

# Role of Contacts in Capacitance Measurements of Solar Cells

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## Abstract

The electronic properties of low cost, thin-film solar cells are complicated by the non-ideal nature of the semiconductor layers. Typically, the fundamental electronic properties of such materials are evaluated using current-voltage and capacitance-voltage measurements. However, in these devices, it is common for the back contact to be non-ohmic. We are exploring the impact of such a back contact on the outcome of standard capacitance-based characterization techniques. We compare computer models of capacitance response with measurements of simple model electronic circuits, and of solar cell devices.

## Introduction

A Solar Cell is a photo-active diode which converts light into electrical energy. With multi-crystalline cells, ideal characteristics are no longer observed, complicating the solar cell model.



Figure 1: Solar Cells on TJ Day Hall of Linfield College, McMinnville Campus

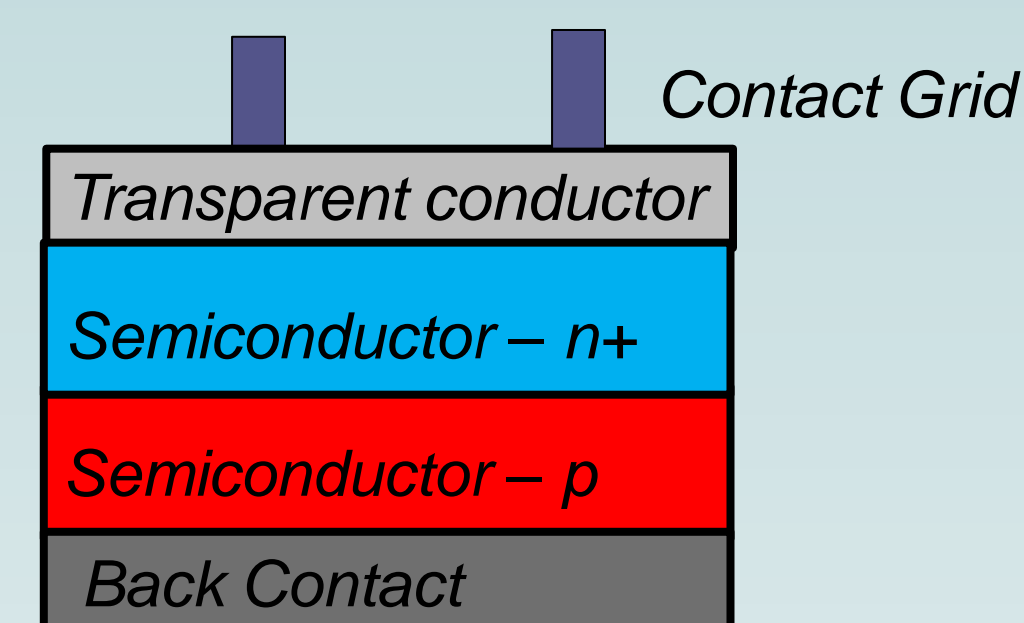


Figure 2: layers in a typical solar cell.

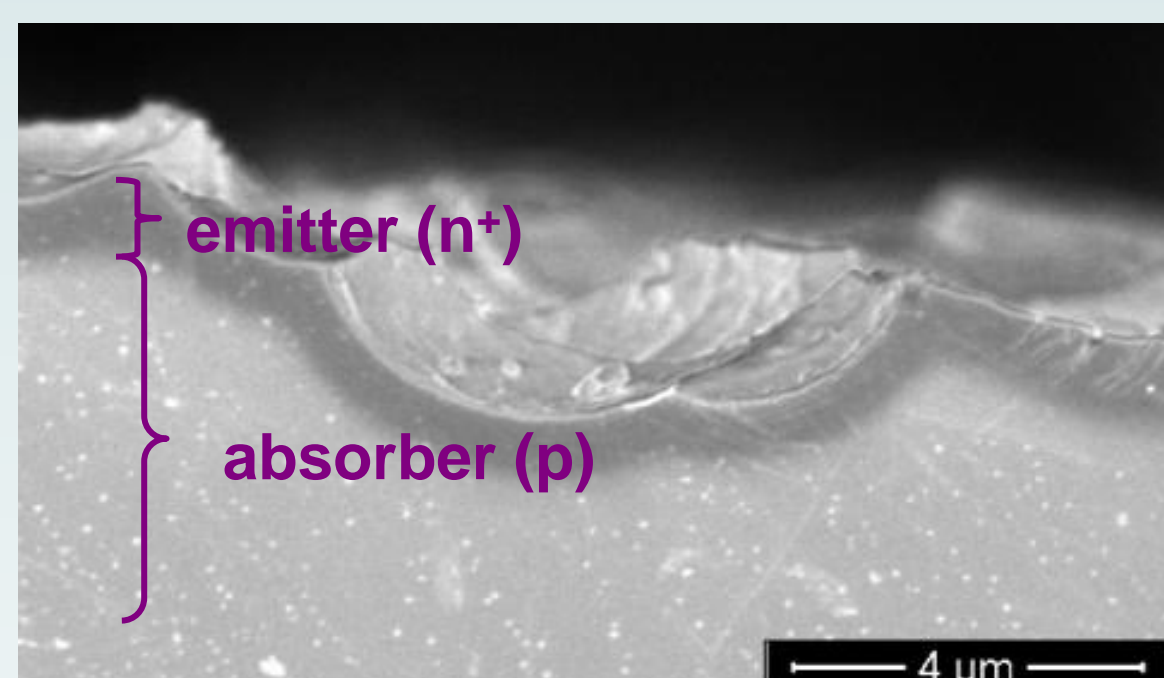


Figure 3: SEM cross-section of a single crystalline silicon solar cell, showing secondary electron contrast (note that the surface is textured to enhance light absorption.)

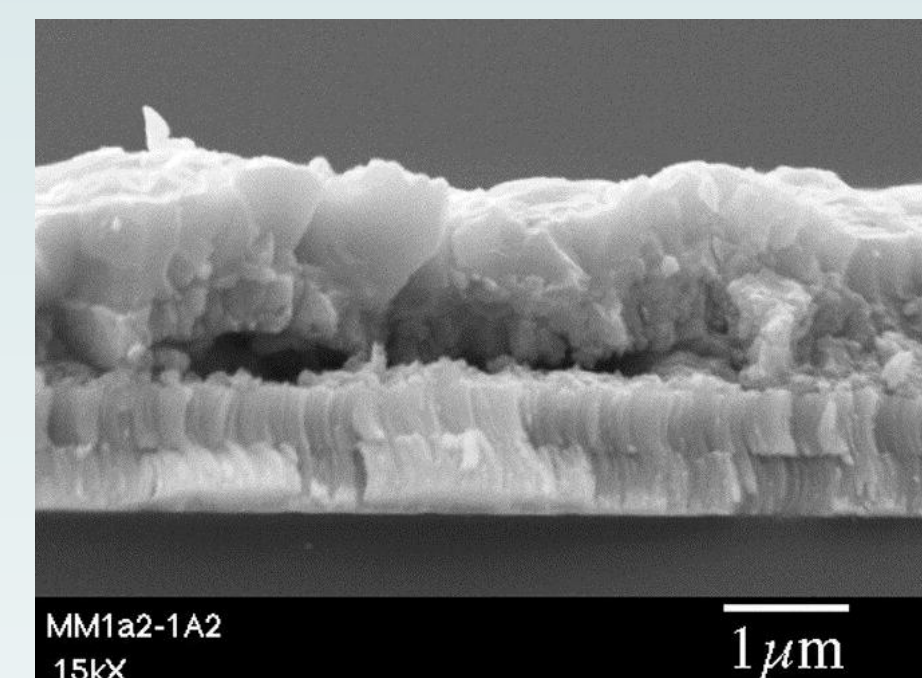


Figure 4: Cross-section of a thin film Cu(In,Ga)Se<sub>2</sub> solar cell. Reproduced from [2].

## PN Junction

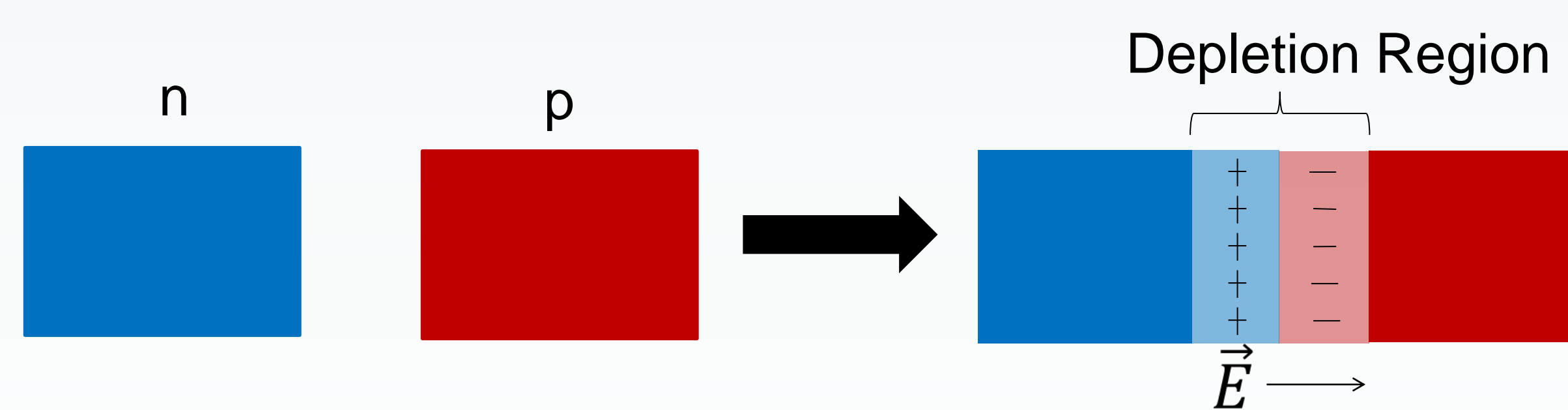


Figure 5: Schematic of the p-n junction at the heart of the solar cell. Diffusion of free carriers across the p-n junction forms a charged region near the junction, resulting in an electric field and counteracting drift current. In equilibrium, these effects balance, creating a fixed region depleted of free carriers, the 'depletion region', of width  $W$ .

## Experimental Techniques

$$\text{Differential Capacitance: } C = \frac{dQ}{dV} = \frac{\epsilon A}{W} \quad (1)$$

### Capacitance-Voltage measurements:

Ideal C-V data provides:

- Doping Densities.
- Depletion Width.
- $V_{bi}$  of cell.

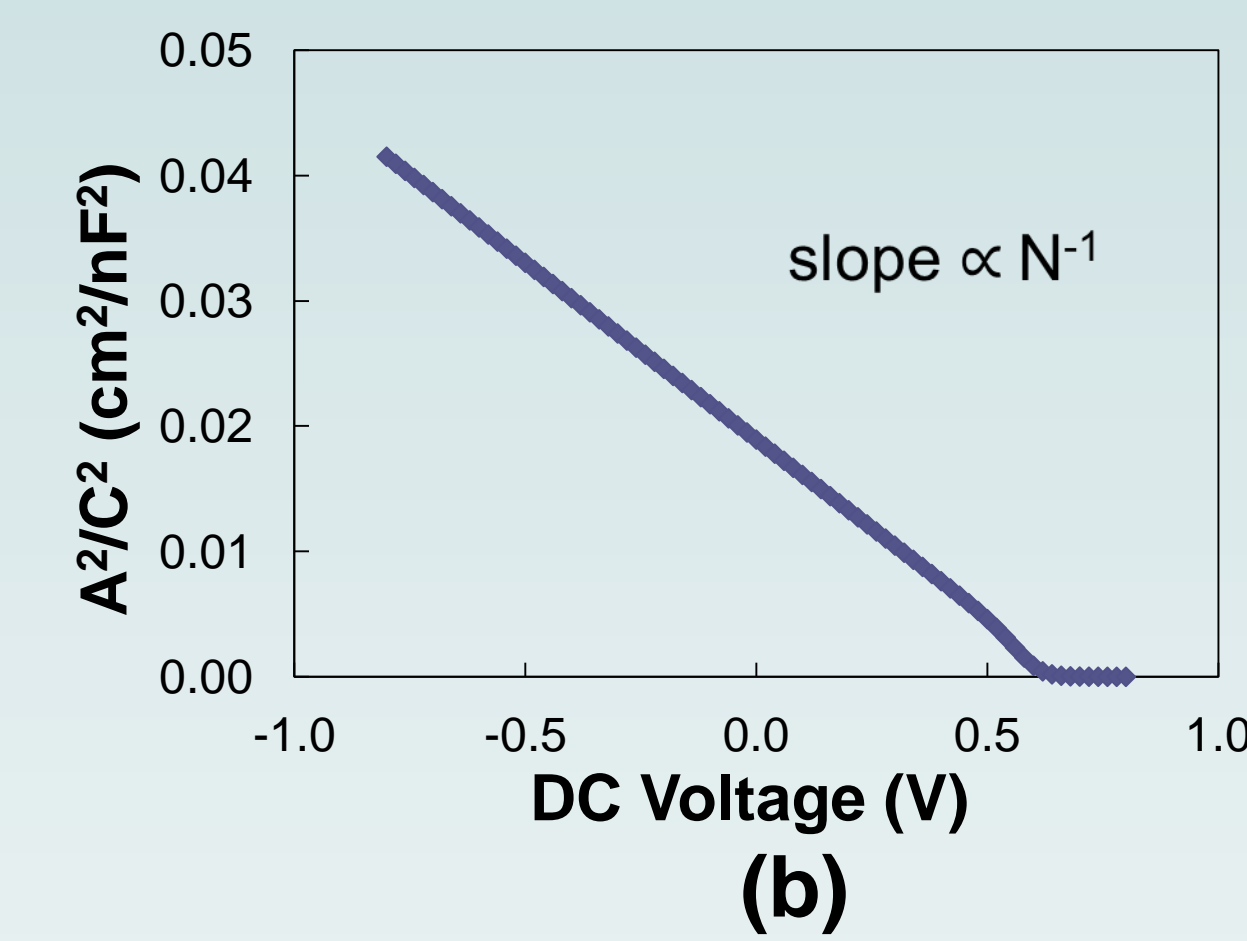
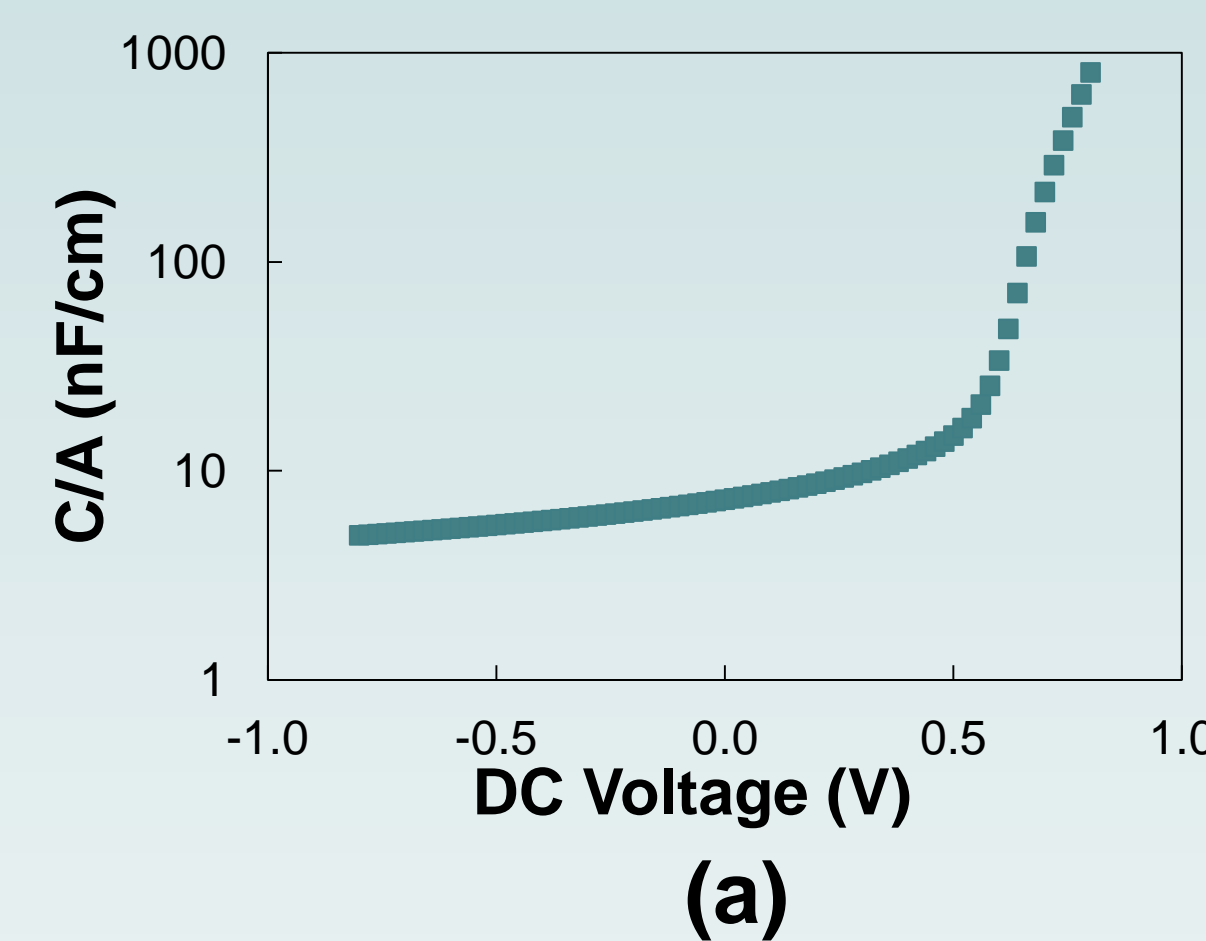
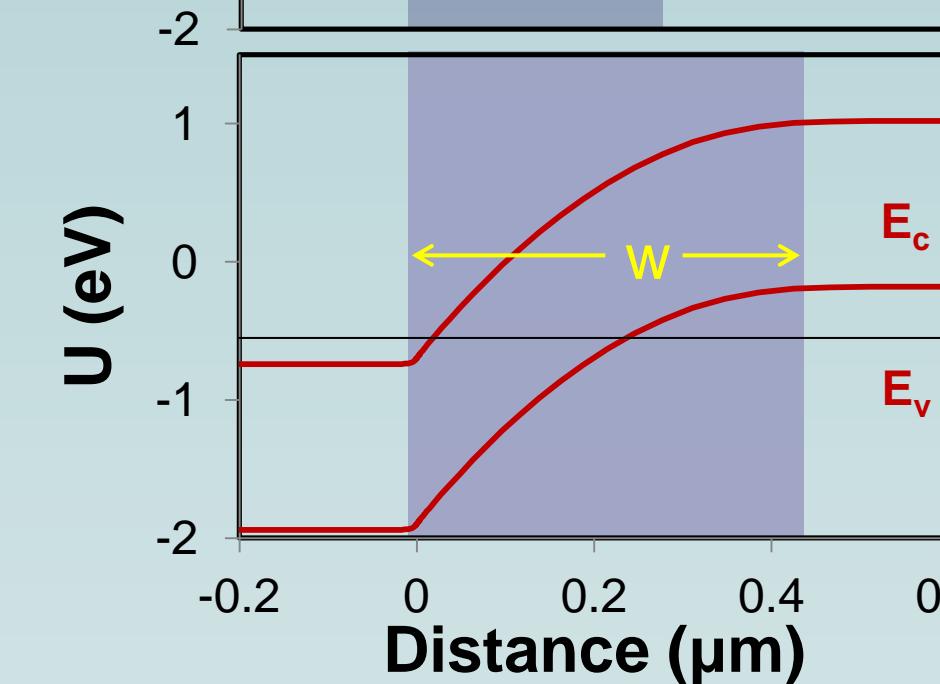
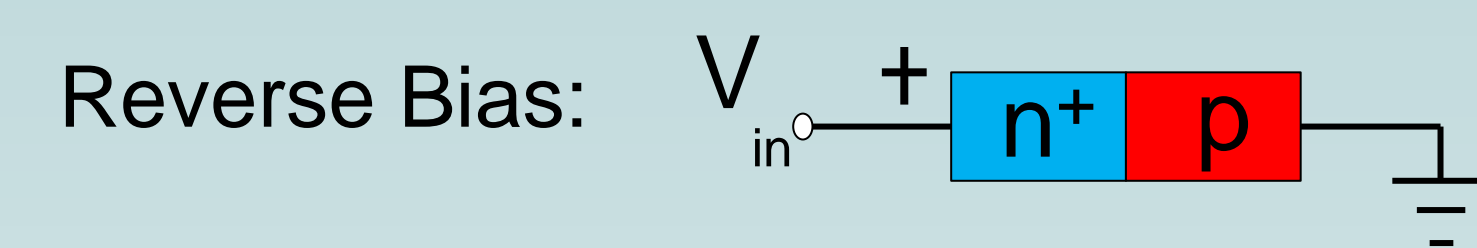
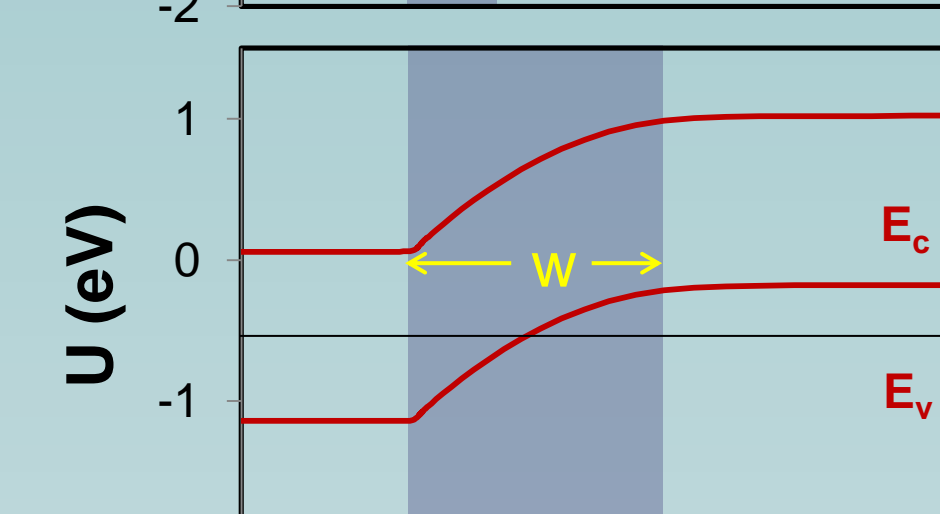
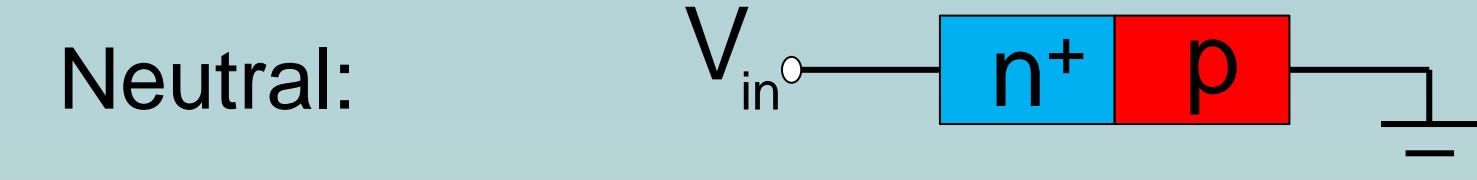
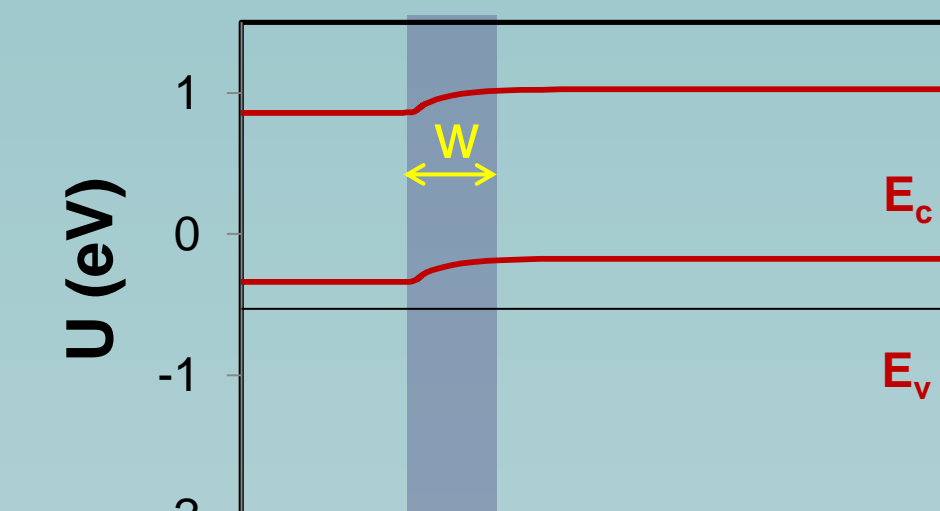
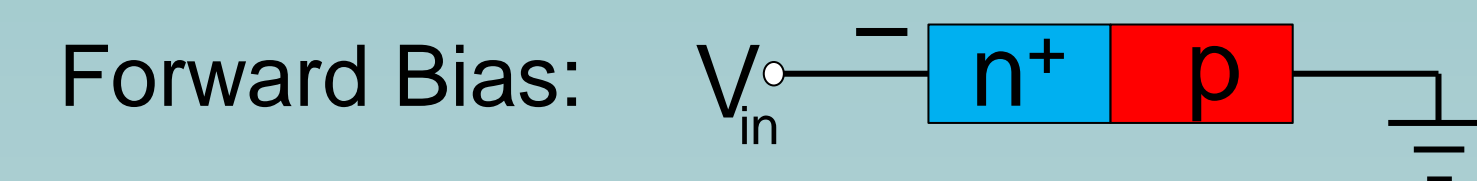


Figure 6: (a) C-V data for a simple n<sup>+</sup>p junction created with SCAPs [1]. Positive DC voltage corresponds to forward bias, decreasing the depletion width, and increasing capacitance. (b) Theoretically,  $\frac{1}{C^2} \propto V$ , and the slope is related to the doping density  $N$ .

## Numerical Models

After seeing the theoretical capacitance with an ohmic contact, it is interesting to analyze the effect a bad back contact has upon solar cells. A bad back contact resists the flow of current from the cell.

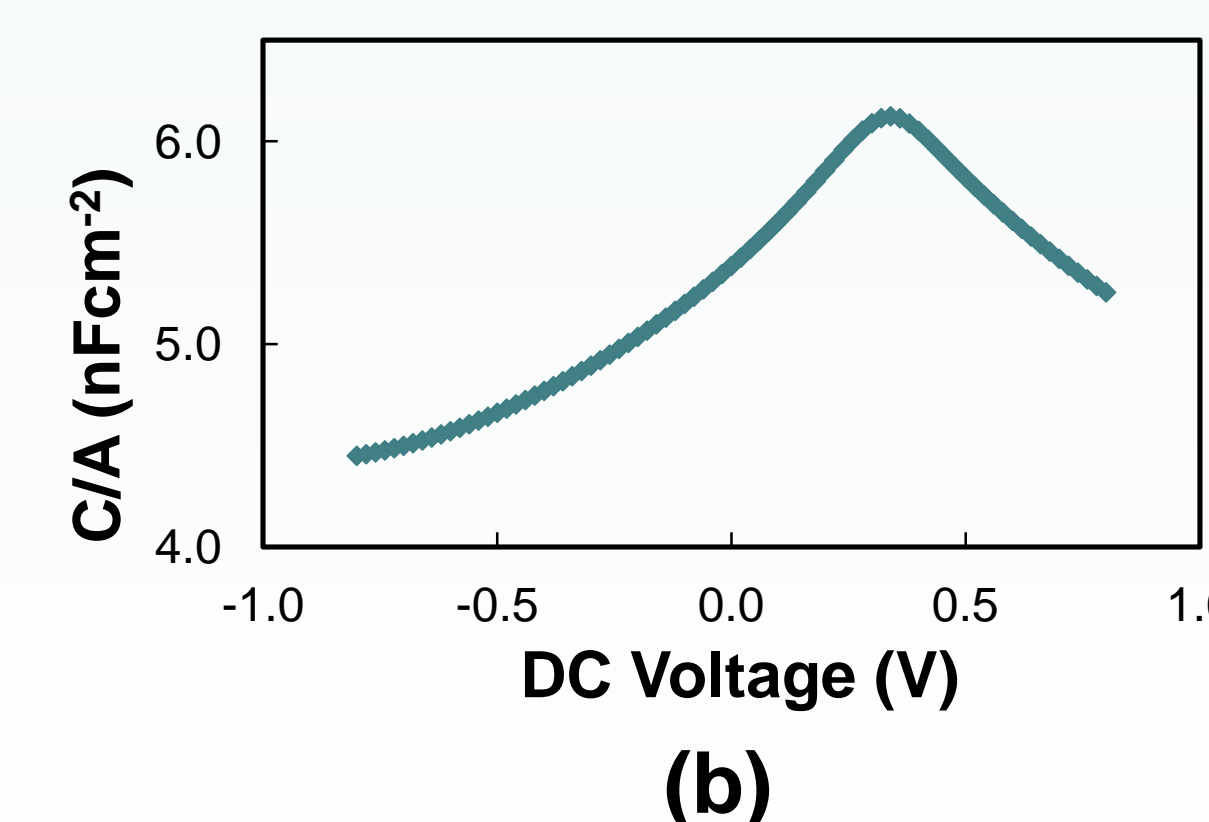
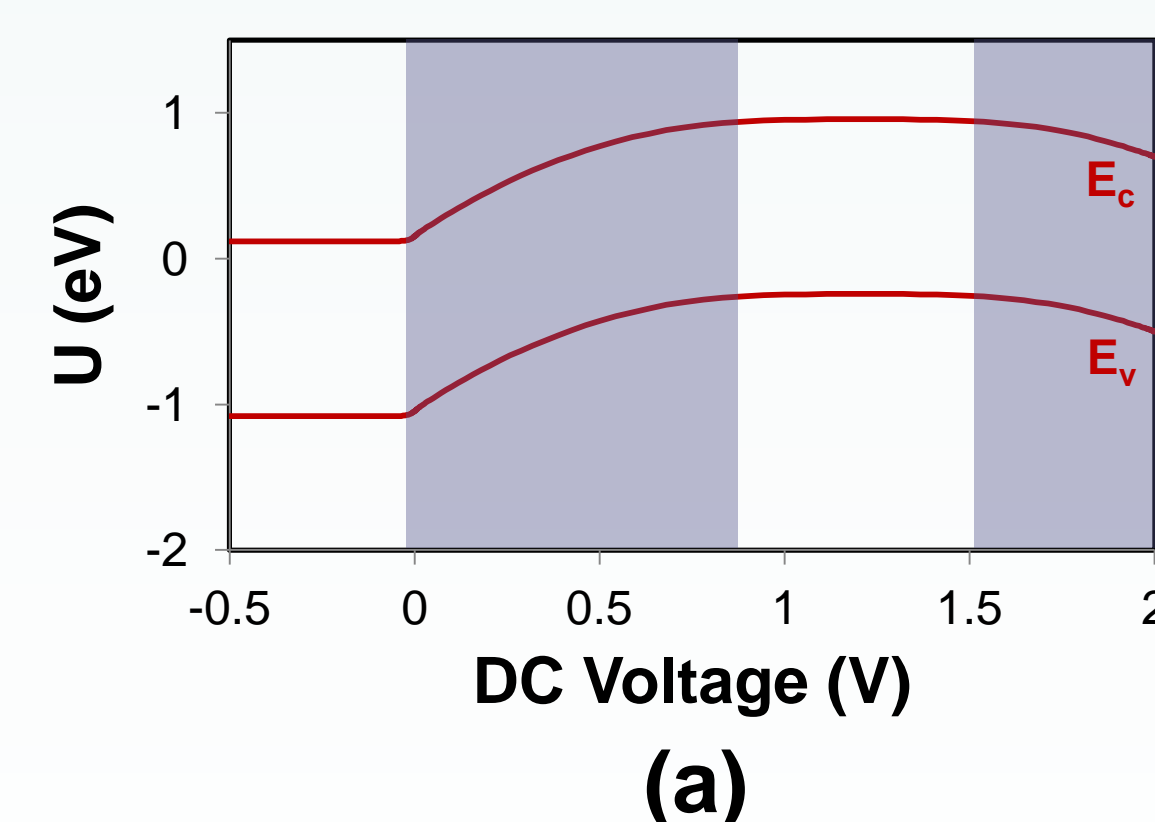


Figure 7: (a) An example of a band diagram for the semiconductor material with a back contact barrier. In order to model this, a voltage difference from the cell and contact was used. Model created with SCAPS [1]; (b) Numerical modeling for CV data using the model shown in (a).

## Circuit Results

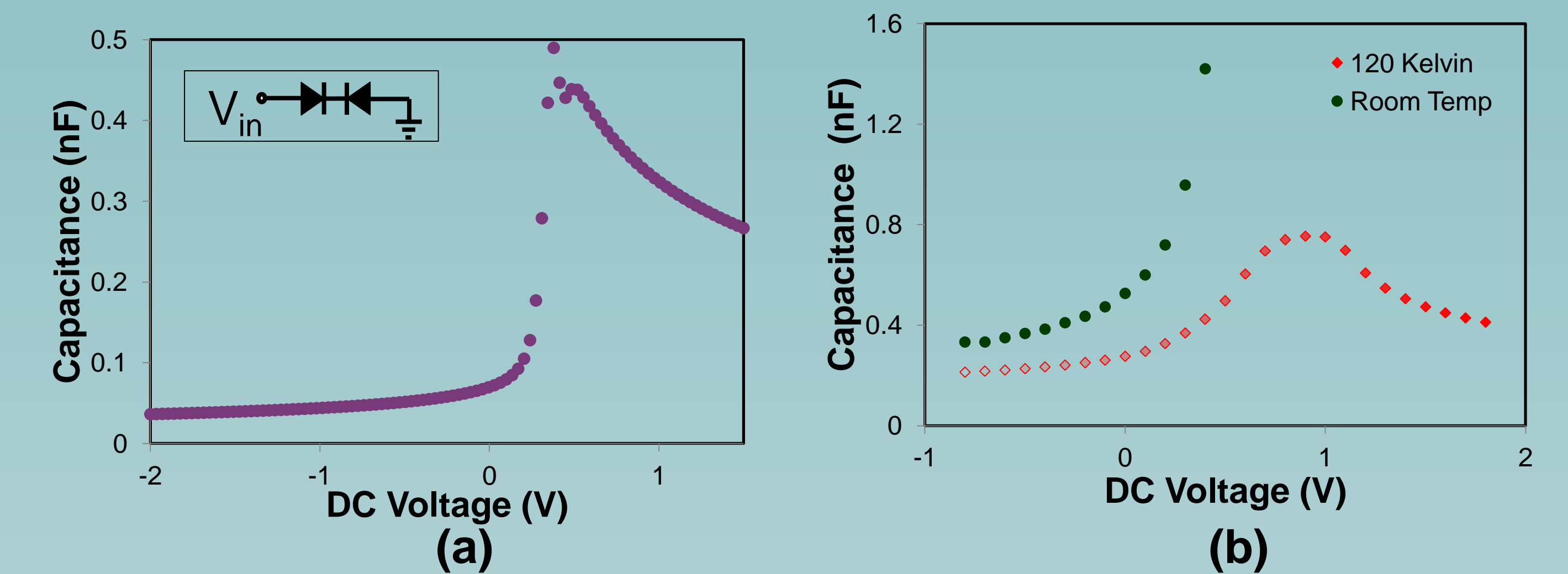


Figure 8: (a) Results for a circuit model of a bad back contact; two back-to-back diodes. Inset: circuit diagram. (b) Recorded data for CIGS solar cell at 120K and room temperature. A bad back contact likely explains the low temperature results.

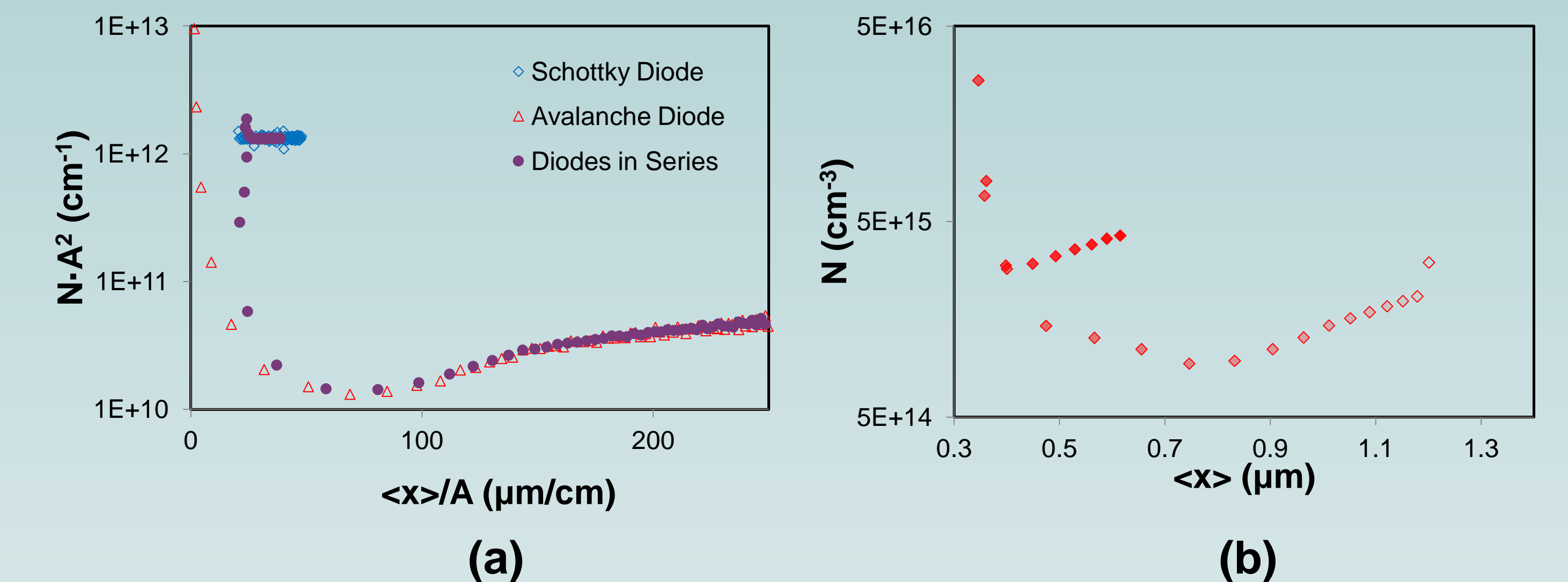


Figure 9: Analysis of data from Fig. 8, using the standard C-V analysis illustrated in Figure 6. (a) Results for each individual diode, and the back-to-back diodes show that the individual diode results can be recovered from back-to-back diode data at appropriate values of bias. (b) Results from the solar cell at 120K may illuminate differences between the top and back of the absorber layer.

## Future Work

- More sophisticated modeling of current transport in a device.
- Explore the nature of the back contact including the height, the dependence of temperature, and sample fabrication details.

## Acknowledgements

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## References

- [1] M. Burgelman, et al., *Thin Solid Films*, **361**, 527 (2000).
- [2] Rockett, et al., *Thin Solid Films* **372**, 212 (2000).
- [3] T. Eisenbarth, et al., *J. Appl. Phys.* **107**, 034509 (2010).