Conformable Conducting Polymer Electrodes used with an Ionic Liquid Gel for Electroencephalography

Camryn Johnson
Biological Engineering Major, Louisiana State University at Baton Rouge

NNIN iREU Site: Centre Microélectronique de Provence, Ecole Nationale Supérieure des Mines de Saint Etienne, France
NNIN iREU Principal Investigator: Dr. George Malliaras, Department of Bioelectronics, Centre Microélectronique de Provence, Ecole Nationale Supérieure des Mines de Saint Etienne
NNIN iREU Mentor: Pierre Leleux, Department of Bioelectronics, Centre Microélectronique de Provence, Ecole Nationale Supérieure des Mines de Saint Etienne
Contact: cjoh197@lsu.edu, malliaras@emse.fr, leleux@emse.fr

Introduction:

Electroencephalography (EEG) is a non-invasive and relatively inexpensive diagnostic tool that typically uses metallic electrodes on the surface of the scalp to measure electrical activity in the brain. Commercial silver/silver chloride (Ag/AgCl) electrodes used in EEG require a liquid electrolyte to decrease the electrode-skin impedance. This electrolyte not only often dries out quickly, preventing recording over longer time periods, but it also can sometimes cause short circuits if it leaks between two electrodes in a high density electrode array [1].

One path to improving EEG electrodes is having a flexible electrode, which improves the contact with the skin and thus decreases the electrode-skin impedance [2]. In a similar effort, conducting polymers are also being researched as a material to be used due to their flexibility, high conductivity, rough surface area (and thus lower impedance), and biocompatibility [3]. Additionally, polymerized ionic liquids are appealing for use as a quasi-solid-state electrolyte in combination with an electrode because they do not run or dry out, solving two of the main problems with electrolytes currently used in EEG [4].

In this project, we improved upon current electrodes by decreasing the electrode-skin impedance and improving time stability using a combination of a conformal substrate, conducting polymer, and an ionic liquid gel. We show that the ionic liquid gel improves the performance and time stability compared to commercial electrodes.

Experimental Procedure:

Figure 1 illustrates the fabrication process for the devices. Gold electrodes were patterned using a standard shadow mask evaporation process onto a two-micron layer of Parylene C. We then insulated the electrodes with two additional layers of Parylene C. Subsequently, standard photolithography was used to expose only the electrode sites to etching. Following etching, the conducting polymer poly(3,4-ethylenedioxythiophene): poly(styrenesulfonate) — PEDOT:PSS — was spun over the entire wafer. The top layer of Parylene C was removed from the electrodes and contact pads, leaving the remaining Parylene C to insulate only the interconnects. This process yields conformal electrodes with a thickness of only 4 μm.

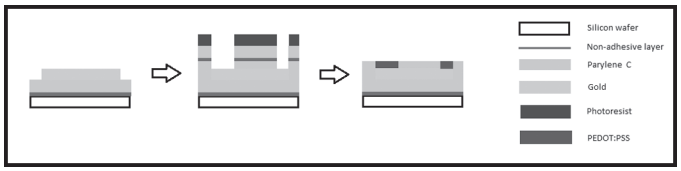

Figure 1: The fabrication process for the electrodes.

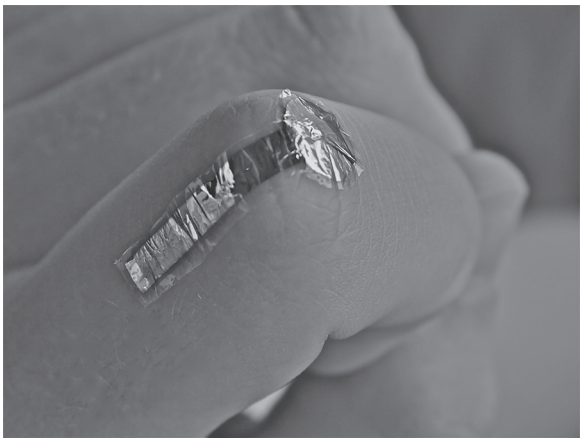

Figure 2: A demonstration of the device's conformability. (See full-color version on inside cover.)

The holder was laser-cut out of Kapton®, and gold was then deposited. This holder was attached to the thin electrode, preventing it from curling up into itself and providing a more stable contact pad than the delicate Parylene C. Figure 2 demonstrates the flexibility of the device.

The ionic liquid gel was made using an ionic liquid (1-ethyl-3-methylimidazolium ethyl sulfate), a monomer (poly(ethylene glycol) diacrylate), and a photo initiator. It was then coupled with the electrode as a quasi-solid-state electrolyte.

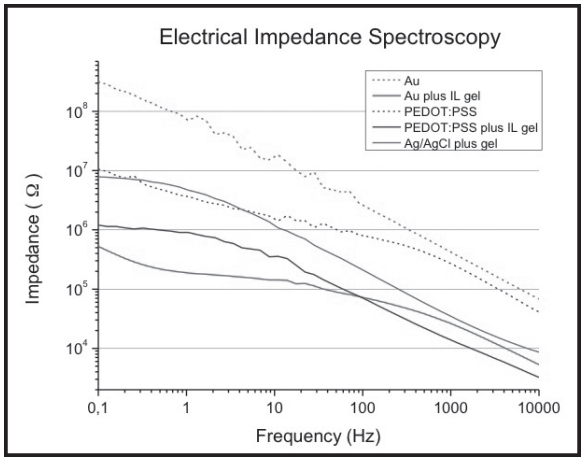

Figure 3: Electrical impedance spectroscopy done on electrodes with gold only, PEDOT:PSS only, gold plus an ionic liquid gel, PEDOT:PSS plus an ionic liquid gel, and commercial Ag/AgCl with a gel.

Results:

We tested the impedance of the ionic liquid gel on electrodes, along with several different controls. We fabricated electrodes with PEDOT:PSS only, gold only, PEDOT:PSS plus the ionic liquid gel, and gold plus the ionic liquid gel. We also tested a commercially available Ag/AgCl electrode used for clinical purposes. Figure 3 shows the electrical impedance spectroscopy for each of these electrodes. The electrode with only PEDOT:PSS demonstrated a better impedance than the gold only, the electrode that performed the worst. The increased surface area of the PEDOT:PSS provides an increased capacitance, thus lowering the impedance. The ionic liquid gel significantly improved the performances of both the gold and the PEDOT:PSS electrodes to a range similar to commercially available electrodes.

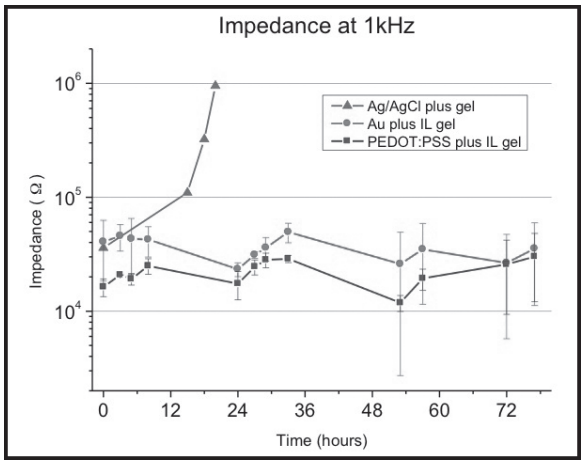

Figure 4: Electrode-skin impedances measured at 1 kHz for electrodes with gold plus an ionic liquid gel, PEDOT:PSS plus an ionic liquid gel, and commercial Ag/AgCl with a gel.

Figure 4 shows the impedance at 1 kHz measured for gold electrodes with the ionic liquid gel, PEDOT:PSS electrodes with the ionic liquid gel, and commercial Ag/AgCl electrodes with a commercial gel over three days. All three electrodes began in approximately the same range, but while the impedance of the commercial electrode steadily increased, the impedance of both the PEDOT: PSS and gold electrodes with the ionic liquid gel maintained relatively consistent low impedance. Both the electrodes with the ionic liquid gel remained at a steady low impedance over three days, while the commercial Ag/AgCl electrode quickly dropped off in performance after only one day. Although both the PEDOT: PSS and the gold electrodes with the ionic liquid gel are in approximately the same range, the PEDOT: PSS electrodes exhibited more stability in performance.

Conclusions:

In conclusion, we developed a process for the fabrication of conducting polymer EEG electrodes with a thickness of only 4 μm. These electrodes are incredibly conformal, improving their recording quality and decreasing their electrode-skin impedance. We also used an ionic liquid gel coupled with these electrodes, which further reducing their impedance. We showed that the ionic liquid gel did not dry out, even over three days, compared to the commercially available gel. This provides a means of recording data with EEG over extended periods of time, which is often a necessity. The gel also functions as a solid-state electrolyte, resulting in less chance of leakage and a short circuit. This solves two of the biggest problems clinicians face when using EEG. These improvements to current electrodes could provide a path to better and more accurate EEG recordings, meaning clinicians could rely less heavily on more invasive diagnostic techniques.

Acknowledgements:

This work was supported by funding from the National Nanotechnology Infrastructure Network International Research Experience for Undergraduates (NNIN iREU) Program, the National Science Foundation, and EMSE-CMP. Special thanks to my PI, Dr. George Malliaras, and my mentor, Pierre Leleux.

References:

[1] L.-D. Liao, I.-J. Wang, S.-F. Chen, J.-Y. Chang, C.-T. Lin, Sensors (Basel, Switzerland) 2011, 11, 5819-34.

[2] J.-Y. Baek, J.-H. An, J.-M. Choi, K.-S. Park, S.-H. Lee, Sensors and Actuators A: Physical 2008, 143, 423-429.

[3] N. K. Guimard, N. Gomez, C. E. Schmidt, Progress in Polymer Science 2007, 32, 876-921.

[4] J. Lu, F. Yan, J. Texter, Progress in Polymer Science 2009, 34, 431-448.