Multilayer dielectric mirror-integrated colored hybrid solar cells

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***Abstract*—In this paper, multi-functional amorphous silicon/organic hybrid solar cells that can create desired reflective colors exploiting a dielectric mirror are presented. Iridescent colors can be easily produced by controlling an angle of incidence and a polarization state of incident light. The presented approach can be applied to building-integrated solar cells, power-generating automobile surfaces, and self-powered electronic devices.**

Keywords—solar cells, coloring, dielectric mirror, interference

I. Introduction

Colorful and see-through solar cells have in recent years generated significant interest since they open up the possibility to harmoniously integrate the solar cells with building envelopes such as ceilings, walls, facades, skylights, and windows. In addition to the buildings, they can be smoothly incorporated with automobile surfaces and various electronics for electric power generation and simultaneously decoration. Neutral-colored semitransparent solar cells using transparent conductive electrodes based on metal nanowires, graphenes, metal meshes, and carbon nanotubes have been demonstrated, which can be applied to power-generating windows [1]. There have also been many attempts to create multi-colored solar cells that can offer more aesthetic functionality into the buildings and automobiles as compared to the neutral-colored solar cells. Moreover, the colored solar cells can be employed in energy-efficient display technologies and wavelength-selective self-powered electronic and optoelectronic devices. Various approaches, which rely on plasmonic resonances in metal-insulator-metal nanostructures patterned at the subwavelength scale and Fabry-Perot resonances in thin-film multilayer structures, have been proposed and experimentally demonstrated [2-4].

In this work, decorative amorphous silicon (a-Si)/organic hybrid solar cells integrated with a multilayer dielectric mirror (MDBR) are described. The MDBR reflects a certain portion of visible light to produce reflective colors and the rest of incident light is efficiently harvested by the hybrid solar cells to generate electric power. Effects of incident angles and incident polarization on reflection spectra and the corresponding color purity of the colored hybrid solar cells are studied. The scheme described here could open the door to a multitude of applications, including building-integrated photovoltaics, energy-saving display systems, and self-powered wearable devices.

II. Results and Discussion

Fig. 1 (a) presents schematic diagram of the proposed colored solar cells where the MDBR is integrated with an anode (ITO) of the a-Si/organic hybrid solar cells. The MDBR is designed to have a narrow photonic band (i.e., high reflection region) for generation of blue (B), green (G), and red (R) reflective colors. Thus, it is necessary to have a small refractive index contrast between two alternating materials in the MDBR: zinc sulfide (ZnS) and tantalum pentoxide (Ta_2O_5) are chosen for the dielectric materials of the MDBR. Reflection spectra of the colored hybrid solar cells at normal incidence are calculated by using transfer matrix method, as shown in Fig. 1 (b). Main peaks in the calculated reflection spectra at desired wavelengths for RGB reflection color generation are achieved, although several other reflection peaks at longer wavelengths are also observed, which could degrade the color purity.

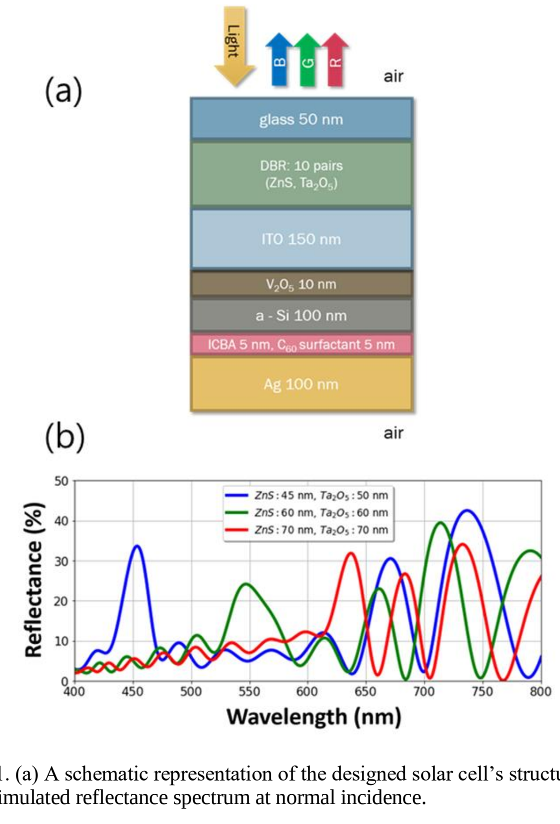

Fig. 1. (a) A schematic representation of the designed solar cell's structure. (b) Simulated reflectance spectrum at normal incidence.

Next, we studied how optical properties of the colored hybrid solar cells are affected by both incident angles and polarization. Fig. 2 exhibit calculated reflection spectra (left) at oblique angles of incidence ranging from 0° to 75° for different polarization, and the corresponding color spaces (right) illustrated on the CIE 1931 chromaticity diagram. It is apparent that the estimated reflective colors of each colored device can be readily tuned by varying the incident angle and the polarization.

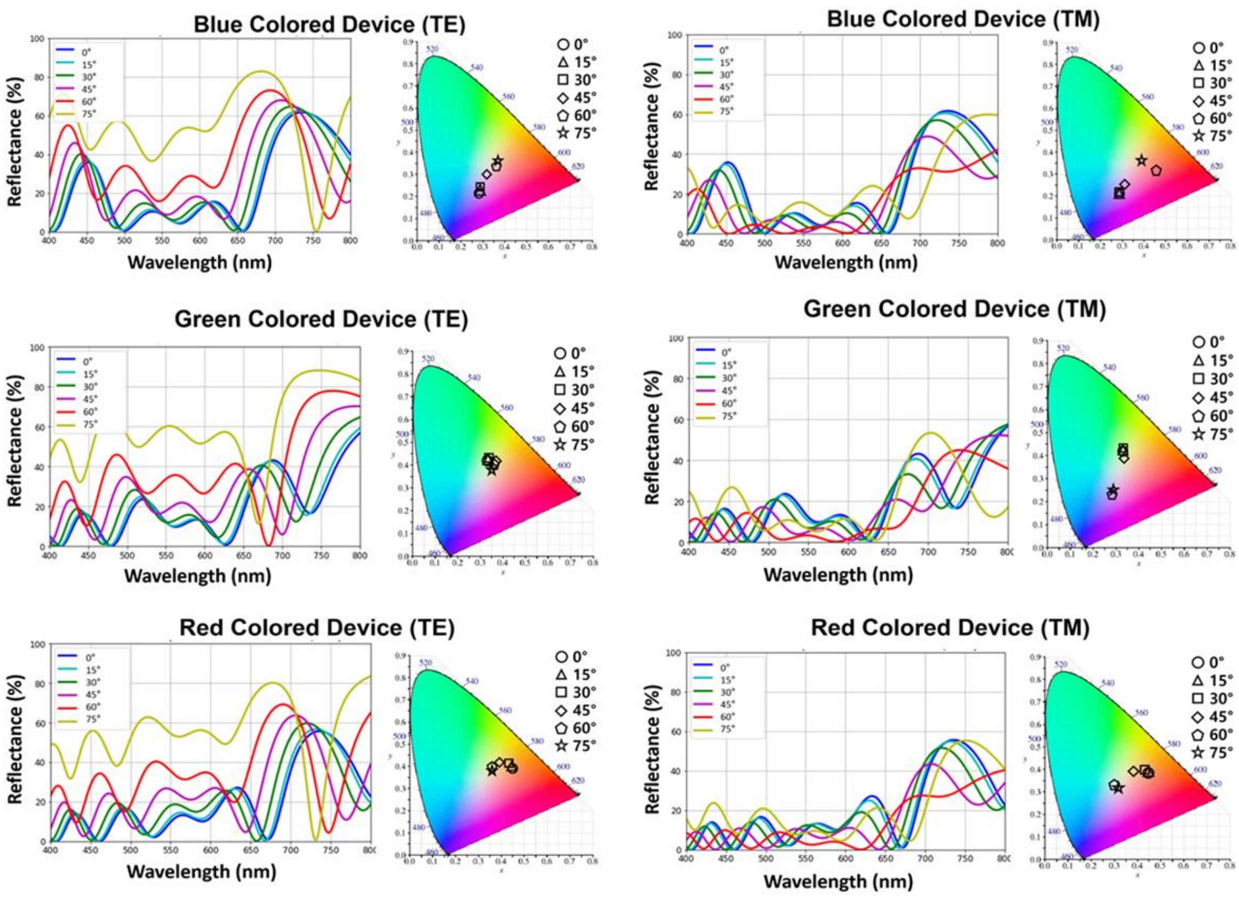

Fig. 2. (Left-hand side) Simulated reflectance spectra of the colored solar cell with different angle of incidence for TE and TM wave. (Right-hand side) Calculated reflectance spectra of colored a-Si solar cell are described on the CIE 1931 chromaticity diagram.

For TE polarization where the electric field is perpendicular to the plane of incidence, the reflection efficiency increases over a broad range of wavelengths at non-normal incident angles. As a result, the calculated color coordinate moves to a neutral region (i.e., center of the chromaticity diagram). For TM polarization where the electric field is parallel to the plane of incidence, on the other hand, the overall reflection spectrum shifts toward a shorter wavelength region with increasing the angle of incidence. It is expected for the B colored cell to show a reddish color at a large oblique angle as the reflection peak at 450 nm moves to the ultraviolet (UV) regime and the several other peaks around 750 nm moves into the visible range. Since the peak at 550 nm shifts toward the blue region and the reflection peaks at 700 nm moves to the red colored region, the resulting color of the G colored cell is expected to be a magenta (i.e., B + R) at a large tilting angle. Due to many ripples in the reflection at the shorter wavelengths, the color space of the R colored cell is found to be near the neutral region.

III. CONCLUSIONS

Dual-functional hybrid solar cells that can generate electricity and create iridescent reflective colors at the same time utilizing the MDBR are described. Incident-angle- and incident-polarization-dependent reflection spectra and the color purity of the colored hybrid solar cells are investigated. The approach described in this work could open up many potential applications such as self-powered electronic devices, decorative solar panels, and power-generating color filters for energy-saving display technologies.

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