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

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Introduction

• A solar cell is a diode. At its heart is a p-n junction, created by doped n-side with an electron donor (phosphorus), and p-side with an electron acceptor (boron).
• Doping creates a depletion region sandwiched between bulk materials where electric field causes current to flow.
• The 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.
• Real solar cells are textured to increase the efficiency of the device.

Theory

• Depletion region, of width W, acts like the insulator in a capacitor: \( C = \epsilon A / W \).
• In this one-sided junction (\( N_d = N_x \)), 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: \( N_x = 2q\epsilon / \pi C \Delta V \).
• Technique theoretically yields an underestimate of the doping density, \( N_x \), 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.

Experiment

• 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
• SEM cross-section (Fig. 2) used to estimate the degree of surface texturing

Results

Doping Densities of p-bulk Region

• Doping densities varied from \( 9 \times 10^{15} \text{ cm}^{-3} \) to \( 2 \times 10^{16} \text{ cm}^{-3} \)
• Mean doping density \( \approx 1 \times 10^{16} \text{ cm}^{-3} \)
• Larger samples had larger doping densities

Conclusion

• 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.

Future Work

• Create 3-D maps of doping density using ToF-SIMS to verify uniformity of doping 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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