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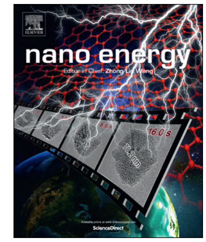

RAPID COMMUNICATION

Performance optimization of flexible a-Si:H solar cells with nanotextured plasmonic substrate by tuning the thickness of oxide spacer layer

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Abstract
Plasmonic thin film solar cells deposited on periodically textured photonic crystal substrates have been extensively studied since the substantially enhanced light absorption. The reduction of parasitic absorption losses in the metal and spacer layers becomes one of the key issues to achieve high efficiency solar cells. Herein, plasmonic amorphous silicon (a-Si:H) flexible thin film solar cells with different thickness of oxide spacer layers are systematically investigated. An increase of the spacer layer thickness leads to an evolution in surface morphology of AZO and final devices. More intriguingly, the increase of spacer layer thickness reduces the absorption in Ag layer while induces more absorption in spacer layer. The highest light absorption in silicon layer is observed as applying 100 nm spacer layer, which is further verified by electrical measurements. Our observations

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demonstrate a versatile and convenient route towards rational design of light harvesting nanostructure for high performance plasmonic solar cells based on a broad range of materials.

Introduction

Hydrogenated amorphous silicon (a-Si:H) thin-film solar cells are promising candidates for both large scale and portable photovoltaics, owing to their merits of low cost, material abundance, non-toxicity and compatibility with various types of substrates. The energy conversion efficiency of a-Si:H thin film solar cells can achieve up to 27% as its optical bandgap is around 1.7 eV according to the theoretical Shockley–Queisser detailed balance limit [1]. So far, the efficiency of state-of-the-art a-Si:H thin film solar cells is limited by 10.09% [2]. The large discrepancy between the theoretical indication and real device performance is attributed to the high density of tail and defect states in the a-Si:H thin film, which is responsible for the recombination losses and in turn low performance of the solar cells [3]. Reducing i-layer thickness will suppress the light-induced carriers' recombination loss, while the light absorption is also reduced. In order to comprise the carriers collection and optical absorption, a variety of random nanotextures [4] and periodic nanostructures including nanogratings [5,6], nanodomes [7–10], nanodents [11,12], nanovoids [13,14], nanoholes [15–17] nanopillars [18,19] nanospikes [20], nanorods [21] and inverted nanocones [22], have been developed to improve the light absorption capability while keeping the a-Si:H layer thickness as thin as possible. Metallic thin films are often integrated in these periodic structures, which can couple incident light into both the photonic and surface plasmon resonance modes in the absorption layer [11,23]. In the case of plasmonic a-Si:H thin film solar cells, the optical parasitic absorption loss in the metal layer is a key issue to be overcome. Recently, we have demonstrated amorphous silicon thin film solar cells on nanodent plasmonic substrate [11,12]. The light absorption loss in the Ag layer can be easily observed for wavelength beyond 600 nm and became more significant in the device with thinner absorbing layer [11]. An Al doped ZnO (AZO) spacer is usually placed between Ag and a-Si:H layer. Besides the limit of materials diffusion [24], the AZO spacer, with a lower refractive index, also acts the function to inhibit the losses in reflected light due to the excitation of surface plasmon resonance. The role of the spacer is to shift the plasmon resonance frequencies toward higher energies, that is already absorbed in the front part of the cell [25,26]. The recent report by Lal et al. indicated that the light confinement in silicon layer can be enhanced by modifying the thickness of AZO spacer layer in nanovoid plasmonic substrate [14]. However, the optical and electrical performance of plasmonic a-Si:H solar cells as a function of the thickness of AZO layer has not been well studied. Herein, a-Si:H solar cells with different thickness of AZO spacer layer on nanodent plasmonic substrate are systematically investigated. It is found that patterned substrates cause remarkable and broadband improvement on light absorption. Finite difference time domain (FDTD) simulation results demonstrate that the light absorption loss on the Ag surface is reduced as the AZO thickness increases, while the thicker AZO absorbs more light. In addition, solar cell with 100 nm AZO can confine the incident light in silicon layers much more effectively, leading to its highest short circuit current (J_{SC}). These results not only provide an effective method to understand the coupling effect of light propagation and electrical transport, but also demonstrated a possible strategy to design and optimize the nanostructured thin film solar cells based on other photovoltaic materials.

Experimental

Fig. 1a schematically shows the layered structure of an a-Si:H thin-film cell deposited on nanopatterned Al substrate. Detailed fabrication processes of the patterned Al substrate can be found in our previous work [11,12]. A 100 nm thick Ag layer was deposited on the patterned Al substrate by direct current magnetron sputtering at room temperature in argon plasma atmosphere. Then, the AZO spacer layers, whose

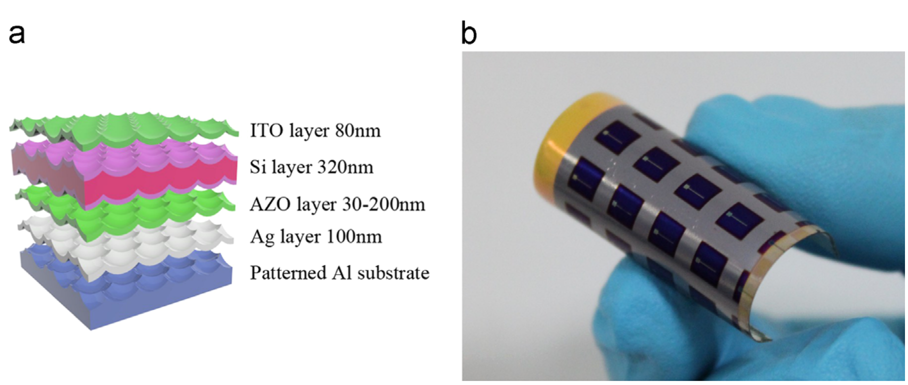

Fig. 1 (a) Schematic view of a-Si:H thin-film cell layer structure. (b) Digital photograph of a-Si:H cell device deposited on patterned Al substrate.