Journal of Fiber Bioengineering and Informatics 6:4 (2013) 369–381
doi:10.3993/jfbi12201303

Piezoelectric Polymer and Piezocapacitive Nanoweb Based Sensors for Monitoring Vital Signals and Energy Expenditure in Smart Textiles

Soyoung Lee [a], Yujin Ahn [a], Arunanand Prabu [a,b], Kapjin Kim [a,*]

[a] *Department of Advanced Materials Engineering for Information & Electronics, College of Engineering, Kyung Hee University, Yongin-si, Gyeonggi-do 446-701, South Korea*

[b] *Department of Chemistry, VIT University, Vellore, India*

Abstract

"Smart textiles", also known as electronic or e-textiles contain embedded sensors capable of monitoring vital signals such as ECG, EMG, respiratory behaviour and are usually fabricated using rigid semiconductors. In this study, we developed a flexible Physiological Sensing Belt (PSB) by embedding silicone rubber/carbon black/conductive carbon layer coated Polyvinylidene Fluoride (PVDF) film between the elastic textile bands for monitoring respiration and the movement of thigh muscles. With an average peak-to-peak interval of 3 sec, the respiration rate could be evaluated to be 20 min^{-1}. We also developed a novel hybrid sensor using PVDF and Thermoplastic Polyurethane (TPU) electrospun nanofiber webs stacked on each other and capable of measuring both static and dynamic pressure simultaneously within all frequency ranges. Based on the samples used, we were able to measure the walking speed of the subject at 4, 336 steps/h and 0.693 m/step at the speed of 3 km/h and with 6, 656 steps/h and 0.751 m/step at the speed of 5 km/h. Overall, when compared to the existing commercially available pressure sensors, the PVDF and TPU nanofiber web based hybrid sensor developed in our study has advantages of high sensitivity, nanoscale thickness, lower hysteresis curve in pressure-capacitance, and can be easily converged with any fabric or textiles.

Keywords: Polyvinylidene Fluoride; Polyurethane; Electrospinning; Nanofiber Webs; Smart Textiles

1 Introduction

"Smart textiles" is the generic term used when textiles or apparels embedded with sensors generate electric signals which can be used to monitor vital signals such as ECG, EMG, respiration, etc. Smart textile has functions to care of the person's physical conditions and to save life by alarming to a nearby hospital through a smart phone or PC, wirelessly [1, 2]. However, existing sensors for measuring vital signals in smart textiles are based on rigid semiconductors, which have no flexibility and also are incompatibile with the fabric. Conductive Ag/AgCl and other gel-type

*Corresponding author.
Email address: kjkim@khu.ac.kr (Kapjin Kim).

December 2013

electrodes used for monitoring ECG or EMG also possess the disadvantage of attaching directly to the skin, resulting in side effects during long-term use [3]. Considering the above limitations with existing sensors, many research groups have recently focused on commercialization of smart textiles embedded with sensors or electrodes based on organic polymers or electrospun nanofiber webs [4-6].

Among the organic materials, Polyvinylidene Fluoride (PVDF) has been widely investigated as a tactile sensor material due to its high piezo-, pyro- and ferroelectric properties. The β-crystalline structure in the PVDF allows tighter packing density and more dipolar alignment giving the polymer its strong piezoelectric properties [7]. On the other hand, Thermoplastic Polyurethanes (TPU) can be used as piezocapacitive sensors for monitoring the loading on limbs or on other body parts. As the weight of a patient is applied to a measuring capacitor, there is a relatively linear increase of capacitance with applied weight which permits the use of simple and low cost electrical circuits to generate a signal that is directly proportional to the applied weight [8]. In spite of this potential, TPUs were overlooked during most of the last decade in favor of PVDF and other piezoelectric materials. Hence in the present study, we developed various types of PVDF and PU based sensors as well as a hybrid sensor involving both PVDF and PU nanowebs which can be applied to smart textiles for monitoring vital signals during resting or exercising.

2 Experimental

2.1 Materials

PVDF (Kynar® 761, M_w=370,000), N, N-dimethylformamide (DMF), acetone and Tetrahydrofuran (THF) were purchased from Samchun Inc., Korea. Three types of TPUs (Estane® R190A, Estane® S190A-43 and Estane® T470A-3) were obtained from Lubrizol, USA. Nickel-copper plated adhesive polyester fabric (J. S Korea Inc., Korea) was used as electrodes for fabricating pressure sensors. All the materials were used as received without any further modification.

2.2 Preparation of Electrospun Nanoweb

PVDF solution was prepared by dissolving 12 wt.-% (w/v) of PVDF in 6:4 (v/v) DMF: acetone mixture at 60 °C for 4 h under continuous stirring, whereas PU solutions were prepared by dissolving 12 wt.-% (w/v) of PU in 6:4 (v/v) DMF: THF mixture at 60 °C under stirring for 24 h. The electrospinning set-up consisted of a syringe pump, needle (23G), high voltage power supply and drum collector. During electrospinning, a positive DC voltage of 20 kV was applied to the PVDF solution at a flow rate of 1.0 ml/h, and in the case of TPU solution, the voltage was set at 17 kV and a flow rate of 1.5 ml/h. For both the solutions, the tip-to-collector distance (TCD) was maintained at 10 cm.

2.3 Fabrication and Measurement of Pressure Sensors

Piezoelectric and piezocapacitive sensors were fabricated by sticking nickel-copper plated polyester fabric to both sides of PVDF and TPU nanofiber webs. The simplified equivalent circuit diagram for detecting the piezoelectric signal is shown in Fig. 1. The output electrical signal generated by