Solar Energy Materials & Solar Cells 140 (2015) 187–192

Contents lists available at ScienceDirect

Solar Energy Materials & Solar Cells

journal homepage: www.elsevier.com/locate/solmat

Roll and roll-to-roll process scaling through development of a compact flexo unit for printing of back electrodes

Henrik F. Dam [a], Thomas R. Andersen [a], Morten V. Madsen [a], Thomas K. Mortensen [b], Mads F. Pedersen [b], Uffe Nielsen [b], Frederik C. Krebs [a,*]

[a] Department of Energy Conversion and Storage, Technical University of Denmark, Frederiksborgvej 399, DK-4000 Roskilde, Denmark
[b] Grafisk Maskinfabrik A/S, Bregnerødvej 92, DK-3460 Birkerød, Denmark

ARTICLE INFO

Article history:
Received 1 March 2015
Received in revised form
21 March 2015
Accepted 4 April 2015

Keywords:
Scaling of equipment
Roll-to-roll machinery
Polymer solar cells
Slot-die
Small flexographic unit
Web handling

ABSTRACT

We report manufacture of fully printed and coated polymer solar cells on a small scale roll-to-roll coater representing the intermediate scale between laboratory and pilot scale. We highlight the enormous span in scale between the laboratory scale and the intended industrial scale by a factor of >100.000 and detail how this enormous scale must be covered by equipment that follow the scale. Especially the intermediate scale between equipment that can fit inside a fume cupboard and the typical pilot equipment with a footprint having the size of a large room presents a challenge that comprises some of the most critical steps in the scaling process. We describe the development of such a machine that comprise web guiding, tension control and surface treatment in a compact desk size that is easily moved around and also detail the development of a small cassette based flexographic unit for back electrode printing that is parsimonious in terms of ink usage and more gentle than laboratory scale flexo units where the foil transport is either driven by the flexo unit or the flexo unit is driven by the foil transport. We demonstrate fully operational flexible polymer solar cell manufacture using this new roll and roll-to-roll (R3) approach and compare with the existing methods.

© 2015 Elsevier B.V. All rights reserved.

1. Introduction

The organic solar cell has a unique strength in the possibility for manufacture using only printing and coating equipment that is known from the graphical industry. This implies high speed manufacture, low embodied energy, low materials usage, a thin outline, mechanical flexibility, a low capital cost for manufacturing equipment, small machine footprint and inherent scalability. Drawbacks currently include a comparatively short operational lifetime of 2–5 years outdoor, a shelf life of 7–10 years, a low power conversion efficiency (PCE) of 10–12% for academic records and 2–4% for practically scaled devices [1]. Especially the process of scaling is critical since the most academic reports employ vacuum processing for one or a few of the layers and almost always employ metal evaporation of the back electrode. These slow (typically) batch operations are a hindrance to scaling efforts where processing of all layers should take place with approximately the same speed in a continuous process. A central development has therefore been methods for printing of the back electrode. The challenge lies in the necessity to print a liquid ink comprising dispersed metal particles, a binder and a solvent on top of the solar cell stack that is sensitive to both the mechanical force of the printing form and the solvents contained in the ink. During drying the solvent in the metal ink may destroy the solar cell stack. This was demonstrated in a study using flat-bed screen printing where different solvents were employed followed by a study of the solar cell performance using light beam induced current (LBIC) measurements [2]. Here solvent penetration was shown to destroy the solar cell function. Some examples to solve this problem has been demonstrated in the literature where insolubilization of the active layer has been one approach [3–6] and the most successful has been use of a thick slot-die coated or printed hole conducting layer based on poly(ethylenedioxythiophene)-polystyrenesulphonate (PEDOT:PSS) [7–11]. A limited number of groups have started to address this central challenge using the scaled and fully additive 2-dimensional printing methods such as flatbed screen printing [7,8], inkjet printing [12–17], flexographic printing [18], rotary screen printing [19–21] and gravure printing [22,23] whereas a few attempts also include the less scalable methods such as spray coating [24,25]. Most significantly the former methods do imply an appreciable scale that is beyond the capacity of most laboratories and there is a significant gap between the laboratory platform that is very suitable for development and the intended industrial environment that the processing methods are intended for. Some of the scale has been bridged in earlier reports on a mini roll coater (MRC)

* Corresponding author.
E-mail address: frkr@dtu.dk (F.C. Krebs).

http://dx.doi.org/10.1016/j.solmat.2015.04.007
0927-0248/© 2015 Elsevier B.V. All rights reserved.

that enables processing using very little material under conditions that resemble the industrial environment better as compared to spin coating. There is however still a gap between the MRC that is a roll or drum coater and the industrial roll-to-roll based coating and printing systems. Especially the printing unit for the back electrode is critical.

In this report we describe the gradual bridging of the scale from the laboratory spin-coating and mini roll coating to a true roll-to-roll coating system where a special flexographic unit is central for printing of back electrodes. We also review the philosophy behind the scaling of the equipment and describe the necessary steps on the path from spin coating to large scale roll-to-roll coating.

2. Experimental

2.1. Materials

The semitransparent electrode material was based on flextrode as described earlier [19] by roll-to-roll slitting into a narrow web width of 5–15 cm suitable for the machine developed here. Poly-3-hexylthiophene (P3HT) was obtained from BASF and phenyl-C_{61}-butyric acid methyl ester (PCBM) was obtained from Merck. The active ink was made by dissolving P3HT (20 mg mL^{-1}) and PCBM (20 mg mL^{-1}) in chlorobenzene at 90 °C for 3 h with stirring. The active ink was slot-die coated at a speed of 1 m min^{-1} with a wet thickness of 12 μm and the drum set to a temperature of 70 °C. The PEDOT:PSS back electrode was prepared as reported earlier [26] by firstly slot-die coating of PEDOT:PSS (F010 from Heraeus) diluted with isopropanol in a ratio of 1:4. A web speed of 1 m min^{-1}, a wet thickness of 15 μm and a temperature of 70 °C was employed. This was followed by slot-die coating a second layer of PEDOT:PSS (AL P 4083 from Heraeus) diluted with isopropanol in a ratio of 2:1. A web speed of 1 m min^{-1}, a wet thickness of 29 μm and a temperature of 70 °C was employed. Finally a third PEDOT:PSS (F010 from Heraeus), diluted 2:1 with isopropanol was coated at a web speed of 1 m min^{-1}, a wet thickness of 38 μm and a temperature of 70 °C. The coating steps for the active layer and the back PEDOT:PSS are shown in Fig. 1.

The final silver back electrode was flexo printed using fast drying solvent based silver ink (5025 from Dupont) at a web speed of 1 m min^{-1} and a drum temperature of 70 °C using the flexographic unit described below as illustrated in Fig. 2.

2.2. Roll-to-roll machinery

The roll-to-roll machine (Fig. 1A) can handle web speeds of up to 20 m min^{-1} and web widths of up to 15 cm. The short drying length makes high web speeds impractical for coating and printing operations but very useful during fast forward and fast rewind of the web when processing many layers on top of each other. The machine has the foot print of a typical office desk and is fitted with wheels such that it can be transported around easily. The high voltage electronics and air extraction pumps (for the printing unit and for the corona unit) are fitted below the desk surface. The machine comprises standard elements from typical roll-to-roll processing machinery: unwinder, edge guide, nip, corona treater with antistatic unit, coating/printing unit, heated drum, infrared/hot air oven (not shown) and rewinder. The machine can also be operated in roll coater mode [11–27] where the foil is wrapped around the heated drum that has a diameter of 20 cm enabling a coating length of 62 cm.

2.3. Flexographic unit

The flexographic printing unit comprises cassette with two axles that rotate in opposite directions through connection with gear-wheels. The cassette mounts on the 4-axis coating stage and it is thus possible to translate the flexographic unit in the *XYZ*-directions and rotate around an axis parallel to the rollers. The axles in the cassette accept two cylinders: the printing roller (or stencil) and the anilox roller. An ink tray can be mounted below the anilox roller. The cassette accepts roller widths of up to 10 cm which is the maximum working width of the unit. The axle carrying the anilox roller is driven by a servomotor the speed of which is controlled by the master encoder of the machine. The driven flexo unit thus always follow the speed of the web accurately. The anilox roller is equipped with two knifes such that it can be operated with just a few grams of ink and to avoid dripping excess ink on the foil when the ink tray is not used (in the case of using small ink amounts). The ink tray can be employed for longer runs but obviously require more ink (25–50 g) as opposed to simple knife operation that can

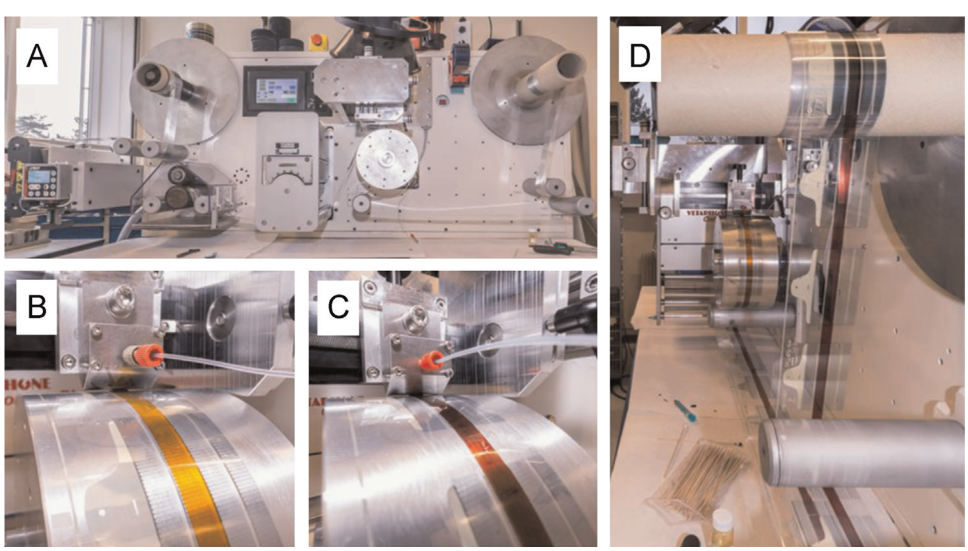

Fig. 1. (A) The compact desk sized roll-to-roll coater/printer comprising unwinder, edge guide, nip, corona treater, coating/printing unit, drum and rewinder. (B) Slot-die coating of the active layer with the wet film visible as an orange–yellow stripe. (C) Slot-die coating of the first F010 PEDOT:PSS electrode on top of the dried active layer visible as a dark brown–red stripe. (D) View along the foil during slot-die coating of the active layer. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Download English Version:

https://daneshyari.com/en/article/6535165

Download Persian Version:

https://daneshyari.com/article/6535165

Daneshyari.com