PROTOCRYSTALLINE SILICON-BASED MULTILAYER PHOTOVOLTAIC CELL

Koeng Su Lim

Korea Advanced Institute of Science and Technology, Department of Electrical Engineering & Computer Science, 373-1 Guseong-dong, Yuseong-gu, Daejeon 305-701, Republic of Korea

Thin film silicon solar cells employing amorphous silicon (a-Si:H) based absorbers have attracted great interest in industrial field due to their easy optical band gap design, low-temperature, low-cost, and large-scale production. However, a-Si:H has a serious light-induced degradation known as the Staebler-Wronski effect that can be suppressed by H_2 dilution. Recently, edge materials such as single layers of H_2-diluted protocrystalline silicon (pc-Si:H) or nanocrystalline silicon (nc-Si:H) were shown to be a better absorber than the H_2-diluted a-Si:H due to better metastability photosensitivity. However, since the former exist just below the threshold of an amorphous-to-microcrystalline transition and the latter exist just above the threshold of the transition, their depositions are very sensitive to the film thickness and H_2 dilution. Finally, an a-Si:H/H_2-diluted microcrystalline silicon (μc-Si:H) superlattice has been proposed as the most promising absorber due to its isotropic transport properties.

In this contribution we present newly developed pc-Si:H multilayer prepared by alternate H_2 dilution under continuous ultraviolet (UV) light irradiation using a photoassisted chemical vapor deposition (photo-CVD) system as a practical imitation of the a-Si:H/μc-Si:H superlattice. We observed fast stabilization and recovery by thermal annealing of pc-Si:H multilayer solar cells than a-Si:H and pc-Si:H single layer solar cells. However, the origin of the excellent light-soaking behavior has been still debated, because they could not provide obvious evidence for their expectation. We also discuss here a quantum-size-effect (QSE) of nc-Si grains regularly distributed in well-ordered a-Si:H matrix and investigate its impact on the light-soaking behavior of multilayer.

Figure 1 shows a schematic diagram of alternated hydrogen dilution (H_2/SiH_4) for an i-pc-Si:H multilayer preparation by using the photo-CVD technique. The i-pc-Si:H multilayer consists of low H_2-diluted and highly H_2-diluted a-Si:H sublayers. This repeatedly layered structure is deposited by just toggling the mass flow control of H_2/SiH_4 between 0 and R under continuous UV light irradiation. Due to the continuous deposition, all interfaces are graded by H_2 and the average deposition rate of the multilayer is comparable to that of conventional undiluted i-a-Si:H. During the deposition, however, the chamber pressure was also slightly toggled with the gas flow control because we maintained the angle of the automatic pressure controller (APC) at a constant value. To find an optimal layered structure, we deposited multilayers with changing R form 15 to 30. We changes a total cycles of H_2/SiH_4 modulation (N) in order to keep the thickness of multilayers at ~ 550 nm. It means that we increase N with the increase in R, because hydrogen coverage near growing surface increases during both the low H_2-diluted and highly H_2-diluted a-Si:H sublayer depositions due to the continuous deposition maintaining the angle of APC.

Figure 2 shows the normalized light-soaked behavior of a pin-type pc-Si:H multilayer solar cell with a structure of glass/SnO_2/undiluted p-a-SiC:H/H_2-diluted p-a-SiC:H/i-pc-Si:H multilayer (640 nm, R = 20)/n-μc-Si:H/Al (cell area: 0.092 cm^2).

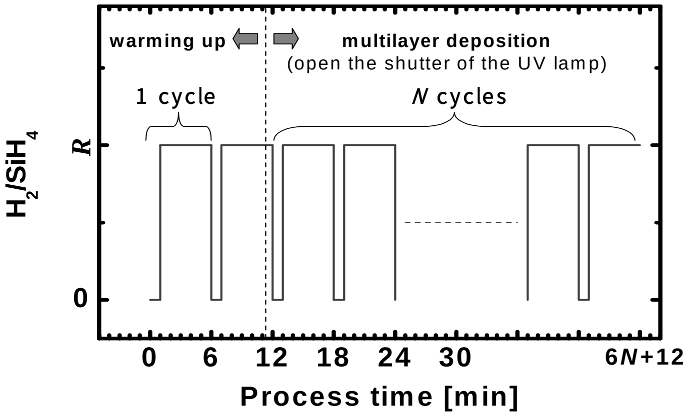

Fig. 1. Schematic diagram of the hydrogen dilution (H_2/SiH_4) modulation for i-pc-Si:H multilayer deposition.

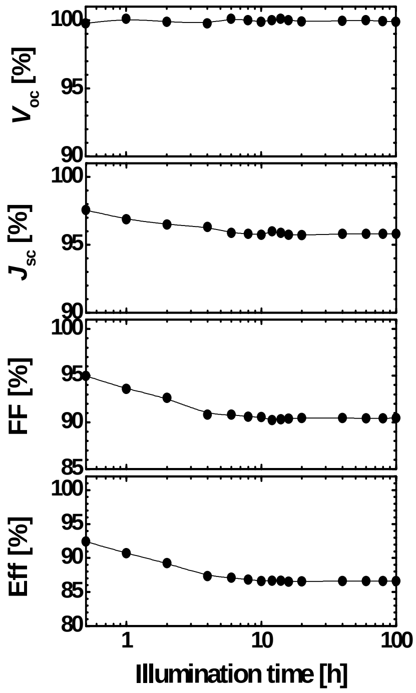

Fig. 2. Normalized light-soaked behavior of a pc-Si:H multilayer solar cell.

In summary, we have achieved a highly stabilized conversion efficiency of 9.0 % for a pin-type pc-Si:H multilayer solar cell fabricated by incorporating the double p-a-SiC:H structure and the layered structure of multilayer processing through alternate H_2 dilution. The fast metastability of the pc-Si:H multilayer leads to light-induced degradation that is superior to conventional a-Si:H and pc-Si:H single layer solar cells. Photoluminescence and Fourier transform infrared spectroscopy produced strong evidence that nc-Si grains embedded in regularly arranged highly H_2-diluted sublayers suppress the photocreation of dangling bonds. Fast light-induced stabilization and recovery by thermal annealing are mainly due to the fast recombination in the isolated nc-Si grains embedded within regularly arranged highly H_2-diluted sublayers.