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Development of a plastic membrane containing micro-hole(s) for a potential bio-sensing application

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Abstract

In this work, a poly (methyl methacrylate) membrane containing micro-holes (MHs) as a prototype of a simple sensing platform of a lab-on-a-chip device has been developed for a potential analysis of clinical fluidic samples. A four probe electrochemical impedance spectroscopy (EIS) setup, with two electrodes placed on each side of the membrane, was adopted for monitoring the MH impedance (Fig. 1a). The setup was used to investigate, if EIS is suitable to sense the trapping of an analyte inside the MHs. Latex micro-beads with a diameter of 10 μm were used to test clogging of the MHs. Additionally, finite element model simulations were performed using Comsol Multiphysics software to theoretically evaluate the sensitivity field of the EIS measurement along the MHs.

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Keywords: poly(methylmethacrylate), lab-on-a-chip, electrochemical impedance spectroscopy, finite element model simulations;

1. Introduction

A particularly important direction in improving the healthcare system is development of portable biomedical devices suitable for rapid detection of infectious diseases at point-of-care (POC) units or at patient's home. Such POC devices would allow earlier disease diagnosis and increased access to the healthcare in previously under-served

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populations and home-testing approach in well-developed countries [1]. The design of these devices must be low-cost, miniaturised and enable simple real-time on-site diagnosis. Electrochemical sensing based microfluidic lab-on-a-chip systems enable simple, relatively selective and sensitive analysis of fluidic samples when handling small amounts of fluids and, thus, allowing their miniaturised design which makes them suitable for POC devices.

In this work, a “sensitive hole” based approach was exploited for developing a prototype of a simple sensing platform of a lab-on-a-chip device for a potential analysis of clinical fluidic samples, where a four probe electrochemical impedance spectroscopy (EIS) setup was employed to monitor impedance changes across the micro-hole MH(s) in a non-conductive poly (methyl methacrylate) (PMMA) membrane.

2. Results and discussion

MHs with a diameter ranging between 20 to 300 μm were perforated in 250 and 500 μm thick PMMA membranes by using continuous CO_2 and pulsed fiber laser ablation and mechanical micro-drilling. Both by continuous CO_2 and pulsed fiber laser perforated MHs were characterised as having a conical shape and low reproducibility in the diameter, while mechanically drilled MHs had well defined cylindrical shape and size. Thus, cylindrical mechanically drilled MHs (a diameter of 100 μm) were chosen to clog their interior by amino-functionalised latex beads (a diameter of 10 μm) and evaluate the corresponding impedance changes. For this purpose, the surface of MHs was rendered hydrophilic using air plasma, and the bead trapping inside the MHs was led by capillary forces. The beads within the MHs were cross-linked by using glutaraldehyde vapour to stabilise the bead “net”. The influence of the aspect ratio of MHs on their impedance was evaluated when using PMMA membranes of two different thicknesses, i.e. 250 and 500 μm , respectively, containing a single MH with a diameter of 100 μm . When comparing the ratio of the impedance of modified and unmodified MHs, EIS measurements along MHs showed that the presence of beads in the MH considerably increased the impedance of the MHs in both cases (Fig.1b). Though the higher impedance ratio, i.e. the higher normalized response, was observed for the MHs perforated in 500 μm PMMA than the ones in 250 μm PMMA. Thus, the lower MH aspect ratio enables the higher normalized response of MH-based impedance measurement.

Finite element model (FEM) simulations using Comsol Multiphysics software performed for differently thick (175, 250, and 500 μm) PMMA membranes, when assuming a 100 μm MH diameter, showed that the highest sensitivity of the EIS measurements is obtained in the middle of a MH (Fig. 1c). FEM simulations were performed according to the previously described instructions [2].

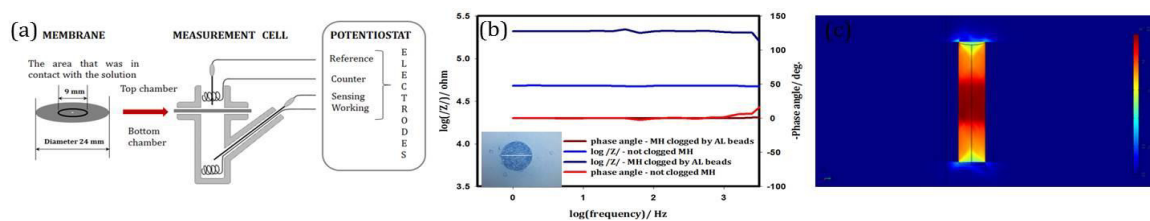


Fig. 1 (a) A schematic representation of the EIS measurement setup; (b) EIS spectra of unclogged and clogged MHs in 500 μm PMMA. The inset shows an optical microscope image of a MH clogged by 10 μm micro-beads, (c) EIS measurement sensitivity along a MH: finite element model (FEM) analysis for 500 μm thick PMMA.

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