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A comparative study of low-cost coating processes for green & sustainable organic solar cell active layer manufacturing

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ABSTRACT

Owing to their facile integration into existing commercial products, high volume manufacturing of organic solar cells (OSCs) can be expected in the upcoming years. Therefore, it is important to evaluate the performance and sustainability of various active layer coating methods for OSCs. Herein, we compare four active layer coating processes: spin-coating, blade-coating, spray-coating and push-coating for poly(2,7-carbazole-*alt*-dithienylbenzothiadiazole):[6,6]-Phenyl-C_{71}-butyric acid methyl ester (PCDTBT:$PC_{71}BM$) active layers deposition. The optical, morphological and photovoltaic parameters of the active layers are studied. The suitability of each coating method for industrial manufacturing of PCDTBT:$PC_{71}BM$ OSCs is discussed in terms of environmental impact, necessary investments and running costs. Our results confirm that, despite producing high quality and high performance OSCs, spin-coating is unsuitable for high volume manufacturing due to the large amounts of materials and hazardous solvents wasted in the process. Blade-coating provides a good balance between low running costs, low environmental impact and decent performances but the process introduces lateral compositional gradients which could be detrimental for large area OSC processing. Spray-coating requires minimal initial investments but has relatively low performance and low manufacturing sustainability. Push-coating yields OSCs which perform as well as spin-coated ones, with a much lower environmental impact and cost. We should thus look forward to seeing whether this green and sustainable technology can develop into a large area coating process in the future.

1. Introduction

Organic solar cells (OSCs) are often referred to as low-cost alternatives to conventional silicon-based photovoltaic devices [1,2]. Consequently, much research has been dedicated to improving their photovoltaic performance and durability to achieve the 10-10 target, one of the key criteria to enable their large volume manufacturing and commercialization [2]. In particular, the past five years have seen the development of active layer materials with very well-engineered molecular structures which enabled the production of OSCs with power conversion efficiencies (*PCEs*) well above the milestone value of 10% [3,4]. Recent findings also suggest that OSCs using these newly developed organic semiconductors are both efficient and can possibly produce lifetimes longer than 10 years, thus opening the path to the 10-10 target [4–6]. However, the fact that the cost of the semiconductors increases with increasing performance is often overlooked. For instance, as of today, a low efficiency poly(3-hexylthiophene-2,5-diyl) can be purchased for less than 300 USD/g, but the current standard electron donor for high *PCE* OSC manufacturing, i.e. PM6, generally costs over 2500 USD/g.

One could argue that, given the small amount of material employed in the ultrathin active layers, the cost of the active material is irrelevant [1]. This is true only if the active layers can be manufactured without generating any active material loss. However, the commonly employed method to fabricate efficient devices, i.e. spin-coating, is far from being a sustainable option when it comes to material loss [7,8]. To fabricate high quality OSC active layers by spin-coating, most of the employed active layer solution is ejected outside of the substrate through centrifugal forces. The wasted active layer solution cannot be recovered and reused [8]. In addition to this lack of sustainability issue, large amounts

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