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Review

Spray coating methods for polymer solar cells fabrication: A review

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ABSTRACT

The main focus of this review article is the introduction of relevant parameters in spray coating processes to provide better understanding on controlling the morphology of spray coated thin films for producing high performance polymer solar cells (PSC). Three main parameters have been identified as major influences on the spray coating processes. These are nozzle to substrate distance, solvent and mixed solvents effects, and substrate temperature and annealing treatment. Such spray coating techniques show great potential for large scale production, since these methods have no limitation in substrate size and low utilization of polymers which is promising to substitute the conventional spin coating methods. Currently available printing and coating methods are also briefly discussed in this review.

Contents

Abbreviations: CN-ether-PPV, poly[oxa-1,4-phenylene-1,2-(1-cyano)-ethenylene-2,5-dioctyloxy-1,4-phenylene-1,2-(2-cyano)-ethenylene-1,4-phenylene]; M3EH-PPV, poly[2,5-dimethoxy-1,4-phenylene-1,2-ethenylene-2-methoxy-5-(2-ethylhexyloxy)-(1,4-phenylenevinylene-1,2-ethenylene)]; P3HT, poly (3-hexylthiophene 2,5-diyl); PCBM, phenyl-C_{61}-butyric acid methyl ester; P3MHOCT, poly-(3-(2-methylhexyloxycarbonyl)dithiophene); PCDTBT, poly[N-9″-hepta-decanyl-2,7-carbazole-alt-5,5-(4′,7′-di-2-thienyl-2′,1′,3′-benzothiadiazole)]; PFB, poly(9,9′-dioctylfluorene-co-bisN,N′-(4-butylphenyl)-bis-N,N′-phenyl-1,4-phenylenediamine); F8BT, poly(9,9′-dioctylfluorene-co-benzothiadiazole); PBDTTT-C-T, poly{[4,8-bis-(2-ethyl-hexyl-thiophene-5-yl)-benzo[1,2-b:4,5-b0]dithiophene-2,6-diyl]-alt-[2-(20-ethyl-hexanoyl)-thieno[3,4-b]thiophen-4,6-diyl]}; PEDOT:PSS, poly (3,4-ethylenedioxythiophene)–poly (styrenesulfonate)

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1. Introduction

One of the major issues in encouraging developments of polymer solar cells (PSC) commercialization is finding a roll-to-roll compatible, high yielding process for low cost production [1–4]. Blade coating [5,6], spin coating [7–9], spray coating [10–15], dip coating [1], screen printing [16], gravure printing [17], and ink-jet printing [18–20] are among the methods used to fabricate the PSC. Table 1 lists the previous researches on PSC prepared using different methods. Spin coating is a standard method that has been used to produce uniform coatings of desired thickness, however, high materials wastage of more than 90% for spin coating makes the materials costs to rise as the film-coated area becomes larger [5,21]. Ink-jet printing methods have attracted attention as part of a promising cost-efficient process for PSC fabrication due to its efficient materials usage, and its direct and precise patterning with a resolution of 20–30 μm, unlike that of spin coating and other conventional methods [22,23]. Unfortunately, ink-jet printing is not easily adaptable to mass volume manufacture, due to its low volume throughput and complexity [24].

Blade coating and slot-die coating are suited to high volume, scale up and commercialization of PSC, since these methods are compatible with high speed, high volume, and low cost roll-to-roll production. A power conversion efficiency (PCE) of more than 6% can be achieved in a blade coating process due to the ability of the donor and acceptor to quickly self-assemble into the desired ordered and interpenetrating morphology during the blade coating process in the absence of centrifugal force [5]. However, in blade coating methods, the wet film formation is relatively low compared to spin coating, and aggregate or crystallite formation at high concentration often occurs during blade coating [25]. Dip coating process is a commonly used method for conventional dyeing and can provide easy and fast deposition of polymer films over a large area [1]. The dip coating process is prompt with single pass formation of the film compared to other spray coating and inkjet print processes and the films formed are free-pinhole [1,26]. However, the formation of the dip coated film is a slow natural drying process making it incompatible for high volume production.

The spray coating techniques have a great potential for large scale production, since these methods have no-limitation in substrate size and low utilization of polymers, promising to substitute the conventional process which is spin coating methods [27]. The ability to access a broad spectrum of fluids with various rheologies, making the production of fully spray coated PSC devices, is possible. However, the usage of spray coating in the production of PSC is faced with one main issue, namely higher film thickness and roughness [28]. Thus, most of the current research concerns on optimizing the morphology of an active layer by using high boiling point solvents [29], additives, solvents mixtures, postthermal annealing [28,29], and additional spray coating methods [11]. To the best of our knowledge, a limited number of review articles have been published on the processing methods of PSC specifically spray coating methods. Therefore, this review aims to summarize relevant parameters in spray coating processes to provide better understanding on controlling the morphology of the spray coated thin films in producing a high performance PSC and commercialization of this technology.

Table 1
List of previous researches on PSC prepared using different methods.

Active layer	Methods	References	Year
M3EH-PPV:CN-ether-PPV	Spin coating	[30]	2005
P3HT:PCBM	Blade coating	[6]	2009
P3MHOCT:ZnO nanoparticles	Pad printing	[31]	2009
P3MHOCT:ZnO nanoparticles	Screen printing	[32]	2009
P3MHOCT:ZnO nanoparticles	Screen printing	[33]	2009
P3HT:PCBM	Spray coating	[28]	2009
P3HT:PCBM	Ink-jet printing	[23]	2010
P3HT:PCBM	Spin coating	[34]	2011
P3HT:PCBM	Gravure printing	[35]	2011
P3HT:PCBM	Spray coating	[10]	2011
P3HT:PCBM	Dip coating	[26]	2012
P3HT:PCBM	Slot die coating	[36]	2012
P3HT:PCBM	Gravure printing	[24]	2012
P3HT:PCBM	Spray coating	[37]	2012
P3HT:PCBM	Spray coating	[27]	2012
POD2T-DTBT:PCBM	Blade coating	[5]	2012
P3HT:bisindene-C60	R2R coating	[38]	2012
PCDTBT:PCBM	Spray coating	[39]	2012
PFB:F8BT	Spray coating	[40]	2014
P3HT:PCBM	Spray coating	[41]	2014
PBDTTT-C-T:PCBM	Blade coating	[42]	2014
PCDTBT:$PC_{71}BM$	Blade coating	[43]	2014

2. Printing methods

Printing is usually been used to describe a method by which a layer of ink is transferred from a stamp to a substrate through a reversing reaction [25]. Fig. 1 contains an illustration of printing apparatus. Printing methods thus include flexographic printing, offset printing, gravure printing, screen printing and ink-jet printing. In the printing method, the

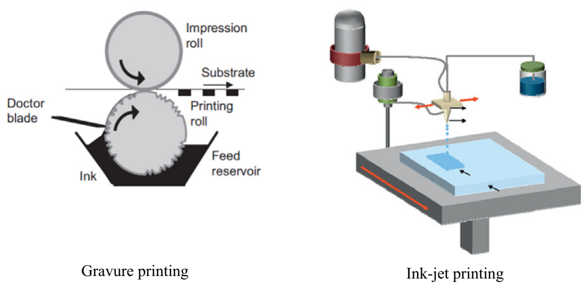

Fig. 1. Illustration of printing apparatus.