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# Direct soldering of screen-printed Al-paste layer on back-side of silicon solar cell using SnAg solder

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ABSTRACT

Direct joining of Al back surface field (Al BSF) in a polycrystalline silicon solar cell using a green Sn-3.5Ag solder by the assistance of ultrasound was investigated. SEM, peel force, electrical resistance and open-circuit voltage ($V_{oc}$) tests were used to study the effect of ultrasonic action time on the performance of the solar cell. The results show that with the increasing of ultrasonic action time, more Al particles in the paste residual layer dissolved into the solder layer. The dissolved Al existed in the bond metal as forms of α-Al and Ag-Al compound phases. The solder bonded directly with the Al-Si eutectic layer under ultrasonic action time of 6 s. The resistance of the joints was 1.27 mΩ and the peel force could reach as high as ∼1.44 N/mm. The $V_{oc}$ of solar cell was 524 mV, which was higher than the 467 mV of solar cell soldered with Ag electrode.



## 1. Introduction

Crystalline silicon solar cell is trending towards high efficiency, low cost [1] and environmental friendliness. In the packaging process, the rear contact of cell requires to be bonded with the top contact of another cell to conduct current in a solar power module [2]. There will be three layers after sintering aluminum powder suspension on the rear side of Si: the Al-doped $p^+$-layer, the eutectic layer and the layer of paste residuals. The sintering process realizes the doping on the rear side of solar cells and produces Al back surface field [3,4]. However, the Al BSF is very difficult to solder. In order to make soldering easier, silver busbars are printed on the back surface, and Cu interconnector ribbons coated with SnPb solder are used to join the silver busbars [5]. The metallization processes are complicated and the noble metals of silver and copper are used. Moreover, the Sn-Pb solders are not environment-friendly. In addition, the silver busbars prevent the formation of BSF, which would raise the recombination rate [6] and lead to a lower open-circuit voltage [7]. If the solder can form direct bond with the Al BSF underneath the metallization, the metallization processes can be simplified, costly Ag can be avoided and the performance and reliability of solar power modules can be improved. However, the oxide film on the surface of Al is very stable, resulting in poor solderability. In recent years, Al and its alloys were successfully soldered with Sn-based alloys. Pure Sn was used to solder Al 2024 directly assisted by ultrasound [8,9]. Sn-3.5Ag solder was also used to solder Al 1070 [10]. Recently, green solders such as Sn-Zn, Sn-Ag and Sn-Ag-Cu have been developed to join the Ag electrodes of solar cells [11,12] and Al ribbon was developed for lower cost than the tin-coated Cu ribbon [13].

Here, we soldered the Al BSF and Al ribbon directly using a Sn-3.5Ag solder with the assistance of ultrasonic waves. The effect of ultrasonic action time on the microstructure, mechanical properties, electric conductivity and photoelectric properties of joints was investigated in details. The work is helpful to realize the packaging of solar cells with low cost, high performance and less pollution.

## 2. Experimental procedure

The commercial polycrystalline solar cells were provided by Shanghai Suiying Photovoltaic Co. Ltd. The solar cell was 200 μm in thickness and the nominal $V_{oc}$ was 0.5 V. The rear side was printed with Al pastes. Commercial Sn-3.5Ag (wt%) alloys were used as filler metals, whose melting point is 221 °C. Pure Al 1060 alloy was used as ribbons, which were 100 μm in thickness and 2 mm in width.

In the process of soldering, 30 mg solders were placed on the surface of Al BSF. Then the ultrasonic waves were applied into the melting solders with a ultrasonic iron. The ultrasonic generator in the iron was equipped with a power supply, a vibrator, a

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transducer, a booster and a sonotrode. The frequency of the ultrasonic vibration was 60 kHz with an amplitude of 3 μm and the power of induction heating was 60 W. After the application of ultrasound for 2 s, 4 s and 6 s during soldering, the solder layer had dimensions of $6 \times 4\ mm^2$. Then the interconnector ribbon was joined to the solder layer on Al BSF surface with the ultrasonic iron.

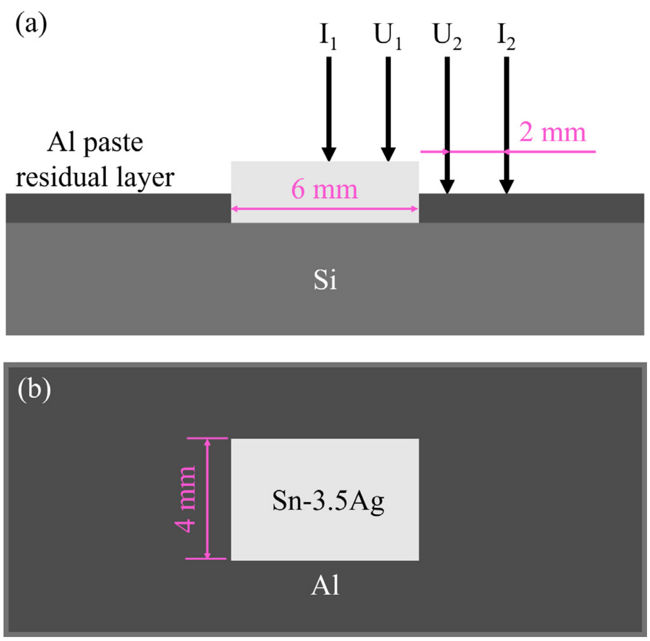


**Fig. 1.** (a) and (b) Schematic of 4-point resistance measurement.

The microstructures of the interfaces were observed by scanning electron microscopy (FEI-Quanta 200F) equipped with an energy dispersive X-ray spectroscopy (EDS). X-ray diffraction (XRD) tests were carried out by Bruker D8 Advance multi crystal diffractometer. A four-point resistance measurement was used to evaluate the electrical conductivity of the joint, as shown in Fig. 1. The values of resistance were provided by KEITHLEY-2420 multifunctional digital meter. Conventional 90° peel tests were performed to evaluate the mechanical properties of the joints using an adapted method of DIN EN 50 461 [14]. The tests were conducted using an microforce tester (Instron-5948). The $V_{oc}$ of solar cell was determined with Oriel Sol1A sunlight simulator ($p$ = 23.5 $mW/cm^2$) and Versa STAT 3 electrochemical workstation.

## 3. Results and discussion

Fig. 2a–c show the microstructure of the interfaces and the element distribution along the corresponding lines under the ultrasonic action for 2 s, 4 s, and 6 s. The thickness of the original Al paste residual layer was about 35 μm and this layer was composed of loosely sintered Al particles. When the ultrasonic action time was 2 s, the solder could wet and bond with the Al layer. The solder layer was mainly composed of β-Sn (Fig. 2a). The EDS results show the phase at point G had compositions of 64% Ag, 32% Al and 4%Sn (at.%), which can be identified as $Ag_2Al$ phase. The Al paste residual layer was still complete, as the element distribution along line AB indicates that the existence of the Al particle layer, with the thickness of about 35 μm. As the ultrasonic action time increased to 4 s, more Al particles dissolved into the solder layer and the solder had

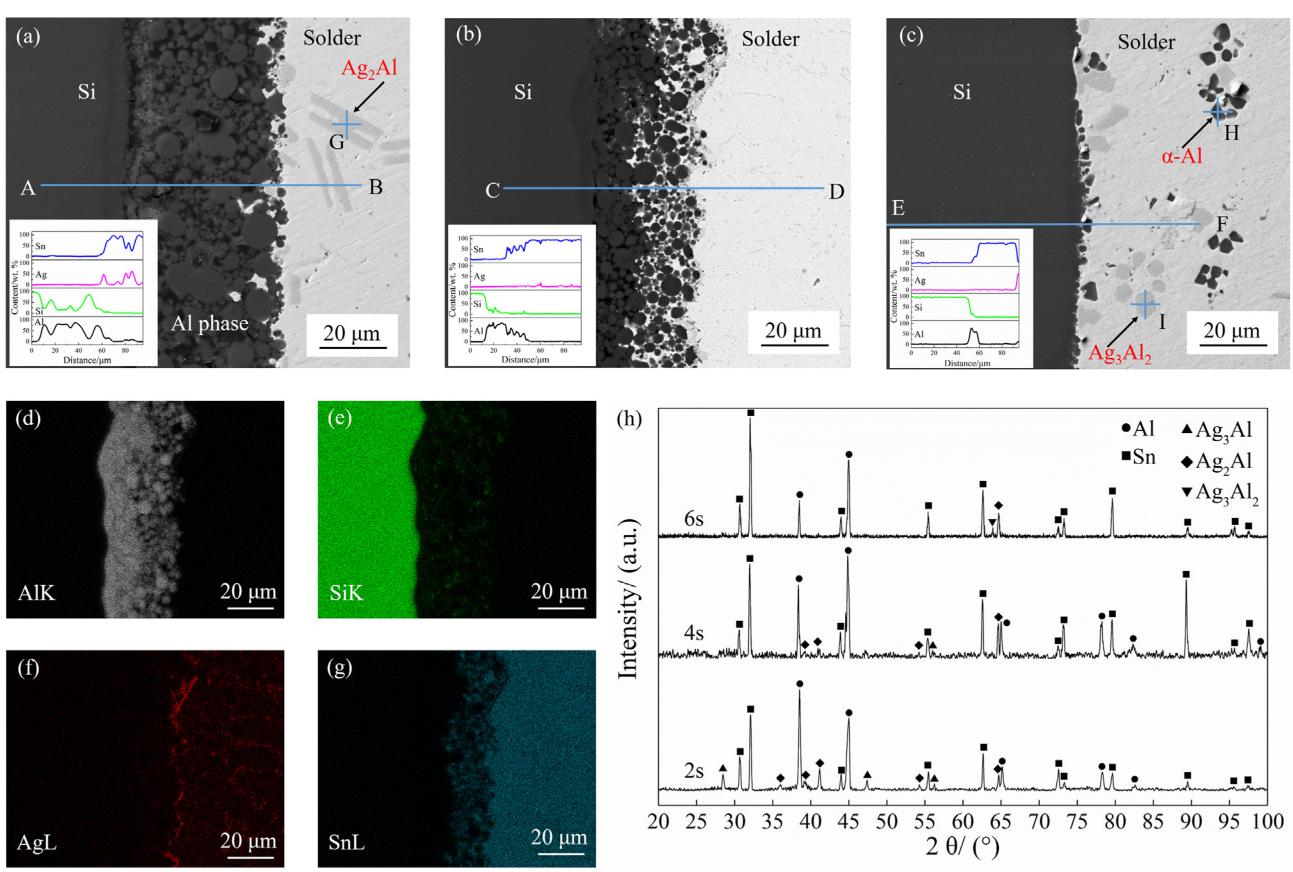


**Fig. 2.** Microstructure of the interfaces and the element distribution along the corresponding lines under the ultrasonic action for (a) 2 s, (b) 4 s and (c) 6 s; EDS Color maps for (b) 4 s of (d) Al, (e) Si, (f) Ag, and (g) Sn; (h) XRD patterns of joints for different ultrasonic action time.