Doping Density Measurements of Textured Solar Cells Using Capacitance-based Techniques

Jennifer T. Heath[1], Amanda Bowers[2], and Emily Van Doozer[2]

[1]Department of Physics, Linfield College, McMinnville, OR 97128, United States

Introduction

Background

- A solar cell is a diode. At its heart is a p-n junction, created by doping the n side with an electron donor (phosphorus), and the p side with an electron acceptor (boron).
- Doping creates a **depletion region** sandwiched between bulk materials where electric field causes current to flow.
  - **Depletion region** – an insulating region surrounding the junction where mobile charge carriers (electrons and positive holes) are swept away.
- The **doping densities** are a fundamental property of the device, and are chosen to optimize the solar cell efficiency.
  - **Doping density**- the number of dopant molecules per unit volume
- Real solar cells are textured to increase the efficiency of the device
  - Texturing poses a potential problem when using capacitance-based techniques to measure doping density.

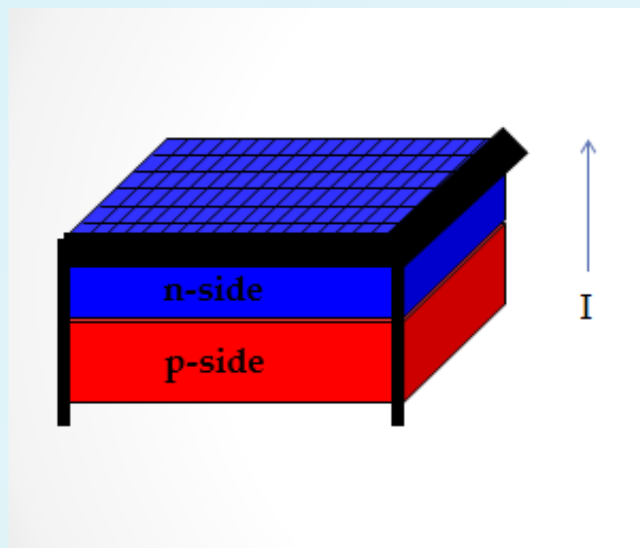


Figure 1. Schematic of solar cell as basic diode. P-side represents bulk material doped with boron, creating positive charge carriers. N-side represents bulk material doped with phosphorus, creating negative charge carriers. Current flows from p-side to n-side within depletion region.

Figure 2. Cross-sectional image of textured surface, obtained using scanning electron microscopy.

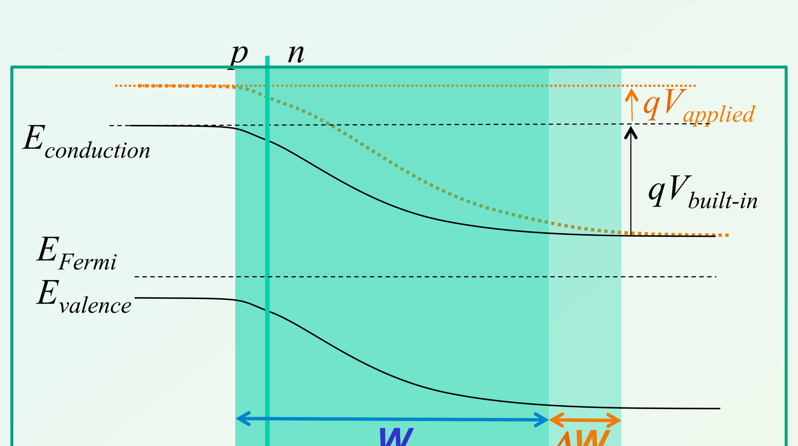
Theory

- Depletion region, of width W, acts like the insulator in a capacitor: $C = \varepsilon A / W$.
- In this one-sided junction ($N_a \ll N_d$), W and C are dominated by the lower doped material.
- W, and therefore Capacitance, varies with applied DC bias.
- Capacitance, measured as a function of DC bias, yields the doping density:

$$N_a = \frac{2}{q \varepsilon_s A^2 \, \partial C^{-2}/\partial V}$$

- Technique theoretically yields an underestimate of the doping density, N_a, for textured samples because of the added microscopic surface area, which is not easily measured.
- Initial purpose: Determine the way in which texturing affects the capacitance results.

Figure 4. Band bending occurs to align the Fermi energy levels. The depletion region is the region in which a built-in electric field exists. By applying external bias, the depletion width W can be varied and the doping density can be measured.



Abstract

Multicrystalline silicon solar cells, similar to those recently installed on T. J. Day Hall, were investigated using capacitance based techniques. Commercial solar cells have textured surfaces to enhance the light trapping. In this project, textured and untextured devices were studied to determine if the increased surface area created by texturing significantly impacts the measurement outcomes. The measured doping densities vary from sample to sample, from 8 x 10^{15} cm^{-3} to 2 x 10^{16} cm^{-3}. This seems to indicate a significant lateral or grain-to-grain variation in doping density within each sample, which overwhelms any possible influence of the surface texturing, These results are being further investigated by comparison with time of flight secondary ion mass spectrometry measurements.

Experiment

Methods

- Applied DC bias to change the depletion width from equilibrium state (Fig. 3)
- Used lock-in-amplifier, current-to-voltage preamplifier and DC power supply measure capacitance
- Non-destructive method
- ImageJ software was used to determine the macroscopic area of sample from digital images (Fig. 4).
- SEM cross-section (Fig. 2) used to estimate the degree of surface texturing

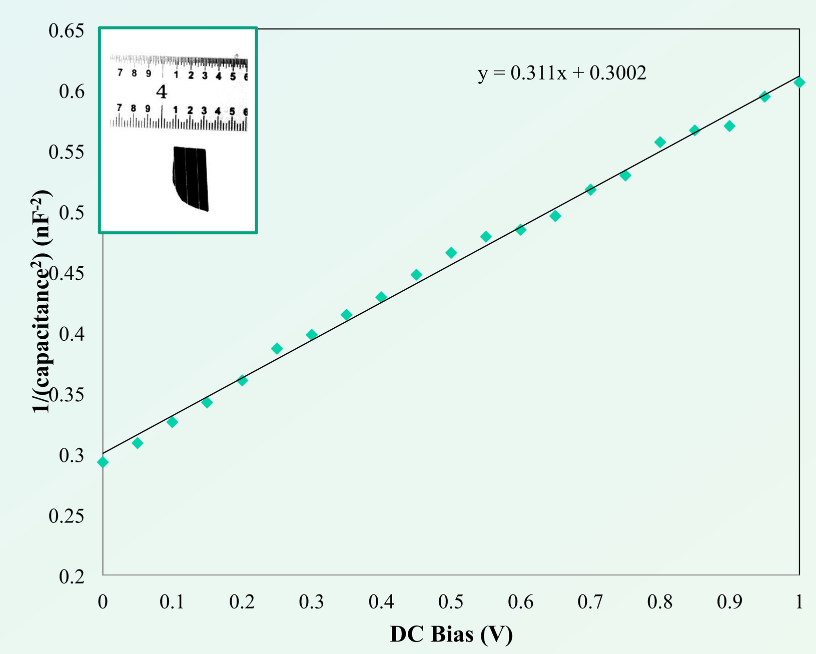


Figure 4. Typical capacitance data. Slope is used to compute doping density.
Inset: Photograph of a typical sample with the reference ruler used to measure sample area.

Results

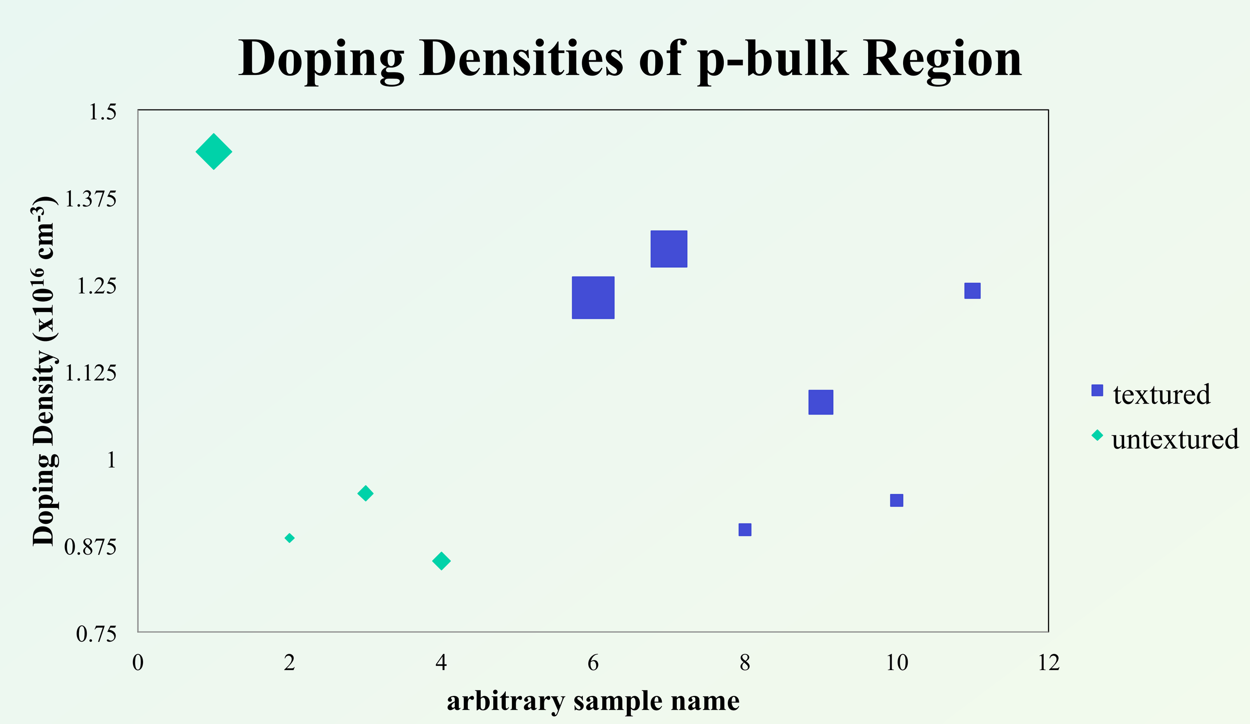


Figure 5. Distribution of doping densities for both textured and untextured samples. Larger samples are portrayed using larger markers.

- Doping densities varied from 9 x 10^{15} cm^{-3} to 2x10^{16} cm^{-3}
- Mean doping density = 1 x 10^{16} cm^{-3}
- Larger samples had larger doping densities

Analysis and conclusions

- Unexpected random scatter in distribution of doping densities
  - May indicate a non-uniform spread in dopant throughout the bulk region of the p-side of the cell.
  - Did not control experiment to measure a single crystal grain or determine the region of the wafer from which a sample was cut.
- Experiment assumed a uniformly doped wafer.
- Question regarding texturing effects on experimental results remains unanswered

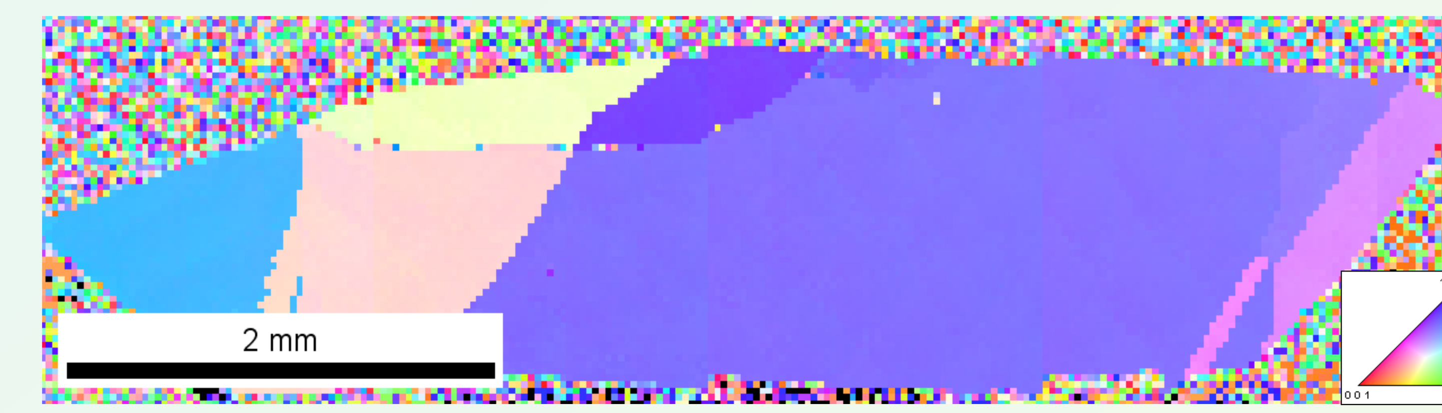


Figure 6. Electron backscatter diffraction image from an untextured sample showing a grain size on the order of millimeters.

- Other methodologies, such as time of flight secondary ion mass spectrometry (ToF-SIMS) can verify accuracy of our results.
- TOF-SIMS data at a single location in the untextured sample shows an even higher doping density of 4x10^{16} cm^{-3} (Fig. 7).

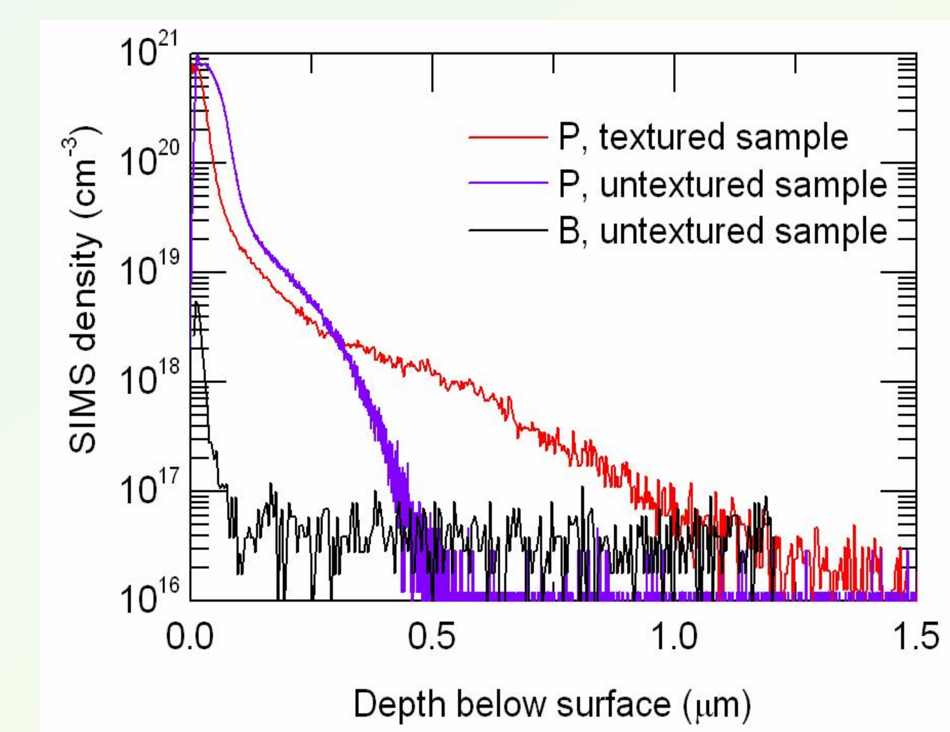


Figure 7. ToF-SIMS data for textured and untextured samples.

The B doping density, 4x10^{16} cm^{-3}, appears larger than that measured by capacitance, perhaps because of variation between different regions of the wafer. The slow decrease in P doping with depth, seen in the textured sample, is an artifact of the texturing.

Future Work

- Create 3-D maps of doping density using ToF-SIMS to verify non-uniformity of samples and determine its spatial distribution.
- Re-measure devices with known uniform doping densities, to determine the real influence of surface texturing.
- Apply these results to understand the influence of texturing on other capacitance-based measurements of device properties.

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