

# POLY(ETHYLENE GLYCOL) (PEG)- MODIFIED POLY(DIMETHYLSILOXANE) (PDMS) FOR PROTEIN- AND CELL-RESISTANT SURFACES IN MICROBIOREACTOR

H.-G. Choi<sup>1</sup>, Z. Zhang<sup>1</sup>, P. Boccazzi<sup>2</sup>, P. E. Laibinis<sup>3</sup>,  
A. J. Sinskey<sup>2</sup> and K. F. Jensen<sup>1</sup>

<sup>1</sup>Department of Chemical Engineering, <sup>2</sup>Department of Biology, MIT

<sup>3</sup>Department of Chemical Engineering, Rice University

## ABSTRACT

We describe the surface modification of poly(dimethylsiloxane) (PDMS) with poly(ethylene glycol) (PEG) and its use in creating protein- and cell-adsorption resistant surfaces in microbio reactors. Surface modification of PDMS is realized by self-assembly of amine-terminated silanes onto hydroxylated PDMS surfaces and subsequent adsorption of a PAA-g-(PEG-*r*-PPG) polymer. Each step in the modification procedure is characterized by X-ray photoelectron spectroscopy (XPS). The modified surfaces are hydrophilic (contact angle  $\theta_a(\text{H}_2\text{O}) = 35 \pm 5^\circ$ ) and show resistance to the non-specific adsorption of several proteins and *E. coli*.

**Keywords:** PDMS, PEG, Protein- and Cell-Resistance, Surface Modification

## 1. INTRODUCTION

Poly(dimethylsiloxane) (PDMS) is widely used in microfabrication for biological applications because it allows rapid prototyping and offers biocompatibility, optically transparency, permeability to gases, flexibility, and durability [1]. Non-specific adsorption of proteins and cell growth on wall are common problems in biological applications of PDMS-based microstructures leading to fouling of sensor surfaces and clogging of microchannels. Since this non-specific adsorption is often driven by the hydrophobic interaction between biomolecules and PDMS surface, device performance can be improved by reducing the hydrophobic interaction through surface modifications.

We present a simple and effective approach for modifying PDMS surfaces by using a poly(ethylene glycol) (PEG)-grafted poly(acrylic acid) (PAA) copolymer. This copolymer generates a hydrophilic surface and provides resistance toward protein adsorption as well as cell growth. The modified surfaces are characterized by contact angle measurements, X-ray photoelectron spectroscopy (XPS), and optical microscopy.

## 2. EXPERIMENTAL

Comb polymers composed of linear poly(ethylene glycol-*r*-propylene glycol) (PEG-*r*-PPG) (86%:14%) were grafted onto PAA at grafting densities of 8%, 16%, 24%, and 50% [2]. Figure 1 shows a schematic of the modification procedure of PDMS. PDMS

**PDMS**

**Hydroxylated surface by O<sub>2</sub> plasma treatment**

**PDMS**

**Amine-terminated self-assembled monolayer (SAM): 2% AHPTS in ethanol, 20 h**

**PDMS**

**Formation of polymer film: 6 wt% at pH 7.5, 20 h**

**PDMS**

The PAA-g-(PEG-*r*-PPG) polymer-coated PDMS surfaces were soaked in PBS buffer solutions that contained insulin, lysozyme, hexokinase, or fibrinogen. After 20 hr of exposure, the PDMS surfaces were rinsed with deionized water and dried in a nitrogen stream. The relative amounts of adsorbed protein were estimated by the N(1s) signal in an XPS measurement. For the adsorption behavior of *E. coli* (DPD2417), the modified surfaces were put into a petri dish, autoclaved, inoculated, and incubated for 20 hr. After the incubation, images of cell adsorbed PDMS surfaces were taken by an optical microscope.

The PAA-g-(PEG-*r*-PPG) polymers were adsorbed onto the PDMS surfaces by electrostatic interactions with the exposed amine-terminated SAMs. High resolution C(1s) XPS spectra showed an increase of a C-O peak (285.7-286.2 eV) upon polymer adsorption, and additional increases in the C-O peak and decreases in the C-C peak (283.6-284.0 eV) with increases in the PEG grafting ratio. These results indicate the successful coating of the PDMS surfaces with PAA-g-(PEG-*r*-PPG) polymer films. The resulting polymer coatings were stable to high temperatures (125°C), in solutions with high salt concentrations, and to sonication.

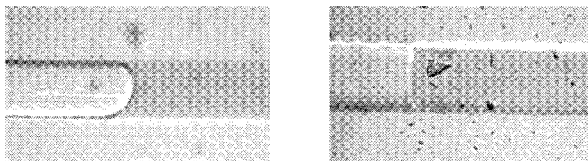


Figure 2. Wettability of PDMS microchannels; PEG modified (left) and native channel (right)

The changes in the surface properties of the PDMS upon modification was demonstrated by wetting experiments. A microchannel with a height of 60  $\mu\text{m}$  and a width of 130  $\mu\text{m}$  was modified by sequential flows of the AHPTS solution (20  $\mu\text{L}/\text{min}$  for 3 hrs) and then the PAA-*g*-(PEG-*r*-PPG) polymer solution (5  $\mu\text{L}/\text{min}$  for 18 hrs). After rinsing with deionized water and drying at 70  $^{\circ}\text{C}$  for 1 day, a stable hydrophilic PDMS channel was formed. Figure 2 shows the wetting of the PDMS microchannel 5 days after the surface modification. For the modified channel, it exhibited enhanced wettability and water could be drawn into the channel without external pressure whereas external pressure had to be applied to push water into the unmodified PDMS channel.

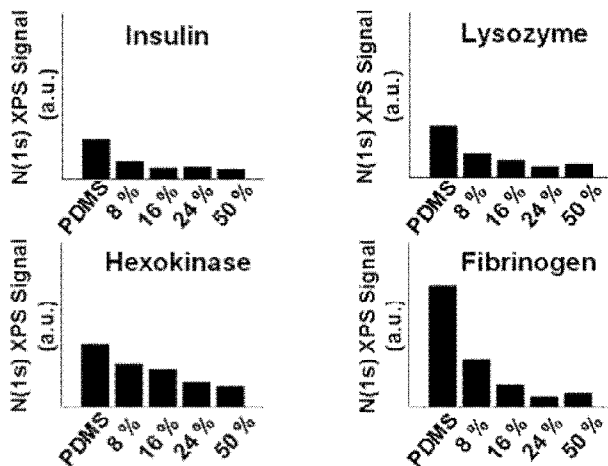


Figure 3. Resistance of PAA-*g*-(PEG-*r*-PPG)-modified PDMS surface to the non-specific adsorption of various proteins.

The protein resistance of the PAA-*g*-(PEG-*r*-PPG)-modified PDMS was evaluated by high resolution N(1s) XPS spectra. Since an amino acid contains at least one nitrogen atom, the intensity of the N(1s) signal in XPS can be used as a metric for comparing the

relative amounts of adsorbed proteins on different surfaces. As shown in Figure 3, the nitrogen signals for the PAA-*g*-(PEG-*r*-PPG)-modified PDMS were reduced for all four proteins compared with native PDMS. There was a further decrease in the N(1s) signal with increasing PEG-grafting ratio. The results suggest that the PAA-*g*-(PEG-*r*-PPG)-modified PDMS surfaces are effective in reducing non-specific adsorption of proteins.

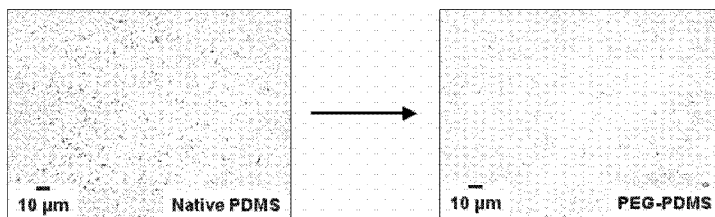


Figure 4. Resistance of PAA-*g*-(PEG-*r*-PPG)-modified PDMS surface to the non-specific adsorption of *E. coli*.

The resistance of PAA-*g*-(PEG-*r*-PPG)-modified PDMS to non-specific cell adsorption was also investigated. Figure 4 shows the difference in *E. coli* adsorption onto the native and modified PDMS surfaces. The number of cells adsorbed onto the modified PDMS surface was ~10 % of that onto native PDMS. The results indicate that surface modification with PAA-*g*-(PEG-*r*-PPG) polymer reduces cell adhesion onto the PDMS surface.

#### 4. CONCLUSION

Self-assembled PAA-*g*-(PEG-*r*-PPG) polymer films provide a cost-effective alternative to the use of homogeneous PEG with functional group, which is hardly available commercially or very expensive, for surface modification. The approach is a straightforward and employs a two-step self-assembly process that can be readily extended to other materials relevant for  $\mu$ TAS applications. The resulting coatings increase the hydrophilic nature of the channel surfaces, retarding non-specific adsorption of proteins and cells.

#### ACKNOWLEDGMENTS

This work was supported by the DuPont-MIT Alliance (DMA) program.

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