Investigation of transport properties of ZnO/PbS heterojunction solar cells

- **Y. Cheng**, M. C. D. Whitaker, R. Makkia, S. Cocklin, V. R. Whiteside, L. A. Bumm, and I. R. Sellers, E. Adcock-Smith, K. P. Roberts, P. Harikumar

- *Homer L. Dodge Department of Physics & Astronomy, University of Oklahoma, 440 W Brooks Street, Norman, OK 73019*
- *Department of Chemistry and Biochemistry, University of Tulsa, 800 South Tucker Drive Tulsa, OK 74104*
- *Department of Physics and Engineering Physics, University of Tulsa, 600 S. College Ave. Tulsa, OK 74104*

Photovoltaics Materials & Device Group, University of Oklahoma: http://www.nhn.ou.edu/~sellers/group/index.html

Introduction

- CQDs could potentially offer efficient solar cells using low cost, solution based techniques.

- Confinement effects existed in CQDs lead to discrete energy levels which could widen the band gap, allowing the optical and electrical properties to be finely tuned by varying the QD size.

- Through Multi-exciton generation (MEG) [1] [2] process and multijunction structure [3] CQDs solar cell has the potential to go beyond Shockley-Queisser limit.

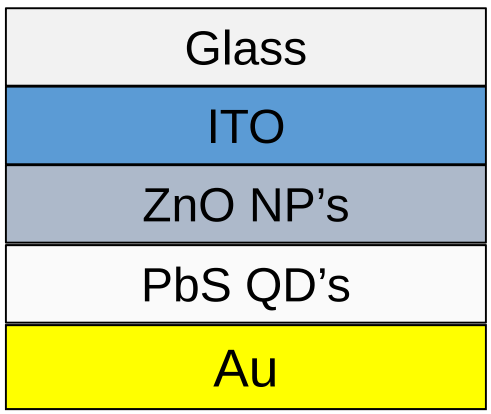
- To further increase the efficiencies, it will be beneficial to investigate transport properties.

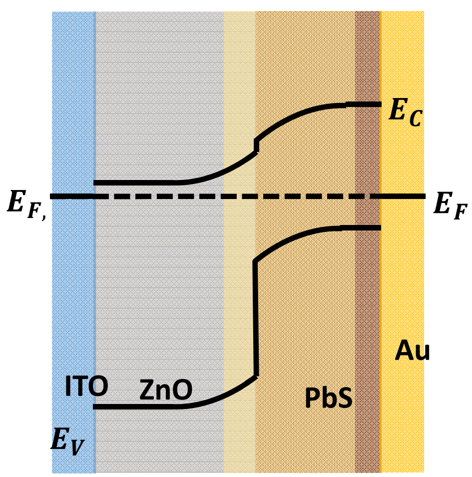
1. *Sambur, et al. Science 330.6000 (2010): 63-66.*
2. *Semonin, et al. Science 334.6062 (2011): 1530-1533.*
3. *Choi, Joshua J., et al. Advanced Materials 23.28 (2011): 3144-3148.*

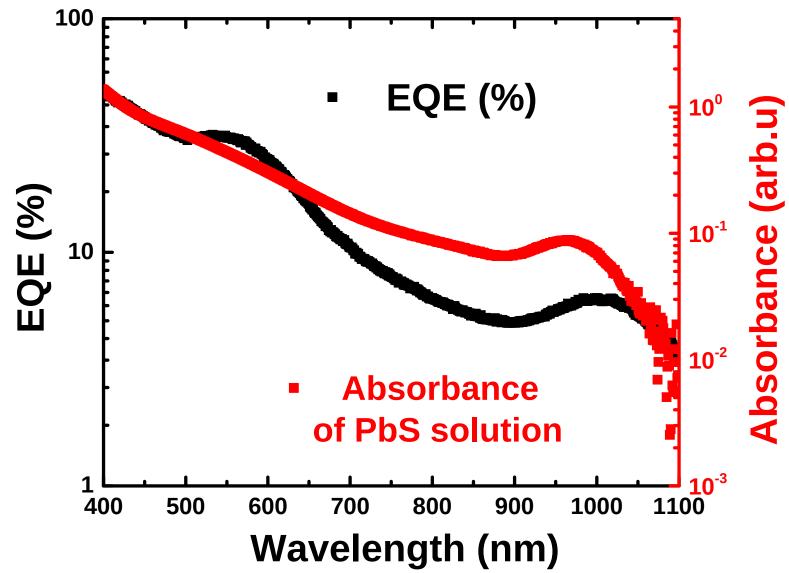
Photo-generated carriers extraction

- Device structure

Glass/ITO/ZnO/PbS/Au

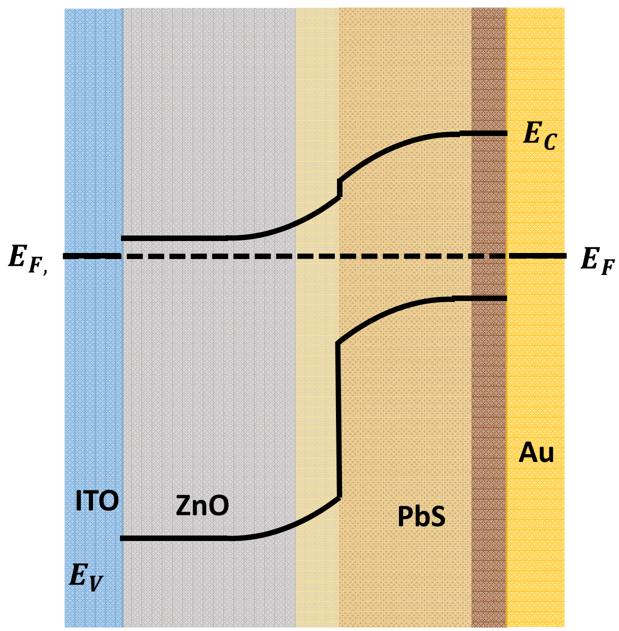






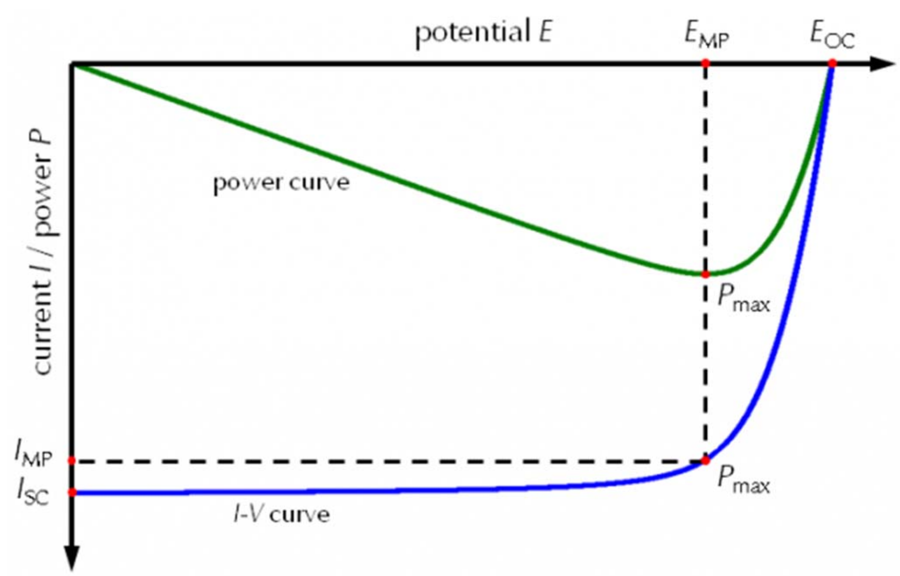
Absorbance and EQE measurements clearly show photo-generated carriers from PbS QDs.

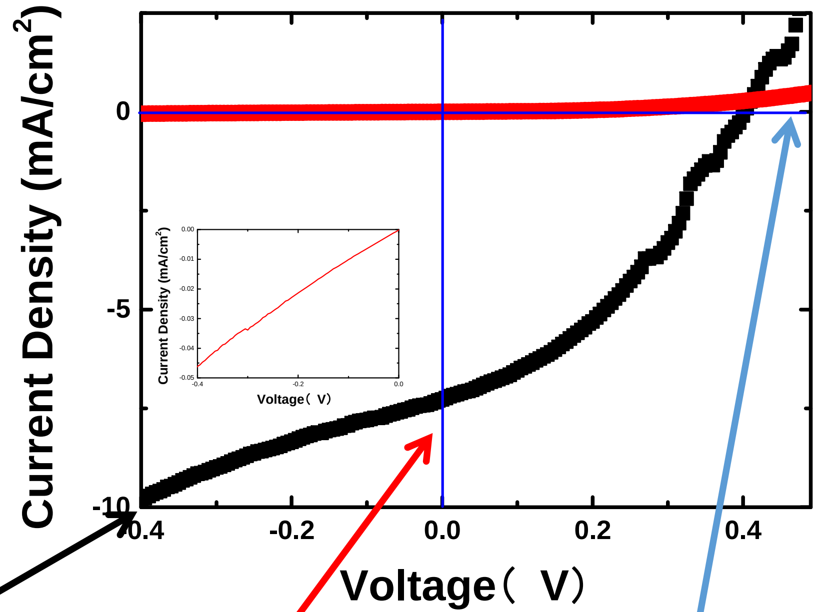
Surface states and Interfaces



- CQDs
- ITO/ZnO
- ZnO/CQDs
- CQD/contact

Device performance





Leakage current, shunt paths which also result in low fill factor

Low Jsc:
Series Resistance
Shunt path

Cross over:
Other barriers create another diode in series shifts the voltag

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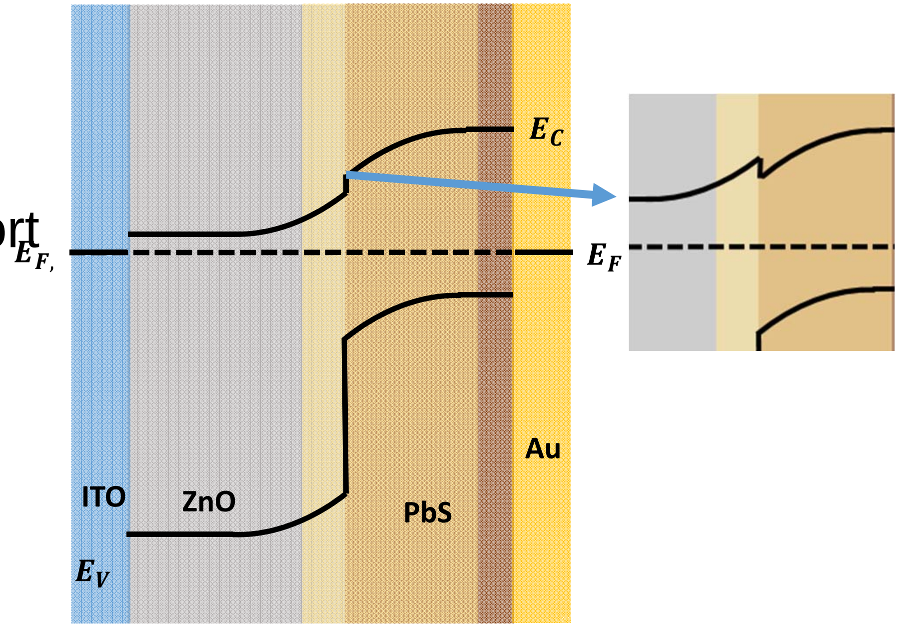
Trade offs

- Thicker PbS layer will increase the total absorption of photons, but the extraction of the photo-generated carriers is limited by the diffusion length.

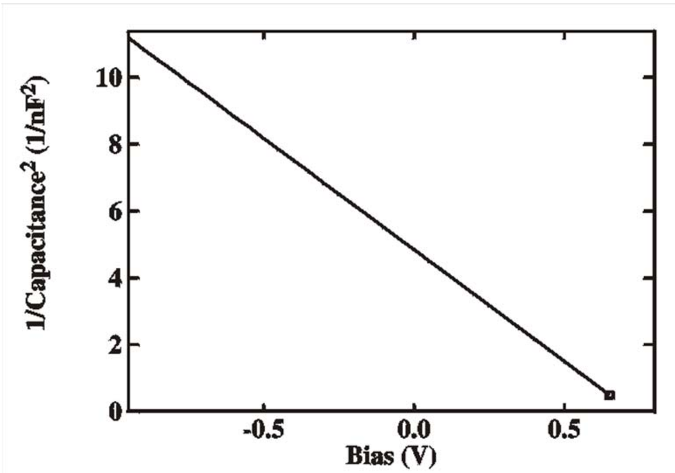
- Doping the ZnO will change the band alignment of ZnO/PbS, which in return influence the electron transport from the CQD layer to ZnO.

- High doping concentration of ZnO will increase depletion width in CQD layer. However, doping will also introduce defects into ZnO layer which decreases the diffusion length



Mott Schottky and Impedance Analysis

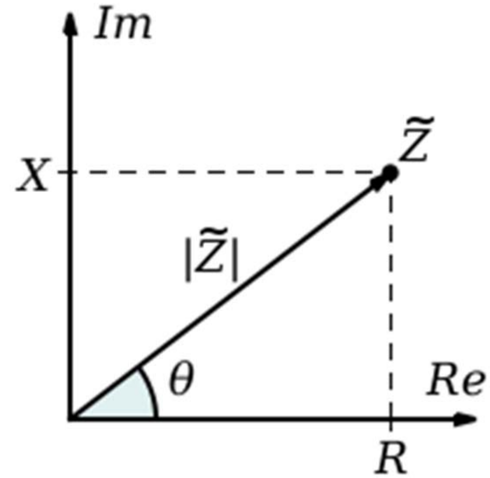
Mott-Schottky Analysis



http://www.stallinga.org/ElectricalCharacterization/2terminal/index.html

$$\frac{1}{C^2} = \frac{2(V_{bi} - V)}{A^2 q \varepsilon_s N_a}.$$

Impedance Spectroscopy

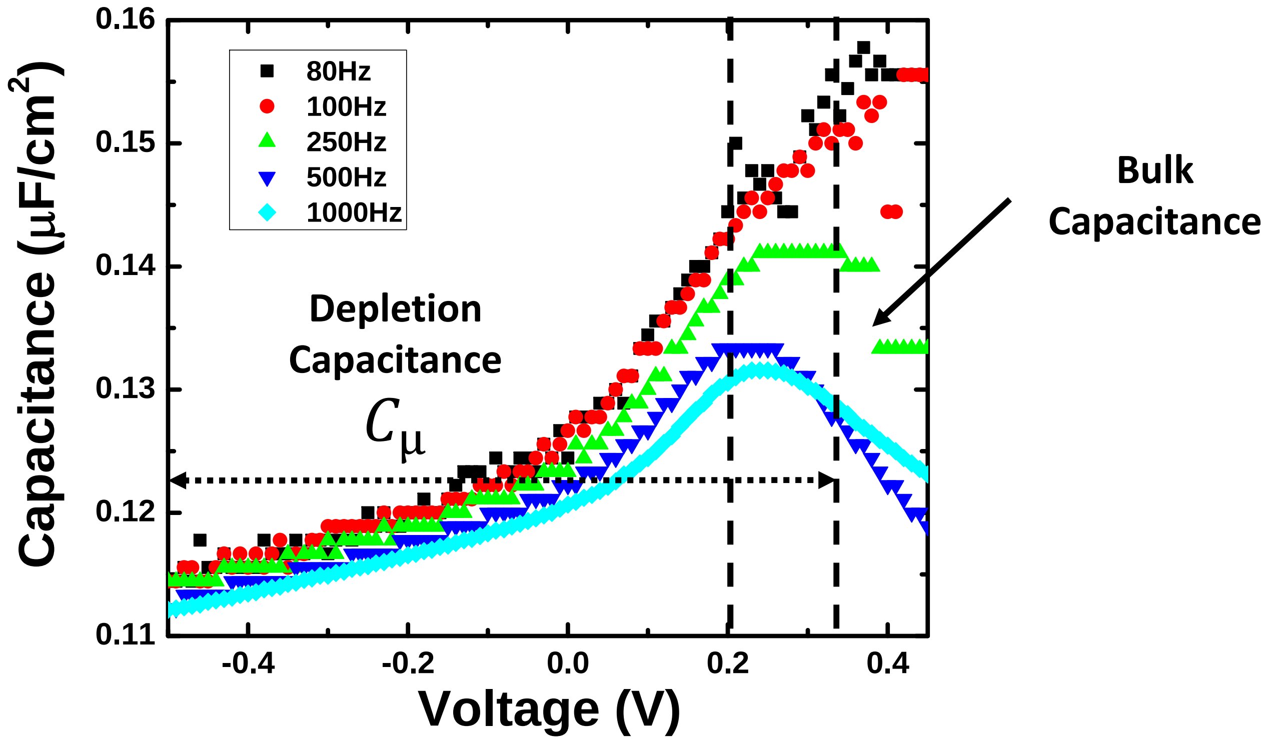


https://en.wikipedia.org/wiki/Electrical_impedance

$$Z_R = R$$

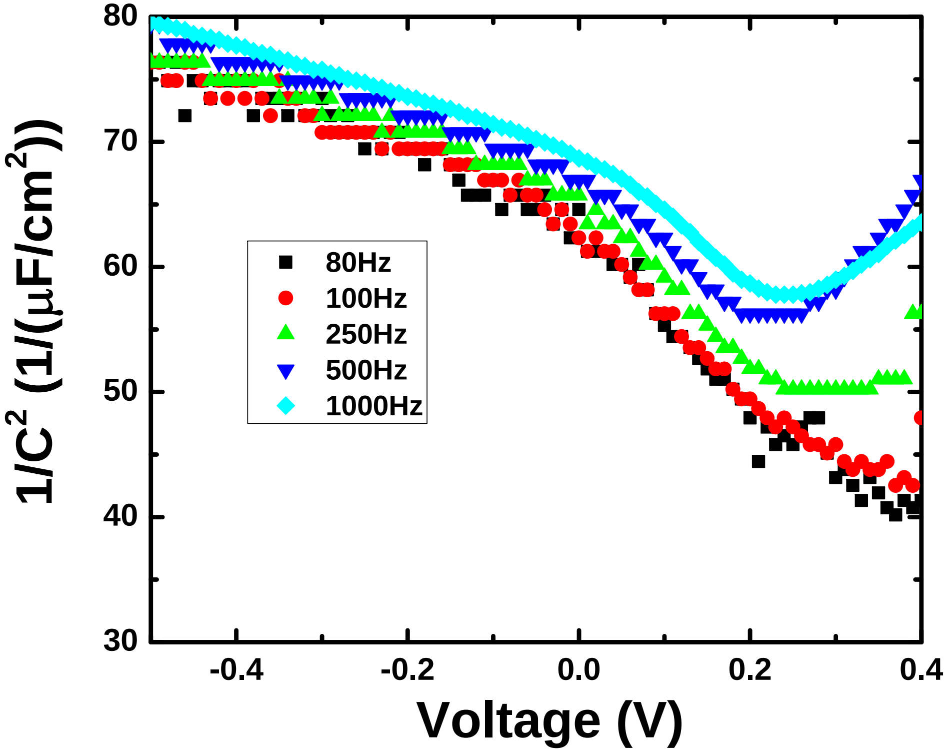
$$Z_C = \frac{1}{j\omega C}$$

Mott Schottky and Impedance Analysis



- **Both Depletion capacitance and bulk capacitance are observed in the C-V plot.**
- **However, increasing the sweeping frequency will lead to the reduction of the capacitance.**

Mott Schottky and Impedance Analysis



80 Hz	0.896 V
100 Hz	0.856 V
250 Hz	0.866 V
500 Hz	0.993 V
1000 Hz	1.164 V

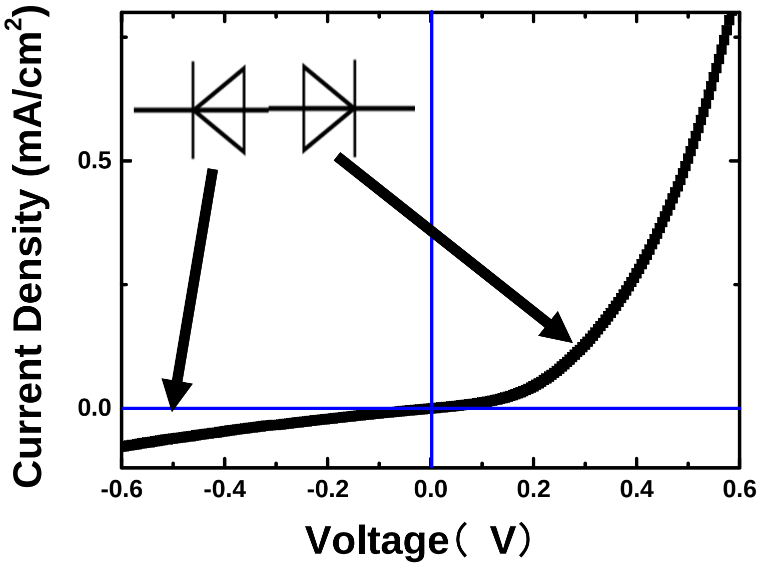
- **The built in voltage extracted from the *1/C* ^2-V plot of different frequencies**

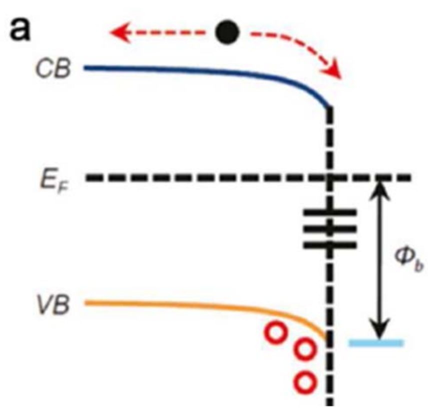
The built in voltage is way too large than expected based on the reported Fermi level difference [1].

This could be existence of other capacitance from the interfaces or traps which shifts the depletion capacitance.

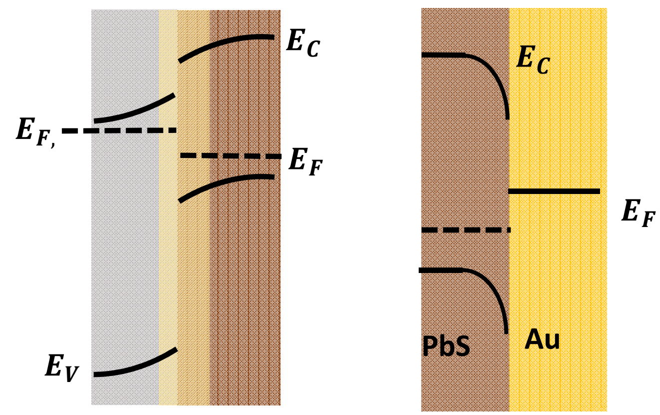
1. *Pattantyus-Abraham, Andras G., et al. ACS nano 4.6 (2010): 3374-3380*

Mott Schottky and Impedance Analysis

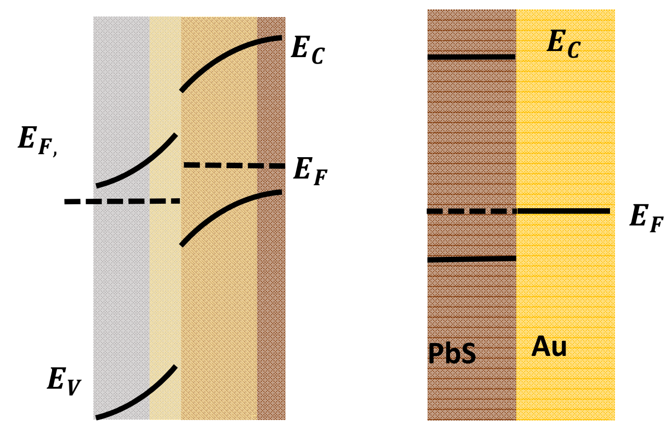




Forward Bias

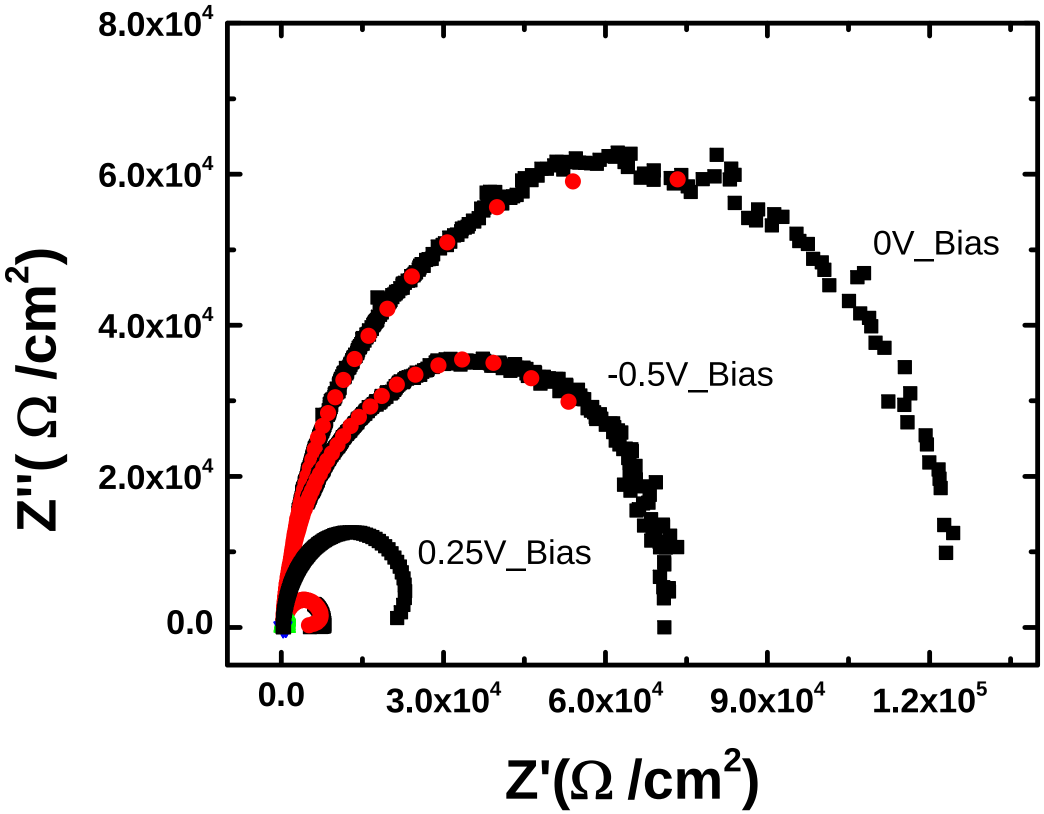


Reverse Bias



Kramer, I. J., & Sargent, E. H. *Chemical reviews*, *114*(1), 863-882.

Mott Schottky and Impedance Analysis

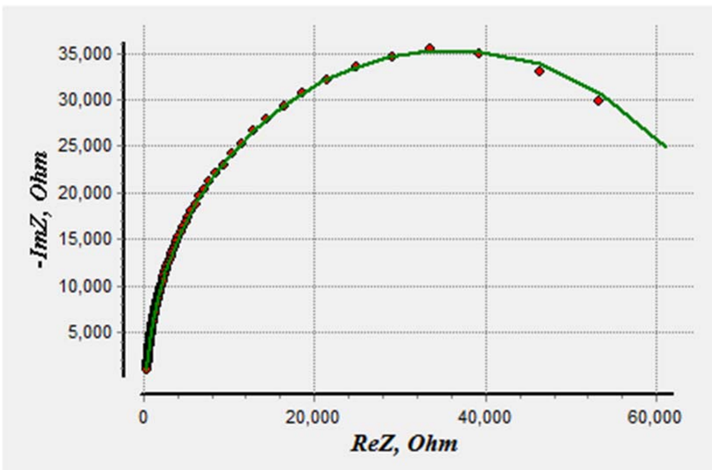


Increasing the forward Bias will shrink the Nyquist cole-cole plot.

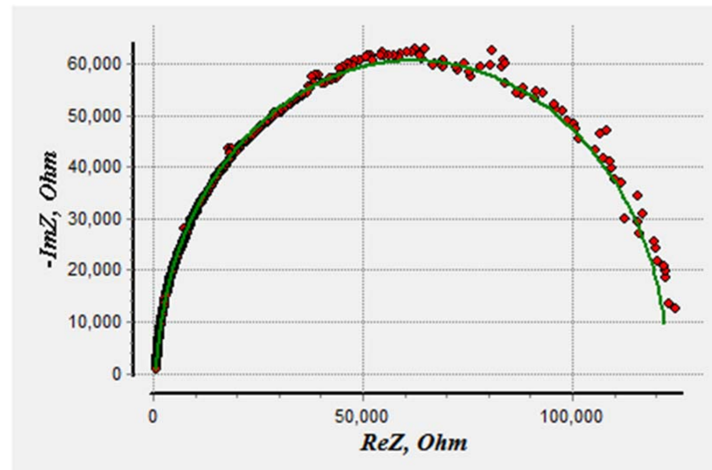
However, when reverse bias the sample with higher voltage will also reduce the impedance at lower frequency.

Mott Schottky and Impedance Analysis

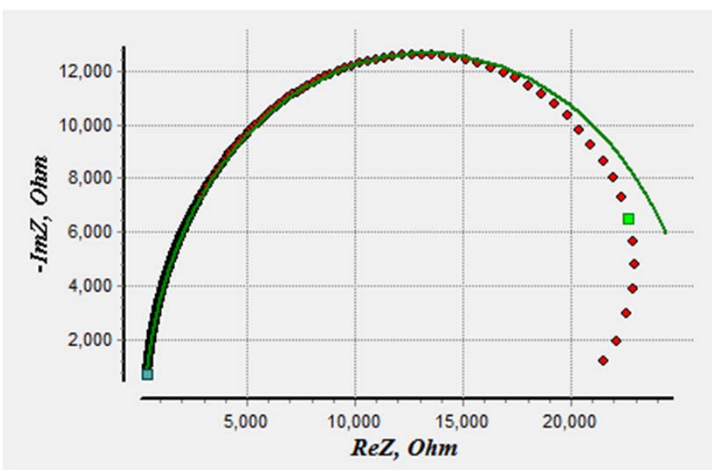
-0.5V



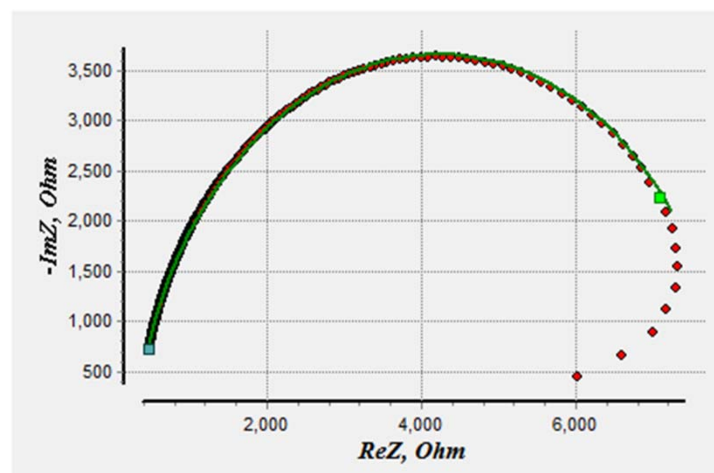
0V



0.25V



0.5V



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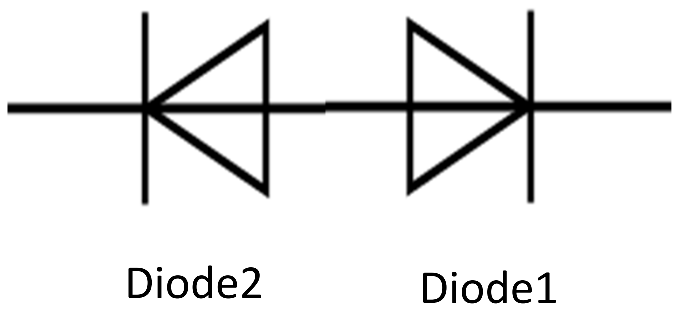

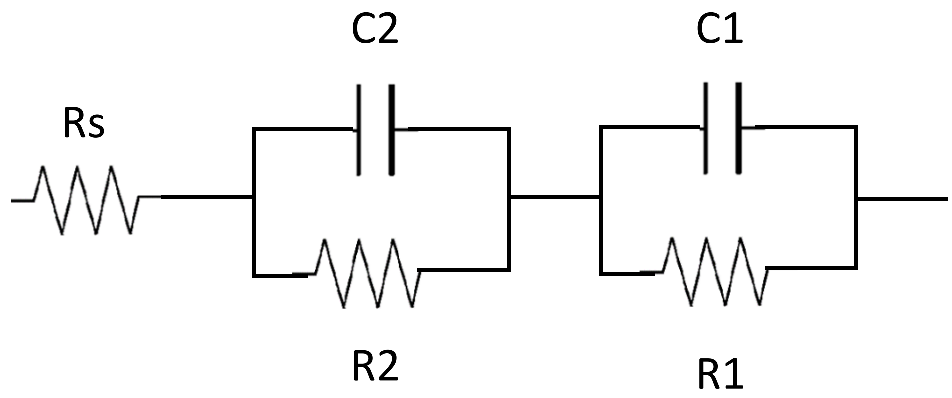

	Rs	C1	R1	C2	R2
-0.5V	362.13	9.2972	70619	67.924	367.47
0V	850.17	10.675	121220	90.005	534.18
0.25V	333.37	12.137	25657	89.671	299.29
0.5V	376.98	12.805	7176.9	63.26	328.84

Future goals

- **Extract more information (eg. Carrier lifetime) from the fitting to investigate the transport mechanism.**
- **Impedance spectroscopy under illumination will also be studied to probe the nature of the second diode behavior.**
- **Influence of different optimization methods on the C-V and impedance will be investigated comprehensively.**

Acknowledgement

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