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Characterization and Optimization of the Contact Formation for High-Performance Silicon Solar Cells

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Abstract – In this paper, p–n junction formation using screen–printed metalization and co–firing is used to fabricate high–efficiency solar cells on single– crystalline silicon substrates. In order to form high–quality contacts, co–firing of a screen–printed Ag grid on the front and Al on the back surface field is implemented. These contacts require low contact resistance, high conductivity, and good adhesion to achieve high efficiency. Before co–firing, a statistically designed experiment is conducted. After the experiment, a neural network (NN) trained by the error back–propagation algorithm is employed to model the crucial relationships between several input factors and solar cell efficiency. The trained NN model is also used to optimize the beltline furnace process through genetic algorithms.

Key words –

I. Introduction

To obtain high-quality contact formation, both screen-printed metallization and co-firing in an infrared (IR) beltline furnace have played important roles in the high-efficiency photovoltaic industry. P-N junction formation has not only influenced crucial electrical characteristics (such as efficiency, open circuit voltage, and fill factor), but also manufacturing cost and time.

Even though there are several disadvantages (such as high grid shading, junction shunting, low metal conductivity, and high contact resistance), screen-printing technology is used extensively for commercial solar cell manufacturing [1]. Screen- printed metalization makes p-n junction contact formation more rapid, simple, and economical compared to the conventional methods such as photo-lithography, buried-contact, and silicon ribbon technologies. Today, a matter of concern is how to alleviate high contact resistance and junction shunting [2-3].

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In order to make the co-firing process more stable and controllable, a systematic characterization experiment to determine and clarify the relationship between process parameters and global optimization using variable parameters is necessary.

II. Experiments

To fabricate n+-p-p+ SC silicon solar cells, p-type, 1.5～2.0 Ω-cm, square textured float zone (FZ)wafers were employed. Saw damage removal by potassium hydroxide (KOH) etching was performed for 3 minutes at 85°C followed by a cleaning step. Before the emitter diffusion process with phosphoric acid on the surface, in order to acquire a hydrophilic feature, sulfuric acid (H2SO4) was oxidized uniformly. Phosphoric acid was then deposited on the front surface of the wafers by spin coating. The coated wafers were fully annealed in a ceramic roller hearth furnace with no metal contamination and eight heating zones, and this was followed by parasitic junction removal through edge isolation. After emitter formation by diffusion, phospho-silicate glass (PSG) was etched from the surface in a dilute HF solution. The next step was depositing a SiNx single layer antireflection coating (ARC) by low-frequency (50 KHz) plasma-enhanced chemical vapor deposition (PECVD) to alleviate reflection losses and to enhance surface and bulk passivation. Ag and Al paste were then screen- printed on the front and back surface, respectively. Lastly co-firing was conducted in an IR beltline furnace with three dissimilar temperature zones.

Ⅲ. Results and Discussion

3.1 Response surface methodology

After NN process models were established, response surfaces were generated to illustrate the relationships between the input parameters and the responses. Any two of the four process parameters were simultaneously varied, while the remaining parameters were fixed at their mid-range values.

For each model, a temperature variation was observed in zone 3 which has a predominant effect on cell efficiency. In addition, high efficiency was observed at belt speeds at the approximate middle range. To highlight the effect of zone 3temperature on cell efficiency, the temperature in zone 3 and belt speed were fixed at 845°C, 870°C at 115 rpm, respectively.

Table 1. Recipe results

Zone 1 Temp.	Zone 2 Temp.	Zone 3 Temp.	Belt speed	Efficiency
557.24 (°C)	821.45 (°C)	847.52 (°C)	117.61 (rpm)	15.81 (%)

3.2 Optimization using GA

Using NN models in combination with GAs, the ideal input parameters that lead to high-quality contact formation can be determined. Synthesized recipe for optimizing the co-firing process are listed in Table 1.

IV. Conclusion

In summary, co-firing experiments were conducted using a central composite experimental design. Four parameters associated with cell efficiency were manipulated, and their effects were investigated using NN models. Mid-range belt speed at fixed middle values of zone 1 and zone 2 temperatures resulted in a high-efficiency cell. Optimization of the co-firing process conditions was successfully achieved using genetic algorithms, and performance was verified by additional experiments. The verification experiments showed an average of 15.44% in efficiency, which is 3.9% improvement compared to the previous DOE experiments.

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