Design, fabrication and characterization of electrostatic micro actuators for microfluidic platforms

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Abstract

Microfluidic devices for lab-on-a-chip applications have become obvious in the past decade. Often, small amounts of liquids need to be handled accurately and at a low power cost. Especially when autonomy is desired, the presence of on-chip micro actuators becomes obvious.

In this paper, a novel family of microfluidic devices based on the electrostatic actuation principle is presented, which enables low-power, on-chip actuation. The fabrication process employs thin film technology and the usage of flexible, biocompatible materials. Characterization of micro valves is investigated from a static and dynamic point of view, yielding reproducible on-off behaviour and a maximum liquid volume displacement rate of 23nl/s at 400 cycles/s.

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Keywords: microfluidics, electrostatics, pull-in, micro valves, micro pumps, thin film fabrication, flexible substrate, MEMS.

1. Introduction

Handling fluids at the micro scale and without external pumping capabilities has proven challenging yet this is desired for many lab-on-a-chip and diagnosis-related applications [1, 2]. Various actuation principles have been presented in literature, including but not limited to piezoelectric, pneumatic, ionic polymer-based and electrostatic [3-5].

Compared to other principles, electrostatic actuation features extremely low-power consumption and convenient scaling, at the expense of higher actuation potentials and reduced liquid volumes [6]. Moreover, our electrostatic micro actuators are made from flexible materials and are adaptable such that...

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the electrostatic field does not cross the transport fluid. This opens up new perspectives towards full integration of microfluidic actuators, channels and sensors onto one platform.

After the fabrication process has been introduced, the results from experiments of micro valves are presented, as these are the basic stones of any active microfluidic system. In these experiments, flow of a non-polar fluid inside the channel is characterized both statically and dynamically.

2. Working principle and fabrication

![Diagram](attachment:image1.png)

Fig. 1. Top view (a) and cross-section (b) of one valve.

The actuation principle is based on the pull-in phenomenon, which is a dynamic instability of a double-plate capacitor with at least one flexible plate, also formally presented in [6]. In the case of a microfluidic actuator, the channel is located between the electrostatic plates, like in Fig. 1. The channel height is only a few microns, in order to avoid excessively high potentials required for pull-in. The fixed plate is located under the channel, the flexible one on top. When a sufficiently high voltage is applied, the channel is locally squeezed and fluid flow is restricted. In this way, a valve is created. Placing three such valves in series and actuating in a peristaltic sequence yields a micro pump with bi-directional pumping capability.

The fabrication process is mostly based on thin-film processing and can be conducted on any type of hard substrate. The structural material for the microfluidic devices is Durimide®, which has a good thermal and chemical stability, is flexible and provides high breakdown voltage limits along with biocompatibility. The main steps and materials are described in Fig. 2. The last fabrication step is the creation of channels by an anodic dissolution process [7,8]. This method allows the creation of channels with length-to-height ratio exceeding 10,000:1, in order to accommodate for direct electrostatic actuation.

![Diagram](attachment:image2.png)

Fig. 2. Fabrication steps required for the fabrication of microfluidic actuators: a) bottom electrode material and insulation; b) anodic dissolution electrode and channel sacrificial material; c) insulation and top electrode material; d) sealing layer; e) channel creation (anodic dissolution).
Fig. 3 presents one of the many types of one-valve actuators, where the flow is being regulated by valves in the middle of the channels. The channel length between the inlets is here 20 mm, while the width is 50 and 100 μm, respectively.

3. Results and discussion

The microvalve was tested both statically and dynamically. The static measurements indicate the ability of the valve to keep the channel closed in a quasi-static situation, whereas dynamical experiments are closely correlated to high-speed switching and peristaltic pumping. Some relevant dimensions, material properties and parameters are listed in Table 1. During the experiments, octane\(^a\) was used inside the channel.

<table>
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<tr>
<th>Table 1. Device dimensions, material properties and parameters used during experiments. Ranges are given in between brackets.</th>
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<tr>
<td>Channel length x width x height [mm x μm x μm]</td>
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<tr>
<td>Valve length x width [mm x mm]</td>
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<tr>
<td>Applied potential [V]</td>
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<tr>
<td>Insulation layer thickness [μm]</td>
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<td>Octane relative permittivity (-)</td>
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<td>Polyimide relative permittivity (-)</td>
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In the static mode (Fig. 4(a)), the micro valve keeps the channel closed for 50 s, at an applied potential of 200 V. The valve displacement, in the order of 5.5 μm, is due to the viscous forces inside the fluid, which make the flexible ceiling bend upwards. The reproducible channel actuation is clearly visible. From multi-point out-of-plane measurements with laser vibrometry, we observed that the channel fully closes while actuated, so that no fluid can pass the valve.

\(^a\) Octane is a non-polar fluid. Polar fluids shield the electrodes and are not suitable in this configuration.
Fig. 4 (a) Quasi-static valve response to a 200 V input block signal. The valve displacement is about 5.5 μm. (b) Volume displacement rate for different block signal input rates (at 150V). The maximum pumping rate (or frequency) is obtained at 400 cycles/s.

The dynamic performance of the valve is obtained by measuring the displacement at different block rates. Due to flow inertia and other factors, the displacement decreases steadily with frequency. The displacement times the rate yields the fluid rate, see Figure 4-Right. For our micro valves, the maximum volume displacement is reached at a block rate of 400 cycles/s and is 23 nl/s for a 1.5 mm long and 0.6 mm wide active region of the valve.

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References