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Extending PVSCAN to Meet the Market Needs for High-Speed, Large-Area Scanning

B. Sopori, W. Chen, Y. Zhang, T. Hemschoot, and J. Madjdpour

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1617 Cole Boulevard
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Extending PVSCAN to Meet the Market Needs for High-Speed, Large-Area Scanning

Bhushan Sopori, Wei Chen, Yi Zhang, Tess Hemschoot, and Jamal Madjdpour

National RenewableEnergy laboratory
1617 Cole Boulevard
Golden, CO 80401

INTRODUCTION

PVSCAN is a versatile instrument that has many applications in the PV industry, including high-speed mapping of material and cell parameters such as defect density, reflectance, and LBIC response. Recently, the PV community has been interested in acquiring this instrument for material and cell analyses and for process monitoring. NREL has made a commitment to devote internal resources to either build PVSCAN or provide technical assistance for those who wish to license the instrument. Consequently, it has become necessary for us to document the pertinent information about the system and to prepare a suitable operational manual. We have also learnt that each buyer may have somewhat different needs that must be accommodated while making each instrument. In particular, there is increasing interest in upgrading the system to have the capability to scan larger substrates and cells, with higher speeds and finer resolution.

This paper explores various issues that arise in developing a commercial instrument such as PVSCAN. Emphasis is on the technical details of the ability to scan fast and the detrimental effects this fast scan can have on the image quality of various material/cell parameters.

A BRIEF DESCRIPTION OF PVSCAN

PVSCAN uses the optical scattering from a defect-etched sample to statistically count the density of defects. It shines a laser beam on the surface of the defect-etched wafer and measures the (integrated) intensity of the reflected (scattered) light. The total integrated reflected light is proportional to the number of scattering centers [1]. Thus, this system provides a signal that is proportional to the local dislocation density. By scanning over the sample, the instrument can map the defect distribution. Furthermore, grain boundaries and dislocations have different characteristic scattering-patterns, and PVSCAN uses these patterns to distinguish between different kinds of defects, as illustrated in Figure 1. Figure 2 is a schematic of the optical system.

PVSAN also provides a quantitative means of measuring the LBIC response of a solar cell at two different wavelengths (0.633 and 0.905 μm) of light excitation. This enables the instrument to separate the near-surface and the bulk recombination characteristics of the cell. The photo-current response for each excitation can be measured and saved by the computer as the external

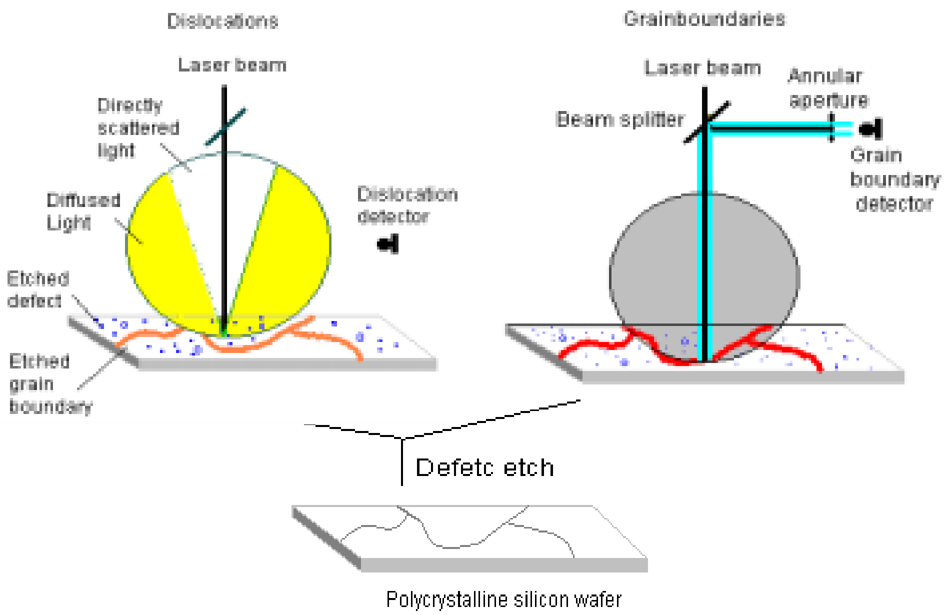


Figure 1. PVSCAN uses differentially reflected light to distinguish between various defect types. After treatment with a special etch, dislocations scatter the incoming laser beam in a cone-shaped pattern which the PVSCAN captures with an integrating sphere (left). Grain boundaries reflect the beam nearly directly, and the PVSCAN redirects a portion of that reflection to a separate detector.

response. PVSCAN's capability of mapping reflectance provides an important step toward identifying losses in the cell because reflectance is a major cause of "efficiency loss" for solar cells. By combining the LBIC reading with reflectance losses, the instrument calculates the cell performance as a function of the light that is actually transmitted into the cell to get an internal photoresponse; this is the core information needed to improve cell performance.

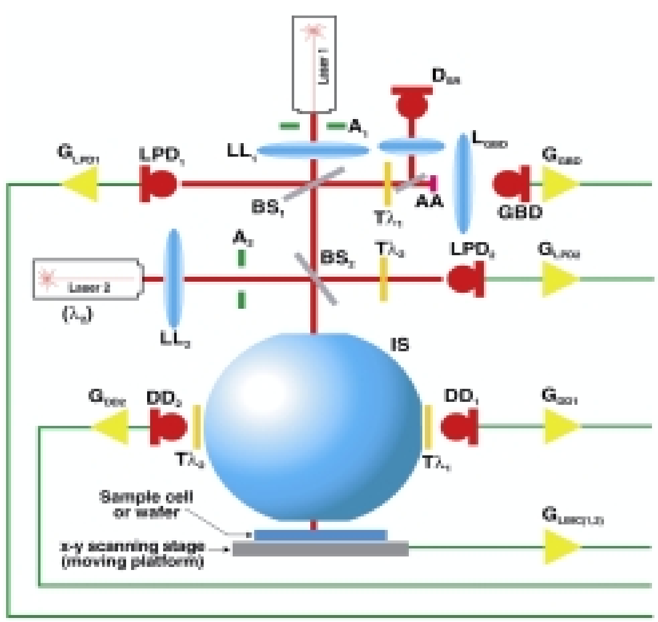


Figure 2. A schematic of the optical system of PVSCAN.

DOCUMENTATION

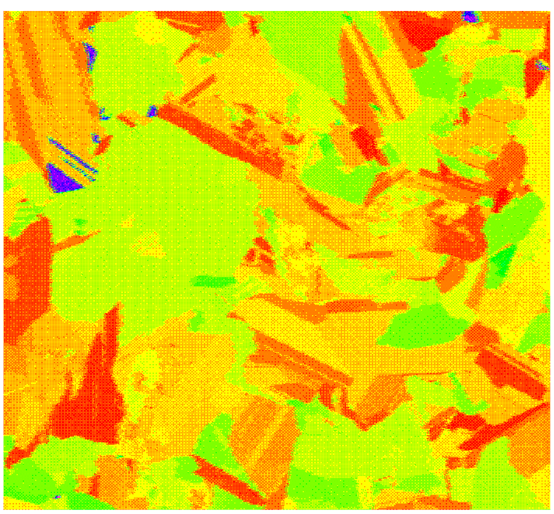
To build a system, one needs a host of documentation of sufficient detail. The documentation includes:
- a complete set of drawings
- listing all parts/naming the parts
- listing functional modules
- an instruction manual.

NREL is in the process of documenting all details that will allow an outside job-shop to fabricate various parts and the chassis.

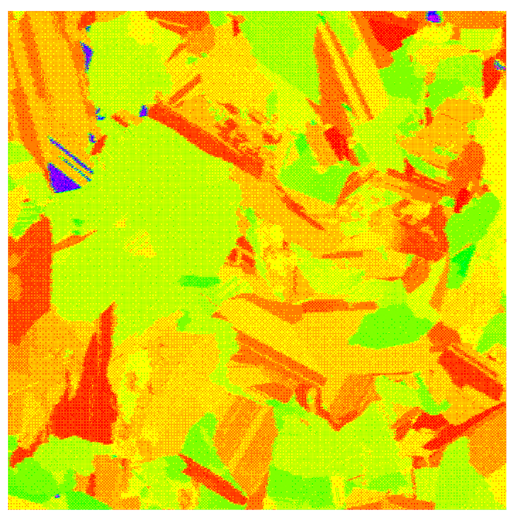
MEETING THE TECHNICAL CHALLENGES

1. Larger scan area

There is increasing interest in going to larger wafers and solar cells. The PVSCAN was originally designed to accommodate 4-in. x 4-in. wafers and cells. However, industry is already making commercial cells that exceed this size. We have received requests to increase the ability of PVSCAN to scan 8-in. x 8-in. cells. It is a straightforward matter to achieve this by switching to an X-Y stage with a larger travel, but an increase in the scan area generally leads to an increase in the scanning time (if the resolution is kept the same). In general, an increase in the sample area by a factor of 4 requires an increase in the scan time by a same factor.



(a) A defect map of a 2-in.x2-in. area at the scanning speed of 3 inch/s. The resolution is 0.001 inch. This scan took about 1 hour.



(b) A defect map of the same area at the scanning speed of 1 inch/s. The resolution is 0.001 inch. This scan took about 2.5 hours.

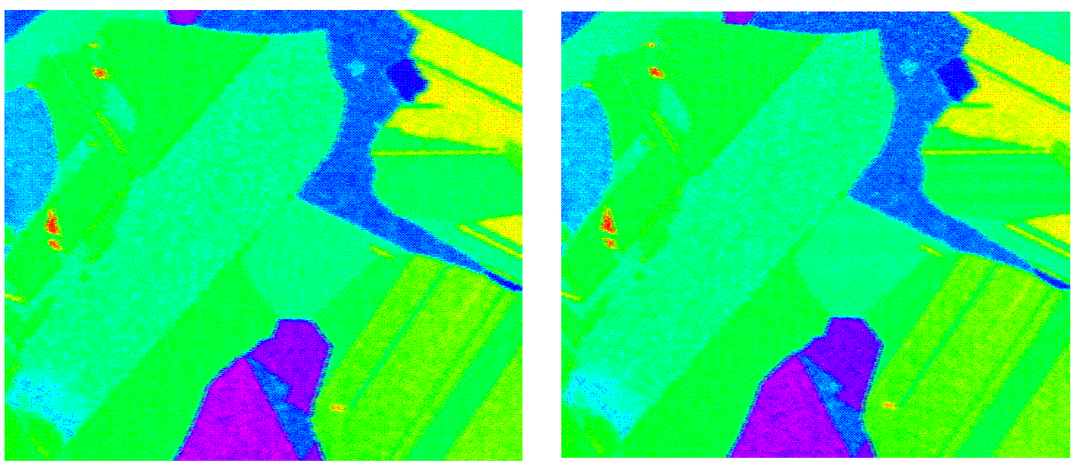
Figure 3. Images of a 2-in. x 2-in. wafer taken at two different scanning speeds, showing nearly identical image quality.

Our approach to increasing the scan area consists of switching to an X-Y stage that has a capability of scanning at a higher speed, typically up to 4 inches per second. Thus, we can scan a 8-in. by 8-in.area, keeping the scanning time and resolution the same as the original PVSCAN. It is crucial that as the speed is increased, the image quality should not deteriorate. Figure 3 compares the quality of the reflectance images of a sample scanned at two different speeds in our system. The resolution is 25 µm, and the difference in the image quality is essentially indistinguishable.

2. Higher resolution

The resolution of a scanning system is a complicated parameter that is determined by:

- Step size of the motors
- Optical beam size
- Time interval between the data-taking events
- Time constant of the electronic signal channel.



(a) **(b**

Figure 4. The defect maps of a 0.5-in.x0.5-in. area. The scanning speed is 0.75 inch/s. The resolutions are (a) 0.001 inch and (b) 0.00025 inch.

In general, the PVSCAN uses a beam size of about 200 µm in the defect mapping mode and smaller size in the LBIC mode. For a motor step of 25 µm, a 50 µm spatial resolution in the image can be achieved. Figure 4 shows that with a typical beam size the scanning resolution has little or no effect on the image quality. Even under higher magnification, Figure 5, the effect is primarily observable as a slight loss in the Y-resolution.

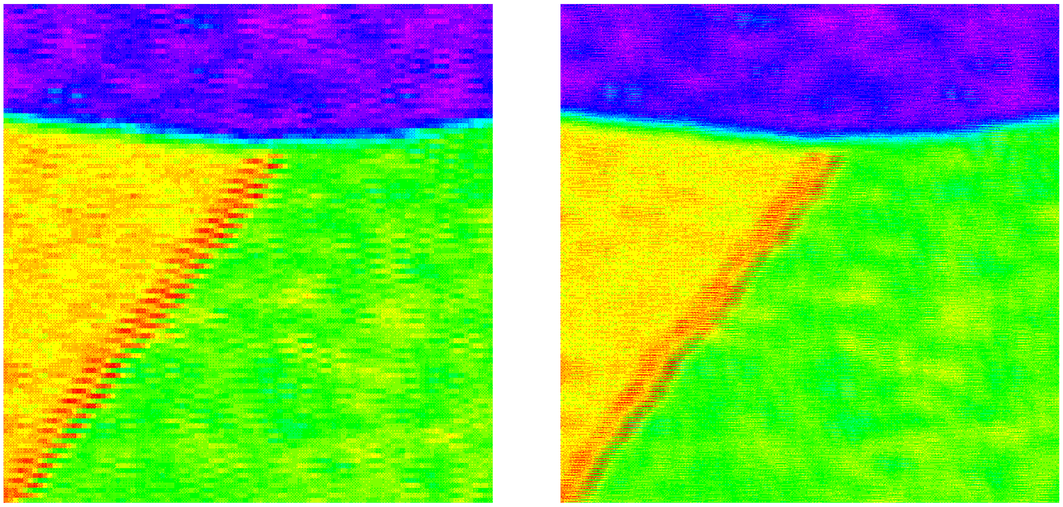


Figure 5. A zoomed-in view of a small region of the sample in Figure 4, showing no effect on the image quality, even when the display is zoomed into a small area.

3. Effect of beam size

It is desirable to have beam size about the same as the lateral step size of the motor. But, in practice, a small beam size makes stringent demands on the optical system. Furthermore, it is important that the beam size exceeds a certain value so that statistical counting of defects is valid. In general, the beam-size requirements for most applications of PVSCAN are only moderate. However, it must be pointed out that mathematically the beam and the motor step have the effect of generating a signal that is an overlap integral of the two. This means that the signal in the "forward" and the "reverse" directions will be shifted laterally. An example of this is illustrated in the scans of Figure 6.

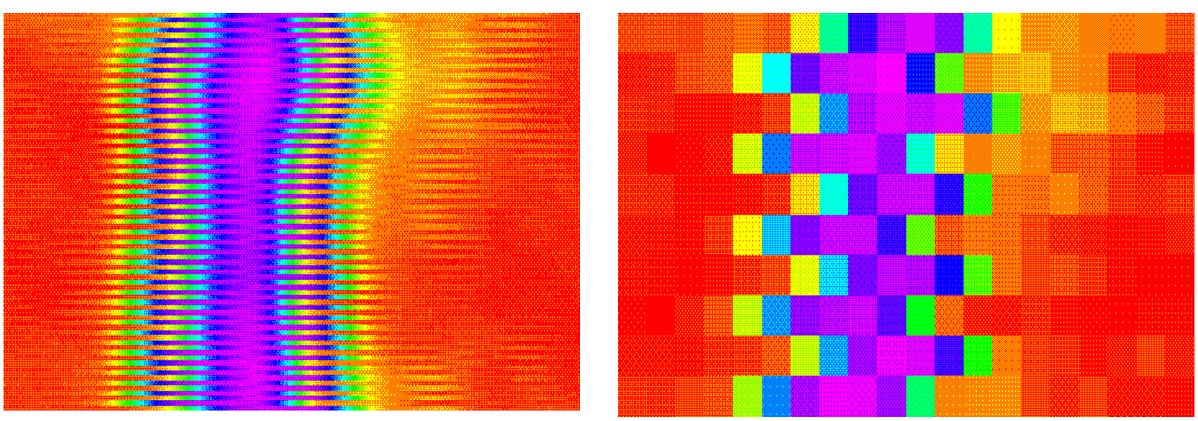


Figure 6. Illustration of the beam-size effect on the scanned image. (a) LBIC image in the vicinity of a metal finger on a solar cell, showing displacement of the signal in the "forward" and the "reverse" directions. (b) A zoomed-in view.

4. Higher-speed scanning

It is generally desirable to have as high a scan speed as possible. However, scanning speed is limited by :

- Maximum speed of the motor(s), resolution of the stepping motor, and the mode of operating the motor (open Vs closed-loop configuration)
- Data-acquisition rate and data-transfer capability
- "Blank" time, in which a Y-step is taken (this time is also used for transferring data from the internal memory to the disk)
- RC time constant of the signal channel(s) and its changes with the gain.

These issues can be optimized to obtain the highest scanning speed. Our system can be operated up to 4 ips without degrading the image quality (as seen in Figure 3).

5. Improvements in the software

The software has been improved to include:

- Statistical module that displays distributions (see Figure 7, showing distribution of defect density in a multicrystalline Si wafer) and other statistical functions
- Additional options on "save" images/scans
- Ease of calibration

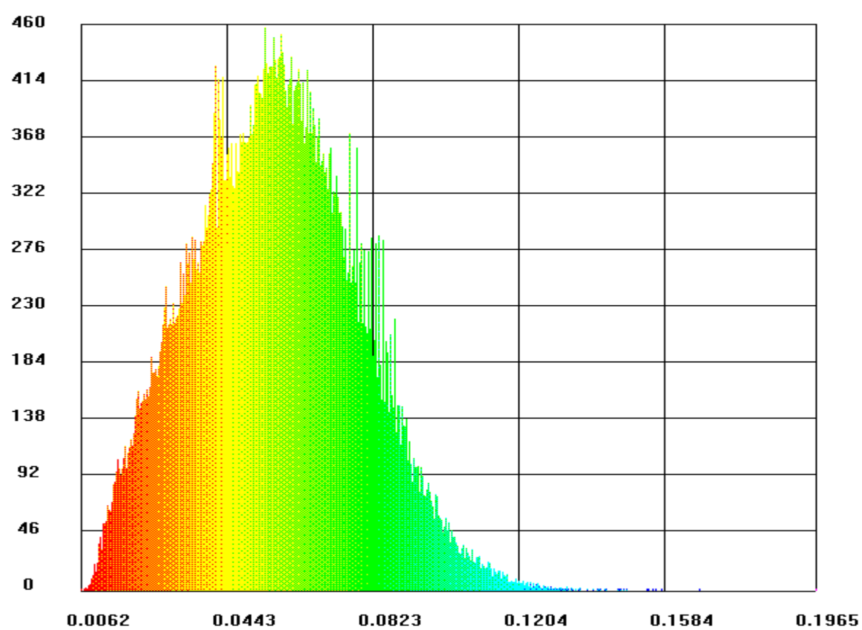


Figure 7. Distribution of dislocations in a mc-Si wafer. The Y-axis shows number of counts and x-axis is the dislocations density, cm-^{2} x10^{4}

CONCLUSION

We have documented the PVSCAN so that it can be built at a job-shop. The operation of the system has been critically analyzed to help the user make an informed decision on setting up the scan parameters and interpret the results. A detailed instruction manual is being written that incorporates examples and results of actual scans. The software has been upgraded to include a number of useful features.

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