

Fabrication & Characterization of Nanostructured Conducting Polymer Films on the Surfaces of Microfabricated Neural Prosthetic Biosensors

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Abstract:

Microfabricated neural prosthetics for implantation into the central nervous system (CNS) must accommodate for the differences in mechanical properties at the electrode/tissue interface. Biocompatibility and low electrical impedance are necessary for proper function. Previously the conducting polymer poly(3,4-ethylenedioxythiophene) (PEDOT) was electrochemically deposited on neural microelectrodes in the presence of crosslinked hydrogels to produce soft, low impedance materials with the potential to improve device performance after implantation. In this study, we evaluate the role of hydrogel concentration and crosslinking on the structure and properties of PEDOT networks deposited in the alginate and poly(vinyl alcohol) (PVA) hydrogels. The optimal electrochemical deposition conditions for lowest impedance, greatest charge capacity and largest surface area are presented.

Introduction:

Our lab has been investigating the role of electrochemically deposited conducting polymers on the long-term performance of microfabricated neural prosthetics [1]. We have also shown that the conducting polymers can be deposited in the presence of hydrogels [2]. In this study, we worked with the conducting polymer PEDOT. In its oxidized state, PEDOT exists as a polycation with delocalized positive charge along its conjugated backbone which are neutralized

by counter ions during electrochemical polymerization [3]. Poly(styrene sulfonate) (PSS) was used as the source of counter ions.

Experimental

ABP Electrode Arrays:

Eight well electrode arrays were purchased from Applied Biophysics. The gold electrodes are delineated with an insulating film and mounted polycarbonate. Each well contained 1 Au electrode with a surface area of $49087 \mu\text{m}^2$.

Material Preparation & Electrochemical

Polymerization:

A solution of 0.25 g PSS (Aldrich) in 100 mL 1X phosphate buffered saline (PBS) (Cellgro) was used to prepare 0%, 0.5%, 1.0%, 2.5%, and 5.0% (w/v) alginate solutions, each containing 20 μl EDOT (Bayer) monomer solution and having a final volume of 20 ml. Crosslinked alginate was prepared by adding a 2% calcium sulfate/DI (Sigma) solution. 0%, 1%, 10%, and 15% (w/v) PVA/DI solutions were prepared, each containing 0.025 g PSS, 10 μl EDOT solution, and having a final volume of 10 ml. Crosslinked PVA was prepared by adding 2% sodium tetraborate decahydrate/DI (Sigma) solution. The hydrogel solutions were placed in separate electrode wells and covered with PBS to complete the circuit.

PEDOT was grown galvanostatically on the electrodes using an Autolab potentiostat/galvanostat PGStat12 (EcoChimie, Netherlands) as the electrical supply. The

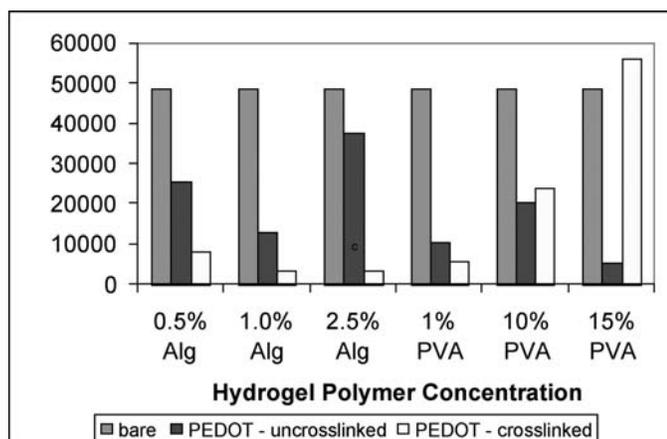


Figure 1. Effect of hydrogel crosslinking on impedance after PEDOT polymerization at 6 mC.

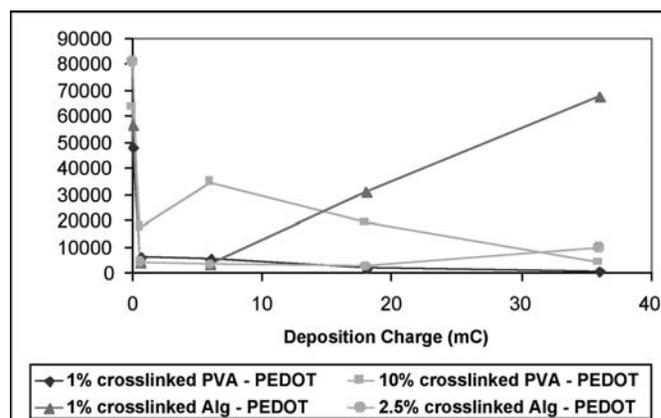


Figure 2. Relation between deposition charge and impedance.

electrode arrays were designed with a counter electrode and each individual well served as a working electrode. A saturated calomel electrode (SCE) was used as the reference electrode. The polymerizations were carried out at room temp. using a current density of 2.04 mA/cm².

Electrical and Morphological Characterization:

The Autolab was also used for EIS and CV analysis of the electrodes. A Leica DMIRB inverted microscope was used to view the PEDOT networks. Images were captured with an Olympus CCD digital camera.

Results and Discussion

Electrical Properties of PEDOT Networks in Hydrogels:

Taking EIS measurements both before and after electrochemical deposition gives qualitative and quantitative information about the effects of PEDOT on the electrical properties of the system, as well as the morphology of the electrode-medium interface. Figure 1 shows the impedance at 1 kHz of the PEDOT coated electrode sites in the presence of different hydrogel conditions with a bare electrode as a control.

PEDOT grown in the presence of 1% and 2.5% crosslinked alginate hydrogels resulted in impedance values of 3357 Ohm and 3334 Ohm, respectively. In the case of the PVA, the 1% crosslinked PVA showed the lowest impedance at 5623 Ohm.

The optimal deposition charge was found by depositing PEDOT for 1, 10, 30 and 60 minutes under a 10 μ A current in the presence of 1% and 2.5% crosslinked alginate as well as 1% and 10% crosslinked PVA hydrogels. The results are shown as a function of deposition charge (current in (A) * polymerization time in (s)). Figure 2 shows that PEDOT in 1% crosslinked PVA hydrogel at 18 and 36 mC resulted in the lowest impedances of 1148 and 2061 Ohm, respectively. This was followed by PEDOT in 2.5% crosslinked alginate at 18 and 6 mC, resulting in impedance values of 2748 and 3334 Ohm, respectively.

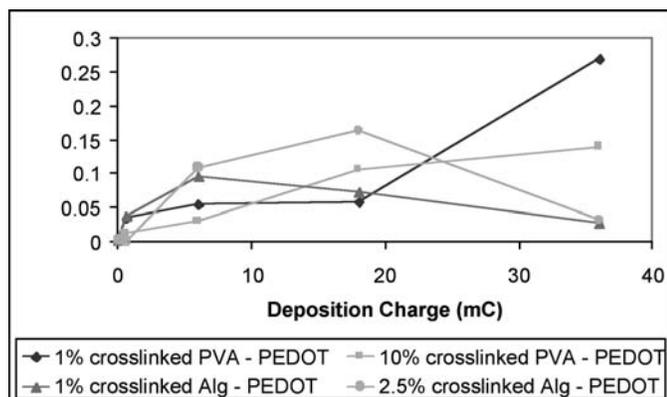


Figure 3. Relationship between charge capacity and deposition charge.

Using cyclic voltammetry under galvanostatic conditions, each coated electrode was swept through a potential of -1.0 to 1.0 V vs. SCE at a scan rate of 100 mV/s. During each cycle, the PEDOT undergoes a reversible redox reaction that is accompanied by the movement of ions into or out of the film. This results in an increased charge capacity shown in CV results. Figure 3 shows that PEDOT in 1% crosslinked PVA at 36 mC results in a charge capacity of 268.8 μ C. The next largest charge capacity (162.9 μ C) is seen in the case of PEDOT in 2.5% crosslinked alginate at 18 mC.

Area Quantification:

Figure 4 shows PEDOT in 1% crosslinked PVA at 36 mC resulted in the largest surface area of $2 \times 10^7 \mu\text{m}^2$. PEDOT in 2.5% crosslinked alginate at 18 and 6 mC also produced relatively large surface areas ($1.71 \times 10^7 \mu\text{m}^2$ and $1.44 \times 10^7 \mu\text{m}^2$, respectively); these conditions also correspond to lower impedances and higher charge capacities.

Conclusions:

The conducting polymer PEDOT was electro-chemically deposited through crosslinked alginate and PVA hydrogels. EIS and CV results show that a 60 minute deposition in crosslinked 1% PVA gave the lowest impedance and the greatest charge capacity at the CNS-relevant frequency of 1 kHz. Surface area quantification confirms that the lowest impedance and highest charge capacity corresponds to the largest PEDOT network.

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References:

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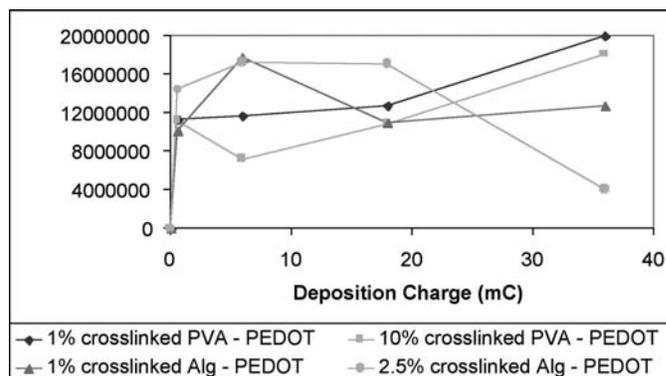


Figure 4. Relationship between relative surface area of the PEDOT network and deposition charge.