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Electrospun Silk Fibroin for Green Smart Sensors

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Summary:
The rapid expansion of the silicon chip industry has led to an increase in interest in green electronics, especially those utilizing bio-composites like silk fibroin (SF). This study presents an electrospun SF membrane adaptable for sensing Escherichia coli. Using a solvent-free process, SF was doped with metabolic indicators, electrospun, and annealed.

Keywords: silk fibroin, electrospinning, biosensor, green electronics, bacteria detection

Background, Motivation an Objective

The significance of green electronics has risen in recent years due to the rapid expansion of the silicon chip industry and the resultant e-waste. Projections indicate that by 2030, the silicon chip industry will double its manufacturing capacity, leading to nearly 75 million tons of e-waste [1]. Sustainability in products is evaluated based on their reusability, lifespan, and recyclability, with biodegradability offering notable benefits for healthcare and environmental applications. In this context, green electronic components made from bio-composites are becoming an appealing alternative to traditional silicon-based technologies.

Silk fibroin (SF) possesses excellent mechanical properties, biocompatibility, and adjustable biodegradability. It also exhibits crystalline polymorphism, enabling it to transform structurally from α-helix domains to antiparallel β-sheets [2]. These attributes make SF a highly promising material for green electronics, offering extensive opportunities for processing, functionalization, and various applications.

In this work, we present an electrospun SF membrane that can be adapted during the fabrication process to function as a sensing device. By doping the silk fibroin films with selective metabolic indicators, such as MacConkey or Chromogenic Coliforms Agar (CCA), the membrane can specifically detect Escherichia coli.

Description of the New Method or System

A 21% (w/w) SF + 20% MacConkey solution was used to electrospin the membrane in the Fluidnatek LE-10 electrospinner, employing a completely green and sustainable process based on a solvent-free solution. The collector was covered with aluminum foil. A total of 1 mL of aqueous solution was electrospun under conditions that ensured a stable Taylor cone. A voltage of +12 kV was applied to the capillary tube, the collector was placed 15 cm from the tip, and the injection rate was set to 0.2 $mL \cdot h^{-1}$. After fabrication, the electrospun meshes were annealed by immersion in absolute methanol for 45 minutes to induce crystallinity [3]. Figure 1 shows the electrospinning and post-treatment annealing set-up.

Results

Figure 2 shows SEM images of the electrospun membranes, both untreated and after annealing, for both the control (SF solution) and the SF + MacConkey solution. Methanol annealing significantly reduces the membrane's porosity and increases fiber thickness. Figure 3 displays the FTIR spectra of the SF membrane (blue), with β-sheets amide I and II peaks at 1620 cm^{-1} and 1515 cm^{-1}, respectively, indicating a higher number of β-sheets transitioning from α-structures after methanol annealing (orange) [4]. We are currently characterizing the porosity using Brunauer–Emmett–Teller analysis and further optimizing the doping of SF with MacConkey and CCA to assess bacterial activity.

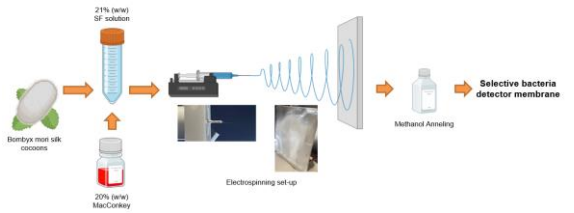

Fig. 1. Schematic representing the solution preparation, electrospinning and post-treatment set-up.

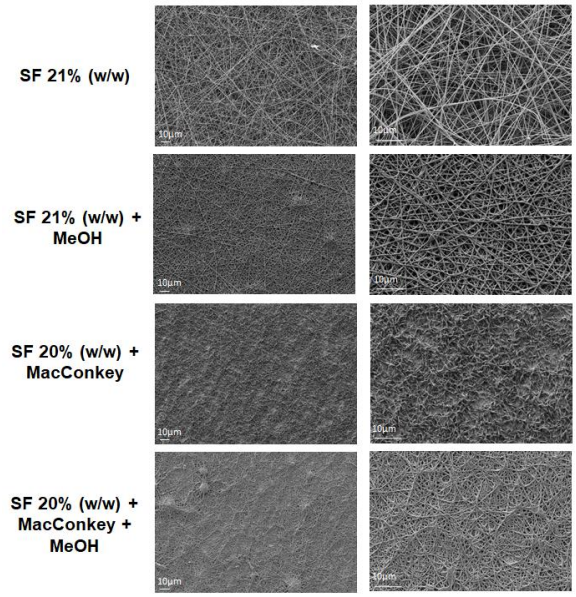

Fig. 2. SEM images of electrospun SF membrane without post-treatment (first row), with methanol treatment (second row), electrospun SF + MacConkey membrane (third row) and electrospun SF + MacConkey membrane with methanol (four row).

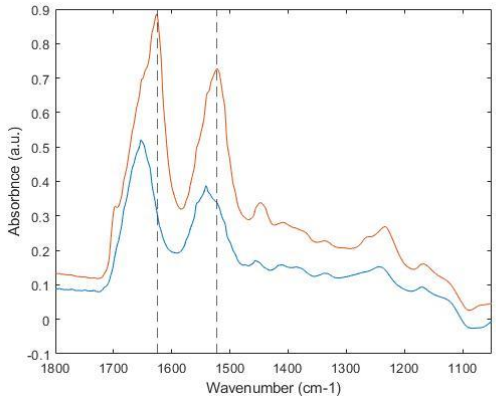

Fig. 3. FTIR spectra of electrospun membranes and β-sheets amide I (1620 cm-1) and II (1515 cm) peaks

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