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Microfabrication of Highly Biocompatible Materials for Energy Applications

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Microfabrication of Highly Biocompatible Materials for Energy Applications

Abstract

The objective of this paper is to use a microfluidic platform for fabricating biocompatible materials. One of the applications of this material is to be used as anode in a microbial fuel cell. In this process, the fibers are fabricated by utilizing a microchannel with three inlets, two sheath flows as well as a core flow. The core flow which is composed of gelatin is hydrodynamically focused by ethanol as the sheath flow. The microfibers created by this technique have various cross sections and will be used a structured porous scaffold. The porosity and biocompatibility of the structure make it an ideal choice for being used as a scaffold for bacterial attachment and biofilm formation. This will consequently results in developing a microbial fuel cell with a higher power density.

Disciplines

Biochemical and Biomolecular Engineering | Energy Systems | Nanotechnology Fabrication

Comments

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MICROFABRICATION OF HIGHLY BIOCOMPATIBLE MATERIALS FOR ENERGY APPLICATIONS

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ABSTRACT

The objective of this paper is to use a microfluidic platform for fabricating biocompatible materials. One of the applications of this material is to be used as anode in a microbial fuel cell. In this process, the fibers are fabricated by utilizing a microchannel with three inlets, two sheath flows as well as a core flow. The core flow which is composed of gelatin is hydrodynamically focused by ethanol as the sheath flow. The microfibers created by this technique have various cross sections and will be used as a structured porous scaffold. The porosity and biocompatibility of the structure make it an ideal choice for being used as a scaffold for bacterial attachment and biofilm formation. This will consequently result in developing a microbial fuel cell with a higher power density.

INTRODUCTION

Many novel materials have been introduced for manufacturing biocompatible substances. In this regard hydrogels are introduced for fabrication of soft and also hard tissues, which has a high potential of cells encapsulation. Rapid prototyping techniques which are used for fabrication of 3-dimensional scaffolds with the structures which are predefined, has become a popular method in this area [1]. In order to design tissue scaffolds in accordance with computer aided design, the PSL (proposed projection stereolithography) platform is utilized where the scaffold material is gelatin methacrylate (GelMA). This method makes it possible to optimize the mechanical properties of the manufactured scaffold [2]. Core-shell CG composites, which are fabricated through the evaporation

process, which is followed by freeze-drying and then crosslinking, demonstrate high mechanical strength, and adequate permeability. This method highlights new criterion for bioactivity specifications of porous scaffolds [3]. Laser nanostructuring has been utilized for fabricating poly (ethylene glycol) diacrylate (PEGda) scaffolds having similar properties to real cell culturing environments. Utilizing the two-photon polymerization for polymerizing has led to 3D structures that have predefined geometries [4].

As another method in the area of tissue engineering vascular scaffolds have been produced through the melt spinning and electrospinning method. The fabricated small diameter tubes demonstrate high cell viability and mechanical strength. Furthermore, the combination of these two methods will provide a successful approach for fabricating double-layered tubular scaffolds [5]. Nanocomposite scaffolds are being produced for biomedical applications. Pectin, chitin and nano CaCO_3 have been utilized for fabricating a nanocomposite scaffold. Lyophilization technique has been utilized for this fabrication. This scaffold demonstrates acceptable amount of toxicity in accordance with cells, thus making possible the cell attachment and proliferation [6].

The three dimensional highly conductive and biocompatible CNT-textile utilized as the anode part of the microbial fuel cell has been effective in improving the performance from the viewpoints of higher current, higher power density and higher energy recovery. This material provides an open space for an effective interaction of biofilm [7]. In a novel approach, biohybrid microfibers which include encapsulated bacteria are fabricated utilizing a microfluidic platform. The

forementioned method which demonstrates a homogenous cell distribution as well as a high percentage of cell viability, has used the pre-gel solution prepared in PBS by mixing PEGDMA and I2959. The sheath flow is the mixture of PEG Mn=400 Da and water [8]. Microribbon-like elastomers are photocrosslinked to form macroporous scaffolds that can provide a 3D environment for the cell growth. The microribbons are synthesized by wet-spinning method, therefore a mixture of type-A gelatin stirred in dimethyl sulfoxide (DMSO) is ejected into a tank of anhydrous ethanol. The microfibers are then methacrylated, fixed and photocrosslinked to form the porous scaffolds [9]. The synthesized Poly lactide (PLA)-based amphiphilic block copolymers bearing pendant amino acid residues are found to present acceptable biocompatibility [10].

In the present work, biocompatible microfibers are fabricated utilizing a microfluidic device. The core material is consisted of type- A gelatin stirred in dimethyl sulfoxide (DMSO). The sheath flow is anhydrous ethanol. The core and sheath flow are controlled using syringe pump (Cole-Parmer, Veron Hillss, IL). Inside the channel, the sheath flow dissolves the DMSO, therefore gelatin fibers are formed. The mixture of gelatin fibers and the DMSO dissolved in ethanol enter the beaker filled with water immediately after the mixture leaves the channel.

EXPERIMENTL PROCEDURE

A microchannel with four chevron-type grooves was utilized for fabricating the microfibers [11-12]. The channel has a symmetric geometry with a single core inlet and two inlets for the sheath flow. The channel is made in two halves of PDMS (Polydimethylsiloxane). In order to fabricate the core flow, a mixture of type-A gelatin (5g) and DMSO (23 ml) was stirred for 12 hours [9]. All the chemical materials were purchased from Sigma-Aldrich. The sheath and core solutions were introduced to the channel using a double syringe pump (Cole-Parmer, Veron Hillss, IL). The sheath flow rate was set to be $200 \mu\text{Lmin}^{-1}$ and the core flow rate was set to be $10 \mu\text{Lmin}^{-1}$. Schematic figure of the experimental setup is shown in Fig.1.



Fig.1. A picture of the experimental setup.

RESULTS AND DISCUSSION

COMSOL mutiphysics simulation has been utilized for simulating the core flow pattern for the whole cross section of the channel. As it has been depicted in the Fig.2, core flow pattern inside the channel is parallel with the vertical walls of channel. But as it reaches the channel exit, it has been focused by the chevrons in horizontal path. The blue color represents the sheath flow and red color represents the core flow. In this simulation sheath and core flow exit the channel freely. It is obvious from figure that the core flow pattern is completely dependent on the chevrons configuration. Before the chevrons, core flow is located between two streams of sheath flow, but as it passes through the chevrons it is completely surrounded by the sheath flow. Chevrons focus the core flow so the core flow pattern is changed to be as illustrated in Fig.2.b.

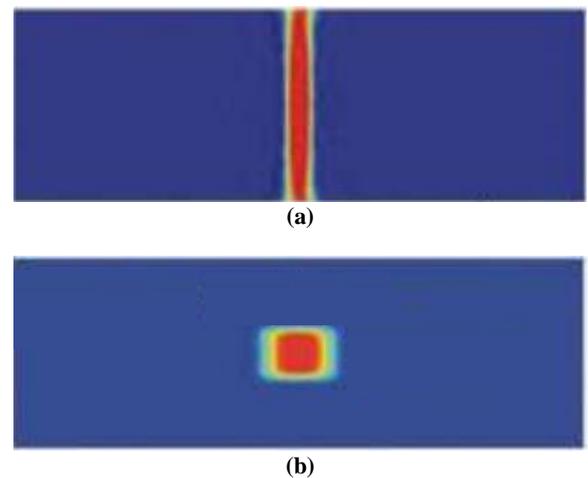


Fig.2. COMSOL Multiphysics simulations of the core flow pattern at a sheath to core flow rate ratio of 200:10 . (a) Core flow pattern at the channel entrance. (b) Core flow pattern after the last chevron.

The microfibers utilized in this method are non toxic, so they are a good choice for the bacteria growth. As the core flow enters the channel, the sheath flow surrounds it. Ethanol dissolves the DMSO, so the microfibers are manufactured. After they enter the water bath, the solution of ethanol and DMSO are dissolved in water and microfibers can be collected. The flexible nature of these microfibers make it possible to press them together to make biocompatible scaffolds. The fabricated scaffolds have a high potential for improving the porosity. Furthermore, conductive nanoparticles can be utilized for coating the porous scaffolds. This procedure will provide the sufficient rate of conductivity to introduce the biocompatible scaffolds as the anode electrode in microbial fuel cells.

CONCLUSION

In the present paper, a novel method has been introduced for fabricating biocompatible microfibers. The most dominant advantage of these fibers is that they are made from non toxic

materials. So, the bacteria can grow on them easily. Furthermore, the porous surface of these microfibers provides a proper environment for the bacterial growth. If these microfibers be pressed together, they can form porous scaffold which would definitely improve the bacteria rate growth as well as the biofilm formation. It is suggested that by coating the scaffolds by conductive nanoparticles such as gold nanoparticles [13], they would become highly conductive. The combination of these factors makes a network formed by microfibers as a viable alternative for the anode part of the microbial fuel cells.

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REFERENCES

- [1] Billiet, T., Vandenhaute, M., Schelfhout, J., Van Vlierbergh, S., Dubruel, P., 2012, "A Review of Trends and Limitations in Hydrogel-Rapid Prototyping for Tissue Engineering", *Biomaterials.*, 33(26), 6020-6041.
- [2] Gauvin, R., Chen, Y., Lee, J., Soman, P., Zorlutuna, P., W. Nichol, J., Bae, H., Chen, Sh., Khademhosseini, A., 2012, 2010, "Microfabrication of Complex Porous Tissue Engineering Scaffolds Using 3D Projection Stereolithography", *Biomaterials.*, 33(15), 3824-3834.
- [3] Caliri, S.R., Ramirez, M.A., Harley, B.A.C., 2011, "The Development of Collagen-GAG Scaffold-Membrane Composites for Tendon Tissue Engineering" *Biomaterials.*, 32(34), 8990-8998.
- [4] Ovsianikov, A. Malinauskas, M., Schlie, S., Chichkov, B., Gittard, S., Narayan, R., Löbner, M., Sternberg, K., Schmitz, K.-P., Haverich, A., 2011, "Three-Dimensional Laser Micro- and Nano-Structuring of Acrylated Poly(Ethylene Glycol) Materials and Evaluation of their Cytotoxicity for Tissue Engineering applications", *Acta Biomaterialia.*, 7(3), 967-974
- [5] Chung, S., Ingle, N., Montero, G., Kim, S., W. King, M., 2010, "Bioresorbable Elastomeric Vascular Tissue Engineering Scaffolds via Melt Spinning and Electrospinning", *Acta Biomaterialia.*, 6(16), 1958-1967.
- [6] Sudheesh Kumar, P.T., Ramya, C., Jayakumar, R., V. Nair, Sh., Lakshmanan, V., 2013, "Drug Delivery and Tissue Engineering Applications of Biocompatible Pectin-Chitin/Nano CaCO₃ Composite Scaffolds", *Colloids and Surfaces B: Biointerfaces.*, In Press, Accepted Manuscript, Available online 31 January 2013.
- [7] Xie, X., Hu, L., Pasta, M., Wells, G., Kong, D., Craig S. Criddle, C.S., Cui, Y., 2011, "Three-Dimensional Carbon Nanotube-Textile Anode for High-Performance Microbial Fuel Cells", *Nano Lett.*, 11, 291-296.
- [8] Daniele, M.A., North, S., Naciri, J., Howell, P.B., Foulger, S.H., Ligler, F.S., Adams, A.A., 2012 "Rapid and Continuous Hydrodynamically Controlled Fabrication of Biohybrid Microfibers", *Advanced Functional Materials.*
- [9] Han, L.H., Yu, S., Wang, T.Y., Behn AW., Yang F., 2012, "Microribbon-like Elastomers for Fabricating Macroporous and Highly Flexible Scaffolds that Support Cell Proliferation in 3D." *Advanced Functional Materials.*
- [10] Hu, Z., Fan, X., Wang, H., Wang, J., 2009, "Synthesis and Characterization of Biodegradable and Biocompatible Amphiphilic Block Copolymers Bearing Pendant Amino Acid Residues", *Polymer.*, 50(17), 4175-4181.
- [11] Hashemi, N., Howell Jr, P. B., Erickson, J. S., Golden, J. P., and Ligler, F. S., 2010 "Dynamic reversibility of hydrodynamic focusing for recycling sheath fluid", *Lab on a Chip* 10, 1952-1959.
- [12] Hashemi, N., Erickson, J. S., Golden, J. P., and Ligler, F. S., 2011 "Optofluidic characterization of marine algae using a microflow cytometer", *Biomicrofluidics* 5, 032009.
- [13] Montazami, R., Liu, S., Liu, Y., Wang, D., Zhang, Q., and Heflin, J. R., 2011, "Thickness dependence of curvature, strain, and response time in ionic electroactive polymer actuators fabricated via layer-by-layer assembly", *Journal of Applied Physics* 109, 104301.