Surface & Coatings Technology xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Surface & Coatings Technology

journal homepage: www.elsevier.com/locate/surfcoat

Polyethylene glycol coating for hydrophilicity enhancement of polydimethylsiloxane self-driven microfluidic chip

H.P. Long, C.C. Lai, C.K. Chung *

Department of Mechanical Engineering and Center for Micro/Nano Science and Technology, National Cheng Kung University, Tainan, Taiwan 701, ROC

ARTICLE INFO

Article history:
Received 31 August 2016
Revised 10 December 2016
Accepted in revised form 17 December 2016
Available online xxxx

Keywords:
Polydimethylsiloxane
Hydrophilic
Polyethylene glycol
O_2 plasma

ABSTRACT

The hydrophilic microfluidic chip that can self-actuate fluidic flow effectively with no extra pump is an important device for bio lab-on-a-chip (LOC) application. Polydimethylsiloxane (PDMS) is a common material for bio-microfluidic chip but suffers from hydrophobic surface problem. In this article, the surface modification of PDMS material for long-term hydrophilicity improvement has been studied by O_2 plasma and polyethylene glycol (PEG) coating. Three kinds of surface treatment namely the O_2 plasma treatment, PEG coating and O_2 plasma followed by PEG coating were performed for hydrophilic enhancement on pristine PDMS. The contact angle measurement was used for examining hydrophilic duration after treatment. The contact angle of pristine PDMS is hydrophobic around $100° \pm 3°$. Using only O_2 plasma treatment made the contact angle of PDMS below 10° initially but its hydrophobicity recovered quickly after 2 h that hindered practical application. Adding PEG coating on the O_2 plasma treated PDMS surface can make hydrophilic behavior retained longer than 400 h. The Fourier transform infrared spectrometer and contact angle variation were used for identifying the evolution of hydrophilicity enhancement. The cross-form microchip was used for testing the self-driven flow of rhodamine droplet into the microchannel successfully. This method is low-cost, disposable and easy to integrate with the microfluidic LOC system.

1. Introduction

Micro-electro-mechanical systems (MEMS) technologies have advanced rapidly in the past two decades and led to the development of lab-on-a-chip (LOC) capable of performing multiple sample operations e.g. mixing, sorting, counting and polymerase chain reaction on a single chip [1–3]. The LOC is a device that integrates one or several laboratory functions on a single chip of only millimeters to a few centimeters to achieve automation and high-throughput screening with the handling of extremely small fluid volumes. LOC devices are often made of polydimethylsiloxane (PDMS) due to its low cost, chemical stability, biocompatibility and transparency [4]. However, PDMS has an intrinsic hydrophobic property, and thus micro-pumps or external pumps such as syringe pumps are required to drive the fluid. Such pumping systems increase the size, cost and complexity of LOC devices. Accordingly, more efficient fluid transportation schemes are required. Various researchers proposed the use of electroosmotic flow (EOF) for transporting and manipulating minute volumes of the sample and reagent within microfluidic channels [5]. In EOF, the flow can be controlled with electric fields rather than valves or pumps, so that fluidic systems with no moving parts can be realized. Potential applications of EOF include miniaturized analytical systems with a performance which rivals the commercial bench-top instruments. However, the transportation of EOF flow needs high applied voltage and is highly sensitive to the surrounding conditions, e.g. the temperature and the substance absorbed on the chip. In terms of self-pumping function built within the chip, the PDMS microchannel surface is treated for a hydrophilic property to provide an effective pumping pressure for fluid transport in microchannels. Among various surface treatment methods, the plasma is an ordinary one that employs different gases like oxygen, nitrogen and so on which react with the PDMS surface and create chemical hydrophilic groups [6,7]. And the O_2 plasma treatment is the most widely applied [8]. Also, a new scanning radical microjet O_2 plasma treatment was employed to make a localized modification and lower the damage of substrate surface for easy cell attachment [9]. However, while the O_2 plasma treatment results in a hydrophilic property of the PDMS surface e.g. a contact angle of ~5°, the inherent hydrophobic property of the surface is soon restored after a few hours. The layer by layer (LBL) deposition is another generally method for surface modification. LBL is a simple emerging process, and there are many examples for the PDMS modification [10,11]. However, a difficulty of LBL modification for PDMS is that organic solvents will cause the PDMS swelling, which limits the application of LBL to enhance PDMS hydrophilicity. To avoid the swelling problem, PEG is chosen to promote the modification [12]. Ethylene glycol (EG) has two types of molecules namely Oligo-EG (OEG) and Poly-EG (PEG). OEG can be used for terminated self-assembled monolayers on Au and Ag surfaces, widely used to reduce the adsorption

* Corresponding author at: Department of Mechanical Engineering, National Cheng Kung University, Tainan 701, Taiwan, ROC.
E-mail address: ckchung@mail.ncku.edu.tw (C.K. Chung).

http://dx.doi.org/10.1016/j.surfcoat.2016.12.059
0257-8972/

function of protein on the surface of microchannels [13]. The PEG is a hydrophilic polymer that can be applied to a dip coating treatment for a significant improvement in the anti-fouling coatings of PDMS devices for biological and biomedical applications [14]. However, the dip process results in a non-uniform coating effect, and thus the average contact angle was only reduced to around 50°. Moreover, PEG modification also results in hydrophobic recovery after 24 h [15].

In this article, we have demonstrated a new surface modification treatment for the long-term hydrophilic improvement of PDMS substrates, in which the substrate is pre-treated with O_2 plasma and then immersed in the PEG solution. The low-cost O_2-plasma-PEG treatment method can extend the hydrophilic duration of surface and avoid the swelling problem of solution treatment. It makes a long-term hydrophilic surface for over 400 h within only 25– 30 min processing time and be easy to integrate with the microfluidic system. The combination of gas-phase and chemical modifications can be a better choice for enhancing surface stability for a variety of LOC applications.

2. Experimental procedure

2.1. Chip fabrication and modification

Fig. 1 shows the schematic process flow of the PDMS microfluidic chip using laser ablation, surface modification and two-step casting. In Fig. 1(a), a simple microchannel pattern was ablated on a PMMA substrate by a CO_2 laser (Versa VL-200, Universal Laser System). The PDMS and a hardener (DOW CORNING PDMS, Sylgard-184 Silicone Elastomer Kit) were mixed in a weight ratio of 10:1 and then placed in a vacuum pump to remove any air bubbles. The PDMS mixture was then poured onto the ablated PMMA substrate and was cured at a temperature of 70 °C for 30 min (Fig. 1(b)). Following curing process, the PDMS layer was stripped from the PMMA substrate to form a PDMS convex mold (Fig. 1(c)). The PDMS mold was treated with O_2 plasma for 1 min and then immersed in 0.1 M PEG solution with an average molecular weight 6000 g/mol (model MW 35000, Sigma-Aldrich) to form an isolation film (Fig. 1(d)). The steps in Fig. 1(b) and (c) were then repeated on the convex mold to form a concave PDMS mold (Fig. 1(e)–(f)). Finally, the PDMS mold was bonded to a blank PDMS substrate to form the microfluidic chip. The fabrication method above is much cheaper and faster than traditional photolithography-based techniques.

Before the chip bonding, three different types of surface treatment were applied, namely O_2 plasma, PEG coating, and O_2 plasma followed by PEG (O_2-plasma-PEG) coating. The various surface properties were then examined by contact angle measurement. The O_2 plasma treatment on the PDMS substrate was performed in an oxygen plasma chamber for 60 s with a chamber pressure of 500 mTorr and at a RF power of 30 W. Meanwhile, for the PEG treatment, the PDMS substrate was simply

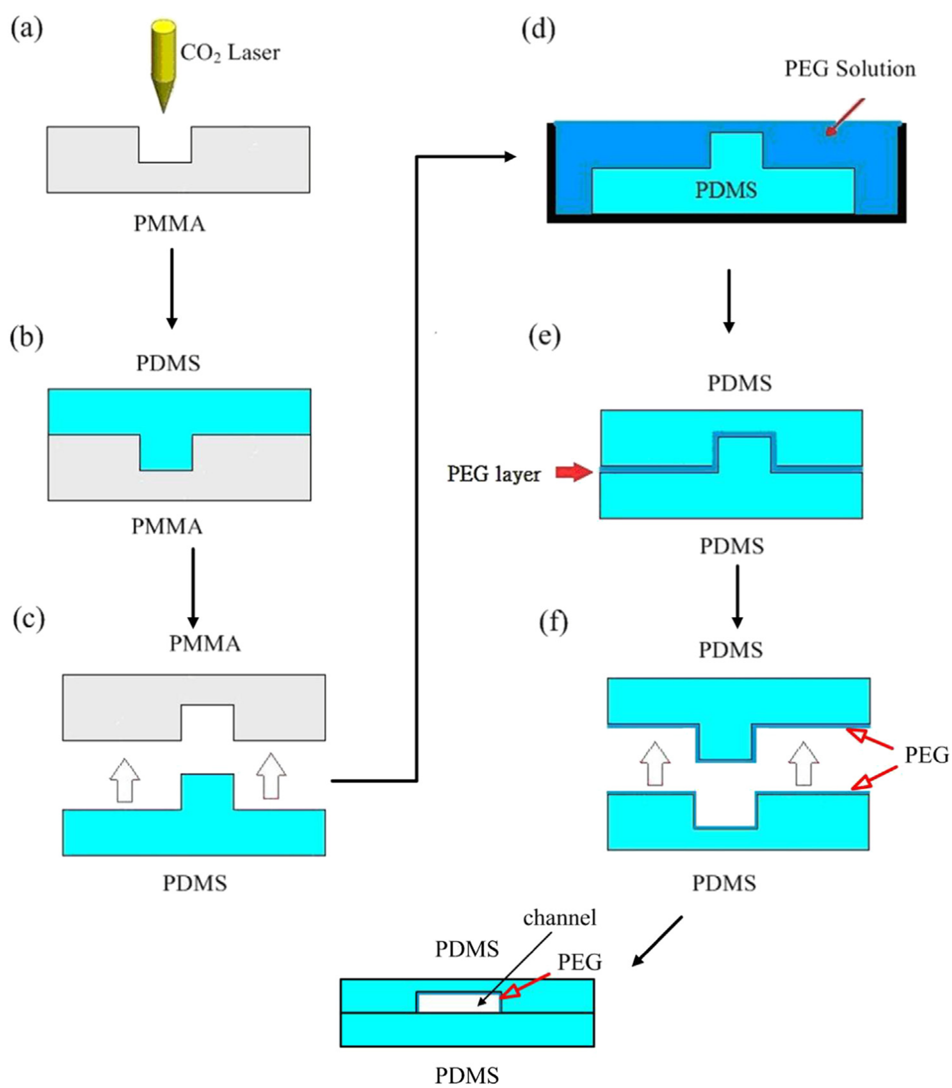

Fig. 1. Schematic process flow of the PDMS microfluidic chip using laser ablation, surface modification and two-step casting.

Please cite this article as: H.P. Long, et al., Surf. Coat. Technol. (2016), http://dx.doi.org/10.1016/j.surfcoat.2016.12.059