NONDESTRUCTIVE TESTING OF POLYCRYSTALLINE SILICON SUBSTRATES BY MILLIMETER WAVES

Y. Ju, Y. Ohno, H. Soyama and M. Saka
Department of Mechanical Engineering, Tohoku University, Sendai, Japan

Abstract: A technique for nondestructive detection of small cracks in polycrystalline silicon substrates used for solar cells was demonstrated. A millimeter wave signal of 110 GHz was used and the amplitude of the reflection coefficient was measured. To increase the testing speed, a slit aperture sensor was used. The crack was detected effectively, while the testing speed was 50×35 mm^2/s. The experimental result indicates that the proposed technique could be used for nondestructive testing of polycrystalline silicon substrates on an assembly line.

Introduction: As a renewable energy source, solar cells have been developed rapidly. For the further spread of solar cells, the development of low cost solar cells is indispensable. Recently, solar cells using polycrystalline silicon substrates have been developed for cost reduction [1]. The substrates are commonly made from the top and tail parts of single-crystalline silicon ingots, which do not satisfy the standards of semiconductor. To increase the efficiency of the solar cell, it is a requirement that the substrate be of a large area and small thickness around 300 μm [2]. During the manufacturing process, the substrate is prone to cracks due to its polycrystalline structure causing rework and thereby increasing the production cost. Recently, we have developed a method using millimeter waves to detect the cracks in the polycrystalline silicon substrates [3].

Millimeter wave is an electromagnetic wave having a wavelength of 1 mm to 10 mm. Millimeter wave has an advantage that it can propagate well in air. Therefore, a coupling medium is not necessary for nondestructive testing. In the 1970s, some researchers have attempted using microwave to detect surface cracks in metallic components [4], where a horn antenna was used. In recent years, some researchers have suggested the use of an open-ended rectangular waveguide in a near-field fashion [5]. Recently, we have developed a millimeter wave measurement system utilizing an open-ended coaxial line sensor for detection and evaluation of small fatigue cracks on the metal surface [6, 7]. However, for the detection of small cracks in polycrystalline silicon substrates, both high spatial resolution and testing speed are required. To satisfy those requirements, we have developed a slit aperture sensor and its detection capability has been confirmed by the preliminary experiment [3]. In the present paper, we demonstrate the detection of small crack in the polycrystalline silicon substrate by using the slit aperture sensor with a high testing speed, where 35mm/s scanning speed was realized.

Experimental Procedure: The configuration of the millimeter wave measurement system is shown in Fig. 1. The photograph of the measurement system is show in Fig. 2. A network analyzer was used to generate a continuous wave signal fed to the sensor and to measure the amplitude of the reflection coefficient at the sensor aperture. The operating frequency was 110 GHz and the standoff distance was 600 μm. A computer was used to synchronize the stage translation in the *x*- and *y*-directions and to create a one-dimensional graph using the measurement results. In order to apply the technique to on-line testing, a high speed testing was carried out by introducing the slit aperture sensor. The sensor has a slit aperture with the dimensions of 50×1 mm. In the experiment, the sensor scanned the sample along the *x*-direction, which is perpendicular to the longest side of its aperture. Therefore, a high spatial resolution was obtained in the scanning direction. To obtain high testing speed, the sensor was controlled to scan the sample continuously with a speed of 35 mm/s. Therefore, for testing an area of 50×35 mm^2, only 1 second is needed.

One polycrystalline silicon substrate containing introduced small crack was used as the sample. The silicon substrate has dimensions of 125×125×0.35 mm. Figure 3 shows the photograph of the sample. As shown in Fig. 3, the crack can be observed clearly by using penetrant testing method, but the crack cannot be observed if there is no the penetrant. This kind of small crack will grow in the process of solar cell production and decrease the efficiency of solar cells.

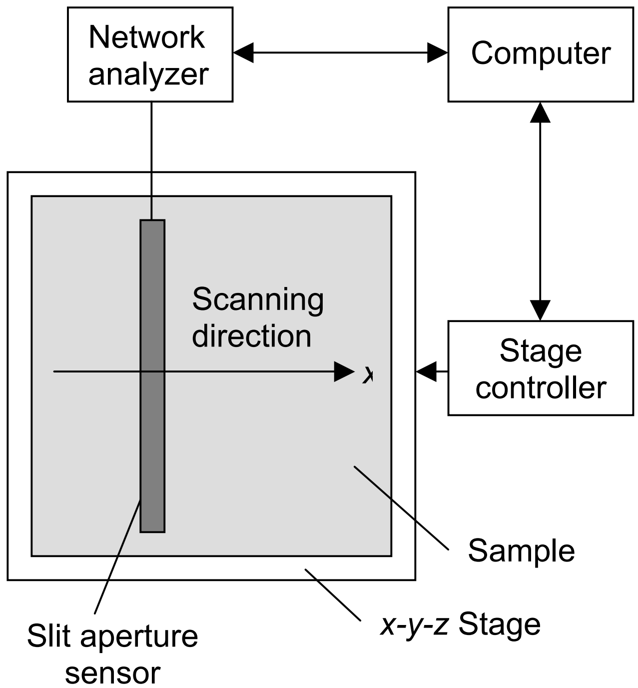

Fig. 1 Configuration of the millimeter wave measurement system

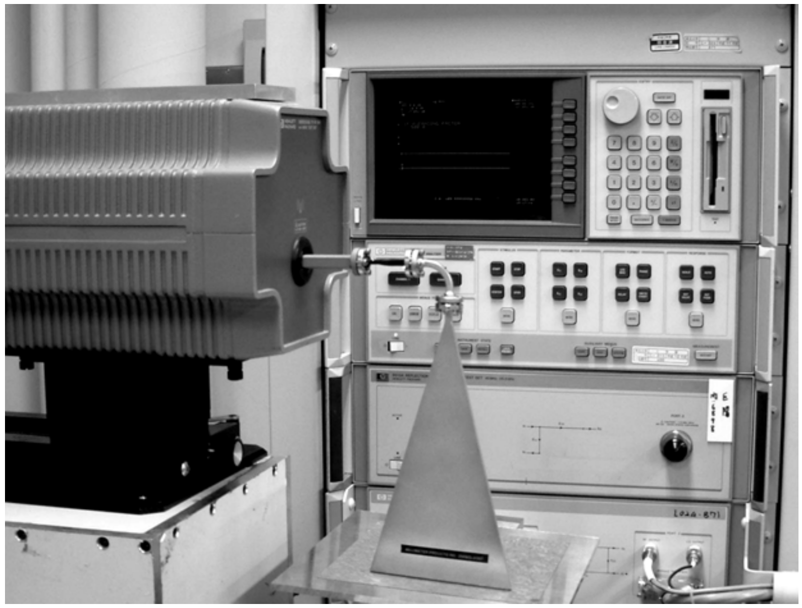

Fig. 2 Photograph of the millimeter wave measurement system

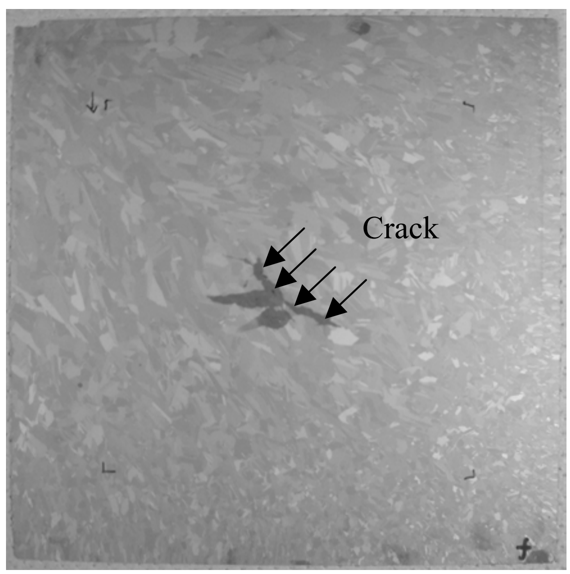

Fig. 3 Photograph of the polycrystalline silicon substrate

Results and Discussion: The measurement results obtained by using the slit aperture sensor are shown in Figs. 4 and 5, respectively. Figure 4 shows the result by scanning the sample in a range of 100 mm, with the speed of 35 mm/s, where 801 data of the amplitude of the reflection coefficient were recorded. The measurement takes 3 seconds. Figure 5 shows the result by

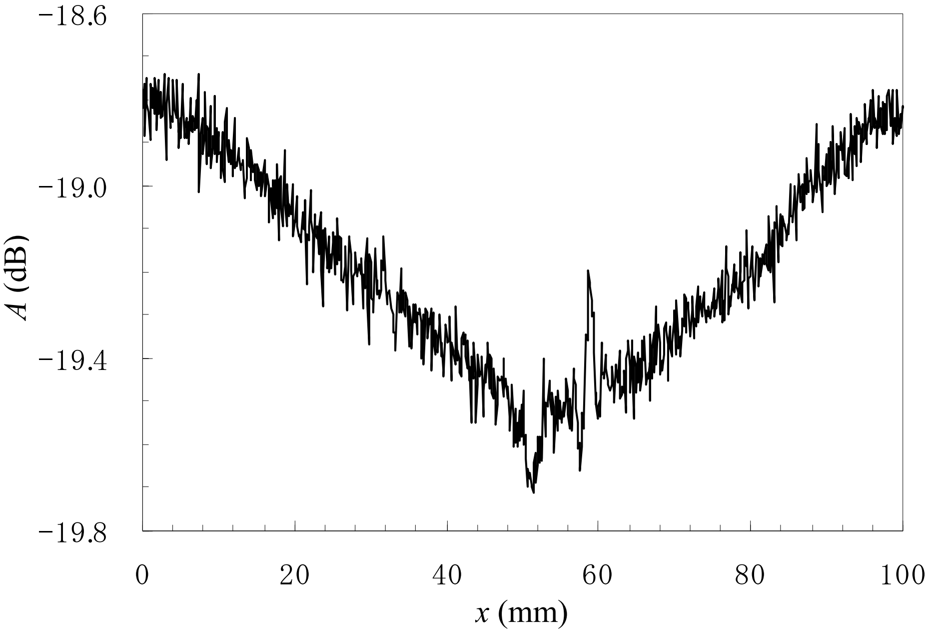

Fig. 4 Amplitude of the reflection coefficient measured by scanning the sample continuously using the slit aperture sensor

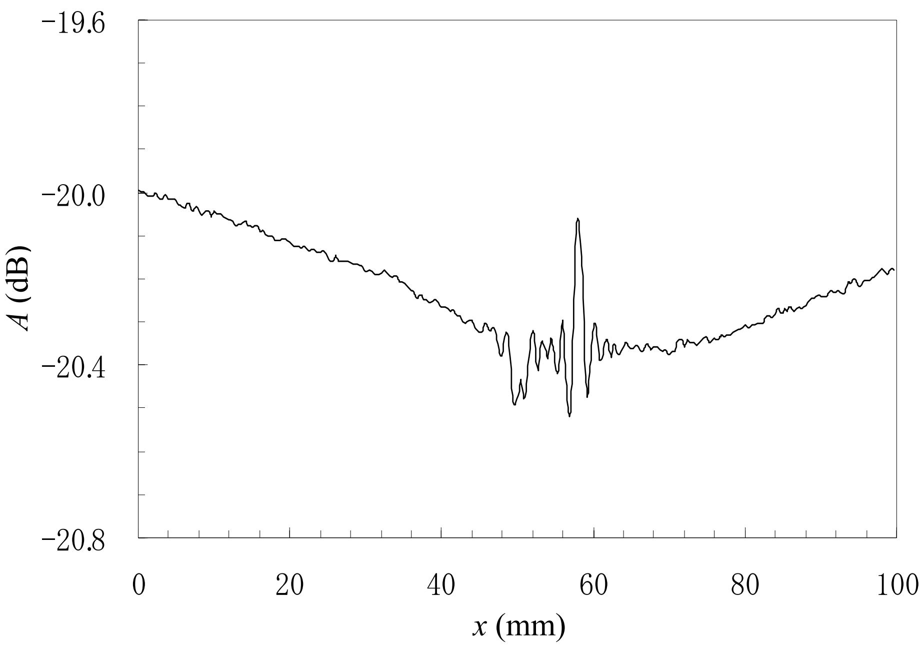

Fig. 5 Amplitude of the reflection coefficient measured by scanning the sample step by step using the slit aperture sensor

moving the sensor step by step with a pitch of 0.4 mm, in a range of 100 mm, where 250 positions were measured and at each position an average of 500 data was recorded. The measurement spends 5 minutes. As shown in Figs. 4 and 5, both scanning methods can detect the crack effectively. Also it is noted that in the case of high speed scanning the measurement result has a little larger noise than that of low speed scanning. To resolve this problem, the simple signal processing was carried out. Figure 6 shows the result by applying the signal processing to the data shown in Fig. 4, where an average of seven data was used. Finally, the similar result as shown in Fig. 5 was obtained. It indicates that by combining the high speed scanning and signal processing the slit aperture sensor can detect small cracks in polycrystalline silicon substrates with a very high testing speed.

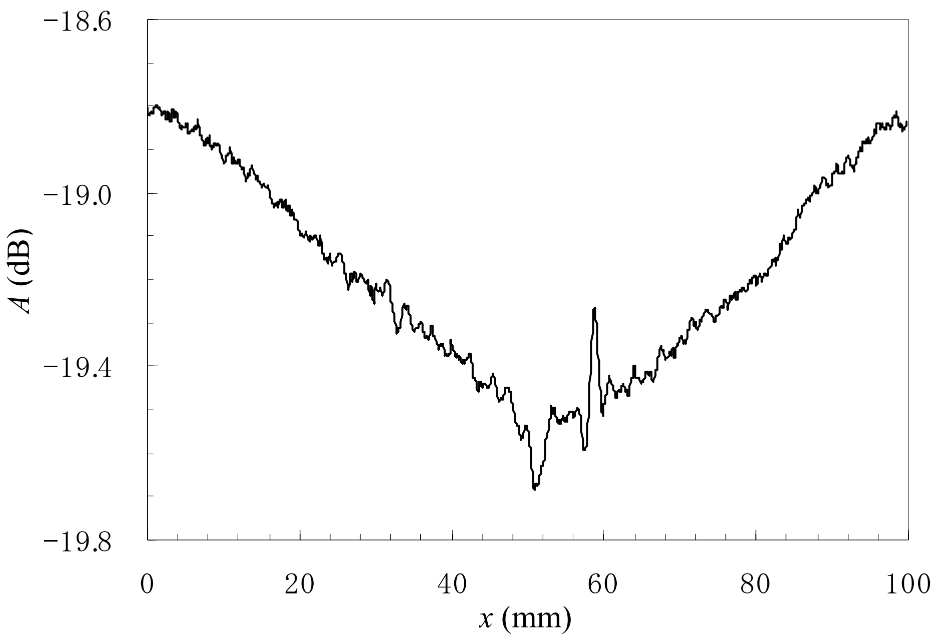

Fig. 6 Result obtained by applying signal processing to the data shown in Fig. 4

Conclusions: The small crack in polycrystalline silicon substrate was detected significantly by using millimeter waves. By using the slit aperture sensor, a very high testing speed of 50×35 mm^2/s was realized. The result indicates that the demonstrated technique has a capability to detect small cracks in polycrystalline silicon substrates on an assembly line.

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