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

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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.

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.
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.

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.

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References: