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Simple roll coater with variable coating and temperature control for printed polymer solar cells

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ABSTRACT

A simple and low cost thin film solution processing system comprising a single roll coating machine has been developed to allow direct investigation of variable parameter effects in roll-to-roll processing. We present roll coating of the active layers in polymer solar cells and validate the instrument by reinvestigating the well known effect of solvent on performance. We obtained a maximum power conversion efficiency of 1.6% for the reference cells, which compares well with reported roll-to-roll coated cells according to ProcessOne, with a relative deviation caused by solvent type nearing 40% on roll coated cells, confirming the solvent to have a significant influence on the performance of the finished cell. We further present a slot-die coating head with an ultra low dead volume allowing for the preparation of roll coated polymer solar cells on flexible substrates with nearly no loss of solution, enabling roll coating testing of new polymers where only small amounts are often available. We demonstrate the formation of >50 solar cells (each with an active area of 1 cm^2) with printed metal back electrodes using as little as 0.1 mL of active layer solution. This approach outperforms spin coating with respect to temperature control, ink usage, speed and is directly compatible with industrial processing and upscaling.

1. Introduction

The polymer and organic solar cell (OPV) is a new photovoltaic (PV) technology that potentially solves the problems of scale, speed and materials abundance that most of the current PV technologies are faced with [1,2]. Even though manufacture of OPVs have been demonstrated on a reasonable scale [3] and OPVs have been demonstrated [4,5] and integrated into product prototypes [6], there is a significant amount of development needed before the technology answers well to the environmental concerns. Life cycle analysis (LCA) studies show that the energy payback time (EPBT) is comparable to the current device lifetimes achieved [7] and when integrated into products the EPBTs are significantly longer than the anticipated operational lifetime of the assembly driven by the OPV, which limits the usability of OPV to cases where they can efficiently replace a more environmentally damaging device [8]. While this does comprise usefulness it also limits the scope and applicability of the technology unless the challenges are efficiently addressed. The majority of polymer solar cells reported to date have been prepared by a combination of spin coating and vacuum evaporation of the layers in the device. This approach has proven highly successful on the laboratory scale where device power conversion efficiencies exceeding 8% has been reported by a few companies [9]. The technology in the available form only presents power conversion efficiencies in the range of 1–2% [10,11] as reported by many independent laboratories. One of the possible reasons for this is the fundamental difference between the manner in which a laboratory device is prepared and optimized and the manner in which an industry would approach the manufacture of the OPV technology. The implications of this are that new developments are thus not readily upscaled or easily transferred to an industrial setting and this in part may hold the explanation for the somewhat slow emergence of polymer solar cells as a technology that is integrated in commercial products.

In this work we present a compact roll coater that enable the preparation of polymer solar cells in a directly scalable manner but on a very small scale that is in fact smaller than currently employed spin coating and doctorblading methods. Very small quantities of ink can be applied and a very accurate control of the wet and dry thickness of the coated film is possible, which is in stark contrast to spin coating. In addition the system enable accurate control of the substrate temperature during deposition and is compact enough to fit in an ordinary fume cupboard, a glove box or a cleanroom as no large extraction systems are needed. Toxic materials are also easily encompassed, since the evaporation of solvent or additives can be kept within the fume cupboard. The system is used to test dependence on solvents used

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for the P3HT:PCBM material in a slot-die coating process in contrast to the spin coated test of solvent dependence [12,13].

2. Experimental

2.1. Roll coater

The roll coater (Fig. 1) is constructed to mimic the coating performed on full scale roll-to-roll processing equipment [14,15] making the transition from lab to production faster and enabling optimization of the ink and processing directly at the lab scale prototyping level.

2.1.1. Mechanics

The system is comprised of a single 300 mm diameter roll where to a (PET) foil is attached. A slot-die coating head is mounted at the top of the machine, on a 3-axis movable stage allowing adjustment of height, angle of attack and horizontal position relative to the foil. The roll is driven by a servo motor through exchangeable gear wheels allowing for a large range of web speeds. In these experiments speeds between 0 m/min and 2 m/min were employed. These speeds are comparable to what is used in larger roll-to-roll processing equipment as described earlier [15]. After the slot-die coating head a fan is mounted to further help the drying of the coated material and an optional IR heater is mounted for use at lower coating temperatures. The system allows coating at controlled temperature, with a heated roll on which the PET substrate is attached, meaning that the substrate is kept at a constant controlled temperature while coating and securing a much narrower temperature distribution through the films when drying.

2.1.2. Coating head

The coating head (Fig. 2) is a slot-die coating head with a very small dead volume of less than 50 μL, allowing use of a minute amount of solution for processing. The head is comprised of two brass parts held together by 4 screws. The front side of the head has a 50 μm deep groove milled into it with a width of 13 mm, between the brass parts, a 0.25 mm thick stainless steel foil is placed with a meniscus guide of 13 mm width and protruding 0.5 mm from the bottom of the head. The meniscus guide has been reported earlier in [16].

2.1.3. Pumping systems

For active layer ink delivery a syringe pump was used together with Braun Medical 5 mL two-component syringes. The connection to the slot-die head was done via a 1.0 μm filter, a Luer to HPLC 1/4 in.-28 thread and a 2 mm OD teflon tube or a stainless steel HPLC tube. For PEDOT:PSS coating a purpose built pressure chamber pump was used due to the higher viscosity (viscosity ~270 mPa s) of the PEDOT:PSS ink.

2.2. Materials

The coating was performed on ITO sputtered PET foil with a thickness of 175 μm and a nominal sheet resistivity of $100\,\Omega\,\square^{-1}$. The ITO layer was patterned into stripes of 13 mm width. The foil was precoated with a doped ZnO layer [15]. Foil areas of 1 m × 15 cm were cut out and mounted on the roll coater. P3HT (poly(3-hexylthiophene)) was obtained from BASF as Sepiolid P200 and PCBM ([6,6]-phenyl-C61-butyric acid methyl ester) was obtained from Solenne BV (technical grade). The solvents used were; chlorobenzene (CB), 1,2-o-dichlorobenzene (ODCB) and 1,2,4-trichlorobenzene (TCB). The P3HT:PCBM concentration was kept the same for all solvents at 21 mg/ml P3HT and 18.5 mg/mL PCBM. The PEDOT electrode-buffer layer was based on Orgacon PEDOT EL-P 5010 from Agfa mixed in a 2:1 (w/w) ratio with IPA. The heat curable screen printing silver ink used was PV410 from DuPont.

2.3. Coating procedure

2.3.1. Active layer

The coating of the P3HT:PCBM material was conducted at a speed of 1.5 m/min. The roll was heated to 90 °C to allow a quick and uniform drying of the films. The flow through the head was set to 0.250 mL/min resulting in a wet thickness of 13 μm and an estimated dry thickness of 0.4 μm. The coated stripe was offset 1 mm from the ITO stripe.

2.3.2. PEDOT

The PEDOT layer was coated with a 1 mm offset from the active layer coating and coated with a flow of 1.25 mL/min for a wet thickness of 65 μm. The layer was coated at a 70 °C roll temperature followed by drying for 20 min.

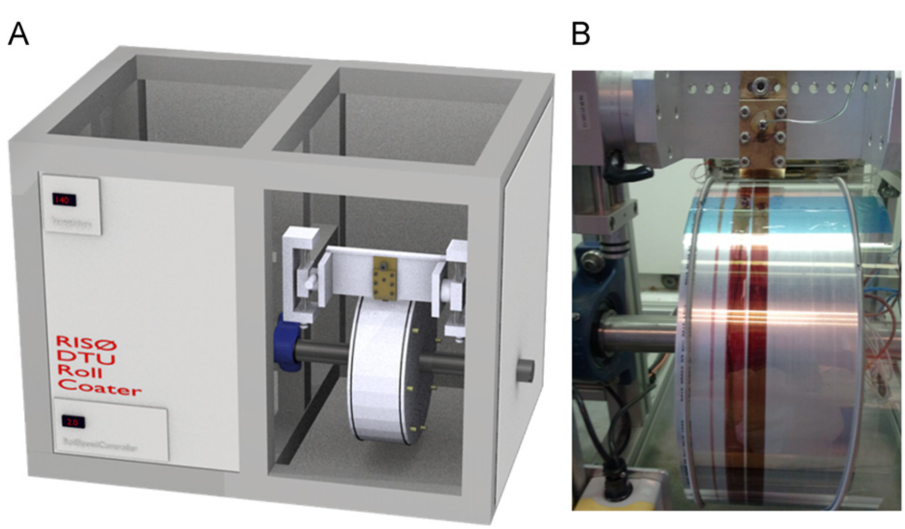

Fig. 1. (**A**) Illustration of the roll coater showing the frame, roll, axis, motor translation stage, pump, heater and slot-die head. (**B**) Picture of the roll with a PET with ITO foil mounted and two stripes coated on the substrate.