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Effects of micropatterning and surface modification of microfluidic channels on capillary water transport

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Abstract

This work is intended to characterize the fluid conducting behaviour of microcapillary systems containing various 3D microstructures and surface modifying molecular layers. The microchannels are patterned by secondary structures mimicking the natural water-conducting tissue (xylem) of dry-habitat plants. The complex microstructure of the microcapillary system was developed by bulk silicon micromachining technology, applying multistep Deep Reactive Ion Etching (DRIE) to fabricate and pattern the microfluidic channels subsequently. The inner surfaces of the capillary systems were covered by Atomic Layer Deposition (ALD) of different oxide layers to control their wetting properties. We demonstrated that the fluid conducting behaviour of the fabricated capillary systems can be systematically controlled by structural patterning and surface modification of the channels.

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Keywords: bioinspired autonomous capillary pump system, 3D silicon microstructure, molecular layer deposition, water conductivity

1. Introduction

Autonomous capillary systems could be substantial brickstones of cheap, simple and self-powered microfluidic systems being capable to manage the sample transport in Lab-on-a-Chip applications [1]. Accordingly the precise control or improvement of the fluid conducting characteristics of these integrable micropumps is in forefront considering their capacity and efficiency. Moreover the management of the achievable flow rate and the transported

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sample amount could be critical regarding various applications considering the requirements of controlled microreactors or high sensitive diagnostic devices also, and had to be adjusted by the geometric and surface parameters of the developed passive pump.

3D geometries of the studied capillary channels were inspired by the complex natural microfluidic system, the water-conducting tissue (xylem) of dry-habitat plants executing effective vertical water transport in strain. The microstructure of their cellulose and lignin based sidewalls are intended to increase the wettability and accordingly the capillary forces and pressure. [2] 3D microstructures provide additional surface and will cause enhanced sample transport, if the roughness is parallel to the flow and pinning is avoided in the channels. [3]

Nomenclature

LoC	Lab on a Chip
DRIE	Deep Reactive Ion Etching
ALD	Atomic Layer Deposition
WCA	Water Contact Angle
AlO_x	Aluminium-Oxide
TiO_2	Titanium-Dioxide
SiO_2	Silicon-Dioxide

2. Experimental

In order to study the effect of secondary substructures of water conducting capillaries different geometric shapes were developed at the bottom of the channels as stripe and serpent type additional grooves or serpent type wale as presented in Fig. 1.

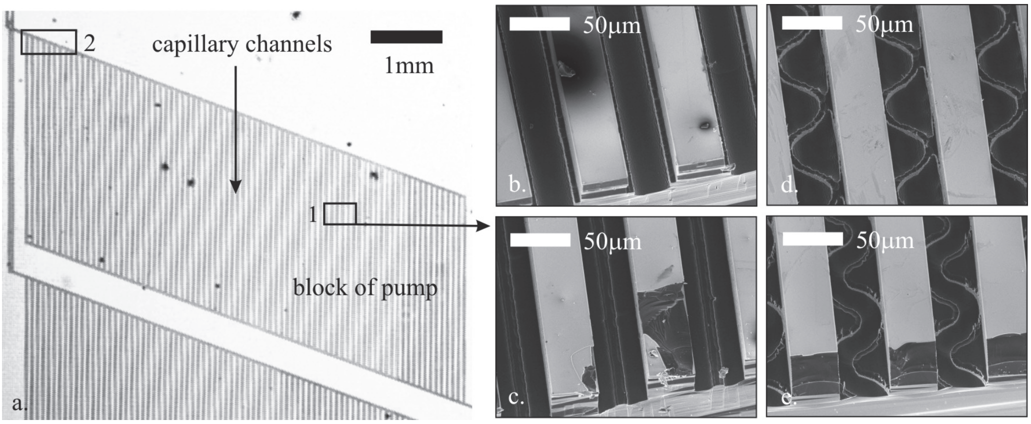

Fig. 1. View of a main block of the capillary system (a.) and the different substructures on the bottom of the channels fabricated by multistep DRIE technique (plain: b., stripe: c., inverse serpent: d., serpent: e.)

The demonstrated structures were fabricated by bulk silicon micromachining applying multistep Silicon DRIE Bosch process. The microfluidic systems were sealed with Borofloat®33 glass wafers by anodic bonding and the channel surfaces were covered subsequently by conform ALD oxide layers, as Aluminum-Oxide (AlO_x) and Titanium-Oxide (TiO_2). The representative water contact angles of the applied surface materials are summarized in Table 1.

Table 1. Water contact angles (WCA) of the different surface layers

Layer	Si / SiO_2	AlO_x	TiO_2
WCA	54°	69°	37°

The combined effects of different 3D micropatterns and surface modification were characterized by flow rate measurements applying ultra fast imaging system for recording fluid movement in the microfluidic systems (Fig. 2). The transported volumetric flow rates were calculated and compared to the parameter of the plain silicon channel as reference.

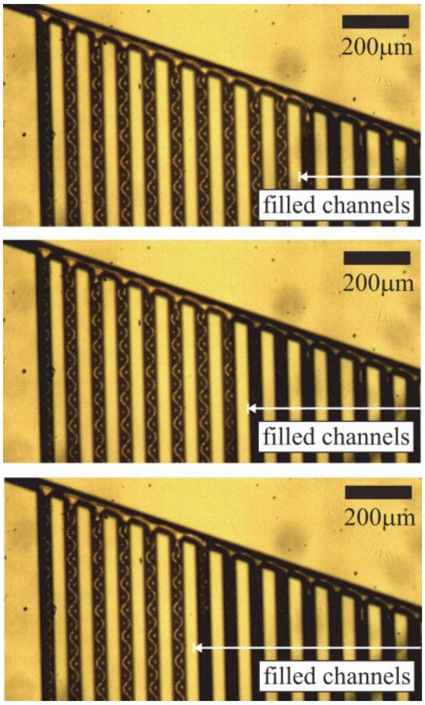

Fig. 2. Subsequent filling of the capillary channels (fast camera recording of the area indicated by 2 in Fig. 1 with time intervals of 8190μs).

3. Results and discussion

The effects of microstructuring and surface modification of the capillary channels are demonstrated by their modified water-conducting capability as volumetric flow rates present in Fig. 3. The bioinspired secondary micropatterns (serpents and stripes) of the capillary channels can increase the volumetric flow rate in the water conducting structures. The surface modification of the channels could cause further improvement in water conducting capability according to the measured surface contact angles and estimated capillary pressures.

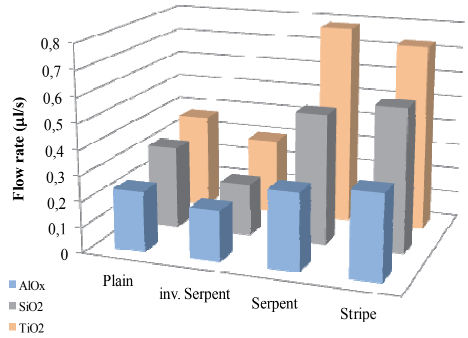

Fig. 3. Capillary flow rates measures in the developed microfluidic systems depending on the 3D microstructure and the surface layer.

We can conclude that the efficiency of the microchannel based capillary pump systems can be improved by applying adequate micropatterning (as groves) and additional surface modification (as TiO_2) layer, enabling development enhanced passive capillary pump systems.

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