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# Blue-light shielding, hard and hydrophobic inorganic and organic silicon stack-films prepared on flexible substrates

Chia-Hsun Hsu [a], Ting-Xuan Liu [b], In-Cha Hsieh [c], Pin Han [a], Shui-Yang Lien [d,*]

[a] Graduate Institute of Precision Engineering, National Chung Hsing University, No. 250 Kuo Kuang Rd., Taichung 402, Taiwan
[b] Department of Electrical Engineering, Da-Yeh University, No. 168, University Rd., Changhua 51591, Taiwan
[c] Daiyi Intelligent Co., Ltd., No.88, Shengli 3rd St., Hsinchu 30264, Taiwan
[d] Department of Materials Science and Engineering, Da-Yeh University, No. 168, University Rd., Changhua 51591, Taiwan

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In this paper, organic silicon and inorganic silicon oxide thin films are prepared by high density inductively coupled plasma chemical deposition system on flexible polymer substrates. The two types of the films are stacked as organic/inorganic/organic silicon structure, and the stacked pair number is varied to investigate its effects on properties of blue-light shielding, hardness and hydrophobicity. The experimental results show that the stacked pair of 6 is favored and it has a blue light transmittance of 58.4% with negligible color distortion. The pencil hardness test indicates that the PET with the 6-pair stacked layer can have a hardness of 4H. The water contact angle measurement reveals that all of the stacked layers regardless the stacked pair number can have high water contact angles and high hydrophobic property, provided by the top organic cover layer that contains C–H hydrophobic groups. The organic silicon and inorganic silicon oxide stacked structure with blue-light shielding, hardness and hydrophobicity can be helpful for applications in optoelectronic devices.



## 1. Introduction

Nowadays electronic devices play an indispensable role in humans' life. The electronic devices tend to be reduced in size, flexible and intelligent. Many of the devices such as tablet and mobile phones equipped with a display screen, on which light-emitting diodes (LEDs) are usually used for both main light source and background illumination because of their low energy consumption, small size, compactness, high durability, high reliability and mercury-free [1–3]. Despite the advantages, some research groups have reported that prolonged exposure in blue light emitted from LEDs may cause incurable damages to cells in retina of human eyes [4–6]. Other major concerns about the development in electronic devices can be mechanical protection and non-wettability. The former is mostly demanded for device surfaces, especially the screen component, for reasons related to not only durability but also esthetics. The non-wettability can be helpful for reduction of water drops or moisture ingress inside devices causing oxidation of electrodes or failure of device performance. Multifunction coatings applied to an electronic device thus attract increasing attentions and requires further development.

In this study, we apply organic silicon and inorganic silicon oxide ($SiO_x$) stacked layers to polyethylene terephthalate (PET) substrates to simultaneously achieve multiple functions including blue-light shielding, hardness and hydrophobicity. The blue light transmittances of the films are shown, and the optimum stacked layer number is discussed. The hardness and hydrophobicity measurements are also presented.

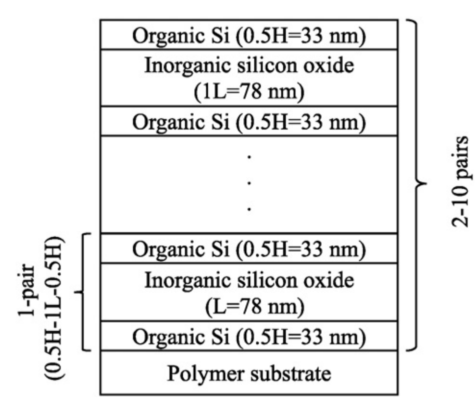


**Fig. 1.** Schematic structure of the organic silicon and the inorganic silicon oxide stacked films on PET. The thicknesses of the layers are indicated.

* Corresponding author.
*E-mail address:* syl@mail.dyu.edu.tw (S.-Y. Lien).

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**Table 1**
Deposition conditions for the organic silicon and inorganic silicon oxide films.

| Parameter | Organic silicon | Inorganic silicon oxide |
|---|---|---|
| Power (W) | 400 | 600 |
| Pressure (Pa) | 0.67 | 0.67 |
| Temperature (°C) | 120 | 120 |
| TMS gas flow (sccm) | 10 | 60 |
| Argon gas flow (sccm) | 40 | – |
| $O_2$ gas flow (sccm) | – | 2 |

## 2. Experimental

Fig. 1 shows the schematic structure of the multifunctional film, in which The PET was used as a substrate. Prior to any deposition process, the PET substrates were cleaned with ethanol, acetone and deionized water, each for 20 min. The organic, inorganic and again organic silicon films were deposited in sequence as one stacked pair by using an inductively coupled plasma chemical vapor deposition system (ICPCVD). The deposition gas mixture was argon and trimethylsilyl silane (TMS) for organic silicon, and was oxygen and TMS for the inorganic silicon oxide. The detailed deposition conditions are summarized in Table 1. The number of the stacked pair was varied from 2 to 10 to investigate the effects on the properties of blue-light shielding, hardness and hydrophobicity. For film characterization, the refractive index of the films was measured using a spectroscopic ellipsometer. The transmittance was determined using a spectrometer conducted to an integrating sphere. The cross-sectional view was characterized by scanning electron microscopy (SEM). The root-mean-square surface roughness (RMS) was measured by atomic force microscopy (AFM). The chemical bond structure was measured by Fourier transform infrared (FTIR) spectroscopy. The hardness of the stacked films was assessed by using a pencil scratch test according to ASTM D3363-92a. The water contact angle was measured by using the sessile drop method with dynamic contact angle system.

## 3. Results and discussion

Fig. 2 shows the refractive indices of the organic silicon and inorganic silicon oxide deposited by ICPCVD in the wavelength range of 380–480 nm. The refractive index is about 1.78 for the organic silicon, and was about 1.46 for the inorganic silicon oxide at the wavelength of 460 nm, which is typically the dominant blue light wavelength for a LED source. Based on the refractive index result, the thicknesses of the organic silicon and the inorganic silicon oxide can be determined to reduce the light transmittance at 460 nm by using the following equation:

$$\lambda_0 = 4nd$$

where $\lambda_0$ is the desired wavelength, n is the refractive index, and d is the film thickness. The calculation result shows that the thickness should be

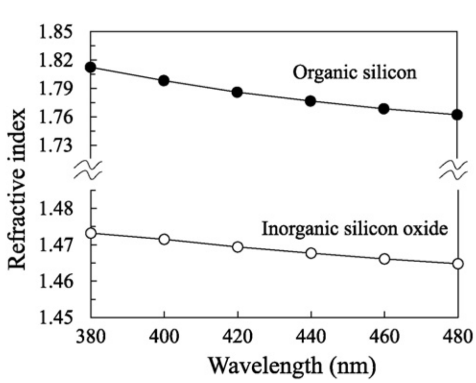


**Fig. 2.** Refractive index spectra of the organic silicon and the inorganic silicon oxide films.

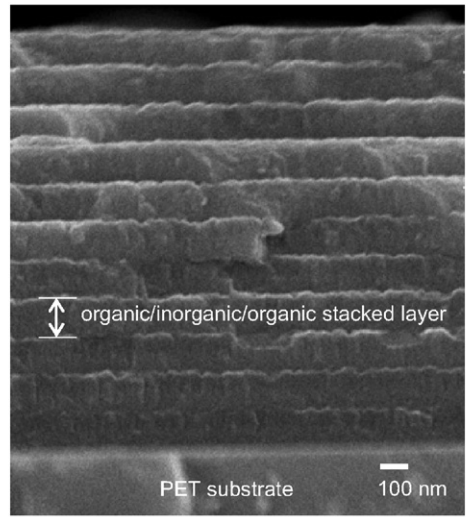


**Fig. 3.** Cross-sectional SEM image of organic/inorganic/organic stacked film.

65 nm for organic silicon, and 78 nm for inorganic silicon oxide. It is known that the high and low refractive indices stacked film, with a $(0.5H\text{-}1L\text{-}0.5H)^x$ structure, can efficiently reduce the transmittance in a certain wavelength region. This can be linked to the reflection of the incident blue light at the bottom interfaces of these three layers. The reflected light waves are in the same phase, forming constructive interference. Thus, most blue light was shielded from the stacked films. Accordingly, the thickness of the high refractive organic silicon layer corresponds to 33 nm, while the thickness of the low refractive inorganic silicon oxide corresponds to 78 nm. A cross-sectional SEM image of a high and low refractive indices stacked film is shown in Fig. 3. The thickness of each organic/inorganic/organic stacked film is around 144 nm, and, as can be seen, the films were deposited uniformly by ICP-CVD.

Fig. 4a shows the transmittance spectra for the samples with 2, 4, 6, 8 and 10-pair stacked layer. It can be seen that the transmittance in the

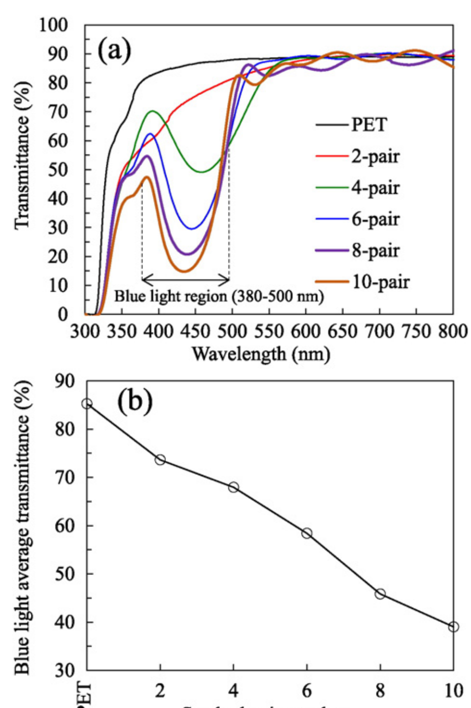


**Fig. 4.** (a) Transmittance for the PET without and with 2 to 8-pair stacked layer, and (b) corresponded average transmittance over 380–500 nm.

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