CHANNEL FLOW NETWORK AT LOW ELECTRIC FIELD WITH HIGH FLOW RESISTANCE COMPENSATION PATTERN

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ABSTRACT

This paper presents the possible factors associated with the degradation that can be generated in a channel network structure and provides a solution to overcome this and assure high reliability. Cyclic capillary electrophoresis, which is the one of the channel network structures, has advantages in downsizing and a low operation voltage. However, there are some problems such as sample loss when the injected plug encounters the junctions in the middle of the channel. This paper explains the phenomenon of the cyclic CE as an example of the channel network structure. In the new design, the quartz cyclic CE chip showed < 2 % degradation per junction. This means the high resolution CE analysis has 100,000 plate numbers after a three and one quarter cycle (20.4 cm) in just a 4 cm x 4 cm chip.

INTRODUCTION

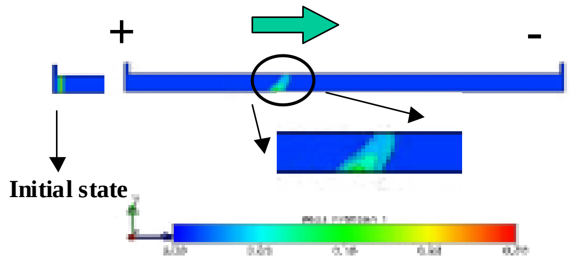
A channel network structure has a wide application and has the capability of downsizing. However, the complex microfluidic factors in this structure have prohibited the reliability and accuracy. Most of micro-analysis chips have a closed channel, which means that the analysis channel does not have any channel junction in the middle of the analysis. The reason for this is that sample loss is generated at the junction and the loss volume of that is not negligible and reliable. [1,2] These properties are too serious disadvantage of the network structure to try making a reliable chip. These problems are worse, if the source of flow is the E-field.

This study focused on these reasons and searched for a methodology to minimize them. For an accurate analysis, a cyclic CE chip was fabricated. Consequently, the sample intensity and the theoretical number were measured when the each junction was passed in the middle of the analysis channel. From the simulations and the test patterns, the major reasons for the signal degradation by the sample loss at junction could be determined, and the optimum structure could be designed. This paper suggests a design rule for a complex network structure, and a high resolution cyclic CE with little sample loss.

PRINCIPLE

It has been suggested that there are three critical causes of sample intensity degradation during migration in the junction structure.

The first reason is the cross E-field in the folded channel structure. In our cyclic CE, four side channels and two injection channels are attached the main separation channel. Therefore, the main separation channel always operates with the two side channels that are connected to the power supply. It is similar to the folded structure. However, in the consequent folded channel, the sample is re-located at the channel sidewall by the cross E-field as shown figure 1(a). This is because the plugged sample was affected by the cross E-field in the channel. In figure 1(b), it could be observed as the y-direction intensity. (vertical direction)

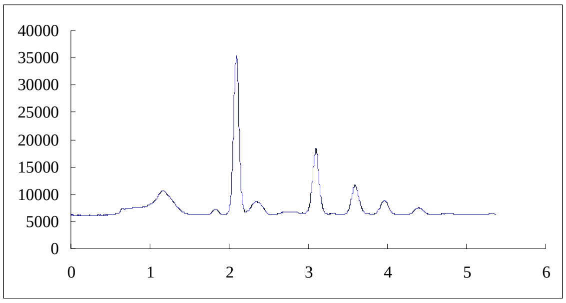


(a)

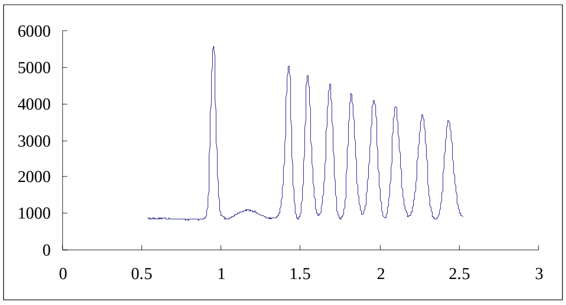
(b)

Figure 1. (a) The re-location sample simulation in the folded channel. (b) The simulation of E-field vector distribution; (Coventor^R Simulation)

In the laser test, if the laser was focused on the center of the channel, the intensity was abruptly lowered. However, in the case of edge focusing, the intensity degradation improved. This was proved by the laser induced fluorescein (LIF) test in our chip. Figure 2 show the result of round trip test between the detection point of the laser. When the injected sample plug migrated to the detector point, the polarity of the electrode was reversed. The plug then migrates reversibly, because the EOF flows oppositely. While repeating this test, the attenuation of the sample intensity could be observed. Figure 2 (a) shows the abrupt attenuation of the sample intensity when center focusing. When focused at the channel edge (fig. 2(b)), it also shows a little attenuation. However, this resulted from the photo bleaching by the repeated laser radiation. In addition, our chip was also designed to reduce the cross E-field minimally as a spiral side channel. It could also reduce these phenomena. However, it was essential to focus on the edge of the channel in order to assure enough sample intensity in laser test.



(a)

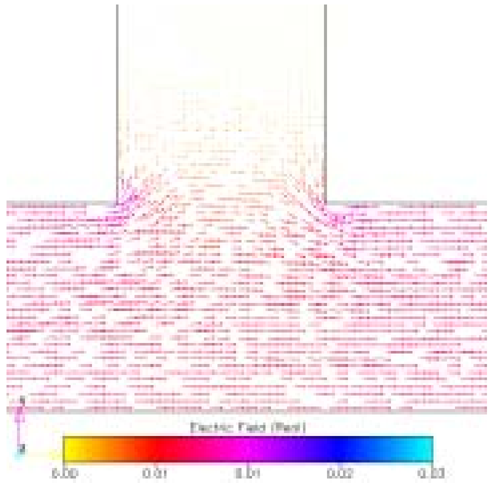


(b)

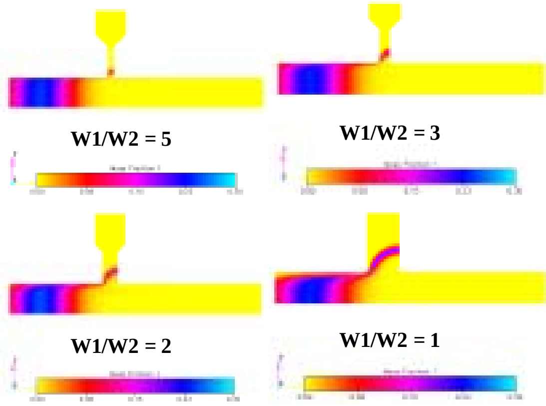
Figure 2. (a) The LIF test result on the center of the channel (b) on the edge of the channel ; 10 uM fluorescein was used as the sample and a 20 mM PH 9.0 borate buffer was used.

The second reason is the force from the water level difference in the reservoirs. This force was inevitable in the test. Although the chip test would be accomplished on the perfect flat table and the optical jig, the water volume could not be completely the same at each reservoir. Therefore, interference flow at the channel network junction occurred, which could be the reason for the sample loss and diffusion. In particular, at a lower electric field, mechanical flow can have a larger effect on the moving sample plug. There is the capillary flow, the inertia force and the force from water level difference of reservoirs in mechanical flows. These forces were analyzed mathematically, and the capillary force of the reservoir could be estimated and the inertia force in the capillary in which the viscosity force would be dominant could be neglected. However, the force from the water level difference could be the dominant flow to affect the sample plug. If the flow resistance from the reservoir to the main analysis channel were increased, this phenomenon would be minimized, because the source of the unwanted flow is mainly mechanical flow.

The third reason is, as described in a previous paper [2], the fringing field at the junction that can also make the sample plug diffused and can induce plug loss. As figure 3 (a) shows, the crossing E-field has a curvature field into the side channel that has a floating charge. By this fringing field, the crossing sample plug suffered from sample loss into the side channel. However, if the width of the side channel were narrower, a smaller sample loss volume is generated, as shown in figure 3 (b).



(a)



(b)

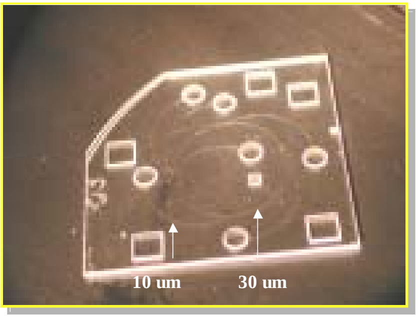
Figure 3. (a) The simulation of the fringing field distribution at the channel junction (b) The sample loss simulation at each channel width; W1 is the main channel width and W2 is the side channel width

In order to avoid these phenomena as the second and third reason, the flow resistance between the reservoir and the main separation channel should be designed to be sufficiently high.

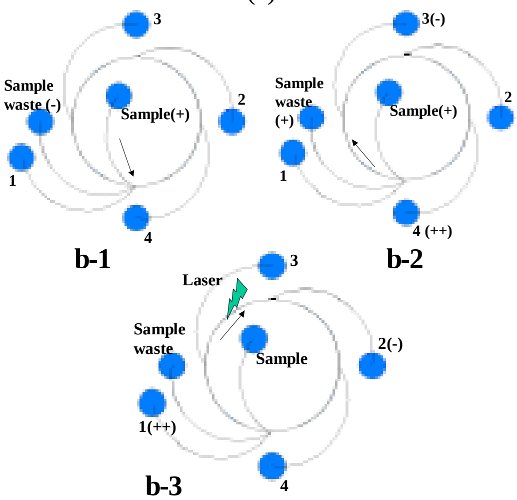
DESIGN

It was essential to design a narrow and long channel between the reservoir and main channel to assure enough flow resistance in order to overcome the

problems, as described in principle chapter.
The width of the side channel was 10 um with a 3 cm length and a 10 um depth. The width of the main separation channel was 30 um (fig. 4(a)).
The operation algorithm for the cyclic CE is shown in the figure 4(b). When the sample was injected through the sample injection channel, electrode 4 was turned on with floating electrode 3 to inject the sample plug into the main channel. In this procedure, at the sample and sample waste electrode, a positive voltage that is smaller than half the voltage, which is loaded at electrode 4, must be loaded in order to avoid sample diffusion into the main channel. The sample then migrates in the circular channel by the synchronous switching electrodes, as shown in Table 1.



(a)



(b)

Figure 4. (a) The fabricated chip; The total chip size is 3.5 cm x 3.5 cm; (b) The operational schematics; (b-1) the sample injection; (b-2) the sample plug in with a drawback; (b-3) the sample plug flows by switching the electrode and investigated by the laser

FABRICATION

Quartz was adopted as the substrate because it has the excellent thermal properties and a high transmittance of laser light and has a uniform electro-osmosis flow (EOF) without any channel coating material. In addition, quartz can have a CMOS compatible process unlike a glass wafer with sodium ions. As described in figure 5, the channel on the quartz chip was wet-etched by a 49 % HF solution using a polysilicon etch mask. The quartz etch rate was 1.2 um/min. The polysilicon was stripped by a 20 % tetramethylammonium hydroxide (TMAH) solution at 90 centigrade for two minutes. The reservoir was patterned by a sandblaster using 20-um sand with a 100-um thick dry film resist (DFR; BF410, Tokyo Ohka Kogyo Co., Japan) etch mask. The DFR etch mask was stripped using acetone at 60 centigrade. The two fabricated quartz wafers were bonded directly at room temperature after SC1 solution cleaning (NH_4OH : H_2O_2 : H_2O = 1:1:5) and acid cleaning (H_2SO_4 : H_2O_2 = 4:1). This step is referred to as initial bonding. Essentially, the bonding area was determined at the initial bonding. To assure a wider bonding area, a 100 : 1 HF dipping step would be added after the cleaning step. It also allowed easy bonding, which did not require any pressure. [3] Subsequently, the wafers were annealed in a 1100 centigrade furnace tube for 2 hours in order to insure a concrete bonding strength.

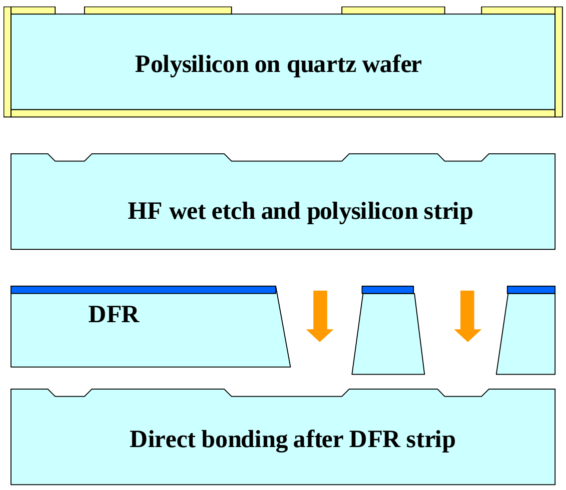


Figure 5. Fabrication sequence

The heated wafers were cooled naturally overnight to avoid the crack in wafer due to an abrupt temperature change.

Table 1. Electrode switching algorithm

Electode1	**Floating**	**Floating**	**V2**	**Floating**	**GND**	**Floating**	**V2**	**……**
Electode2	**Floating**	**Floating**	**GND**	**Floating**	**V2**	**Floating**	**GND**	**……**
Electode3	**Floating**	**GND**	**Floating**	**V2**	**Floating**	**GND**	**Floating**	**……**
Electode4	**Floating**	**V2**	**Floating**	**GND**	**Floating**	**V2**	**Floating**	**……**
sample	**V1 ***	**V1**	**Floating**	**V1**	**Floating**	**Floating**	**Floating**	**……**
waste	**GND**	**V1**	**Floating**	**V1**	**Floating**	**Floating**	**Floating**	**……**
	One cycle					**Next cycle**		

*** V1 = V2 / 2-100**

RESULTS

Using this design, the high resolute separation of the dichlorofluorescein (DCF; Merck co., Germany) and fluorescein-5-isothiocynate (FITC; Aldrich co., USA) could be accomplished with a minimal sample loss. Figure 6. shows the separation results from the design of the 10 um width and 3 cm length side channel. This result was achieved after two and a half cycles (14.1 cm) with the first peak occurring at 1.57 cm and the second peak occurring at 7.85 cm. The liquid velocity was slower when the buffer concentration was higher. Therefore, the mechanical flow listed above would be more dominant. Fig. 6 (c) shows this problem. After the first peak (quarter cycle), the unwanted two peaks mean sample loss occurred at the junction as a result of the mechanical flow. Of course, if the sample concentration were smaller, it would be minimized, as shown in fig. 6(d). In the case of a 30 um width and a 3 cm length side channel, there was sufficient flow resistance, as shown in figure 7. In addition, the test time would be faster than in the former case for the lower flow resistance. However, the baseline would be rougher, and a noise peak would be observed immediately after the main peak by the fringing field at the junction. The theoretical plate number was dramatically increased at each repetitive turn. (fig. 8) If the difference in the analyte mobility were smaller, it would possible to migrate for more than four cycles (over 26 cm) and the theoretical number would be higher. The E-field for the EOF was as much as 350 V/cm. In addition, the sample loss per cycle (four junctions) was < 10 %. However, an approximately 5 % sample loss was generated by a photo bleaching effect. Therefore, just 5 % sample loss per one cycle is estimated to have occurred. However, in the case where the laser was focused on the center of the channel, the sample plug was diminished before a one and a half turn.

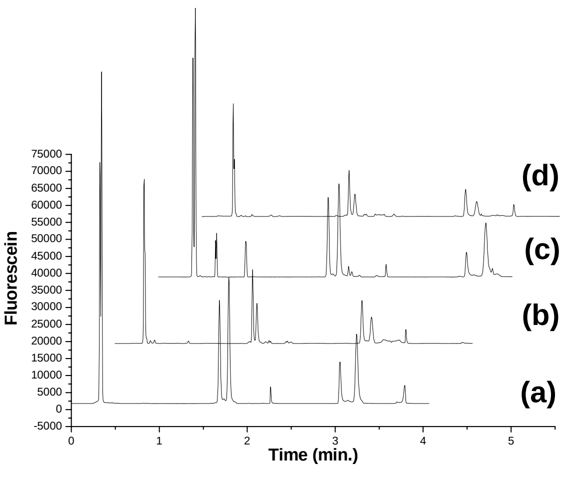


Figure 6. The LIF test results of the cyclic CE with a 10 um width side channel; (a),(b) 10 mM buffer, (c) 20 mM buffer (d) 20 mM buffer with 5 uM sample; 10 uM DCF and a FITC for the sample and a borate buffer was used

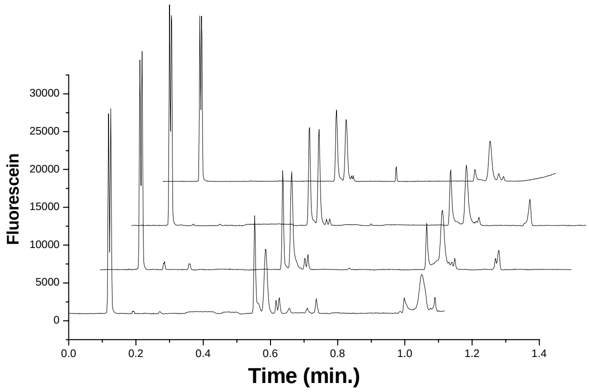


Figure 7. The LIF test results of the cyclic CE with a 30 um width side channel; 10 uM DCF and FITC for the sample and borate buffer was used

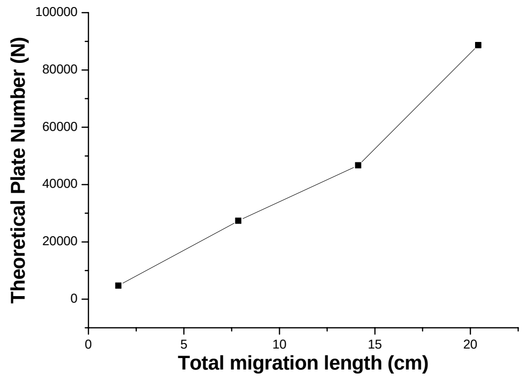


Figure 8. The increasing theoretical plate number as circulating in the cyclic CE

ACKNOWLEDGEMENT

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