Developing a high throughput metallization approach for silicon solar cells based on flexographic printing

A. Lorenz[1], A. Kalio[1], T. Barnes Hofmeister[1], S. Kroh[1], A. Kraft[1], J. Bartsch[1], F. Clement[1], and D. Biro[1]
[1] Fraunhofer Institute for Solar Energy Systems ISE, Heidenhofstr. 2, 79110 Freiburg, Germany

ABSTRACT

Rotational printing methods like flexographic printing are a highly interesting approach for a high throughput front side metallization of silicon solar cells. Within the present contribution, flexographic printing has been applied for the seed layer front side metallic-zation on Czochralski-grown silicon wafers. Three seed layer silver inks with different viscosities have been prepared for the experiment. The impact of printing pressure on the seed layer finger width has been investigated. It was found that printing pressure has a strong impact on the width of flexo printed fingers. Contact fingers down to 32 µm width could be realized by applying the optimum printing pressure. The fabricated solar cells achieved an average conversion efficiency of η = 18.7 % after silver light-induced plating.

1. Introduction

Silicon solar cells feature a front and rear side metallisation, which is usually applied by flatbed screen printing. However, screen printing is limited in respect of throughput and the ability to transfer very small amounts of cost-intensive silver paste. Rotational printing methods are a highly interesting approach to increase throughput rates and reduce silver consumption significantly. Particularly flexographic printing has proven to be well-suited for high-speed transfer of fine line contact grids on textured silicon wafers [1]. Ultrafine line seed layer fingers down to 25 µm width on industrial Cz-silicon wafers have been demonstrated using this technology [2]. The flexo printed seed layers are subsequently reinforced using silver or nickel-copper-silver light induced plating (LIP) [3]. Within this work, the potential of flexographic printing for solar cell front side seed layer metallization is demonstrated on 156 x 156 mm² Czochralski-grown (Cz-Si) silicon wafers.

2. Experimental Approach

Three types of seed layer silver inks for front side metallization using flexographic printing have been prepared in-house. The viscosity of the ink formulations has been varied by adding a different amount of resin. Ink 1 had a viscosity of η_1 = 135 mPa·s and contained no resin. Ink 2 contained a specific amount of resin and had a viscosity of η_2 = 155 mPa·s. Ink 3 has been prepared with the double amount of resin compared to ink 2 and had a viscosity of η_3 = 339 mPa·s. Seed layer front side metallization has been applied on industrial Cz-Si wafers (156 x 156 mm²) using flexographic printing and all three ink variations. Within a separate pre-test, printing pressure has been varied by adjusting the vacuum substrate holder perpendicular to the axis of the printing cylinder (z-direction) in 5 µm-steps. Using the results of this test, the optimum printing pressure for uninterrupted contact fingers has been adjusted for the fabrication of the flexo printed solar cells. The cells have been dried directly after printing in a cabinet dryer at T = 200°C. All cells have been fired in a fast firing furnace at T_{FFO} = 920°C. Seed layer finger width w_s has been measured at two defined positions on 10 cells per group using confocal microscopy. Subsequently, the seed layer front side metallization has been reinforced with 85 mg Ag using Ag-LIP. Specific contact resis-tance of the front contact has been determined using transfer-length-method (TLM). I-V-measurements have been carried out on all cells using a Manz industrial cell tester and sorter with Halm I-V-measurement device. The results have been compared to typical values of screen printed cells on the used material.

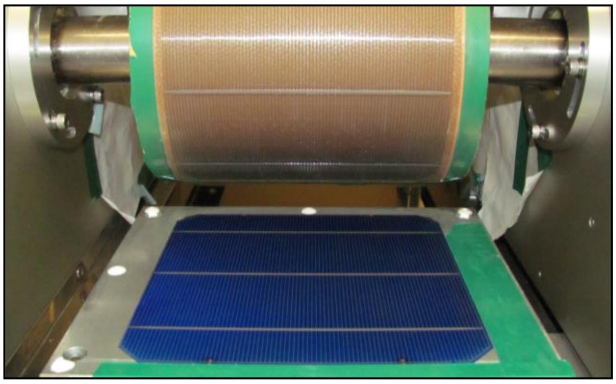

Fig. 1 Experimental platform for solar cell metallization using flexographic printing

3. Results and Discussion

The variation of the printing pressure showed that the flexo printed seed layer finger width w_s depends strongly on the printing pressure (respectively z-position of the substrate holder). Adjusting the travel distance of the substrate holder by 85 µm in z-direction and thus increasing printing pressure led to a finger width increase of Δw_f = 48 µm (137 % related to the smallest achieved average finger width) (fig. 2). The smallest individual finger width has been determined with $w_{s,min}$ = 32 µm at substrate holder position z_{min} = 10 µm.

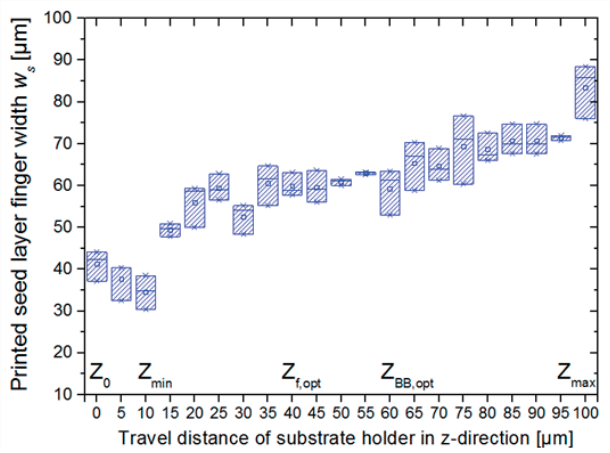

Fig. 2 Impact of printing pressure respectively z-position of the substrate holder on the printed finger width

Specific contact resistances between $\rho_{c,min}$ = 3.3 mΩcm² (ink 2) and $\rho_{c,max}$ = 4.7 mΩcm² (ink 1) have been measured after Ag-LIP which confirmed a good contact of the seed layer inks on the 90 Ω/sq emitter.

Figure 3 shows the conversion efficiency of solar cells which have been printed with seed layer ink 1, 2, and 3 after Ag-LIP. The best group (ink 1 + Ag-LIP) achieved an average conversion efficiency of η =18.7 %. The best individual cell within this group achieved a conversion efficiency of η_{max} = 18.8 %. Comparing the results to typical values of screen printed cells on the same material (grey-shaded area) demonstrates that flexo printed cells with Ag-LIP can achieve results which are similar to fully screen printed solar cells.

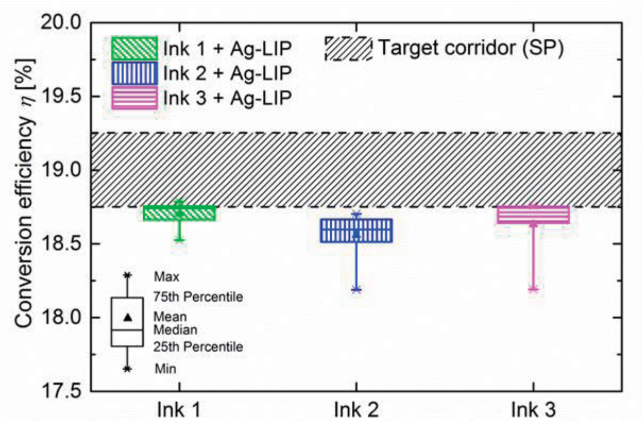

Fig. 3 Conversion efficiency η of solar cells with flexo printed seed layer inks 1 to 3 and Ag-LIP. The grey-shaded area shows the typical efficiency of screen printed cells on the same material.

4. Conclusion

The results of the pre-test comprising a systematic variation of printing pressure clearly showed that this parameter is a key factor to control the width of flexo printed contact fingers. This corresponds to the results of previous studies in the field of flexographic printing [4;5]. The printed seed layer finger width w_s increased by up to 137 % after traversing the substrate holder by 85 µm in *z*-direction (and thus increasing printing pressure). Finger widths down to $w_{s,min}$ = 32 µm could be realized by applying the optimum pressure.

Specific contact resistance of all three inks after Ag-LIP was in an acceptable range compared to screen printed cells. Yet, decreasing ρ_c further by optimizing the ink formulation would help to reduce series resistance r_s of the cells and thus help to increase fill factor *FF*. The best cell group (ink 1) achieved an average conversion efficiency of η = 18.7 % after Ag-LIP which is comparable to screen printed cells on the same material.

The results underline the potential of flexographic printing technology for the seed layer front side metallization of silicon solar cells. The economic advantage of a considerably higher throughput compared to screen printing makes this technology not only interesting for a seed and plate approach but also for new solar cell concepts like multi-busbar solar cells.

REFERENCES

[1] S. Thibert *et al.*, "Silver ink experiments for silicon solar cell metallization by flexographic process", *Proc. of the 38th Photovoltaic Specialist Conference, (*IEEE, Austin 2012)

[2] A. Lorenz *et al.*, "Flexographic Printing – High Throughput Technology for Fine Line Seed Layer Printing on Silicon Solar Cells." *Proc. of the 28th EUPVSEC,* Paris 2012, pp. 1017–1023

[3] J. Bartsch, "Advanced front side metallization for crystalline silicon solar cells with electrochemical techniques. " PhD, 2011.

[4] M.F.J. Bohan *et al.*, "Evaluation of Pressures in Flexographic Printing", *Proc. of the 55th Annual Technical Conference TAGA*, Montreal 2003, pp. 311–320.

[5] D. C. Bould *et al.*, "Effect of impression pressure and anilox specification on solid and halftone density" *J. of Engineering Manufacture* 2011, vol. 225, no. 5, pp. 699–709, 2011.