Thin Solid Films 635 (2017) 63–65

Contents lists available at ScienceDirect

Thin Solid Films

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

Post-deposition catalytic-doping of microcrystalline silicon thin layer for application in silicon heterojunction solar cell

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ARTICLE INFO

Article history:
Received 11 October 2016
Received in revised form 25 January 2017
Accepted 1 February 2017
Available online 3 February 2017

Keywords:
Catalytic-doping
Shallow doping
Microcrystalline silicon
Conductivity
Lifetime
Heterojunction

ABSTRACT

The silicon heterojunction (SHJ) solar cell is one of the most promising candidates for the next-generation high-efficiency mainstream photovoltaic technology. It consists of a crystalline silicon wafer coated with a stack of functional thin-films on both sides. Conventionally, intrinsic and doped hydrogenated amorphous silicon (a-Si:H) is used as the passivation layer and emitter or back surface field (BSF), respectively. Hydrogenated microcrystalline silicon (μc-Si:H) is considered as a more advantageous alternative to the a-Si:H emitter and BSF layers due to μc-Si:H's higher electrical conductivity giving rise to lower series resistance. In this contribution, we use the catalytic doping process, so-called "Cat-doping", to post-dope n-μc-Si:H thin-layers in such a way that the conductivity can be increased to higher levels than those achievable in as-grown n-μc-Si:H for the application in SHJ solar cells. We show that the conductivity of the μc-Si:H films notably increases after the Cat-doping. We also investigated the impact of Cat-doping on the conductivity of the different μc-Si:H and on lifetime.

1. Introduction

The SHJ solar cell has shown high open-circuit voltage (V_{oc}) because their surface dangling bonds are effectively passivated by high quality hydrogenated amorphous silicon (a-Si:H) thin films leading to low surface recombination. Consequently, the SHJ solar cell has demonstrated high efficiencies of over 25% [1–4]. These SHJ solar cells generally consist of a high quality crystalline silicon wafer coated with a stack of various functional layers on both sides; doped a-Si:H carrier selective contacts, transparent conductive oxide, metal contacts as well as intrinsic a-Si:H surface passivation layers. Typically, p- and n-a-Si:H layers have high absorption coefficients which lead to high parasitic absorption losses when deposited at the front side of solar cells resulting in low short circuit current density (J_{sc}). Hydrogenated microcrystalline silicon (μc-Si:H) is an appealing alternative for the front a-Si:H carrier selective contacts because its absorption coefficient at short wavelengths is much lower than that of a-Si:H leading to lower parasitic absorption. In addition, the conductivity of μc-Si:H can be considerably increased than that of a-Si:H which can reduce series resistance. However, the conductivity of μc-Si:H is largely dependent on its crystallinity and doping concentration. The deposition conditions of μc-Si:H are usually compromised at optimal trade-off because the crystallinity of μc-Si:H tends to be suppressed as dopant gas flow increases [5–7] limiting the conductivity of μc-Si:H. Matsumura et al. presented that the properties of as-grown silicon films and wafers could be tuned using catalytic-doping (Cat-doping) process even after depositions [8,9]. This Cat-doping process is a post-doping process where dopant gases can be decomposed by catalytic cracking reaction at the hot surface of the wires and, subsequently, the decomposed species contribute to the doping of the silicon surface at a shallow depth. As a consequence, the conductivity of Si films can be further improved using this technique [10].

In this contribution, we first fabricate various intrinsic Si thin films having different crystalline volume fraction and their electrical properties are mainly characterized. P Cat-doping is performed on the as-grown intrinsic Si thin films in order to clearly confirm the impact of P Cat-doping. Subsequently P Cat-doping is carried out on the as-grown n-μc-Si:H films to check their applicability to the back or front surface field layers in SHJ solar cells. The different n-μc-Si:H films are tested which are fabricated at different deposition conditions but have the similar material properties. The influence of P Cat-doping on the conductivity and effective lifetime of n-μc-Si:H films and wafers with film stacks are investigated. Finally, the effect of Cat-doping conditions and post-annealing is studied to improve the lifetime. In this study, the correlation between deposition conditions, materials properties and Cat-doping are discussed.

2. Experimental details

Intrinsic μc-Si:H (i-μc-Si:H) films with a thickness of 150– 350 nm and n-type μc-Si:H (n-μc-Si:H) with a thickness of 50 nm were deposited on glass using plasma enhanced chemical vapor deposition with a very high frequency (81.36 MHz) generator. During depositions of the i-μc-Si:H, silane (SiH_4) to hydrogen (H_2) ratios ($r_{SiH4/H2}$) were varied

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http://dx.doi.org/10.1016/j.tsf.2017.02.003
0040-6090/