Novel Process to Fabricate Raised Polymer Electrodes for Electroencephalography

Fiona O'Connell
Materials Engineering, Loyola University Maryland

NNIN iREU Site: Centre Microélectronique de Provence, Ecole Nationale Supérieure des Mines de Saint Etienne, France
NNIN iREU Principal Investigator: Dr. George G. 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: fmoconell@loyola.edu, malliaras@emse.fr, leleux@emse.fr

Abstract and Introduction:

Twenty percent of epileptic patients are unable to receive drugs and must undergo surgery, requiring an invasive procedure to determine the epileptogenic zone. Electrodes are implanted into the brain and neural activity is monitored for one week while electroencephalography (EEG) is used concurrently to create multi-layered recordings. EEG systems use conducting gels to adhere electrodes to the scalp. However, current EEG systems suffer from poor long-term skin adherence and are difficult to apply around the implanted electrodes.

The purpose of this work was to develop a novel process for the fabrication of flexible conducting polymer electrodes for EEG, which would record long-term signals. For the electrode insulator, Parylene-C (PaC) was deposited into a flexible, biocompatible, thin film. The electrodes were patterned via photolithography and consisted of metal deposited on a conducting polymer layer. To provide high conductivity and biocompatibility, poly(3,4-thylenedioxythiophene) doped with poly(styrene sulfonate) (PEDOT:PSS) was used as the conducting polymer. The electrodes were designed to protrude from the PaC matrix through the use of a sacrificial polyvinyl alcohol (PVA) layer. The sacrificial layer increased the surface contact area at the skin to electrode interface while decreasing impedance. Once fabrication was completed, the device was released from the glass substrate by dissolving the PVA in water, resulting in conformable and flexible electrodes.

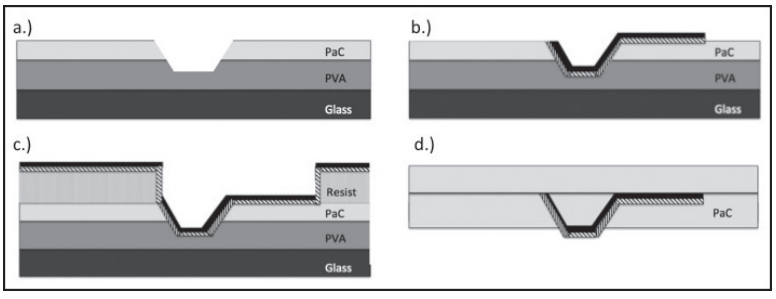

Figure 1: Process flow diagram for the fabrication of electrodes. a.) electrode patterning, b.) channel patterning and PEDOT and Au deposition, c.) lift-off of resist and excess PEDOT andAu, and d.) PaC deposition and peel off.

Fabrication Process:

The development of the following process for flexible polymer electrodes was largely based on reversing methods described in the literature [1]. The fabrication process, shown in Figure 1, began with the deposition of a 2.5 μm sacrificial layer of 10 wt.% PVA onto a cleaned glass substrate. The solution was spin-coated onto the substrate at 500 rpm for five seconds, followed by 1500 rpm for 30 seconds and finally the substrate was baked for five minutes at 95°C. After, a 2.5 μm layer of PaC was chemically vapor deposited onto the PVA layer.

Subsequently AZ 9260 resist was spin-coated onto the PaC layer and the substrates were patterned using conventional photolithography and oxygen plasma etching techniques A second layer of resist was spin-coated and the samples underwent lithography and etching. The excess resist was not removed after the second etching, as it was a necessary scaffold.

A PEDOT:PSS (Clevios PH 500, HC Starck) and ethylene glycol mixture (4:1 by volume) was then spin-coated onto the twice patterned PaC at 1700 rpm for 30 seconds and baked at 65°C for 60 seconds, and again spin-coated at 1000 rpm for 30 seconds followed by a five minute annealing at 110°C to produce a 200 nm layer. Next a 100 nm layer of gold (Au) was deposited using thermal joule source evaporation. The excess resist, Au and PEDOT were removed by soaking the substrate in acetone for approximately one hour. A final layer of PaC was deposited using the same parameters

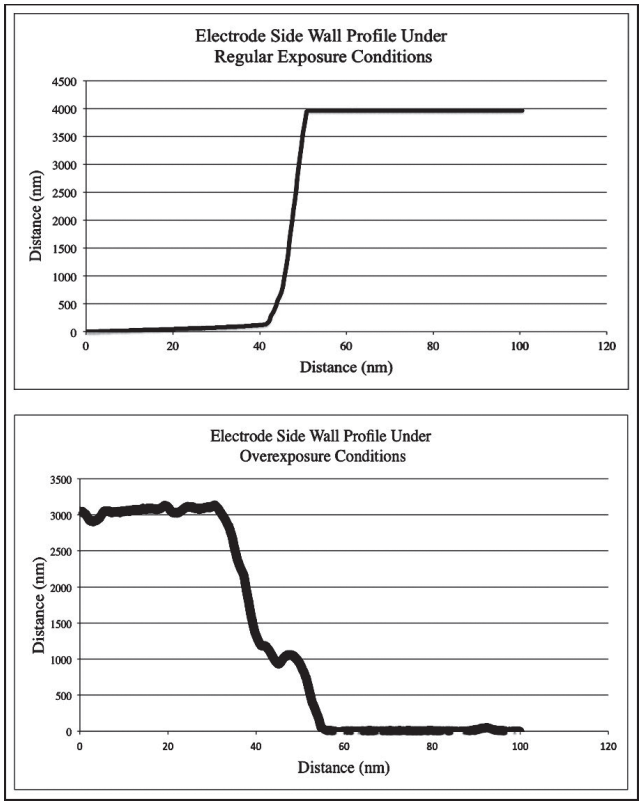

Figure 2: Effect of overexposure of site pattern on sidewall slope.

as above. Finally, the device was peeled off of the glass substrate after a 6-hour soak in DI water to dissolve the PVA and release the PaC.

Results and Discussion:

During process development, the Au layer originally lacked continuity along the sidewalls between the site and channel patterns due to inadequate step coverage of metal evaporation. The necessary slopes were eventually attained by overexposure during the first lithography step. The duration of exposure that provided the optimal slope was ten seconds using SI 1813 Shipley Microposit photoresist. The effects of exposure time were analyzed using an Ambios XP2 profilometer. [Figure 2]

Through the optimization of both etching steps, electrodes were developed that protruded from the PaC matrix and provided stress relief during peel off. The PVA layer not only served as a sacrificial layer, it also allowed for the actual protrusion. By etching several microns into the PVA layer, when the device peeled off the glass substrate, the sites raised above the PaC matrix. The raised PEDOT electrode sites increase the surface contact between the skin and electrodes, decreasing impedance. The optimal first etching time for these electrodes was eight minutes and the second etching time was three minutes. After fabrication, the electrodes were tested for conductivity and displayed acceptable conductivity for their use.

Conclusions and Prospects:

A novel process has been developed to produce conformable, biocompatible electrodes. The procedure reverses the standard fabrication steps in order to have the desired electronics mounted on a flexible PaC platform. The electrodes exhibited adequate conductivity.

Future work will focus on further optimizing the above process in order to fabricate electrodes of different and smaller dimensions. Once optimization of the process is completed, both stretchable electrodes as well as stretchable substrates will need to be explored in order to formulate a complete EEG system. Organic electronics have become an exciting new possibility in the area of research over the past twenty years and definitely have the potential to revolutionize current methods for epilepsy diagnosis.

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References:

[1] Ismailova, E., Doublet, T., Khodagholy D., Quilichini P., Ghestem A., Yang S.Y., Bernard C., Malliaras G. (2011) "Plastic neuronal probes for implantation in cortical and subcortical areas of the rat brain", Int. J. Nanotechnology, Vol. 10.