# Developing highly transparent colored reflectors for building-integrated photovoltaics (BIPV)

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**Introduction:** Building-integrated photovoltaics (BIPV) combines photovoltaics and architecture, converting urban buildings from energy users to energy producers. However, the appearance of standard PV modules is not favorable to be integrated into building skins. Therefore, aesthetic appearance and color control are essential for BIPV application and have led to a growing interest in the development of colored photovoltaic modules [1]. The colored PV modules can be realized by integrating various colored reflectors (CRs). Another important requirement for BIPV is an anti-glare (dazzling) function to mitigate the specular reflection of the sun light. Therefore, surface texturing of BIPV modules is preferable for this purpose. In this study, we fabricate CRs based on the optical interference effect of dielectric multilayers with high and low refractive index materials, which is similar to butterfly's wings [2]. The color is tuned by modifying the configuration (thickness and refractive indices) of dielectric multilayers. We apply this technology to textured glass substrates for developing highly transparent CRs with aesthetic appearance.

**Experiment:** In this work, $TiO_2$ and $SiO_2$ were applied as high and low refractive index materials, respectively. $TiO_2/SiO_2$ multilayers were grown on textured glass substrates by multi-targets radio-frequency (RF) sputtering system operated at room temperature. The pressure of the chamber is maintained at 0.32 Pa during the deposition. The substrate tray was rotated during the sputtering for better uniformity. As shown in Fig. 1, multilayers are composed of five units of the $TiO_2/SiO_2$ stack with constant thicknesses. The reflectance spectra from the wavelength ($\lambda$) of 300 to 1200 nm were measured by a spectrometer with an integral sphere (PerkinElmer Lambda 950). CRs with 4 different hues, including purple, blue, yellow, and red, have been achieved by controlling the thicknesses.

**Results and discussion:** Figure 2 shows reflectance spectra of the $TiO_2/SiO_2$ multilayers deposited on textured glass (RMS = 4 $\mu$m). Here, the thickness of the single unit of $TiO_2$ and $SiO_2$ layers ($L$) is varied from 130 to 210 nm, and the thickness ratio of $TiO_2$ to $SiO_2$ is fixed at 0.25. As shown in Fig. 2, the main reflectance peak shifts to the long $\lambda$ region as the $L$ increases from 130 to 210 nm, while the reflectance besides the main peak maintains at a low level to pursue the high transmission. We transform reflectance spectra in Fig. 2 to corresponding colors on CIE 1931 diagram, as shown in Fig. 3 [3]. Colors of fabricated CRs are purple ($L$ = 130 nm), blue ($L$ = 150 nm), yellow ($L$ = 170 nm), and red ($L$ = 210 nm). So far, we have fabricated mini-modules with these CRs and Si heterojunction solar cells. The detailed information will be presented during the conference.

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**Reference:** [1]. M. Pagliaro, *et al.,* Prog. Photovolt.: Res. Appl. **18**, 61−72 (2010). [2]. K. Chung, *et al.*, Adv. Mater. **24**, 2375−2379 (2012). [3]. T. Smith and J. Guild, Trans. Opt. Soc. **33**, 73 (1931).

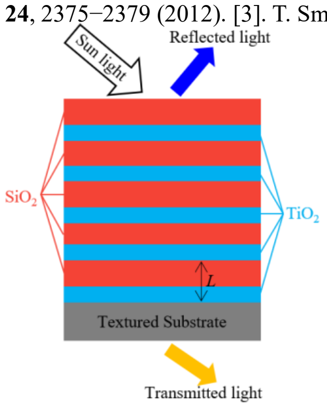


Fig. 1. Structure of a CR

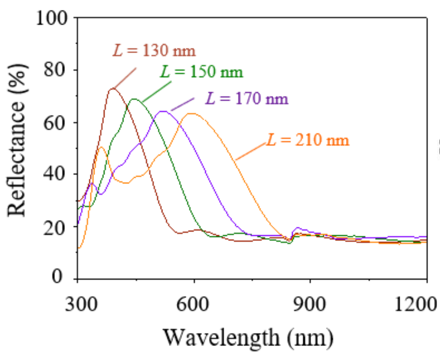


Fig. 2. Reflectance spectra of CRs of different $L$

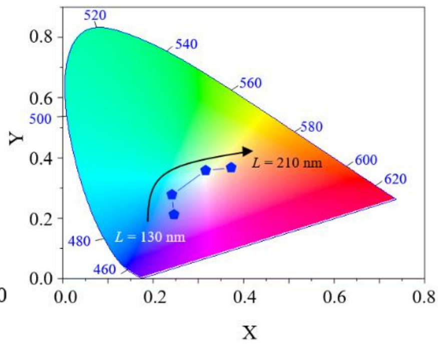


Fig. 3. Corresponding colors of CRs in CIE-1931 diagram