Solar Energy 146 (2017) 44–49

Contents lists available at ScienceDirect

Solar Energy

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

Patterning and formation of copper electroplated contact for bifacial silicon hetero-junction solar cell

Jian Yu [a,b], Jiantao Bian [a], Yucheng Liu [a], Fanying Meng [a], Zhengxin Liu [a,b,*]

[a] Research Center for New Energy Technology, Shanghai Institute of Microsystem and Information Technology (SIMIT), Chinese Academy of Sciences (CAS), 235 Chengbei Road, Shanghai 201800, PR China

[b] University of Chinese Academy of Sciences, 100049 Beijing, PR China

ARTICLE INFO

Article history:
Received 18 April 2016
Received in revised form 23 September 2016
Accepted 14 February 2017

Keywords:
Silicon heterojunction solar cell
Metal electrode
Copper plating
Patterning

ABSTRACT

In this work, tungsten doped indium oxide (IWO) film was deposited as anti-reflection coating and conductive layer for silicon hetero-junction (SHJ) solar cell, which meant the necessity to mask the pattern of grid electrodes for selective plating. We investigated the plating process and compared three different masking resists suitable for large area SHJ solar cells. The results revealed that light-sensitive dry film was appropriate as plating resist due to its simple process, high resolution and rectangular shape. As a proof of concept, copper plated SHJ solar cell with an efficiency of 22% was fabricated in SIMIT's R&D line. Compared with screen printed finger, copper plated finger showed narrow width, higher aspect ratio and lower bulk resistivity, leading to decreased shading loss without increasing girds power loss. The metallization refinement contributed 2.80% of power loss reduction, which indicated the possibility to achieve higher efficiency by copper metallization after well optimization.

1. Introduction

Amorphous/crystalline silicon hetero-junction (SHJ) solar cell is a promising candidate for low cost, high efficiency solar cells and modules owing to its remarkable low recombination, high Voc, simple structure, low process temperature and low temperature coefficient (Kleider et al., 2015; Mishima et al., 2011; Shen et al., 2013). In addition, benefiting from the bifacial-ready symmetric transparent conducting oxide (TCO) structure, the scattered light to the opposite side of emitter can further boost solar cell's current and efficiency. Panasonic has presented its SHJ solar cell with high efficiency of 24.7% (Taguchi et al., 2013), and this record has been increased to 26.33% for back contact SHJ solar cell.

Typically, screen printing low temperature silver paste as conductor grids is the common technique for SHJ solar cell's metallization. However, limited by the temperature mandatory of SHJ solar cell, the annealing temperature above 260 °C must be strictly avoided (Jeyakumar et al., 2014). Therefore, the screen printed finger after annealing is porous, with many voids in size of hundreds nanometers (Yu et al., 2014a), resulting in its resistivity three to six times higher than the high-temperature counterparts (Wolf et al., 2012). That is, additional silver is required to limit the resistive loss, which leads to increasing cost.

Copper is considered as a perfect alternative for solar cell's metallization for its high conductivity (the second highest conductive element after silver) and low price (only about 1/100 of silver). Furthermore, copper plating is a low cost and industrially proven technology that can overcome the limitations of screen printing technology. According to our previous work (Yu et al., 2016), resistive loss would obviously increase for low temperature silver paste when finger width below 50 μm for H pattern grids design. However, the copper plated finger width can reach as narrow as 30 μm with lower contact resistance and finger resistance, showing promising application. Therefore, recent progresses dedicated to metallization of SHJ solar cell are utilizing plated copper to replace low temperature silver paste as electrode material, which benefit from reduced optical and resistive losses, resulting in higher efficiency (Heng et al., 2015; Lee et al., 2015; Muñoz et al., 2012; Uto et al., 2014).

For copper metallization of SHJ solar cell, TCO film is not just as contact layer and anti-reflection coating, but as a barrier layer to prevent copper diffusing into silicon. Fortunately, IWO film is an effective copper diffusion barrier until 800 °C, which means excellent long term stability at solar cell module's operating temperature (Yu et al., 2014b, 2016). In this paper, we employ plated copper to replace screen printed low temperature silver paste for SHJ solar cell, after investigating pattern methods and developing

* Corresponding author at: Research Center for New Energy Technology, Shanghai Institute of Microsystem and Information Technology (SIMIT), Chinese Academy of Sciences (CAS), 235 Chengbei Road, Shanghai 201800, PR China.

E-mail address: z.x.liu@mail.sim.ac.cn (Z. Liu).

http://dx.doi.org/10.1016/j.solener.2017.02.022
0038-092X/

plating process. The plated SHJ solar cell shows excellent properties and means great potential to achieve even higher efficiency after proper optimization.

2. Experimental details

2.1. Preparation of SHJ substrates

The 5 in. (125 mm × 125 mm) n-type c-Si (1 0 0) wafers with resistivity of 1–6 Ω cm were used as the substrates. The wet-chemical process with an alkaline solution was applied to remove saw damage and create a random pyramid surface texture anisotropically. The wafers were then cleaned with a standard wet-chemical cleaning sequence RCA clean 1 and 2, followed by a dip in dilute HF (1%) and a deionized water rinse. Both intrinsic and doped a-Si:H layers on the front and rear side were deposited for the emitter and back surface field at a low substrate temperature of less than 180 °C by plasma enhanced chemical vapor deposition (PECVD), respectively. On the front side, a-Si:H (i) and boron-doped a-Si:H (p+) layers were deposited, followed by the deposition of a-Si:H (i) and phosphorus-doped a-Si:H (n+) layers onto the rear side. Power densities and deposition pressures were in the range of 10–30 mW/cm^2 and 20–300 Pa. The electrode distance and $[SiH_4]/[H_2]$ flow ratio were 25 mm and 2, respectively. Low damage and high atomic-H density of hydrogen-plasma treatment were realized under the conditions of 200 Pa, 30 mW/cm^2 and a hydrogen flow rate of 600 sccm, which were chosen before and after the i-a-Si:H deposition so that the thickness of i-a-Si:H could be maintained. Then, tungsten doped indium oxide films, with the thickness of 80 nm on both sides, were deposited by using a reactive plasma deposition (RPD) system installed with a 1 wt.% WO_3-doped In_2O_3 target. The deposition was performed in 10–30% O_2/Ar mixture at the working pressure of 0.25–0.50 Pa. The substrate holder was maintained at 120 °C during the deposition.

Following RPD, the samples were sorted into two groups. Group A was metalized by electroplating Cu/Sn stack layer. The patterned SHJ substrate was fixed in a special holder. Each side was connected to DC power source for direct plating by three electric contact points contacting to busbars. Copper was plated under the conditions of 2 A (∼7.5 ASD), 15 min with phosphorous-copper anode (0.02–0.1% phosphorous content). Then, copper was covered by plated tin coating as soldering layer with 0.5 A (∼1.9 ASD), 5 min with high purity tin anode. The temperature of copper solution and tin solution was 30 °C. The detailed process will be discussed later. Group B was metalized by screen printing silver grids on both sides and annealed at 200 °C for 30 min.

2.2. Measurement systems

Spectroscopic ellipsometer (J.A. Wollam Co., Inc. M-2000) was used to measure the thickness of IWO film to match the thickness proper as an antireflection layer for SHJ solar cell. The geometries were measured by Olympus Optical microscope with a CCD camera and 3D measuring laser microscope (Olympus OLS-4100). Surface morphologies and microstructures were investigated by field-emission scanning electron microscope (FE-SEM) measurement. Finally, SHJ solar cells were characterized by using current-voltage (I-V) measurements under standard test conditions.

3. Results and discussion

3.1. Plating process for bifacial SHJ solar cells

According to the structure of bifacial SHJ solar cell, IWO film is deposited as anti-reflection coating and conductive layer, which means plating metal on IWO film directly is non-selective. Therefore, resist material with patterned openings is necessary to mask IWO film. The detailed plating process for bifacial SHJ solar cell is shown in Fig. 1. After preparing SHJ substrate, copper seed-layers with thickness of 100 nm were deposited by physical vapor deposition (PVD) on both sides of IWO films for better adhesion and electric contact. Then, plating resist was prepared. As for light-sensitive resist, the unexposed resist could then be dissolved easily by 1% Na_2CO_3 at 45 °C to form designed finger pattern, when placed under a UV exposure machine with photo mask. Thus, selective electroplating was achieved and both surfaces were plated simultaneously with a special fixture. After plating, plating resist was stripped by a 3–5% NaOH solution at 40–50 °C. Finally, thin copper seed layers were etched back selectively to form copper electroplated SHJ solar cell.

3.2. Pattern methods for bifacial SHJ solar cells

Different masking techniques have been evaluated for SHJ solar cells. Hot-melt resist material with the negative H-pattern front grids was deposited by inkjet printing technique (Papet et al., 2013). It is an effective masking technique, but requiring many printing passes for bifacial masks. Also, pattern was achieved by inkjet printing a functional ink on a resist surface (Li et al., 2015), but still needing subsequent thermal process and development. Besides, conventional liquid photolithography based process including spin-coating step is applied for small area (Geissbuhler et al., 2014) which is hard to transfer to large area solar cell and

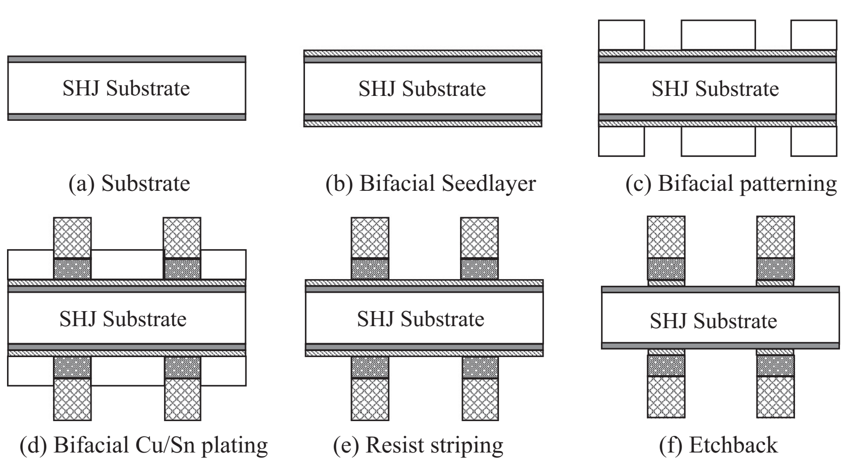

Fig. 1. The plating process for bifical SHJ solar cell.