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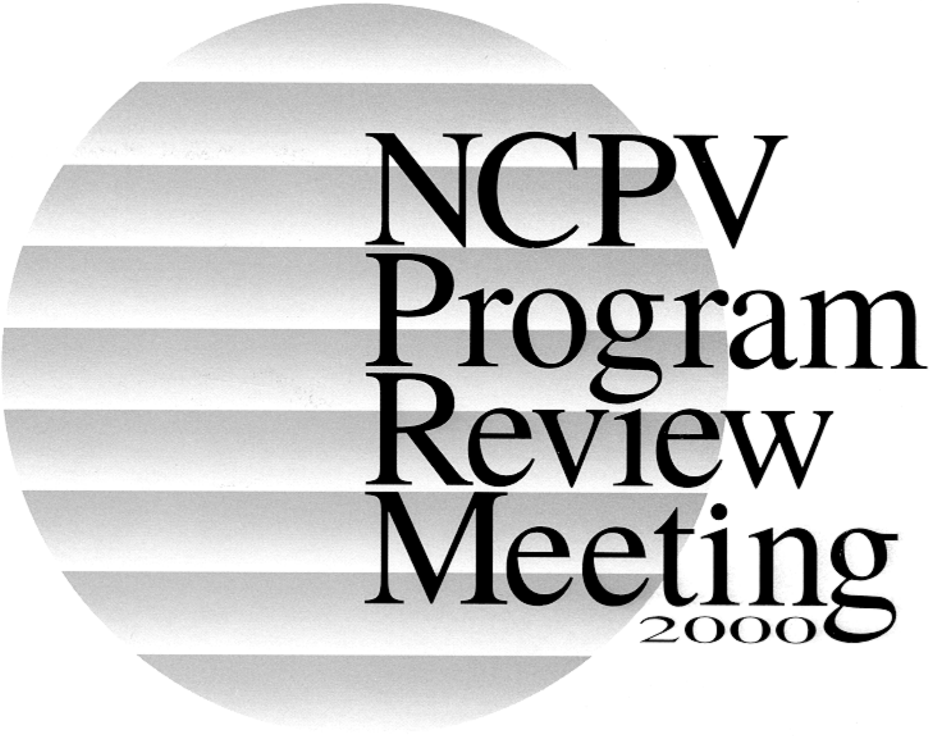

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Detailed Characterization of Si Substrates and Solar Cells with High-Speed PVSCAN

B. L. Sopori, W. Chen, Y. Zhang, and J. Madjdpour
National Renewable Energy laboratory,
1617 Cole Boulevard, Golden, CO

V. Yelundur, J. Jeong, and A. Rohatgi
Georgia Institute of Technology, Atlanta, GA

ABSTRACT

This paper describes some applications of PVSCAN– an instrument developed for rapid characterization of photovoltaic (PV) materials and devices. It measures defect distribution, reflectance, and external and internal responses of light beam induced current at two wavelengths of optical excitation.

1. Introduction

PVSCAN is an optical scanning system that has many applications in the PV industry, including high-speed mapping of material and cell parameters such as defect density, reflectance, and light-beam-induced current (LBIC). In response to the PV community's needs, we have recently made improvements on the system that give it the capability to scan larger substrates and cells, with higher speeds and finer resolution, and provide statistical information that can be very valuable for analyzing low-cost solar cells.

This paper briefly describes the operation of the instrument and presents some examples to illustrate recent improvements and how they can be used to characterize some important issues in PV technology.

2. A brief description of PVSCAN

PVSCAN uses the optical scattering from a defect-etched sample to statistically count the density of defects. A defect-etched wafer is illuminated with a laser beam and the (integrated) intensity of the reflected (scattered) light is measured by a photodetector. The detector signal is proportional to the number of scattering centers—providing a signal that is proportional to the local dislocation density [1]. By scanning over the sample, the instrument can map the defect distribution. In multicrystalline materials, PVSCAN can distinguish between various crystallographic defects using their scattering-patterns to simultaneously generate maps of grain boundary and dislocation distributions in a wafer. Figure 1 is a schematic of the optical system. The various symbols used are identified in the figure caption. A detailed description of the system is given elsewhere [1]. Some important features of the system are: (i) provides mapping capability at two different wavelengths, $\lambda_1=0.63\,\mu m$, $\lambda_2=0.98\,\mu m$; (ii) monitors dislocations and grain boundaries simultaneously by detectors DDi and GBi, respectively; (iii) has capability to measure diffuse as well as specular components of reflectance simultaneously; and (iv) the incident light power illuminating the test wafer or cell is continually monitored.

PVSCAN also provides a quantitative means of measuring the LBIC response of a solar cell at two different wavelengths (0.633 and 0.980 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 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.

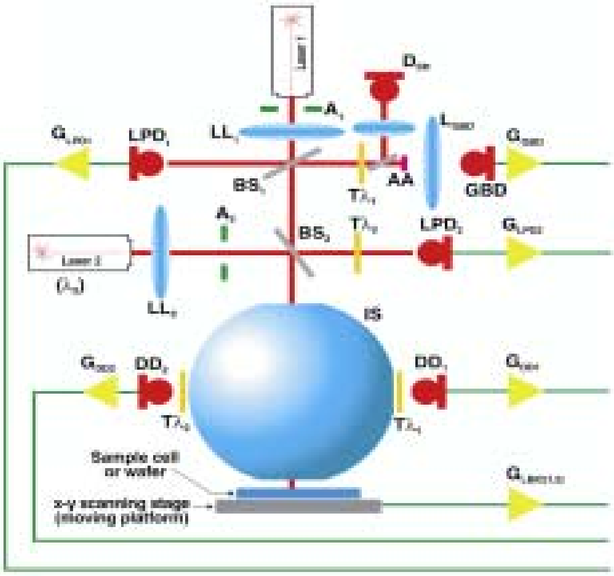

Figure 1. A schematic of the optical system of PVSCAN.

A_i = aperture, BSi = beam splitter, DD_i = dislocation density detector, GBD = grain boundary detector, Gi = amplifier gain, IS = integrating sphere, Lli = laser focusing lens.

3. Characterization

Because PVSCAN can perform analysis of both materials and devices parameters, we can illustrate some examples of each of these.

The efficiency of a Si solar cell is controlled by the impurity and the defect content in the substrate. Because gettering removes most of the dissolved lifetime-killing impurities, one finds a direct correlation between dislocation density and the local cell performance. Thus, it is necessary to measure the local variations in the defect density of the wafer. Defect maps are also important to improve the crystal growth because defect distributions reflect the nature of thermal stresses during the growth. The standard procedure for defect mapping involves polishing the wafer by a chemical-mechanical procedure before defect etching [2]. This procedure is time consuming and particularly difficult for ribbon samples. We have recently developed a procedure that abates this step. Figure 2 shows a defect map of a ribbon that uses our new procedure of chemical polishing and defect etching.

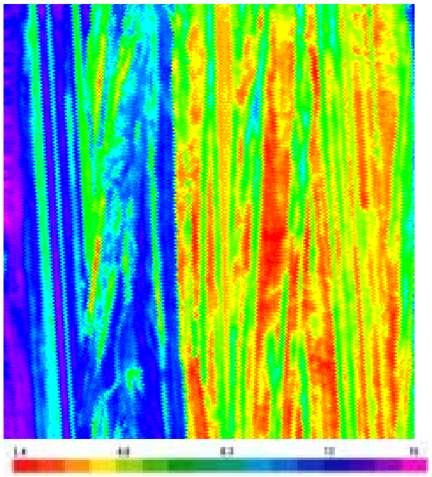

Figure 2. A defect map of a ribbon sample. Sample size: 1.4-in. x 1.5-in. The defect density values are those shown in the legend x10^6 cm^{-2}.

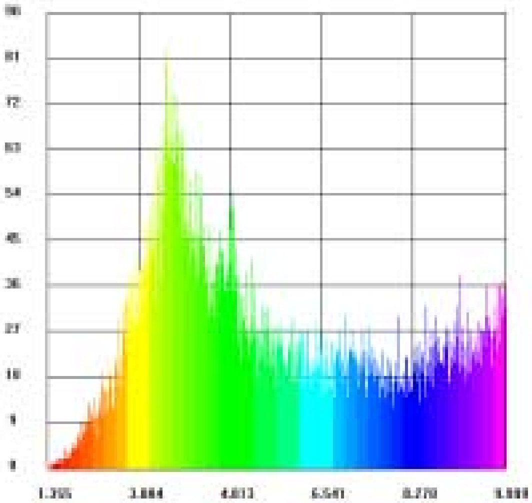

Figure 3. Distribution of defects in the sample shown in Figure 2.

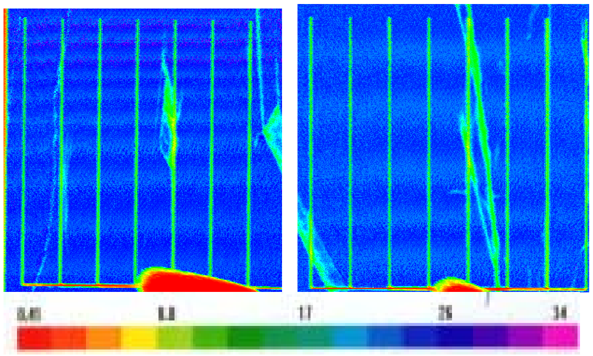

Figure 4. LBIC response maps of two ribbon cells

Another feature recently added to the system is the display of the statistical parameters. Figure 3 shows the distribution of defect density in the ribbon shown in Figure 2 which has an average value of 7.3x10^6 cm^{-2}.

The average value is also important to compare the performance of non-uniform solar cells. It is a common experience that small-area spectral responses or minority-carrier diffusion-length measurements do not correlate well with the cell performance. However, the averaged LBIC at λ = 0.980 μm, determined by PVSCAN, correlates well with cell performance. Figures 4a and 4b show LBIC maps of two ribbon cells—the averaged responses of the cells and their cell parameters are given in Table 1.

Table 1. Cell parameters and the averaged LBIC response of two devices shown in Figure 4.

Cell ID	Cell A	Cell B
Jsc, mA/cm2	29.65	28.96
Voc, mV	558.5	550
FF	0.744	0.74
Response, mA/cm2	24.05	23.57

4. Summary

The capabilities of PVSCAN have recently been extended to meet the current requirements of the PV community. These include: (i) Larger scan area—up to 8-in. x 8-in., (ii) higher-speed scanning—up to 4 in/s, (iii) improved system software with capabilities that help characterizing mc-Si cells, and (iv) improved procedures for faster and more convenient sample preparation [3].

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