Development of Conductive Fibrous Hydrogels for Neural Interfaces

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Introduction

Recently, conductive hydrogels have garnered significant attention and permitted momentous improvements in neuroscience due to their tissue-like softness, chemical steadiness, and sufficient electrical conductivity. They have been utilized as interfaces for neural electrode arrays to improve their biocompatibility and lower protein adsorption. In particular, these materials have the potential to circumnavigate the mechanical mismatch between the neural probes and the implanted tissue. Therefore, the transition from rigid to soft interfaces can improve the performance of the recording/stimulating devices by minimizing tissue irritation, scarring, and neuronal cell loss.

Demand for durability

Alas, the chronic application of such interfaces is still challenging due to the poor adhesion of soft hydrogels to metallic electrodes and their relatively low stimuli-responsive characteristics. The latter can significantly affect the specific capacitance of the electrodes on the neural probes.

The utilization of porous, high surface area and stimuli-responsive hydrogels may compensate for these physiochemical shortcomings, offering multifunctional properties such as low electrical impedance, better mechanical properties, lower thickness, and on-demand controlled release of bioactive agents.

Project Goal

Synthesis and fabrication of a fibrous conductive hydrogel with semi-interpenetrating polymer network (semi-IPN) structure comprised of temperature-responsive poly(N-isopropyl acrylamide) (PNIPAAm)-based copolymer and polythiophene (PT) to be used as a neural interface.

Synthesis of cross-linkable block copolymers

The synthesis of thermoresponsive P(NIPAAm-*co*-GMA) with different monomer feed ratios was performed via free-radical copolymerization in an aqueous solution. After 5 hours of polymerization, high molecular weight copolymers (118000<Mw<230000) with narrow molecular weight distribution (1.14<PDI<1.23) were achieved. The FTIR spectra of the dialysed copolymers are demonstrated in figure 1. As the percentage of NIPAAm monomers in the initial feed decreases (from NGd97, in which NIPAAm/GMA feed ratio is 97/3, to NGd70, where mentioned ratio is 70/30), the GMA characteristic peaks at 1720, 1240, and 910 cm^{-1}, progressively increases (The peaks are corresponded to O-C=O stretching of GMA's ester configuration, and C–O–C stretching of epoxide groups, respectively).

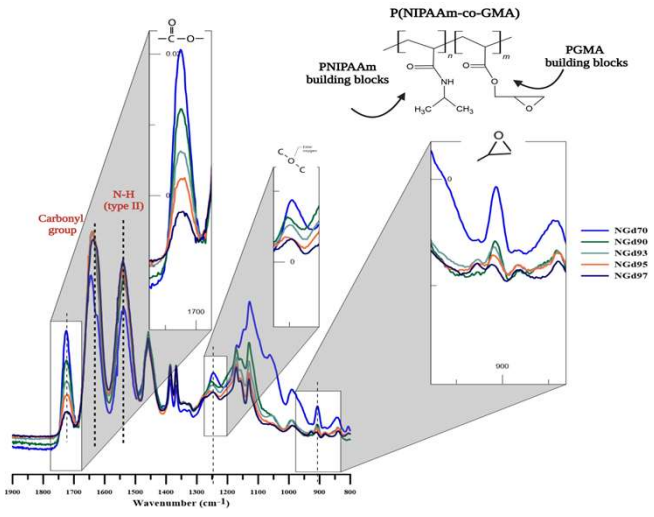

Figure 1. FTIR spectra of the synthesized crosslinkable P(NIPAAm-co-GMA) polymers.

It was observed that:

- The reaction kinetic is highly dependent on the GMA initial content.
- NG copolymer is water soluble for GMA content less than 7%.
- There is a good balance between hydrophilicity and GMA presence for NG95.

A fibrous semi-IPN from a thermogelling copolymer, a hydrophilic dendrimer and a conductive polymer

The synthesized (PNIPAAm)-based copolymer showed thermogelling property close to 37°C. With the addition of a degradable hardener, the copolymer can be further chemically crosslinked and stabilized.

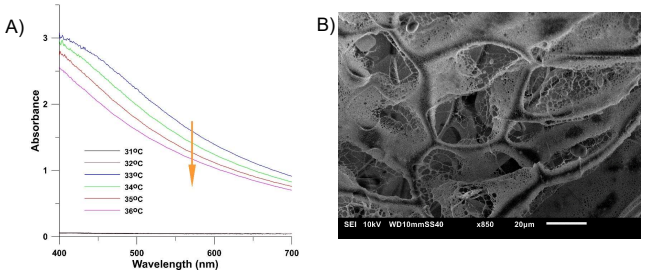

Figure 2. A) Determination of the NG95 LCST B)SEM image of lyophilized NG95 bulk hydrogel

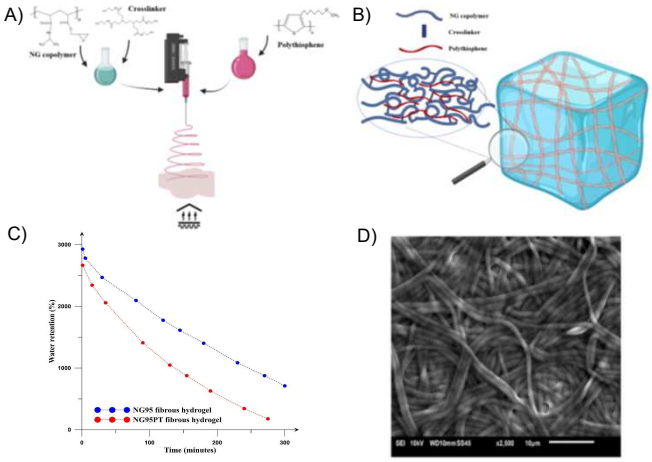

Figure 3. Schematic representation of A) NG95PT electrospinning and post-heat treatment and B) conductive fibrous semi-IPN NG95PT hydrogel. C) Water retention of NG95 and NG95PT. D) SEM image of nanofibrous semi-IPN network swelled in water and then dried.

The NG copolymer showed excellent electrospinability. Addition of PT to the electrospinning solution significantly lowered the impedance the semi-IPN and slightly increased its hydrophobicity. The fibrous conducting semi-IPN was coated on the bare neural probes. The material showed good adhesion to the substrate and excellent morphology resilience upon hydration.

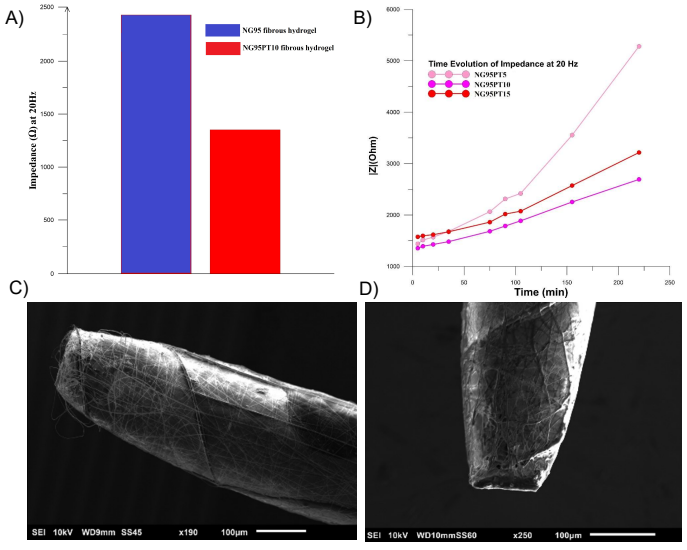

Figure 4. Impedance values at biomedically significant frequencies A) of NG95 fibrous hydrogel and the semi-IPN, and B) their relevant impedance time dependency. SEM of fibrous semi-IPN coated on a neural probe C) spun and crosslinked, and D) inserted in semi-stiffed hydrogel and dried afterwards.

CONCLUSIONS

An innovative method for fabricating fibrous hydrogels derived from P(NIPAAm-*co*-GMA) copolymers has been demonstrated. The post heat treatment led to the formation of highly crosslinked nanofibers. As a coating of a neural probe, the material adhered well to the substrate and retained its morphology. The incorporation of PT in the stimuli-responsive hydrogel promoted the synergetic effect between the two components leading to the formation of a superior fibrous semi-IPN with remarkable electrochemical properties.

ACKNOWLEDGMENTS

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