low-cost / high-efficiency tandem-type thin film silicon solar cells

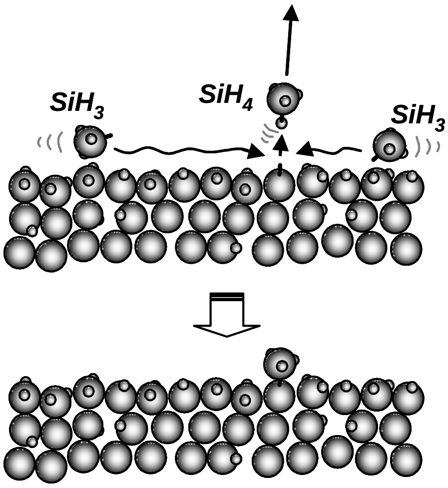

Fig. 2. Schematic sketch of surface-reaction process of a-Si:H growth by SiH_3 radicals.

Figure 2 shows schematic concept of surface reaction of a-Si:H sketched on the basis of experimental results obtained using a variety of surface-reaction-diagnostic techniques as well as gas-phase-reaction-diagnostic techniques applied to the growth process of a-Si:H and μc-Si:H from SiH_4-/H_2-reactive plasmas. Dominant film precursor is assigned to be SiH_3 radical for both a-Si:H and μc-Si:H growth, SiH_3 reaching the film-growing surface starts diffusing on the surface and abstract surface-covering bonded H to create a reactive site, and another SiH_3 diffusing on the surface finds the site to form Si-Si bond.

Performance of a-Si:H and μc-Si:H solar cells is mainly governed by the number density of carrier-recombination centers (dangling bond density in both cases) incorporated in active i layer, therefore, relevant surface-reaction process for determining the number density of dangling bonds in the resulting film should be identified. In this aspect, we have to keep in our mind the basic concept of thin film growth, i. e., the microscopic structure in the resulting material is determined by the top-surface and sub-surface structures during film growth, because the surface (or subsurface) at one instant becomes a part of bulk at the next instant by a successive film growth.

Many knowledge about the growth of a-Si:H and μc-Si:H have been accumulated in this decade, and dangling-bond density, for instance, has started to be controlled.

Now we have to start challenging to control the photo-induced degradation in a-Si:H. The Relationship between the degree of photo-induced degradation in a-Si:H based solar cells and the number density of Si-H2 bonds incorporated in a-Si:H, and the relationship between the number density of Si-H2 bonds in the resulting a-Si:H and the contribution ratio of higher silane-related reactive species (HSRS) such as Si_4H_9 during film growth, and furthermore the relationship between the contribution ratio of HSRS and the deposition parameters such as substrate temperature and plasma parameters (electron temperature and electron density) have recently been suggested. Therefore, control of the plasma parameter is the key point to improve the photo-induced degradation properties in a-Si:H, and high-efficiency tandem-type thin film silicon solar cells will be practical when the photo-induced degradation in a-Si:H is completely controlled, since two third of total electricity generation is governed by a-Si:H top cell in the tandem-type solar-cell structure.

Finally it should be noted here that large area uniform growth of high quality materials at high growth rate is also crucial key issue for actual industrialization of low-cost / high-efficiency thin film silicon solar cells, indicating a great importance of large-area-uniform high-density plasma production.