LAMINATION METHOD FOR SEMITRANSPARENT SOLAR CELLS: MECHANISM AND MATERIAL

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Abstract - Semitransparent solar cells not only can convert sun light into electricity but also allows passing the visible light and show promising applications for power-generating windows. To fabricate the semitransparent solar cells, the lamination method is commonly technique because of its easy processing and low fabrication cost. The key of this method is how to form the mechanic and electronic contact between active layer and top transparent electrode. This paper reviews major advances in lamination method that has contributed to the efficiency enhancements, including the development of adhesives and mechanism.

Index Terms - Lamination method, semitransparent solar cells, power-generating windows.

I. INTRODUCTION

In recent decades, the photovoltaic (PV) has been used widely as an energy source to replace natural resources, for example gas, oil, and coal. PV devices can easily mount on ground, rooftop, wall or everywhere as long as they are exposed to the sunlight. Semitransparent solar cells (STSCs) is potential application of PV devices for power-generating windows because of their advantages such as visible light transparency and light-to-electricity conversion [1]. Window panels, skylights, or skyscrapers can also become an electricity sources in such an approach. Therefore, STSCs can have a huge effect on the building electricity consumption [2]. Currently, silicon(Si)-based STSCs products are the most commonly used on the market because of their stability and sufficient efficiency. However, the Si-based STSCs is difficult to adjust their intrinsic color and thus affects the aesthetic appeal. These challenges of Si-based STSCs can be overcome by semitransparent polymer and perovskite-based PV. The STCSs structure is showed in Fig. 1.

In order to fabricate the STSCs, laser patterning or chemical etching was used to form any micro-hole shape on effective area of a-Si solar cell, named a see-through a-Si solar cell [3]. A. Takeoka and co-workers found that laser patterning method can create micro-holes more uniform than chemical etching. However, this process required a significant amount of time to cover a small area, so they chose the chemical etching method. In case of crystalline silicon-based STSCs fabrication, mechanical wafer engineering was applied [4]-[6]. This approach used precise dicing saw to produce perpendicular grooves on the front and rear side of the silicon wafer, and consequently holes were formed at their crossing point with variable diameter. This resulted in a partial optical transparency of the solar cell. The STSCs can also be made by simply controlling the thickness and morphology of the photoactive film and opaque metal layer [7]-[9]. Kim et al. reported that the visual transparency of perovskite solar cells can be improved through making the ultralsmooth surface of perovskite layer using a short spinning with vacuum drying method and a thin Ag top electrode (10 nm) coated with MoO_3 (20 nm) [9]. Power conversion efficiency (PCE) of 11.0% and 8.7% for the front and back incidence, respectively, were achieved. Using this approach can be applicable to all thin-film solar cells; however, it still requires complex equipment such as vacuum thermal evaporator leading to high fabrication cost and unsuitable for commercial manufacture.

To date, there are many excellent alternatives to replace thermally evaporated metal thin electrodes in the STSCs, for instance, carbon nanotubes (CNTs), graphene, poly(3,4-ethylendioxythiophene):poly(styrenesulfonate) (PEDOT:PSS), and metal nanowires (MeNWs). These materials are versatile with solution deposition methods. To make these materials as a top electrode of the STSCs, the lamination process is one very potential technique owing to its benefits including large-area, low-cost, and flexible device fabrication. The key of this method is how to create the effective mechanic and electronic contact between top semitransparent electrode and the rest of solar cell. This paper reviews the development of adhesive material and mechanism in lamination method that has contributed to the efficiency enhancements.

II. MECHANISM OF LAMINATION METHOD

In 1998, Granstrom and co-workers used lamination method followed by controlled annealing to produce two-layer polymer diodes [10]. Afterwards this process was widely introduced to fabricate the STSCs.

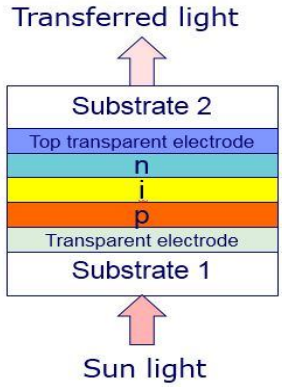


Figure 1. Graphical illustration of the STSCs

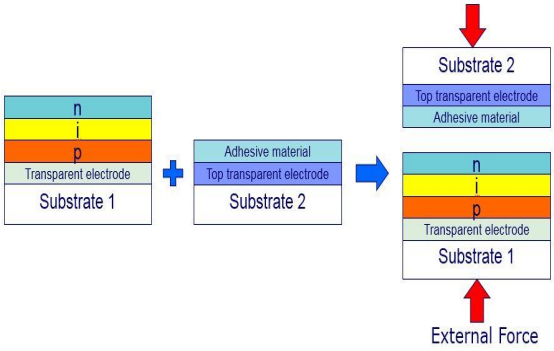


Figure 2. Mechanism of lamination method

The mechanism of lamination method is showed as in Fig. 2. In this process, the bottom part of the STSCs containing active layer is fabricated by conventional methodologies on glass or flexible substrates, whereas the top transparent electrode is separately coated by solution-based methods on another substrate. Then, the top and bottom parts of the STSCs are assembled by a light external force. Such an approach will avoid using vacuum deposition process. The lamination process has the capacity to produce various device architectures of solar cell, like single cell [11]-[18], tandem cell [20]-[21]. It is worth saying that the lamination method is one simplicity and low cost.

III. TOP TRANSPARENT ELECTRODE MATERIALS

The top electrode of the STSCs requires materials that have high optical transparency, low sheet resistance and easy of using solution-based deposition methods. To date, there are various materials that can meet these required criteria and reported in the literature applying the lamination method such as PEDOT:PSS [11]-[13], CNTs [14], graphene [15], MeNWs [16]-[19]. Among these materials, the MeNWs is the most potential candidate owing to its unique properties in terms of both optical transparency and sheet resistance. The MeNWs is also easily coated on glass/flexible substrate with various wet-coating processes consisting of doctor blading, spin-coating, Meyer rod coating, and spray-coating. In addition, the MeNWs can be synthesized with various metals, including Ag [22]-[23], Au [24], Ni [25], and Cu [26]-[27]. With the versatile metal materials and coating process, the MeNWs showed a dominant performance comparable to those of other transparent electrodes [28].

IV. ADHESIVES

The adhesives play an important role in lamination method to connect the top and bottom parts of the STSCs while assembling. they significantly affect the electrical contact between the active thin film and top transparent electrode. The adhesives have to satisfy following criteria: high conductivity and optical transparency, as well as good adhesion. In addition, these materials are compatible with solution-based deposition methods. Therefore, conventional glues, as in [29], cannot used for these purposes. Ouyang et al. reported that the PEDOT:PSS mixed with D-sorbitol can adhere various films together [30]. In this research, such compound worked as an electric glue with high transparency and was used to fabricated a polymer light-emitting diode by lamination process. The properties of mixture of PEDOT:PSS and D-sorbitol were investigated and improved to produce the STSCs [17], [31], [32]. Makha and co-workers optimized the D-sorbitol content for effective adhesion, film thickness of the PEDOT:PSS/D-sorbitol adhesive to planarize the metal mesh, and pre-annealing temperature of the of the laminate electrode for removing water from the PEDOT:PSS [17]. With this approach, the best cell performance was achieved with D-sorbitol concentration of 30 wt% per milliliter PEDOT:PSS dispersion, thin thickness of 1.3 µm, and pre-annealing temperature of 120^0C for 10 min before lamination.

Besides the PEDOT:PSS/D-sorbitol adhesive, Bryant et al. introduced a novel transparent conducting adhesive (TCA) for lamination method [18]. This TCA was specifically designed to have extremely high transparency and conduction paths vertically. To fabricate the TCA the PEDOT:PSS was blended with an acrylic microemulsion pressure sensitive adhesive such that the final fraction of the PEDOT:PSS was 0.0175 in dry TCA film. Using this TCA the average PCE of 13.3% and 9.8% for the front and back side, respectively, were achieved.

CONCLUSION

In summary, we have highlighted recent progress on the lamination method for fabricating the STSCs. This is one the promising methodology with full solution-processability, low cost, simplicity, and self-encapsulation. The STSCs fabricated with lamination process showed encouraging efficiency comparable to device by conventional processing

methods. Such an approach will reduce the influence of vacuum deposition process and head for industrial production.

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