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RAPID COMMUNICATION

Stitchable organic photovoltaic cells with textile electrodes

Seungwoo Lee[a], Younghoon Lee[a], Jongjin Park[b,**], Dukhyun Choi[a,*]

[a]*Department of Mechanical Engineering, College of Engineering, Kyung Hee University, Seocheon-Dong, Giheung-Gu, Yongin-Si 446-701, Republic of Korea*
[b]*Samsung Advanced Institute of Technology (SAIT), Mt. 14-1, Nongseo-Dong, Giheung-Gu, Yongin-Si, Gyeonggi-Do 446-712, Republic of Korea*

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Abstract
Organic photovoltaic cells (OPV) have been extensively studied and got great attention for a next-generation flexible power source due to their unique properties such as flexibility, light-weight, easy processability, cost-effectiveness, and being environmental friendly. Film-based OPVs however have a limitation for the applications in wearable products since they are not compatible with textile-based wearable products. In this study, we introduce a textile-based OPV as a stitchable power source. A large-area textile electrode can provide effective optical and mechanical characteristics for trapping incident light and high-durability. In order to define the power conversion efficiency (PCE) in the textile-based OPV, we suggest the theoretical approach to determine the contact area on a textile electrode by using Hertzian theory. It is demonstrated that our textile-based OPV can provide the enhanced short circuit current density, J_{sc}, of 13.11 mA cm^{-2} under 1 Sun condition, resulting in the PCE of about 1.8%. We expect that our textile-based OPV and theoretical approach might open the promising way to realize a compatible power source for wearable electronics.

Introduction

Sustainable renewable energy systems that utilize the resources from nature such as solar, wind, and wave energies have attracted much attention due to the environmental issues and limited fossil fuels [1]. Among various renewable

*Corresponding author. Tel.: +82 31 201 3320; fax: +82 31 202 8106
**Corresponding author. Tel.: +82 31 280 6728; fax: +82 31 280 9308
E-mail addresses: jongjin00.park@samsung.com (J. Park), dchoi@khu.ac.kr (D. Choi).

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energies, photovoltaic cells are one of the cleanest, most applicable and promising alternative energies, using limitless sunlight [2,3]. Particularly, organic photovoltaic cells (OPV) have been extensively studied due to their unique properties such as flexibility, light weight, easy processability, cost effectiveness, and environmental friendliness [4-10]. These properties have competitive advantages over inorganic solar cells because they allow for the implementation of thin, light-weight, stretchable solar cells as a flexible power source [11-14]. They have found applications in the military, where soldiers need electricity for portable devices in remote areas [15]. In addition, there are many similar applications where personal, mobile wearable devices can be utilized [16]. However, most previous OPV studies have used flexible film-based cells, and they can be applied to wearable electronics such as smart watches and Google glasses. However, next-generation wearable electronics will be integrated with textile-based items such as clothes and bags, so that such film-based OPVs might be hard to be used to those wearable systems [17]. Therefore, it is crucial to design and develop textile-based power sources that are compatible with textile products.

Recently, fiber-based solar cells have been reported for wearable applications [18-22], but weaving of fiber-based solar cells remain a great challenge. Herein, this study introduces a textile-based OPV for a stitchable power source. A large-area textile electrode is prepared and characterized for optical and mechanical characteristics. Importantly, we suggest a theoretical approach to determine the contact area on textile electrode by using Hertzian theory in order to define the power conversion efficiency (PCE) on a textile-based OPV. Finally, we demonstrate an enhanced short circuit current density and determine the PCE of our textile-based OPV. We expect that our textile-based OPV and theoretical approaches might provide a promising avenue for finding power sources compatible with wearable electronics.

Experimental

Fabrication of OPV

First, an indium thin oxide (ITO) substrate with a sheet resistance of 200 Ω/square was prepared as a bottom electrode. A zinc oxide (ZnO) sol-gel solution was spin-coated on the ITO and cured at 150 °C for 30 min for an electron transport layer. The sol-gel solution was prepared with zinc acetate dehydrate (99.999% metal basis) and ethanolamine dissolved in 2-methoxyethanol, where the concentration of zinc acetate was 0.5 M. The solution was mixed for 20 min at 80 °C prior to spin-coating. We applied a poly (3-hexylthiophene):[6,6]-phenyl C_{61}-butyric acid methyl ester fullerene derivative (P3HT:PCBM) mixture as a bulk heterojunction (BHJ) photoactive layer, where P3HT is used as an electron donor and PCBM is employed as an electron acceptor. P3HT and PCBM were dissolved in chlorobenzene (CB) at 65 °C for 18 h and blended at a ratio of 1:1. The P3HT:PCBM blend was spin-coated at 900 rpm for 60 s and then, thermal pre-annealing was performed at 120 °C for 10 min in a nitrogen atmosphere. The hole transport layer (molybdenum trioxide, MoO_3) was thermally evaporated with the thickness of 15 nm. Finally, a silver thin layer was deposited as a top electrode by thermal evaporation for a reference sample [23-29]. In order to create textile-based OPVs, we could apply a gold textile electrode instead of the silver layer.

Characterizations

The morphology characterization was obtained using a field emission scanning electron microscope (FE-SEM, Carl Zeiss LEO SUPRA 55). In order to confirm the light scattering effect, we used UV-spectrophotometer (Cary 5000, VARIAN) by using specular and diffuse reflectance modes. To verify the mechanical durability of our textile electrode, we measured the two-probe resistance under the repeating bending loads by using a bending machine (Z-tech). PECs of OPVs were measured using a Keithley 2400 source meter and a simulated AM 1.5 global solar irradiation with an incident power density of 100 mW/cm^2 using a solar simulator (HS-technologies).

Results and discussions

As mentioned above, film-based OPVs have low compatibility with textile products, and fiber-based OPVs remain to overcoming limit of fiber weaving. Our textile-based OPVs are highly compatible with textile products, thus proving the facile stitchability on textiles, as shown in Figure 1a. We could have applied our textile-based OPV to clothing

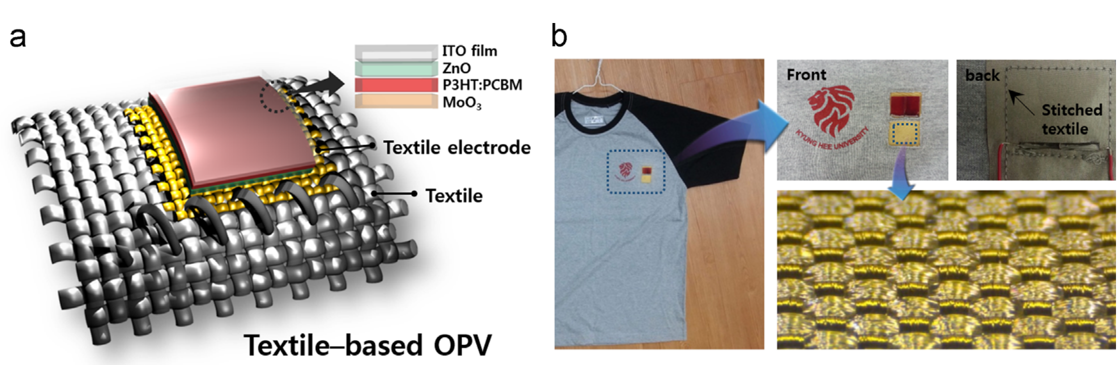

Figure 1 Stitchable OPV with a textile electrode. (a) Concept of a stitchable OPV on a textile electrode. (b) Photographs of the textile-based OPV integrated with clothing.