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Modeling the Behavior of the Surface to Liquid Interfaces of an Electrolytic Liquid

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Abstract

Understanding the mechanism for charge transfer between electrodes within an electrolyte dissolved in water is vital to better understanding the sources of electrical noise in the system. This research compares the electrical properties of liquid top gated graphene devices with the properties of two metal probes to model the system. By measuring the impedance of these systems at different frequencies, it is possible to model the electrical properties of the devices and to consider techniques to improve signal to noise at graphene interfaces.

Motivation

To model the electronic behavior of a graphene device in a biological environment for future use as a biosensor.

Background

To model the current between two electrodes connected by an electrolyte solution, one can use a resistor (R) and a capacitor (C), wired in parallel. The electrolyte transfers ions for current while a metal uses electrons. The ions in the electrolyte are not able to move into the metal directly, creating an effective capacitor. A rare reaction, called a redox reaction, can release an electron to complete the circuit and is modeled as a resistor element.

Simplified model- Metal/Liquid/Metal

Impedance is a general term for what limits the current within a circuit. It can be measured with a lock-in amplifier. The parallel resistor/capacitor model can then be used to fit the impedance versus frequency.

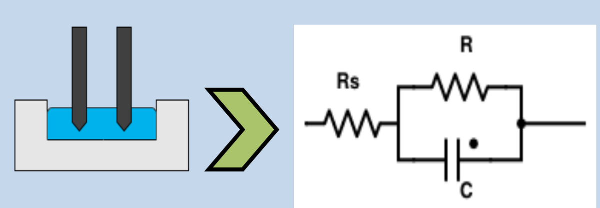

Figure 1. Circuit representation of the model

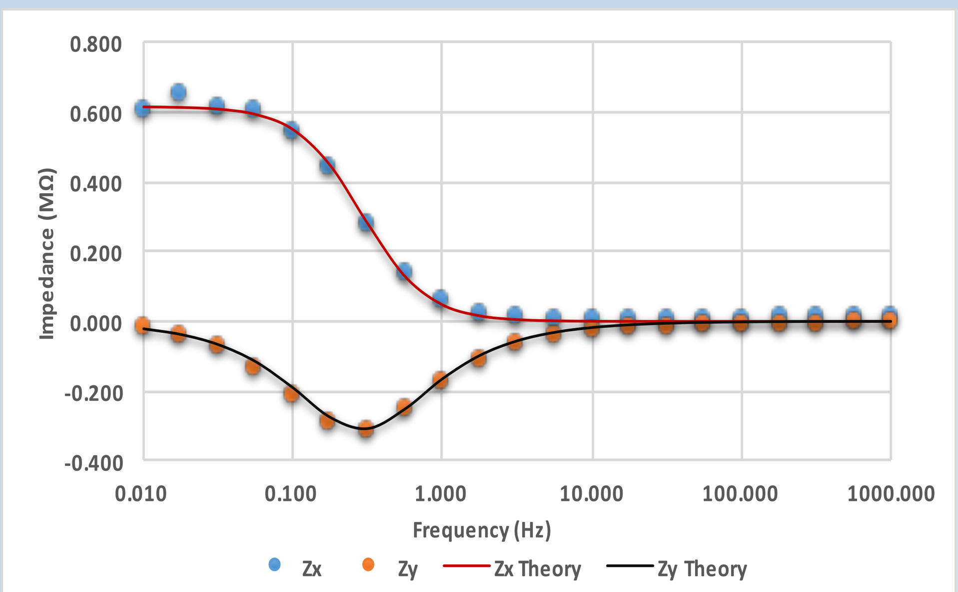

Figure 2. Physical model translated into a circuit through impedance over frequency

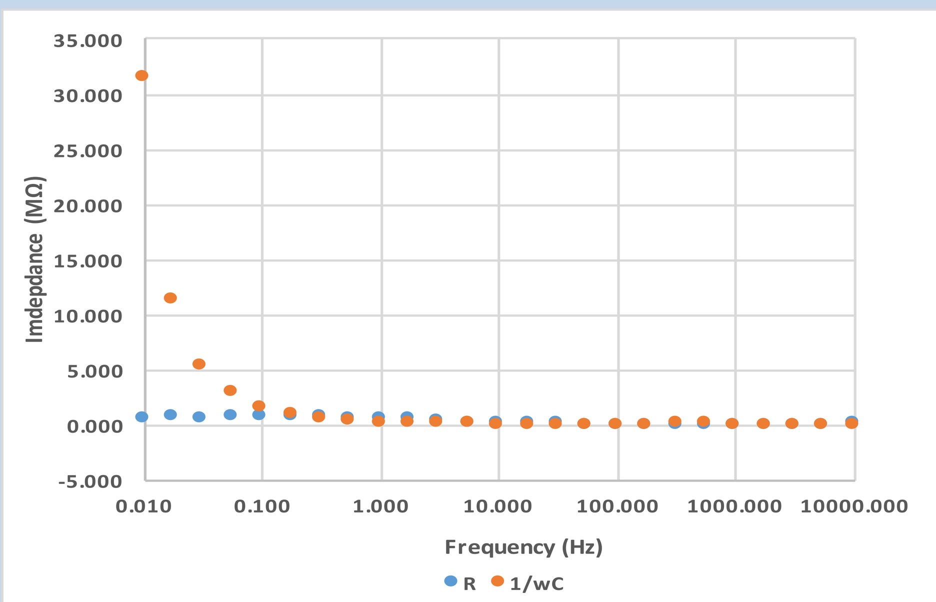

Figure 3. Graph of modeled resistance and capacitance versus frequency. Note the resistance is constant with frequency.

By fitting the data in Figure 2, an electrolyte concentration of 5.00 mM creates an effective resistance of 615 kΩ and effective capacitance of 900 nF.

Graphene Model

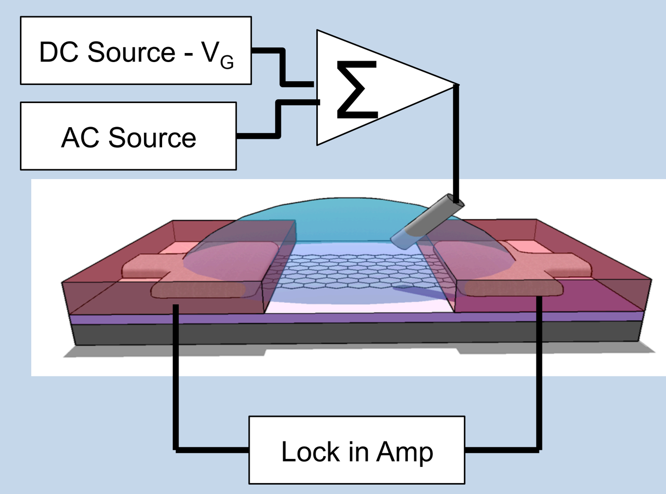

Figure 4. Schematic of graphene measurement in which an AC voltage is applied to a liquid top gated graphene device and the collected current is measured from the graphene

To take maesurments of the impedence of the graphene system we,

- Apply a gate voltage
- Sweep the frequency
- Measure the current
- Use a lock-in amplifier to separate the real and imaginary phase of the current signal

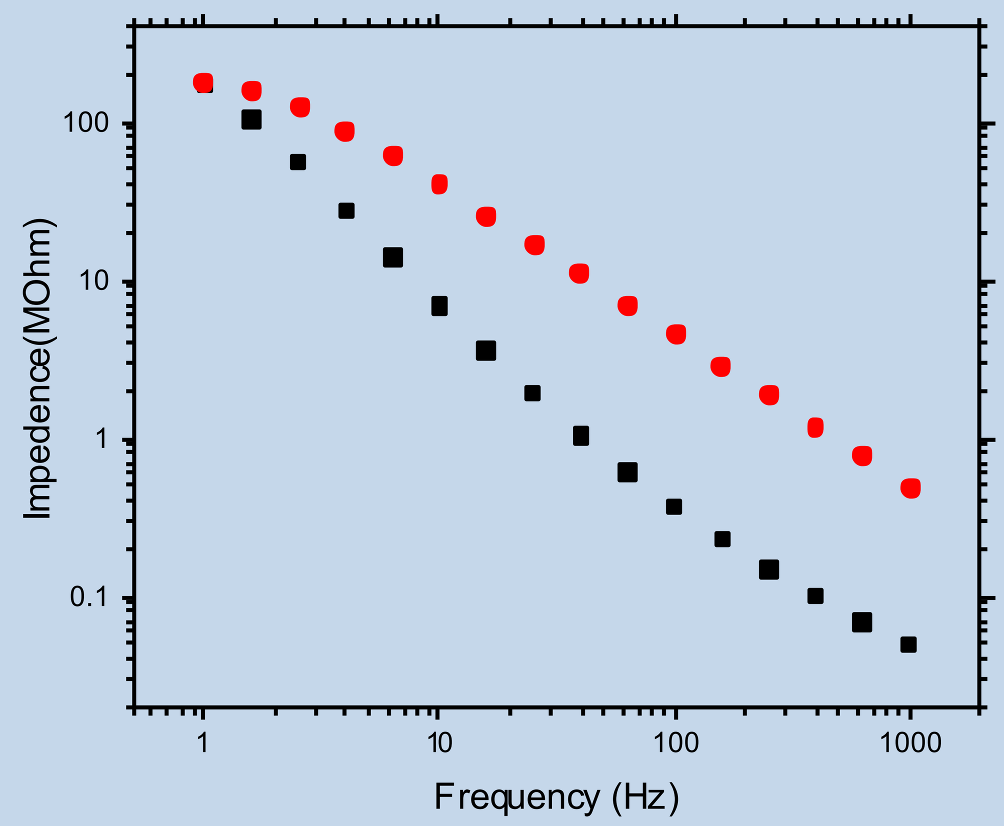

Figure 5. Model of our system on a graphene device. Imaginary impedance is molded as a capacitor (red) and real impedance is molded as a resistor (black).

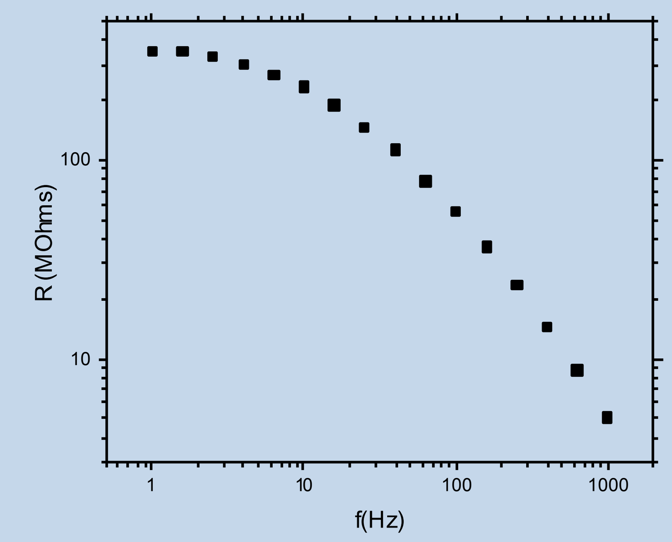

Figure 6. Graph of resistance verses frequency as calculated from the real impedance.

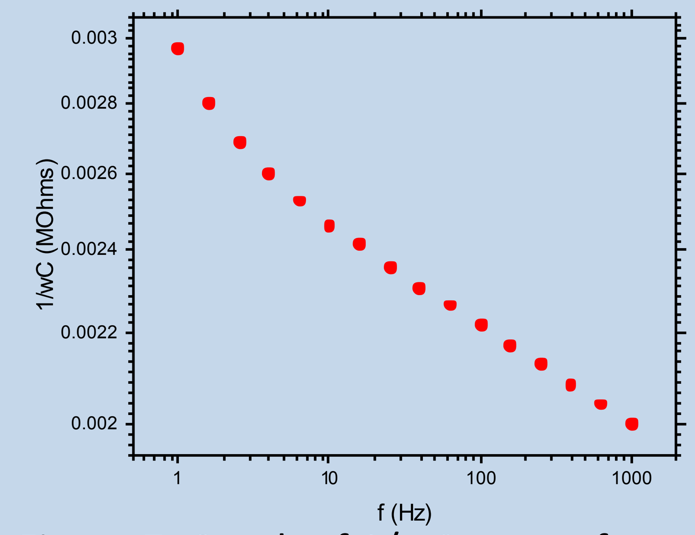

Figure 7. Graph of 1/wC versus frequency as calculated from the imaginary impedance.

The graphene system differs from the metal probes because its resistance depends on the frequency of the signal, similar to the capacitance. In fact, the impedance follows that of a constant phase element:

$$Z \propto \frac{1}{f^{ip}} = \frac{1}{f^{p}}\left[\sin(p\pi/2) - i\cos(p\pi/2)\right]$$

Evidently, electrons can transfer across the liquid-graphene surface more easily at high frequency. This change may be caused by the interface re-using electrons for multiple cycles. If so, the real impedance would act as a noise source rather than an effective resistance.

Future Work

We hope to consider ways to use the simple model to predict the concentrations of our electrolyte solution.

We also hope to further study the resistance as it relates to noise.

References

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[2]Robinson, D.A. The electrical properties of metal microelectrodes. *Proceedings of the IEEE* 56, 1065-1071 (1968).

[3] Crosser, M.S., Brown, M. A., McEuen, P.L. & Minot, E.D. Determination of the Thermal Noise Limit of Graphene Biotransistors. *Nano Letters*150720103852006 (2015).

Acknowledgements

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