

Enhanced performance of SubPc planar heterojunction solar cells with a novel luminescent sensitizer of 4,4'-bis[(N-carbazole)styryl]biphenyl



Yanqiong Zheng^{a,b,1,*}, Fang Yang^{a,1}, Chao Wang^a, Junle Yu^a, Bin Wei^{a,b}

^a Key Laboratory of Advanced Display and System Applications of Ministry of Education & School of Materials Science and Engineering, Shanghai University, 149 Yanchang Rd., Shanghai 200072, China

^b Shanghai Engineering Research Center of Flat Panel Display, Shanghai University, 149 Yanchang Rd., Shanghai 200072, China

ARTICLE INFO

Keywords:

Small-molecule solar cells
SubPc
Luminescent sensitizer
BSB-Cz

ABSTRACT

Here, the conventional luminescent material 4,4'-bis[(N-carbazole) styryl] biphenyl (BSB-Cz) is used as luminescent sensitizer in boron subphthalocyanine chloride (SubPc)/C₆₀ planar heterojunction (PHJ) solar cells for the first time. When inserting 3-nm BSB-Cz between the MoO₃ and donor layer, the power conversion efficiency (PCE) of SubPc/C₆₀ PHJ is improved from 1.21% to 1.72%. BSB-Cz at 3–8 nm all enhances the short-circuit current (*J*_{sc}) and open-circuit voltage. As BSB-Cz is capable of absorbing short-wavelength solar light and re-emitting long-wavelength light which is exactly located at the absorption wavelength range of SubPc and C₆₀. The *J*_{sc} increase is attributed to the electron-blocking effect of BSB-Cz together with matched photoluminescence spectrum of BSB-Cz and the absorption spectra of SubPc as well as C₆₀, which enhances the incident photon number for SubPc and C₆₀. AFM images indicate that the bumpy surface of 3-nm BSB-Cz is filled in by the subsequent SubPc layer, thus decreases the surface roughness. However, thicker BSB-Cz results in significantly increased RMS roughness with decreased fill factor. The thickness of BSB-Cz maybe decides the only donor or two competing donors at the donor/acceptor interface, which affects the exciton dissociation and recombination in the overall device.

1. Introduction

Small-molecule organic solar cells (SM-OSCs) have drawn much attention for their attractive properties, such as, flexibility, light weight, low cost, mass production, and easy fabrication [1–3]. At present, the power conversion efficiency (PCE) of OSCs has achieved 10%, and much effort has been made for getting higher efficiency [4,5]. There are some methods for improving the performance of SM-OSCs, such as, designing novel materials and device architectures, optimizing the anode and cathode buffer layers, and fabricating tandem OSCs [6,7]. Inserting an additional layer between the exciton transporting layer and active layer has also proven to be an effective method for exciton-blocking or faster charge transport [8,9]. For example, M. A. Stevens and A. C. Arango as well as Y. Xiao group prepared cascade devices by inserting additional donor layers [10,11]. A. Kovalenko et al. employed the same idea of inserting a fullerene layer to reduce recombination in the inverted solution-processed SM-OSCs [12]. In 2015, our group have explored the application of novel 5,10,15-tribenzyl-5H-diindolo[3,2-a:3',2'-c]-carbazole (TBDI), N,N'-diphenyl-N, N'-bis(1-naphthyl)-1,1'-

biphenyl-4,4'-diamine (NPB), and 1,1'-bis (di-4-tolylamino phenyl) cyclohexane (TAPC) as electron-blocking layer between donor and MoO₃, and these layers all increased the photocurrent of the control device [13].

Recently, SubPc acting as efficient donor material was frequently applied together with C₆₀ in SM-OSCs, due to its significantly high open circuit voltage (*V*_{oc}) > 1.0 V [14,15]. The SubPc/C₆₀ planar heterojunctions (PHJs) showed a higher performance by inserting UV-ozone treated ZnO, ascribed to the higher work function of ITO/ZnO substrate and improved SubPc absorption [16]. Y. Gao et al. found that the performance of SM-OSCs could be greatly improved by inserting a thin SubPc interlayer due to the hole extraction at the anode [17]. It was reported that the SubPc:C₆₀ based charge generation layer was also a promising connecting unit used in organic light-emitting diodes (OLEDs) to obtain a high current density and high efficiency [18]. By considering the complementary absorption of BSB-Cz, SubPc, and C₆₀, SubPc is chosen as donor in this work [19].

BSB-Cz was ever applied in organic laser devices owing to its special linear molecular structure showing horizontal orientation, and strong

* Corresponding author at: Key Laboratory of Advanced Display and System Applications of Ministry of Education & School of Materials Science and Engineering, Shanghai University, 149 Yanchang Rd., Shanghai 200072, China.

E-mail address: zhengyanqiong@shu.edu.cn (Y. Zheng).

¹ These authors contributed equally to this work.

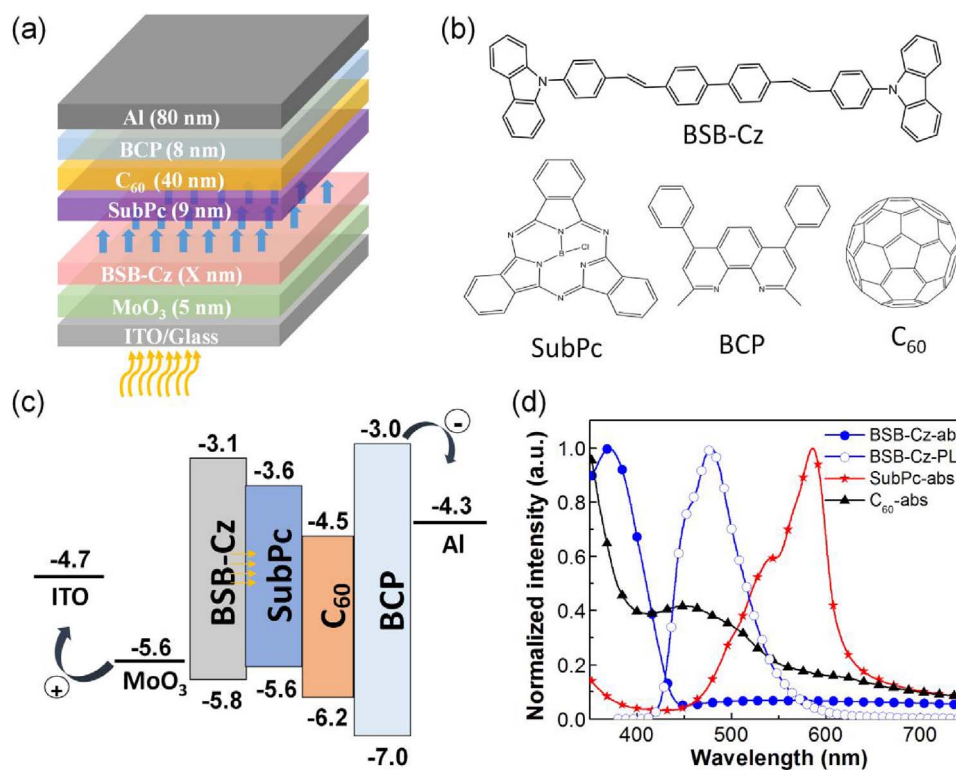


Fig. 1. (a) Device architecture of SM-OSCs showing the re-emitting of BSB-Cz; (b) Molecular structures of BSB-Cz, SubPc, C₆₀, and BCP; (c) Schematic energy level diagrams of all the materials used here; (d) Absorption spectra of pristine BSB-Cz, SubPc, as well as C₆₀ films and PL spectrum of BSB-Cz film on quartz substrates.

as well as narrow luminescence spectrum [20–22]. In 2010, a single emitting layer of BSB-Cz was used to fabricate an OLED to investigate the suppression of the electroluminescence roll-off by reducing carrier injection barrier [23]. C. Adachi group found a very narrow emission centered at the wavelength of 462 nm for the BSB-Cz:4,4'-bis(9-carbazolyl) biphenyl (CBP) blend film in 2007 [24]. They also observed spectrally narrow emissions from the edges of electrically pumped OLEDs with a fine line shaped waveguide structure composed of BSB-Cz emitting core layer and silver cladding layer [25].

BSB-Cz based organic laser devices presented good characteristics with reduced amplified spontaneous emission (ASE) threshold and relaxed roll-off characteristics under high current density [26]. In all the above work, BSB-Cz just acted as the main emitting layer. However, in this work, BSB-Cz functions as a luminescent sensitizer for the first time by considering the complementary re-emitting wavelength of BSB-Cz and the absorption wavelength of SubPc as well as C₆₀. Simultaneously, BSB-Cz also functions as electron-blocking layer owing to the shallower lowest unoccupied molecular orbital (LUMO) energy level of 3.1 eV than SubPc layer. The influence of BSB-Cz thickness on the performance of SubPc/C₆₀ PHJs, absorption spectra, photoluminescence (PL) spectra, and the morphology of BSB-Cz/SubPc composite films were investigated. The detailed mechanism was discussed.

2. Experimental

The SM-OSCs were fabricated with a structure of indium tin oxide (ITO, 150 nm)/MoO₃ (5 nm)/BSB-Cz (X nm)/SubPc (9 nm)/C₆₀ (40 nm)/BCP (8 nm)/Al (80 nm). All the organic chemicals were purchased from Lumtec Corp. (Taiwan). All the organic and metal layers were deposited sequentially on clean ITO substrates with a sheet resistance of 15 Ω sq⁻¹ at the rates of 0.5 Å/s and 5.0 Å/s in vacuum chamber, respectively. Prior to deposition, ITO substrates were consecutively cleaned by ultrasonic bath in dilute detergent solution (cleanser essence:putty-powder, 1:1 (w/w)), deionized water, acetone, and isopropanol, and then dried in a drying cabinet, finally treated by

UV-ozone (UV-ozone Cleaner, intensity of UV light is 15 W) for 30 min. In this work, the thickness of BSB-Cz varied from 0 nm, 3 nm, 5 nm, to 8 nm. The active area of the devices defined by the overlap between the ITO anode and the Al cathode was 0.04 cm².

The current density-voltage (*J-V*) characteristics of PHJs in dark and under illumination were measured by using an AM1.5 G (100 mW/cm²) solar simulator (Sun 3000, ABET Technologies, China), and recorded by a Keithley 2400 source meter. External quantum efficiency (EQE) spectra were carried out under standard measurement conditions on a 7-SCSpec solar cell measurement system (7-STAR Co., Ltd., China). Absorption and PL spectra were recorded by a UV-vis spectrophotometer (U-3900H, Hitachi, Japan) and a spectrofluorometer (FLSP920, Edinburgh Instruments Corp., UK), respectively. Atomic force microscope (AFM) images were obtained in tapping mode using a scanning probe microscope (Nanonavi SPA-400SPM, Japan). Here, all the measurements for devices were performed immediately after fabrication at room temperature in air under ambient conditions without any encapsulation.

3. Results and discussion

Fig. 1(a) demonstrates the device architecture of PHJs fabricated in this work, showing the schematic re-emitting of BSB-Cz after absorbing solar light. Molecular structures of BSB-Cz, SubPc, C₆₀, as well as BCP and the energy levels of all the materials are shown in Fig. 1(b) and (c). Fig. 1(d) depicts the absorption spectra of pristine BSB-Cz, SubPc, and C₆₀ films together with PL spectrum of the BSB-Cz film on quartz substrates. The absorption spectra of SubPc, C₆₀, and BSB-Cz are complementary to each other, and almost cover all the wavelength range from the ultraviolet region to 700 nm. It is important that the absorption of BSB-Cz will not interfere that of the following SubPc and C₆₀ layers. Meanwhile, the PL spectrum of BSB-Cz is located at 400–600 nm, which could increase the incident photon number for the SubPc layer deposited subsequently.

The SubPc/C₆₀ PHJs were fabricated with varying BSB-Cz thickness

Download English Version:

<https://daneshyari.com/en/article/5435436>

Download Persian Version:

<https://daneshyari.com/article/5435436>

[Daneshyari.com](https://daneshyari.com)