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Effect of binding force between silver paste and silicon on power degradation of crystalline silicon solar module

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ABSTRACT

The long term reliability of crystalline solar modules is critical to the cost effectiveness and the commercial success of photovoltaic. The binding force reduction between silver paste and silicon leads to power degradation during subsequent qualification tests or outdoor using. Hence, it is very important to investigate the binding force of busbar and its influence. In this paper, the relationship between power degradation and the binding force of busbar was investigated. Significant results about binding strength of busbar were found as a result of different silver pastes. For crystalline silicon solar cells with 1.6 mm width busbar, the binding force between silver paste and silicon is not less than 2.0 N so as to let the modules made by such cells pass qualification tests. The results laid the foundation for studying the mechanical performance of front contact metallization system for screen-printed crystalline silicon solar cells.

1. Introduction

The crystalline silicon solar module is a workhorse for photovoltaic energy in a long time, so the reliability of crystalline solar modules is critical to the cost effectiveness and the commercial success of photovoltaic [1–4]. At present, the sintered silver paste made by screen-printing process is widely used for the front electrode of industrial crystalline silicon solar cells. In order to match high emitter square resistance and narrow finger, a 40 μm line width fine screen-printing has been used into cell production. In order to reduce silver consumption, the hollowed-out silver busbar has also been used into crystalline silicon solar cells. These technologies weak the binding force between busbar and silicon, and would lead to additional field failures and unacceptably large module power degradation. Some silver pastes are capable of contacting high resistive emitters and lead to higher efficiency, but their binding force is weak. Now this phenomenon perplexes silver paste and cell producers, so it is urgent to know how much force is enough for the binding between silver paste and silicon. Lots of authors have studied the current transport mechanism between silver paste and silicon, but few people investigated the relationship between module power degradation and the binding force of busbar [5–7]. In this paper, some kinds of silver pastes from different manufacturers were used to assess power degradation. The relationship between power degradation and the binding force of busbar was investigated. Significant results about binding strength of busbar were found as a result of different silver pastes. It was observed that the binding force between silver paste and silicon is not less than 2.0 N, so as to let the modules made by such cells with 1.6 mm width busbar pass qualification tests, and achieve 25 years lifetime. The results laid the foundation for studying the front contact metallization system of screen-printed crystalline silicon solar cells.

2. Experimental methods

The 156 mm × 156 mm (238.95 cm^2) boron-doped industrial single crystalline silicon wafers were used for our experiments. After lifetime measurements, the as-cut wafers were treated by chemical iso-texture for saw damage etch and light trapping. The texturization process was done in two steps. The first step was to remove damage on the surface caused by sawing. This step was carried out in about 10% NaOH solution kept at 80 ± 2 °C. This removed about 30 μm outer layer from all sides. The second step was to produce straight upright pyramids on a freshly prepared damage free surface. After a thorough wash in flowing deionized water, the wafers were etched in a solution consisting of 1.0% NaOH and 20% isopropyl alcohol by volume at 80 ± 2 °C. The wafers were washed in the flowing deionized water followed by boiling in dilute HCl to remove the metallic impurities. Finally the wafers were washed again in the flowing deionized water and were dried with an air jet, and then followed by $POCl_3$ diffusion to form the 60–65 Ω/square emitters.

After edge-isolated and phosphorus glass removal, the SiN*x*:H antireflection coating was deposited on the emitter by a tube PEC-

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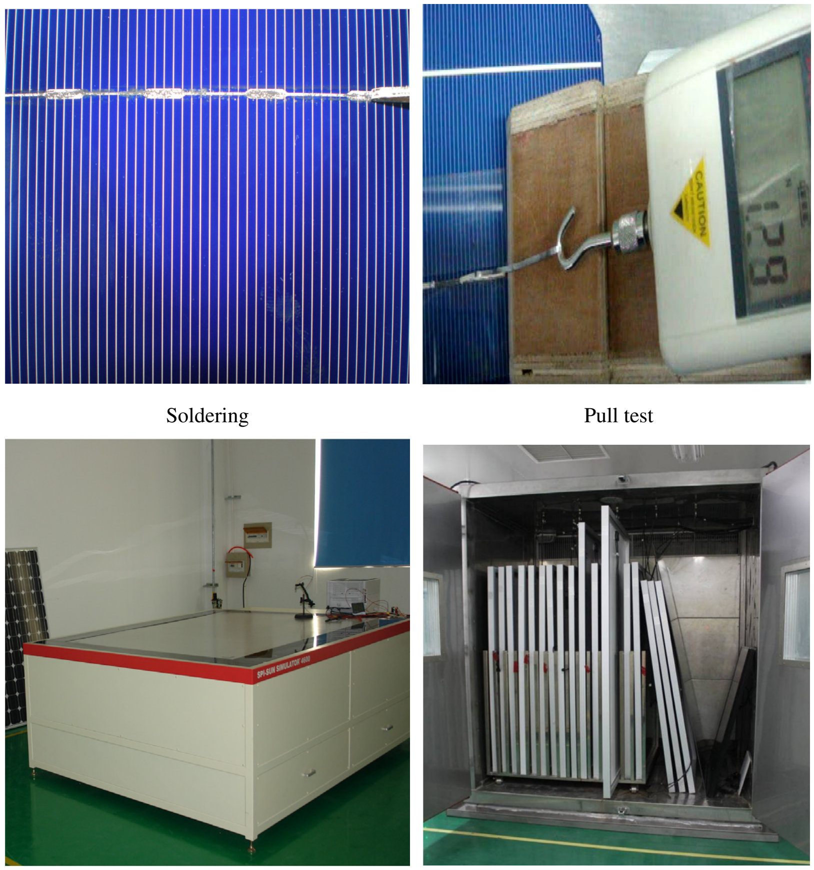

Soldering | Pull test

Module performance test | Environment chamber test

Fig. 1. Experimental setup.

VD using SiH_4 and NH_3. The imaginary part (extinction coefficient) of these films is nearly zero in the measured wavelength region of 0.3–0.8 μm. The refractive index is 2.03 at a wavelength of 632.8 nm. Then screen-printed silver thick film back contact, screen-printed aluminum paste back surface field and silver thick film front contact were prepared and co-fired rapidly in a belt furnace. The testing and sorting of solar cells were performed by Berger testing system.

In our experiments, four kinds of front contact silver paste were used. The binding force of solar cells between silver paste from different manufacturers and silicon were measured by HG-500 tensometer.

After the binding force measurements, the tabbing and stringing of solar cells by using a 1.6 mm width tinned copper ribbon were carried out by manual welding respectively. These 72 pieces single crystalline silicon solar cells were laminated one module in series that three schottky diodes were built in. 24 cells were serially connected with a bypass diode across each string. The modules were divided into groups named A, B, C and D respectively according to silver pastes from different manufacturers. The module performance testing was carried out by Spire 460 [8].

Before beginning damp heat test (DAH), the above modules were exposed to sunlight to an irradiation level of 5.5 kWh/m^2 while open-circuited.

The experimental setup is shown in Fig. 1. After initial power measurements, the solar modules were put into test chamber made by Votech in Germany for a DAH, the test conditions are 1000 h at 85 ± 2 °C, 85 ± 5% relative humidity (RH) [8].

Table 1
The binding force of busbar between different silver pastes and silicon.

Silver pastes	Binding force of busbar (N)				Average (N)
A	3.23	3.47	3.38	3.39	3.37
B	1.80	1.96	2.32	2.04	2.03
C	1.35	1.28	1.17	1.26	1.27
D	0.23	0.12	0.26	0.18	0.20

3. Results and discussion

3.1. Effect of binding force between silver paste and silicon on power degradation of solar modules

The binding force of solar cells between silver pastes and silicon is indicated in Table 1.

From Table 1, the binding force of busbar for Paste A ranges from 3.23 N to 3.47 N; the binding force of busbar for Paste B ranges from 1.80 N to 2.32 N; the binding force of busbar for Paste C ranges from 1.17 N to 1.35 N; the binding force of busbar for Paste D ranges from 0.12 N to 0.26 N.

Power of solar modules before and after DAH is indicated in Table 2. From Table 2, we found that the power degradation of module C and D is more than 5% after DAH, and the power degradation of module A and B is less than 5% after DAH. According to IEC 61215 [9], the module B can pass qualification tests, so the binding force of busbar for Paste B is enough for a reliable solar module, i.e. the binding force between silver paste and silicon should be more than 2.0 N.