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# Study of crystalline silicon solar cells with integrated bypass diodes

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This paper reported a novel method of integrating bypass diodes into crystalline silicon solar cells. Bypass diodes which have the opposite p-n junction were formed by printing specific paste on the local surface of solar cells using screen printing, while infrared laser was applied to isolate the diode from the cell after firing. A module of crystalline silicon solar cells with integrated bypass diodes was fabricated and the *I-V* characteristics were measured under different shade conditions. The experimental results clearly showed that the integrated bypass diodes can effectively stabilize module's short circuit current while reduce the module power loss when shaded as well.

**crystalline silicon solar cells, bypass diode, integration**

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## 1 Introduction

Module is a significant component of the PV system, and the performance of the PV system is directly affected by the stability and reliability of the modules. Modules consist of serially connected solar cells. The output current might be reduced when part of the module is shaded or breakdown. Simultaneously, the working current of the solar cells that were in normal conditions is reduced too. These all lead to a serious reduction of output power of the module. A more serious problem that can arise is the degradation and eventual failure of the array due to localized overheating resulted from a reverse voltage provided by the solar cells in normal conditions [1, 2]. To solve the problem, bypass diode is integrated into the modules in a traditional way. The bypass diode is parallel connected with the serially connected solar cells. When part of the solar cells is shaded or under poor conditions, the current can be shunted by the bypass diode, thus, avoiding damage of the solar cells [3]. However, a drawback of this method is that the power output loss of the module increases due to the all shunted solar cells in the string.

As shown in Figure 1, a typical PV module consists of 36 serially connected cells, and a bypass diode is in parallel connected with each group of 18 solar cells. When part of the serially connected 18 solar cell group is shaded, they will be shunted by the bypass diode, which leads to a great loss of the voltage output of the module. The power output of the module also decreases due to the voltage loss.

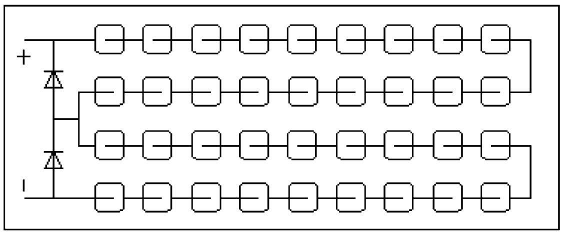


**Figure 1** A typical solar cell module.

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So if each solar cell is fabricated with an integrated bypass diode, then the shunting effect can work on every solar cell and reduce power output loss.

The integrated bypass diode is widely used in compound semiconductor solar cells and multi-junction solar cells [4, 5]. It's extremely rare to apply integrated bypass diode to c-Si solar cells either domestically or abroad. One of the representative works was achieved by Green's team [6]. In their work, the bypass diodes on the c-Si solar cell surface were gained by evaporating aluminum and burning through p-n junction. The bypass diode was in parallel connection with solar cell through the main grid. The drawback of this method is that the FF of the solar cells is reduced due to the additional shunting resistance. The test results indicated that the solar cells can be protected by the integrated bypass diode and the power output of the module arrays can also be enhanced when part of the solar cells are shaded [7, 8].

In this paper, bypass diode was integrated into the c-Si solar cells by screen printing. Then a module of these solar cells with integrated bypass diodes was fabricated and showed an obvious shunting effect when it was locally shaded. As a result the power loss induced by local shading can be reduced effectively.

## 2 Experiments

### 2.1 Solar cell process and characterization of the integrated bypass diodes

In this paper, the bypass diode was integrated into the c-Si solar cells by screen printing appropriate paste. The preparation processes were as follows.

1) Prepare solar cells with antireflection layer in conventional process, which is shown in Figure 2.

2) The screen printing process is shown in Figure 3. Firstly, Ag-Al paste is screen printed on the rear side of the solar cell to form rear electrode.

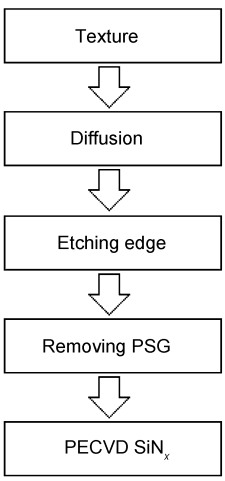


**Figure 2** Conventional c-Si solar cell process.

3) Screen print Al paste on the rear side to form back surface field.

4) Screen print Ag-Al paste on the front side to form front electrode of the bypass diode.

5) Screen print Al paste on the front side of solar cell to form front side field of the bypass diode.

6) Screen print Ag paste on the rear side of solar cell to form rear electrode of the bypass diode.

7) Screen print Ag paste on the front side of the solar cell to form front electrode.

8) Gain solar cells with bypass diode by high temperature firing.

9) Isolate the bypass diode from the solar cell substrate by 1064 nm laser.

The performances of the solar cell and integrated bypass diode are then characterized by DC voltage/current source and infrared thermal imaging camera.

### 2.2 Connection scheme of the modules and measurement

In this module, the bypass diode is in parallel connection with a neighboring solar cell through solders. That is, the bypass diode on solar cell A is in parallel connection with solar cell B, and the bypass diode on solar cell B is in parallel connection with the solar cell C.

Figure 4 shows the connection scheme of the module. Figure 5 shows the electrical circuit connection of a real product.

In this paper, 10 pieces of solar cells with integrated bypass diodes were serially connected to form a module. The *I-V* curves of the module were gained in different shade conditions both before and after applying bypass diode. The shade area increased from 0% to 100% with 25% each step.

## 3 Results and discussion

The solar cell with integrated bypass diode is shown in Figure 6. The 18 mm×18 mm square area represents the integrated bypass diode.

The Al paste was screen printed on the front surface of the solar cell, then during the firing process, it burnt through the $SiN_x$ layer and alloyed with the Si substrate, thus forming a locally $p^+$ layer on the front surface of the solar cell. So a tunnel junction occurred due to the $p^+$ and $n^+$ layers existing in the interface between the bypass diode and the solar cell. And the leakage current induced by the tunnel junction can affect the performance of the solar cell. In order to solve the problem, laser isolation was used to isolate the bypass diode from the solar cell substrate.

Figure 7 shows the infrared thermal images of the solar cells under reverse bias before and after laser isolation.