Hydrogel electrode materials

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Abstract

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Abstract: The fabrication of hydrogel electrode materials via inkjet/extrusion printing, wet-spinning and physical cross-linking will be presented. Electrode characteristics such as conductivity, contact resistance, impedance and electrode connectivity will be discussed in detail.

1 Introduction: Nanobionics: the merging of biology and electronics using the most recent advances in nanotechnology will play a significant role in the future development of medical implants and prosthetic devices. The realisation of novel material platforms that facilitate nerve cell regeneration, can control muscle cell regrowth, or that act as efficient platforms for endothelial cell growth is envisaged. In addition, the development of artificial muscle fibres for use in wearable prosthetics will benefit from advances in nanotechnology and the development of bio-composite materials.

The field of Bionics has to date been dominated by the use of traditional conductors such as metals and by traditional electromechanical devices such as motors. The advent of organic conductors (such as carbon nanotubes) with the emergence of nanotechnology will revolutionize the field of Bionics, enabling us to more effectively bridge the chasm that currently epitomizes the interface between biology and electronics. However, carbon nanotubes (CNTs) alone will not provide the blend of biological, mechanical and electronic properties required for the next generation of Bionics.

CNTs possess unique electronic and mechanical properties [1]. A key challenge in exploiting these phenomenal properties is to overcome practical difficulties in processing them from their as-produced state. These difficulties arise as a result of the hydrophobic nature of CNTs and associated strong attractive interactions between adjacent CNTs [2]. Considerable effort is currently being directed towards combining polymers and carbon nanotubes into composites with unprecedented mechanical and electrical properties.

A range of biomaterials have proven suitable hosts for CNTs, and potentially provide the basis of highly effective material platforms for Bionics. Chitosan is used in single-polymer scaffolds, as it is structurally similar to the extracellular matrix component glycosaminoglycans and is biodegradable in humans [3]. Gellan gum is US FDA and European Union (E418) approved for food and medical usage, and has found wide application as a multifunctional gelling, stabilising and suspending agent as well as an emerging material for tissue engineering applications [4].

2 Results and Discussion: We report the formation of hydrogel electrode materials based on the addition of conducting carbon nanotube fillers to biopolymers. In particular, we will discuss three processing methods for fabricating conducting hydrogel materials: inkjet/extrusion printing, wet spinning and physical cross-linking.

Inkjet/extrusion printing has attracted interest for its potential in fabricating scaffolds for biomedical applications. A range of deposition systems was used to assemble soft material by sequential deposition of biopolymer solutions and CNT dispersions, followed by hydration to achieve a hydrogel. These deposition systems include a liquid handling system, a commercial printer, a syringe-controlled deposition system and a custom built inkjet printing system capable of dispensing inks from multiple reservoirs (similar to colour printing) [5-8].

Wet spinning is an attractive method used to produce micron-diameter fibres suitable for use in a range of biological applications. Conducting biopolymer-CNT-biopolymer fibers were prepared using our recently developed approach of polyelectrolyte complexation [9-11].

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Physical cross-linking of a biopolymer solution via addition of cross-linking agents such as Ca^{2+} is a well established fabrication method for hydrogels. This technique has been applied to CNT dispersions [11-13].

The percolation behaviour of our CNT-laden hydrogels was investigated using a novel experimental technique utilising a custom, in-house designed apparatus for simultaneous measurements of hydrogel conductivity and mass [12]. Percolation studies (Fig. 1) revealed that a carbon nanotube concentration of 1.3% by weight is required to achieve electrical conduction through the hydrogel.

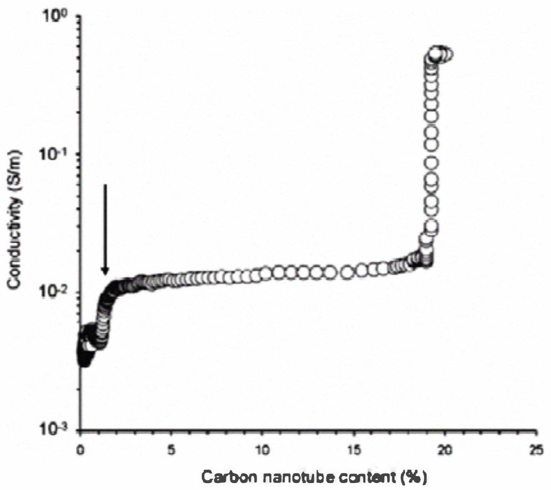

Fig. 1. Log of conductivity as a function a function of carbon nanotube content (% weight) for a gellan gum-CNT hydrogel. The arrow indicates the percolation threshold.

3 Conclusion: We envisage that these composite hydrogel electrode materials will be developed further into a means by which electrical signals may be propagated through conducting bio-materials. Unlike normal composites, the polymer matrix is an ionic conductor exhibiting a high conductivity below percolation. Hence at the threshold percolation the changeover is from ionic to electronic conduction, raising many interesting possibilities for sensors and other electrochemical devices.

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