

# Characterization of Ionic Liquid Gels used with Conformable Conducting Polymer and Textile Electrodes used for Electroencephalography

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## Abstract and Introduction:

Current electrodes for electroencephalography (EEG) and electrocardiography (ECG) recordings require the use of a liquid electrolyte to decrease the impedance at the electrode/skin interface. However, the liquid electrolyte can begin to dry within a few hours, limiting the time for usable data to be gathered. Recent efforts have been taken to combat this and other factors, leading to the creation of ionic liquid (IL) gels. IL is a substance that is conductive and liquid at room temperature, but can polymerize, creating a gel, upon UV curing. It has been shown that these IL gels have been mostly on par with its liquid electrolyte counterpart in terms of conductivity, and have also proven to maintain low impedance for much longer durations [1]. Additionally, a new gold (Au) electrode as well as the return of textile electrodes, are on their way to surpassing the performance of the standard medical electrode.

A more adhesive IL gel was produced to further improve the interface coupling. In this report, characterization of these new IL gels was performed, showing that improved adhesion does not compensate for conductivity lost due to deviation from the standard IL recipe. Information concerning trends in impedance with reference to IL gel volume, IL deposition, PEDOT:PSS deposition, and textile versus Au electrodes is also reported.

## Device Fabrication:

A flexible Kapton® film sheet of 125  $\mu\text{m}$  was used for the Au electrode substrate. CAD software was used to design the electrode schematics that were patterned on the Kapton sheet using a LPKF electronic laser cutter. Chromium (Cr) followed by Au were evaporated onto the substrate in thicknesses of  $\sim 30$  nm and  $\sim 100$  nm, respectively. Poly(3,4-ethylenedioxythiophene):poly(styrenesulfonate), or PEDOT:PSS, was deposited on the heads of the electrodes.

Our first deposition method used two drop casts. The first was baked at 90°C for 2-3 minutes. The second was baked at 110°C for one hour. Our second deposition method involved four spin

coatings, progressively getting thicker. The spin coater's RPM was as followed for each layer: 1500, 1300, 1000, 650. Finally, a single drop cast was performed.

Our third deposition method used a post-treatment of ethylene glycol. Replicas of these deposition methods were performed using a mixture of PEDOT:PSS and IPA in a 3:1 ratio. General cleaning and O<sub>2</sub> surface activation occurred between each major steps. Textile electrodes were patterned with polydimethylsiloxane (PDMS), saturated in PEDOT:PSS, and then baked at 110°C for one hour.

Ionic liquid gels, supplied by an outside company, came in two components, IL + monomer and photoinitiator. Components were mixed together using specified ratios provided by the company and drop-casted on the heads of previously fabricated Au electrodes. Separate molds were also used as a control to test conductivity versus adhesion. Ultraviolet (UV) curing was performed with curing times that were dependent upon the IL formula being used. Distance between the IL composite and the UV lamp remained a constant 3 cm. For textile electrodes, 20  $\mu\text{l}$  of IL was deposited, followed by another 20  $\mu\text{l}$  of IL composite before curing.

## Experimental Procedure:

UV curing times were discovered by drop-casting small samples on a glass slide and using a UVGL-58 handheld UV Lamp, set to long wave-365 nm. Curing intervals of five seconds were performed while physically testing the degree of polymerization between each interval.

Total UV curing time was recorded when samples displayed desired polymerization characteristics. These polymerization characteristics were such that each sample was determined to be solid yet release IL upon physical stimulation. This insured that our samples were reasonably resilient and exhibited conductive capabilities. Samples that were too dry were very adhesive and had low conductivity.

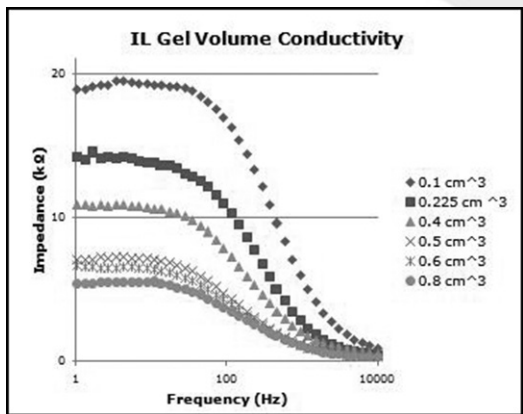


Figure 1: Impedance measurements of different IL gel volumes.

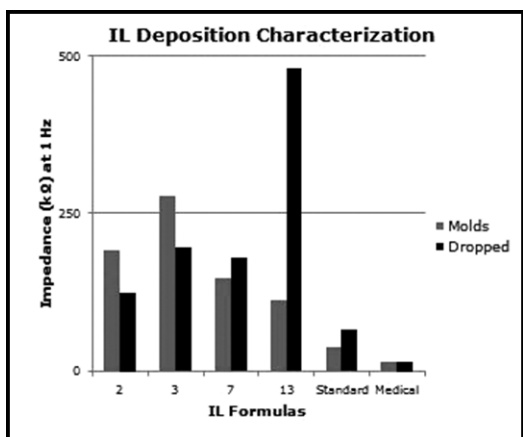


Figure 2: Impedance measurements of different IL formula differentiating drop casting versus external molds.

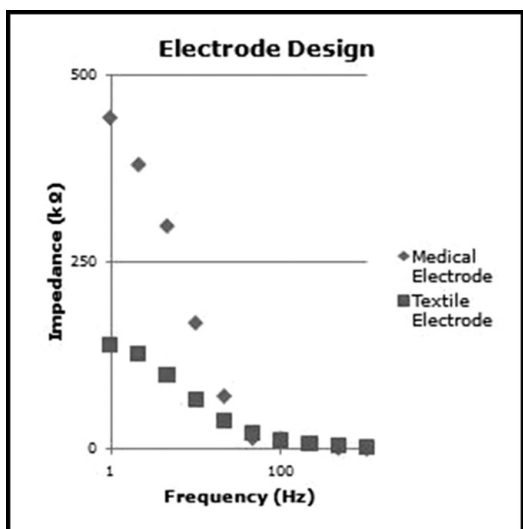


Figure 3: Impedance measurement of textile electrode versus standard medical electrode.

For impedance measurements, a cleaning solution of 75% H<sub>2</sub>O and 25% ethanol was applied to the areas of the arm that would host the electrodes. The counter terminal was placed on the posterior side of the forearm, near the wrist. The working/source terminals were placed 3 cm superior to the counter electrode. The reference terminal was placed on the lateral side of the elbow, 20 cm superior of the working and source terminals. Standard medical electrodes were used as a control at the reference and counter terminals while the test electrodes were used at the working/source terminal. After each impedance test, the electrode in question was removed and the area on the skin was cleaned before the next test was performed.

## Results and Conclusions:

It was shown that increasing IL gel volume decreased electrode impedance, instead of specifically thickness or surface area. However, this continuous decrease in electrode impedance was not linear and is assumed that a critical gel volume would then decrease conductivity. We also found that while some adhesive IL gels show a significant decrease in impedance when drop-casted directly on electrodes, as compared to an external IL gel mold, they exhibit overall less conductivity than the standard IL gel formula. Additionally, spin-coating four layers of PEDOT:PSS + ethylene glycol and then adding the extra drop-cast greatly improved the adhesion between the PEDOT:PSS and the Au, making it much more durable. However, conductive properties did not change. Finally, it was found that textile electrodes exhibited much less impedance than the Au or standard medical electrode.

## Future Work:

Because there is still a potential for adhesive IL gels, more formulas will be synthesized and tested. Additionally, while the new PEDOT:PSS deposition method did exhibit more durable properties, the current process is very time consuming and wasteful of PEDOT:PSS. Thus, a more refined method, or possibly a better method, needs to be found.

## Acknowledgments:

I would like to thank the National Nanotechnology Infrastructure Network International Research Experience for Undergraduates (NNIN iREU) Program for this fantastic opportunity. Credit also goes to the National Science Foundation (NSF) for funding. Finally, I would like to thank my PI, George Malliaras, my mentors, Thomas Longaret and Dr. Esma Ismailova, and everyone else at the Bioelectronics Lab (BEL) for all of their help and guidance.

## References:

- [1] Leleux, P., C. Johnson, X. Strakosas, J. Rivnay, T. Hervé, R. Owens, and G. Malliaras. "Ionic Liquid Gel-Assisted Electrodes for Long-Term Cutaneous Recordings." *Advanced Healthcare Materials* (2014): Web.