Frequency and Voltage Dependence of Series Resistance in a Solar Cell

Alexander Ogle, Thaddeus Cox, Dr. Jennifer Heath
Department of Physics, Linfield College, McMinnville, OR

Abstract

While admittance measurements of solar cells are typically conducted in reverse or at zero bias, and analyzed using the depletion approximation, the operating point of the solar cell is in forward bias, and the series resistance is often estimated using IV curves with a high forward current. In this mode, the device is no longer in the depletion regime, and the large number of injected minority carriers alters the transport properties significantly. In our CuInGaSe₂ devices, we measure negative values of capacitance at high forward bias, which may be linked to injected minority carriers and carrier transport limitations, although our calculations of capacitance may also be influenced by series resistance. In this study, we compare AC and DC measurements of voltage dependent series resistance to try to better understand the negative capacitance signal.

Introduction

Solar cells:
• Imperfect → need to understand carrier trapping, recombination and transport better

Admittance Spectroscopy:
• Useful tool to characterize electronic properties
• Weird → shows negative capacitance

Negative Capacitance:
• Shows up at V > Vbi
• Not inductive
• Predicted by model including Rs(V)
• Need to measure Rs(V)
• Extract device parameters
• Then we can better understand device performance

Capacitance Voltage/Frequency Data

High forward bias:
• Injection of minority carriers
• Appearance of negative capacitance

Rs from Impedance Method

R_s from Double-Light Method (DLM)

Double-Light Method (DLM)[2]:

\[ R_s = \frac{V(1) - V(2)}{I(1) - I(2)} \]

where V(1) and I(1) represent the point on the less illuminated curve corresponding to Δj greater than the illumination current, jL1. V(2) and I(2) represent the point on the more illuminated curve corresponding to Δj greater than the illumination current, jL2.

R_s from Differential Resistance Analysis

Differential resistance is determined by finding the inverse of the slope between consecutive points on the IV curve. In the regime where our R_s is negligible, we can say:

\[ R_s \approx \frac{V(i+1) - V(i)}{I(i+1) - I(i)} \]

Comparisons

Rs from Light Method (DLM)[2]:

\[ R_s = \frac{V_1 - V_2}{I_1 - I_2} \]

While admittance measurements of solar cells are typically conducted in reverse or at zero bias, and analyzed using the depletion approximation, the operating point of the solar cell is in forward bias, and the series resistance is often estimated using IV curves with a high forward current. In this mode, the device is no longer in the depletion regime, and the large number of injected minority carriers alters the transport properties significantly. In our CuInGaSe₂ devices, we measure negative values of capacitance at high forward bias, which may be linked to injected minority carriers and carrier transport limitations, although our calculations of capacitance may also be influenced by series resistance. In this study, we compare AC and DC measurements of voltage dependent series resistance to try to better understand the negative capacitance signal.

Moving Forward:
• Use series resistance data to correct IV and CV curves
• Obtain fundamental values for main diode of solar cell
• Better understand limitations to device performance

Conclusions

• Significant Rs seems to be present in devices which also exhibit negative capacitance phenomenon
• Rs(V) behavior is consistent with a model predicting negative capacitance
• Impedance measurements seem to give the best estimate of differential Rs. DLM may be affected by photoconductivity or phototransistor effects. Differential resistance always shows the total resistance, Rs + Rp.

Acknowledgements

Special thanks to Bill Shafarman at University of Delaware for providing samples. Funding was provided by the Linfield Research Institute and Linfield Student-Faculty Collaborative Research Fund.

References: