Solar Energy Materials & Solar Cells 163 (2017) 164–169

Contents lists available at ScienceDirect

Solar Energy Materials & Solar Cells

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

Colored a-Si:H transparent solar cells employing ultrathin transparent multi-layered electrodes

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ARTICLE INFO

Keywords:
A-Si:H
Building-integrated photovoltaic
Multi-layered electrode
Ultrathin transparent electrode

ABSTRACT

We fabricated hydrogenated amorphous silicon (a-Si: H) transparent solar cells using ultrathin transparent multi-layered electrodes (TMEs) as rear-side transparent electrodes for building-integrated photovoltaic (BIPV) windows. Each TME included a bottom layer, thin Ag layer, and optoelectronic controlling layer (OCL). The TMEs were experimentally designed to have high transparency and conductance. The fabricated a-Si:H transparent solar cells showed optimal performance with a 6.36% power-conversion efficiency and 23.5% average transmittance (500–800 nm) when TMEs with a thickness less than 160 nm were incorporated. We demonstrated that the reflection color of the cell could be tuned without serious loss of cell efficiency by varying the thickness of the OCL. The backside colors were predicted to be the coordinates on a CIE 1931 chromaticity diagram using the reflection spectrum from the cell and emission spectrum of a 50 W LED light source. The developed a-Si:H transparent solar cells exhibited high efficiency and show feasibility for incorporating various colors in the photovoltaic and aesthetic functionalities of BIPV windows.

1. Introduction

Human residential areas are the main emitters of greenhouse gases and consumers of electrical power. Recently, zero-energy building (ZEB) technologies have attracted great interest in connection with climate change and the depletion of fossil fuels [1]. As one of the promising candidates among ZEB technologies, building-integrated photovoltaic (BIPV) systems can improve energy-consumption efficiency and reduce environmental side effects by using solar energy on-site to provide electricity without CO_2 emissions [2]. Transparent solar cells can be used, as parts of ZEB technologies, in roofs, facades, and windows. In addition, they can be used in automobile sunroofs [3]. When transparent cells are used as BIPV windows, they can work as bifacial cells, providing the benefit of electrical generation [4,5]. If they are to work well as parts of various building designs, BIPV windows need to appear in various colors to match the aesthetic requirements of those designs.

Hydrogenated amorphous silicon (a-Si: H) solar cells are suitable for semi-transparent or transparent solar windows for several reasons: Si is non-toxic; a-Si:H-based solar cells are easy to fabricate on large-area glass substrates; these cells have proven their long-term stability in the field [2,6]. In a-Si:H solar cells, transparent conducting oxide (TCO) layers are commonly used for front-transparent conducting electrodes (TCEs), where the front color of a cell is determined by the reflection from the TCO layer. To date, indium tin oxide (ITO), fluorine-doped tin oxide and zinc oxide (ZnO) TCEs have been used widely in various optoelectronic devices: flat-panel displays, optical sensors, touch screens, and solar cells [7–9]. Among them, ITO has the best conductivity and transparency, but its higher price, because of the scarcity of indium, and chemical instability are the concerns that arise when considering the use of ITO [10–12]. In our previous reports, we developed transparent a-Si:H cells with enhanced efficiency and transmittance without metal grids [13,14] and showed the possibility of color-tuning by controlling the thicknesses of Cu_2O layers [15,16]. However, in general, controlling the colors of cells by changing the thicknesses of TCO layers results only in variations of the conductivity

Abbreviations: a-Si:H, hydrogenated amorphous silicon; BIPV, building-integrated photovoltaic; EQE, external quantum efficiency; GZO, ZnO:Ga; ITO, indium tin oxide; NW, nanowire; OCL, optoelectronic controlling layer; OMO, oxide-metal-oxide; TCE, transparent conducting electrode; TCO, transparent conducting oxide; TME, transparent multi-layered electrode; ZEB, zero-energy building

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http://dx.doi.org/10.1016/j.solmat.2017.01.017
Received 23 May 2016; Received in revised form 11 January 2017; Accepted 12 January 2017
Available online 26 January 2017
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