Electroosmotic Micropumps for Lab-on-Microchip

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The electrokinetic effect is the most common one used for nonmechanical pumping of aqueous solutions in microchannels. The main problem of electroosmotic micropumps is water electrolysis and bubble generation on metal electrodes. Therefore, for most applications, electrodes are placed into open reservoirs. Since the distance between electrodes in this scheme is large, significant pump rates require operation voltages in the kV range. Placing of electrodes within microchannels allows low-voltage pumping and enables local control of fluidic manipulations. In principle bubble generation can be suppressed by applying AC voltage over an array of interdigitated asymmetric electrodes or by pulsing a zero net current signal across electrodes at low frequencies, but this kind of micropumps with AC activation is extremely sensitive to the hydrostatic pressure difference and cannot be used for practical applications.

We have developed an electroosmotic micropump with integrated electrodes and a gas permeable poly(dimethyl)siloxan (PDMS) cover to allow electrolysis gases to escape through. The maximum pumping velocity in the field-free region is about 100 µm/s corresponding to a flow rate of 5 nl/min for operating voltages of 4-6 V. The application of higher voltages results in visible gas bubbles, because the generation rate of electrolysis products exceeds the gas permeability of the PDMS cover. Electroosmosis and electrolysis are tightly interrelated effects. Electroosmosis requires an ion current in the fluid and a continuous ion current is only possible if electrolysis takes place at the metal electrodes. Therefore, one option to cope with the bubble generation is to place the electrodes outside the main flow path using gel or liquid bridges as ion conductors.

The pumping pressure can be increased, when the ratio of the channel dimensions (channel height to channel width) is made much less than 1. The photosensitive polymer SU-8 was successfully used for the practical realization of the suggested vertical narrow gap micropump. It allows the fabrication of rib structures with aspect ratios up to at least 20 and vertical side walls. The newly designed electroosmotic micropumps use polyacrylamide gel electrodes to eliminate a gas bubble generation inside the main channel. First experimental results are presented.
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Introduction
At present, most of the microfluidic systems are fabricated by means of micromechanical procedures on glass or polymer substrates. This approach makes it difficult to integrate control and detection functions on a single chip. A novel concept for a monolithically integrated Application Specific Lab-on-Microchip (ALM), presented in [1], employs a standard CMOS ASIC (Application Specific Integrated Circuit) as substrate for the microfluidic system and complex circuitry for fluid handling, process control and data acquisition.

Crucial for the labchips is the transport of reagents and analytes from reservoirs to reaction chambers and back. In order to achieve high throughputs in such systems, the design of high pressure electroosmotic pumps is necessary. Electroosmotic micropumps are water electrolysis and bubble generation on the metal electrodes. Therefore, for most applications, electrodes are placed in open reservoirs. Since the distance between electrodes in this scheme is large, significant pumping rates require operation voltages in the kV range. Placing of electrodes within microchannels allows low-voltage pumping and enables local control of fluidic manipulations.

AC electrokinetic micropump
A theoretical analysis of the electroosmotic pumping generated by an AC potential applied to an array of asymmetric pairs of electrodes has been elaborately described in [2-4]. We have studied pumping properties of AC electrokinetic micropumps using interdigitated asymmetric electrode arrays, fabricated on glass substrate and oxidized silicon wafer and shown in Fig. 1.

All measurements were carried out immediately after pressure balancing because even short pumping time (10-20 sec) increases the back pressure and stops the fluid movement. Fig. 2 shows the fluid velocity as it varies as a function of the applied voltage. It reaches a maximum value of (40-50) µm/s at (7-9) V<sub>pp</sub>. A higher voltage generates gas bubbles and degrades electrodes because of electrolysis and electrochemical reactions in the fluid. We conclude that this kind of micropumps is extremely sensitive to the hydrostatic pressure difference and therefore cannot be used for practical applications on labchips.

Vertical narrow gap electroosmotic micropump
The maximum working pressure of an electroosmotic pump in a rectangular channel is reciprocally proportional to the square of the channel height. In order to increase the pump pressure the height of the channel needs to be reduced. This method was implemented successfully for the design of high pressure electroosmotic pumps [5, 6]. For a planar integration we have suggested a pump design with several vertical microchannels as depicted in Fig. 3. The pump velocity in the field-free region of the channel is the function of the pump geometry and can be increased, when the ratio d/h is made smaller than 1 [7]. This important result is illustrated in more detail in Fig. 4.

The practical realization of the suggested vertical narrow gap micropump is subject to two major technological issues: First, it requires rib structures with an aspect ratio of 20-30. SU-8 is a widely used high contrast epoxy based photoresist mainly designed for MEMS applications. It cannot be used for practical applications on labchips. Second issue is water electrolysis and bubble generation. Electroosmosis and electrolysis are closely interrelated effects. Electroosmosis requires an ion current in the fluid and a continuous ion current is only possible if electrolysis takes place at the metal electrodes. Therefore, one option to cope with the bubble generation is to place the electrodes outside the main flow path using gel [8] or liquid [9] bridges as ion conductors. Another option is the use of gas transparent cover materials on top of the pumps [10]. We have developed an electroosmotic micropump with integrated internal gas and a permeable poly(dimethyl)siloxan (PDMS) cover to allow electrolysis gases to escape through. The maximum pumping velocity in the field-free region is about (100) µm/s corresponding to a flow rate of 5 nl/min for operating voltages of 4-8 V. The application of higher voltages results in visible gas bubbles, because the generation rate of electrolysis products exceeds the gas permeability of the PDMS cover.

Electroosmotic micropumps with gel electrodes

The newly designed electroosmotic micropumps use polyacrylamide gel electrodes to eliminate a gas bubble generation inside the main flow path. Fig. 6 shows pump microphotographs before gel lithography. The patterning of polyacrylamide gel using a photolithographic technique is presently not optimized. Another problem of these pumps is gel shrinkage during dehydration. Fig. 7 shows the pump with one chemical polymerized gel electrode. With this micropump the pumping speed about 200 µm/s in 8 mm long channel at electrodes voltage of 40 V has been observed.

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References