Solar Energy 159 (2018) 465–474

Contents lists available at ScienceDirect

Solar Energy

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

Bifacial color realization for a-Si:H solar cells using transparent multilayered electrodes

Gayoung Kim[a,b], Jung Wook Lim[a,b,*], Myunghun Shin[c,*], Sun Jin Yun[a,b]

[a] ICT Materials Research Group, Electronics and Telecommunications Research Institute (ETRI), 218 Gajeong-ro, Yuseong-gu, Daejeon 34129, Republic of Korea
[b] Department of Advanced Device Technology, University of Science and Technology (UST), 217 Gajeong-ro, Yuseong-gu, Daejeon 34113, Republic of Korea
[c] School of Electronics and Information Engineering, Korea Aerospace University, Goyang-city, Gyeonggi-do 412-791, Republic of Korea

ARTICLE INFO

Keywords:
BIPV
a-Si:H solar cell
Transparent cell
Bifacial colored transparent solar cell

ABSTRACT

Transparent hydrogenated amorphous silicon (a-Si:H) thin-film solar cells, in which the colors of the front and rear faces can be adjusted individually, were developed for implementation in building-integrated photovoltaic (BIPV) windows. The proposed ultrathin transparent multilayered electrodes (TMEs) are highly conductive and transparent, consisting of a bottom layer of gallium-doped zinc oxide (GZO), a thin metal layer of Ag, and an optoelectronic controlling layer (OCL) of GZO. They can be used for both the front and rear electrodes of transparent a-Si:H solar cells, and the resulting solar cells show a 5.0% average power conversion efficiency and 18.3% average transmittance. The various dual colors on the front and rear of the cell can be individually adjusted by changing the thickness of the OCL on each face of the TME, without significantly changing the efficiency. The cell colors were quantitatively investigated using the color coordinates in a chromaticity diagram based on the International Commission on Illumination (CIE; 1931) standard to show that the simulated and observed colors match well under both LED and fluorescent light sources. We also show that the observable color of the BIPV windows is determined by indoor and outdoor light sources, and dynamically varies as a function of illuminance of the light source as the day gradually progresses into night. This study helps to elucidate the color behavior of the BIPV windows and to develop a-Si:H BIPV windows that show various colors with stable electrical power generation.

1. Introduction

Building-integrated photovoltaic (BIPV) systems have been developed over the last decade with the objective of fulfilling increasing energy demand, and they have also been considered as aesthetically pleasing building components (Benemann et al., 2011; Fung and Yang, 2008; Lim et al., 2013; Yoon et al., 2011). Solar windows with various exterior and interior colors are especially needed.

Dye-sensitized solar cells (DSCs) are transparent in structure and have therefore been studied for their applicability in solar windows (Hagfeldt et al., 2010; Park and Kim, 2008; Yoon et al., 2011); however, DSCs suffer from poor stability due to electrolyte leakage and dye degradation at high temperatures (Lee et al., 2008; Otaka et al., 2004). DSCs with different cell colors have been realized by using different types of dyes and electrolytes. Dyes are used as light absorbing materials in DSCs, and controlling the cell color using the dye can cause a large variation in efficiency, even inducing very low efficiencies in the range of 1.6–2.7% (Otaka et al., 2004). Organic solar cells have shown promise for the realization of various cell colors and for achieving easy control of transparency. However, their efficiency remains very low, and compared to inorganic solar cells, their stability is unfavorable for use as long-term reliable BIPV components considering building lifecycles (Ameri et al., 2010; Kong et al., 2014; Lee et al., 2014; Nikiforov et al., 2013). Conventional crystalline-silicon-based solar cells are opaque and therefore impracticable for use as solar windows, and their efficiencies vary in a wide range of 13.0–19.8% with cell-color variation (Selj et al., 2011).

Hydrogenated amorphous silicon (a-Si:H) thin-film solar cells have emerged as promising candidates for solar windows because they can be feasibly produced on large-scale glass substrates at low cost. A-Si:H-based devices have already shown high stability in solar cells, displays, and semiconductor devices (Maurus et al., 2004; Müller et al., 2004; Rech and Wagner, 1999; Shah et al., 2004; Yang et al., 2011). Among various types of a-Si:H solar cells, aperture-type cells, which pass color-neutral light through laser-scribed patterns on metal grids, suffer from poor visibility and an inherent trade-off between efficiency and

* Corresponding authors at: Electronics and Telecommunications Research Institute (ETRI), 218 Gajeong-ro, Yuseong-gu, Daejeon 34129, Republic of Korea (J.W. Lim); School of Electronics and Information Engineering, Korea Aerospace University, Goyang-city, Gyeonggi-do 412-791, Republic of Korea (M. Shin).
E-mail addresses: limjw@etri.re.kr (J.W. Lim), mhshin@kau.ac.kr (M. Shin).

https://doi.org/10.1016/j.solener.2017.11.019
Received 6 July 2017; Received in revised form 2 November 2017; Accepted 9 November 2017
Available online 15 November 2017
0038-092X/