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SPEED LIMITATION IN SPATIAL UNIFORMITY MEASUREMENTS OF SOLAR CELLS USING A BEAM PROJECTOR

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Abstract: We examined the potential sources that limit the measurement speed in our recently demonstrated apparatus to inspect spatial uniformity of solar cells using a beam projector. Using a repeated trigger measurement function of the source-meter and fast moving video images, we showed that the measurement speed was mainly limited by the video signal modulation. As a result, reliable measurements of short circuit current with about 30 ms per position could be achieved.

Keywords: Solar cell, Spatial uniformity, Speed limitation, Measurement speed.

1. INTRODUCTION

We recently demonstrated an apparatus to inspect spatial uniformity of solar cells using a spatial light modulator such as a digital micro-mirror device (DMD) in a beam projector without any mechanical movement [1-3]. A beam projector has great advantage of controlling the light beam irradiating solar cells with high-speed, including the agile change of localized irradiation and image pattern, compared to conventional laser beam induced current (LBIC) technique. In LBIC technique, a photo-generated current induced by the laser beam focused on the surface of solar cell is measured as the focused position is scanned using a mechanical motion stage [4-6].

As the size of solar cell is getting bigger through the progress of solar cell fabrication technology, spatial uniformity measurement with fast speed is being required to cover large area. Therefore, LBIC technique may not be practical because the scanning speed and the scanning area are limited by motion stage and its movable range, respectively. In addition, generation of acoustic and vibration noise due to mechanical movement is inevitable, which results in higher uncertainty.

In our demonstration, we controlled a beam projector through a video graphics array and acquired short circuit current data through a computer via GPIB interface. The measurement speed was limited to be a few hundred milliseconds per position by the scheme of the measurements. For further improvement of this apparatus, it is important to know the ultimate speed limitation that we could achieve using the present technology.

In this presentation, we examined the sources that potentially limit the measurement speed without breaking the reliable measurement condition and discussed about the achievable capability of our apparatus.

2. SPATIAL UNIFORMITY MEASUREMENT

In our implementation of apparatus to inspect spatial uniformity of solar cell or module using a beam projector, we designed and constructed it to cover the rectangular image of 1.5 m and 0.8 m on the optical table. The light beam from a projector irradiated from the height of about 1 m as shown in Figure 1. The beam projector had a resolution of 1024×768 (XGA), a luminous flux of 3000 ANSI lumens, and contrast ratio of more than 2000 in specification. The whole measurement apparatus was covered with black fabric for dark room environment.

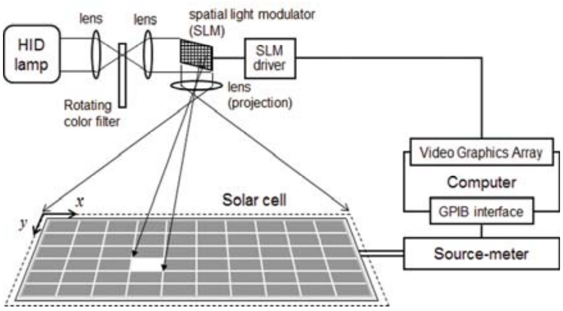

Figure 1. Measurement apparatus for spatial uniformity of solar cell or module.

While the beam projector irradiated the optical table with a full white image, we measured photocurrent distribution at 300 positions covering the entire area using a photodiode (PD) array. The maximum value of irradiance was twice as much as the minimum value. Therefore, we needed to make this irradiance distribution flat before spatial uniformity measurement and we attempted gray scale adjustment at each pixel of the DMD. As a result, we could obtain the flat irradiance distribution with the maximum deviation of ±2.6 %.

A 15.6 cm×15.6 cm square shaped poly-crystalline solar cell was placed on the optical table with the same surface height of the PD array and irradiated by the image pattern of the beam projector. Short circuit current of the solar cell was measured with the source-meter. The short circuit current was measured sequentially as the image pattern scanned over the entire area of the solar cell and finally represented by a two- or three-dimensional map to show the spatial uniformity of the solar cell. Figure 2 shows the spatial uniformity measurement result of the solar cell when the square image size was 3 mm×3 mm corresponding to 2×2 pixels of DMD. As shown in Figure 2, the solar cell exhibited a relative deviation of more than 10 % depending on the position.

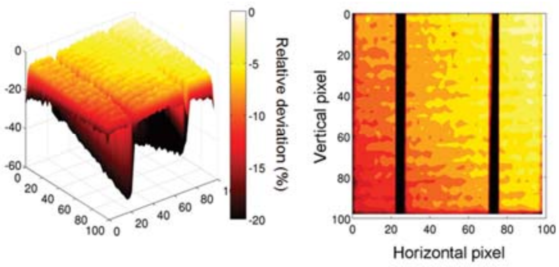

Figure 2. Relative distribution of short circuit current of the solar cell scanned by 2×2 pixel image.

3. EXAMINATION OF SPEED LIMITATION

To examine the ultimate speed limitation of the spatial uniformity measurement using our apparatus, we used a repeated trigger measurement function of the source-meter for fast acquisition of short circuit current. The minimum integration time of the analogue-to-digital converter of the used source-meter was 0.167 ms that corresponded to 0.01 PLC (power line cycles). We could acquire up to 2500 data at once using a buffer memory of the source-meter. We prepared five video images with a rate of 30 frames per second, where a 2.6 cm×2.6 cm square white image with black background was scanning from left to right and from top to bottom over the same type of solar cell with the same size as shown in the previous section. Different duration for which the white image stayed at a position was assigned to each video image from 30 ms to 70 ms with a step of 10 ms. We categorized the acquired short circuit current data into clusters with the same location of the white image and examined the repeatability of the data.

4. EXPERIMENTAL RESULTS

Under constant full white image irradiation, the short circuit current data from the solar cell were acquired with an integration time of 0.01 PLC as shown in Figure 3. The maximum sampling time was about 3 ms and the period of the short circuit current fluctuation was about 8.3 ms that corresponded to 120 Hz, which was mainly caused by the intensity fluctuation of the AC driven lamp. The complicated fluctuation pattern was due to the combined effect of the intensity fluctuation of the lamp with video signal modulation. In this case, a reliable measurement of short circuit current was impossible.

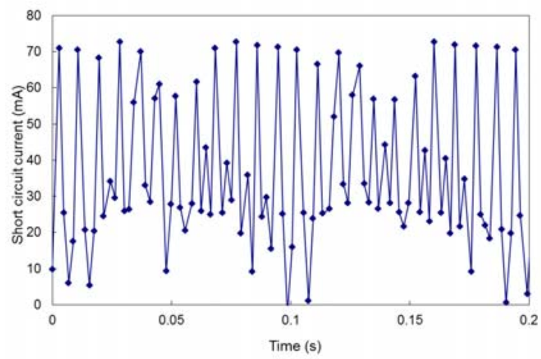

Figure 3. Short circuit current of the solar cell with integration time of 0.01 PLC.

Therefore, we increased the integration time for stable reading of short circuit current and finally obtained a standard deviation of less than 1 % when it was 1 PLC (=16.7 ms) as shown in Figure 4. The maximum sampling time was about 19 ms in this case.

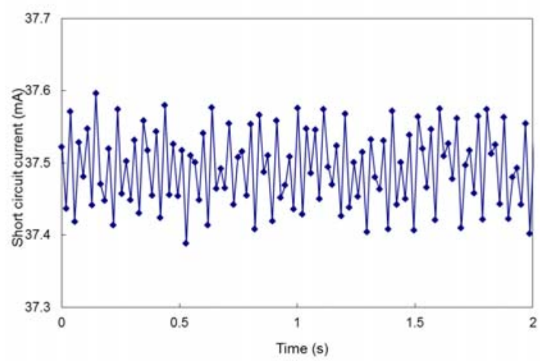

Figure 4. Short circuit current of the solar cell with integration time of 1 PLC.

When we applied the prepared video images to the solar cell, we obtained a series of short circuit current that varied with the position and the duration of the white image.

To represent those data in a combined figure, we set the time of the first data as reference for each duration. Then, we multiplied the time interval between the data and the reference by the moving speed of the white image. We used this value as the horizontal position of each data. The moving speed of the white image was determined to be the width of white image, that was 2.6 cm, divided by the duration.

We calculated the relative deviation of the measured short circuit current from the averaged value of the first cluster measured when the duration was 70 ms. Then, we plotted the relative deviation as a function of the horizontal position in Figure 5 for one scanned line.

We could clearly observe the six clusters of data having similar deviations and the data in each cluster were identified by the same white image location. The discrepancy of deviations between the clusters was caused by the non-uniform irradiance distribution of the white image because the irradiance was not flattened in these measurements [3]. There were two bus electrode lines within the second and fifth cluster, which was the reason for relatively larger deviation in those two clusters than the remaining clusters where the maximum deviation was less than 1.5 %.

Consequently, it was possible to obtain reliable measurement results even with the duration of 30 ms. This duration actually corresponds to the maximum moving speed of the white image that can be achieved from the beam projector with a video signal modulation.

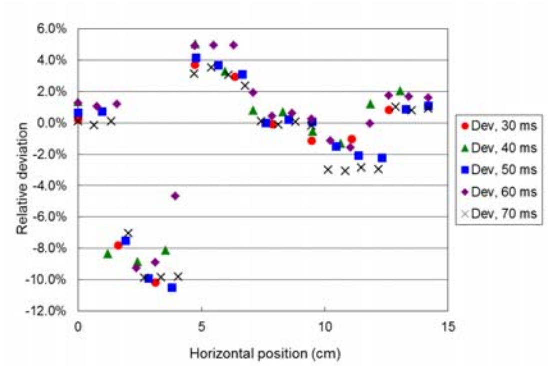

Figure 5. Deviation of short circuit current as a function of horizontal position and duration of white image.

5. CONCLUSION

We demonstrated that it is possible to measure the spatial uniformity of solar cell with a measurement speed of about 30 ms per position using a beam projector, which is limited by the video signal modulation. It means that we can measure the spatial distribution of the short circuit current within 3 s with a spatial resolution of 1.56 cm that corresponds to division into one hundred equal parts for a square shaped solar cell with a width of 15.6 cm.

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