Electroactive polymer membranes as substrates for for point-of-care devices

Ricardo Brito-Pereita[1,2,3], André S. Macedo[1,3], Senentxu Lanceros-Méndez[1,4,5], Vanessa F. Cardoso[1,2]

[1]CF-UM-UP, University of Minho, Campus de Gualtar, 4710-057 Braga, Portugal
[2]CMEMS-UMinho, University of Minho, Campus de Azurém, 4800-058 Guimarães, Portugal
[3] IB-S, University of Minho, 4710-057 Braga, Portugal
[4]BCMaterials, UPV/EHU Science Park, 48940 Leioa, Spain
[5]IKERBASQUE, Basque Foundation for Science, 48013 Bilbao, Spain;

ABSTRACT

Point-of-care devices (POC) are becoming essential for medical assistance in emergency situations or location with difficult access to medical infrastructures. In this work, innovative microfluidic substrates based on electroactive poly(vinylidene-*co*-trifluorethylene)-P(VDF-TrFE) with tuned morphologies and adequate physicochemical properties were developed using electrospinning and phase inversion techniques, as alternative to commercially available two-dimensional microfluidic substrates based mainly on cellulose. Their hydrophilicity was tuned using plasma treatments and barriers were implemented using wax printing to fabricate a design able to carry out glucose assays as a proof of concept.

KEYWORDS: Point-of-care, µPAD, P(VDF-TrFE), Electrospinning, Phase inversion, Wax-printing.

INTRODUCTION

Microfluidic paper-based analytical devices (µPADs) are a suitable option for simple, fast and portable devices for medical diagnosis in locations where complex laboratory equipment may not be accessible. Cellulose paper is an economical, compact and lightweight substrate for microfluidic devices, as passive capillary flow discards the need for an external pump due to its natural hydrophilicity [1]. Poly(vinylidene-*co*-trifluorethylene) (P(VDF-TrFE)) is a biocompatible and electroactive polymer characterized by its piezoelectricity: the ability to convert mechanical stimuli into an electrical response and vice-versa. This copolymer possesses high dielectric constant and excellent mechanical properties regardless of the processing method [2]. P(VDF-TrFE) can be tailored into oriented and non-oriented fibres membranes using electrospinning (ES) technique. It can also be tailored into porous films by using techniques based on phase inversion which allows porosity and pore size control: nonsolvent induced phase separation (NIPS), where the liquid or vapor phase in the polymeric solution is diffused by submerging it in a nonsolvent coagulation bath, and also by solvent evaporation (SE), where a fixed evaporation rate at room temperature results in controlled polymer crystallization [3]. P(VDF-TrFE) is hydrophobic, which prevents capillary flow through membranes or films. This can be overcome by using plasma treatment, which introduces functional groups into the surface of the material by exposure to plasma (Ar and O_2 are commonly used) making it superhydrophilic [4]. Combined with wax-printing of hydrophobic barriers, a solutions can be guided to reaction chambers for analysis. Here we present a study on P(VDF-TrFE)-based electrospun membranes and porous films obtained by phase inversion as alternative substrates for the manufacture of µPAD devices. A comparison to the commonly used, commercially available *Whatman No. 1* cellulose filter paper is also performed, along with wax-printing proofs of concept on the developed substrates.

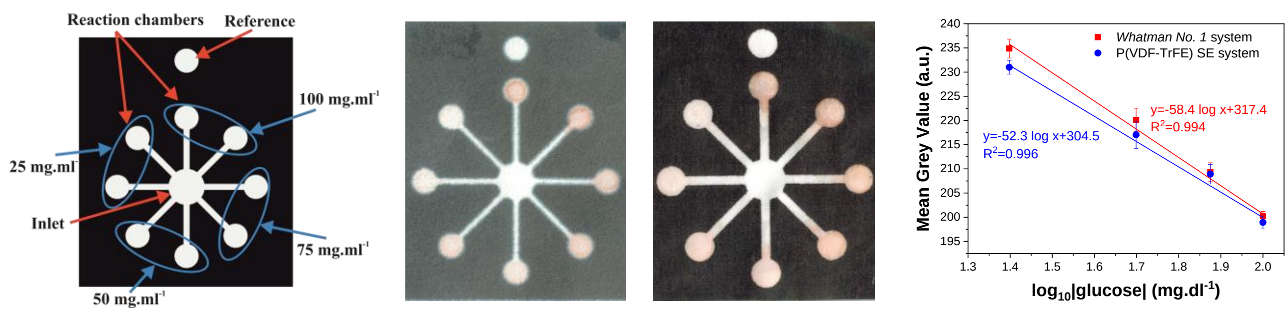
EXPERIMENTAL

P(VDF-TrFE) with different morphologies were prepared by electrospinning - random and oriented fibres- , NIPS and SE – porous films. Plasma treatment (O_2) was applied to all samples to tune their hydrophilicity and a specific design (carried out with a computer-aided design software) was printed on the substrates using a wax printer, and subsequently cured at 100 ºC to make the wax permeate the substrate and reach the opposite surface. A glucose assay kit (Trinder – Endpoint, FAR Diagnotics) was used on these substrates as proof of concept.

RESULTS AND DISCUSSION

Concerning the substrates' properties, the Young modulus was significantly higher in the P(VDF-TrFE) oriented ES membranes (181 ± 7,3 MPa dry and 163 ± 5,1 MPa wet) and non-oriented and SE membranes, when compared to the *Whatman No. 1* paper (13.6 ± 0.7 MPa dry and 0.5 ± 0.15 MPa wet). In fact, all P(VDF-TrFE) membranes showed Young modulus above 70 MPa, independently of the processing conditions or morphology. With respect to FTIR-ATR analysis, no noticeable variations are observed on any of the **P(VDF-TrFE)** substrates before or after plasma treatment**s,** remaining in the electroactive **β-**phase, which is suitable for the development of active substrates for microfluidics. Contact angle (CA) tests show the plasma treated substrates express a superhydrophilic behavior. In turn, untreated substrates present CAs up to 131 ± 3.2°, showing a superhydrophobic behavior. Capillary flow tests were performed in order to evaluate the capability of the processed P(VDF-TrFE) substrates to be used in microfluidic systems. Without plasma treatment, passive capillary flow is non-existent. Plasma-treated samples show capillary flow rates ranging from 35.7 ± 2.5 to 88.3 ± 3.7 $mm.min^{-1}$.

The proof of concept consisted in colorimetric assays based on the detection and quantification of glucose at different concentrations (0, 25, 50, 75 and 100 $mg.ml^{-1}$) carried on commercial *Whatman No.1* and P(VDF-TrFE) SE films (as a representative example). Images of these assays and their corresponding calibration curves are presented in Figure 1. A gradual increase of red color intensity translates the increase in glucose concentration. The calibration curves, which present the correlation of color intensity between chambers is denoted as mean gray values and the logarithm of glucose concentrations, demonstrating good correlation with R^2 coefficients of 0.99 in both substrates. Moreover, it is observed a higher contrast of the wax in the P(VDF.TrFE) substrates and contrarily to *Whatman No. 1* the printed walls did not expand 700 um after the curing process.



a) b) c) d)

Figure 1 – a) Schematic of the microfluidic system; Glucose assays carried on b); b) *Whatman No. 1* system. c) P(VDF-TrFE) SE system; d) Calibration curves for each Whatman *No. 1* and P(VDF-TrFE) SE systems.

CONCLUSION

The results demonstrate that by properly controlling the processing conditions, it is possible to tailor the morphology, hydrophilicity, capillary flow rate and mechanical proprieties of P(DVF-TrFE) substrates making them suitable for the development of POC devices, as additive to the current commercially paper substrates. It is to notice that the electroactive properties of these substrates can be further explored to give rise to a new generation of active POC devices.

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REFERENCES

[1] Y. Yang, E. Noviana, M.P. Nguyen, B.J. Geiss, D.S. Dandy, C.S. Henry, Paper-Based Microfluidic Devices: Emerging Themes and Applications, Analytical Chemistry 89(1) (2017) 71-91.

[2] C. Ribeiro, C.M. Costa, D.M. Correia, J. Nunes-Pereira, J. Oliveira, P. Martins, R. Goncalves, V.F. Cardoso, S. Lanceros-Mendez, Electroactive poly(vinylidene fluoride)-based structures for advanced applications, Nat Protoc 13(4) (2018) 681-704.

[3] V.F. Cardoso, A.C. Lopes, G. Botelho, S. Lanceros-Méndez, Poly(vinylidene fluoride-trifluoroethylene) Porous Films: Tailoring Microstructure and Physical Properties by Solvent Casting Strategies, Soft Materials 13(4) (2015) 243-253.

[4] D.M. Correia, C. Ribeiro, V. Sencadas, L. Vikingsson, M. Oliver Gasch, J.L. Gómez Ribelles, G. Botelho, S. Lanceros-Méndez, Strategies for the development of three dimensional scaffolds from piezoelectric poly(vinylidene fluoride), Materials & Design 92 (2016) 674-681.

CONTACT

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