Thin Solid Films 675 (2019) 109–114

Contents lists available at ScienceDirect

Thin Solid Films

journal homepage: www.elsevier.com/locate/tsf

Characterization of SiNx:H thin film as a hydrogen passivation layer for silicon solar cells with passivated contacts

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ARTICLE INFO

Keywords:
Silicon nitride
Passivated contact
Passivation
Solar cells

ABSTRACT

Silicon nitride (SiNx:H) films are generally used as passivation and anti-reflection layers in solar cells, and they are usually made by plasma-enhanced chemical vapor deposition (PECVD). Silicon nitride could act as a hydrogen diffusion source, and it also plays a role in chemical passivation. In this study, we investigated the improvement of the passivation characteristics of the passivated contact structure by a PECVD SiNx:H hydrogenation process and the characteristics of SiNx:H for improving the passivation characteristics. It was confirmed that the passivation characteristics cannot be predicted only by the mass density of the SiNx:H film, and the chemical bonding ratio in the SiNx:H thin film is also important. In addition, higher passivation characteristics can be obtained when SiNx:H thin films with higher S—H bond concentration and dominant $N_2Si{-}H_2$ bonds are used.

1. Introduction

Hydrogenated silicon nitride (SiNx:H) layer deposited by plasma-enhanced chemical vapor deposition (PECVD) is used as a hydrogen source for improving the performance of semiconductor-based electronic and electric devices. The diffused hydrogen from SiNx:H by heat treatment associates with impurities and defects in bulk and passivates them [1,2]. There are two mechanisms proposed to describe the hydrogen desorption mechanism from SiNx:H films, either through the diffusion of atomic hydrogen, and/or molecular hydrogen [3,4]. Benoit et al. proposed that the hydrogen desorption reaction occurs mainly through dissociation reactions between Si—H and N—H bonds giving free molecular hydrogen and generating new Si—Si or Si—N bonds, which are observed by the bonding and mass measurements of SiNx:H before and after annealing [5]. Therefore, the chemical bonding configuration in SiNx:H can be used as an indicator of the hydrogen release potential, while the mass density of SiNx:H is proposed as another criterion. Low density ($< 2.5\,g/cm^3$) films desorb high amount of H (over 1×10^{17} at./cm^2) and are permeable to H, while higher density ($\geq 2.5\,g/cm^3$) films act as barriers and do not allow H to pass through them [5]. However, several studies have shown that a higher hydrogen desorption from SiNx:H by the annealing process does not simply lead to a higher degree of bulk passivation in the multicrystalline silicon solar cells [6–8]. Rather, the degree of bulk passivation increases as the density of the SiNx:H film increases. Therefore, additional research is needed to improve passivation quality by hydrogenation.

The stagnant efficiency of silicon solar cells has increased in recent years with the development of various structures such as heterojunction back contact, polycrystalline on oxide passivating contact and tunnel oxide passivated contact structures [9–11]. This is accomplished by applying a passivated contact structure onto the previously proposed back contact and heterojunction structures [12]. The passivated contact structure provides interface passivation by placing a few-nanometer-thick layers of thin intrinsic amorphous silicon or oxide thin films between the bulk and the heavily doped layer. Furthermore, the highly doped layers provide band-bending in the bulk, resulting in a field passivation effect [12,13]. In addition, it is possible to eliminate complicated processes such as contact patterning and local doping formation process for minimizing the recombination area and improving the contact resistance. The passivated contact structure further enhances the passivation effect through the hydrogenation process which can passivate grain boundaries in the high-doped layer and the pin-holes

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https://doi.org/10.1016/j.tsf.2019.02.016
Received 1 August 2018; Received in revised form 19 January 2019; Accepted 10 February 2019
Available online 11 February 2019
0040-6090/