Microelectronic Engineering 140 (2015) 11–17

Contents lists available at ScienceDirect

Microelectronic Engineering

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

Pressurization method for controllable impulsion of liquids in microfluidic platforms

G. Flores *, F. Perdigones, C. Aracil, J.M. Quero

Dpto. Ingeniería Electrónica, Universidad de Sevilla, Spain

ARTICLE INFO

Article history:
Received 9 January 2015
Received in revised form 14 April 2015
Accepted 22 May 2015
Available online 29 May 2015

Keywords:
Integration
PCB
Impulsion
Microfluidic platform

ABSTRACT

In this paper, a pressurization method for manufacturing an independent impulsion system is proposed. The method consists in inserting a deformable material filling a microchamber, leading to its pressurization, which will be on charge of the movement of fluid. The reached pressure involves a wide range of positive values which match well for its application in microfluidic systems, such as Lab on a Chip. It has to be highlighted that the portability of microfluidic platforms is improved due to the fact that the use of external pumps to impulse the fluids can be avoided. So, the paper is focused on the displacement of fluid from one part of the microfluidic circuit to another, with the minimum error, in steady state. The control on the impulsion of liquids only depends on the volume of material which has been inserted. This method is intended to be used with an actuation system, in order to perform the impulsion of fluids in a controllable manner. The permeability of the system has been also studied. The experiments have shown good impermeability during 1 h, time enough to perform the subsequent activation after pressurization. A microfluidic circuit, including the pressurized system, has been implemented for testing and as an example of a certain application.

1. Introduction

The handling of small volumes of fluids is an important issue in the development of Lab on a Chip (LOC) devices. There are many methods to achieve fluid flow [1]. However, in general, the motion of fluids is generated by external pumps connected to the microfluidic platform, making portable devices not possible due to the size of those pumps. Many micropumps have been reported for fluid impulsion in LOC applications [2], allowing the transport of controlled small volume of fluids. Different methods of activation are reported [3], but they usually present high power consumptions and require large areas of the LOC platform [4], increasing the cost and making the integration difficult. Therefore, the incorporation of these devices into the market is a hard task [5].

In order to overcome these problems, one of the strategies found in the state of the art, is the design of devices that incorporate a pneumatic system to store pneumatic energy [6–9]. Thanks to this approach, external pumping is not necessary, since there are provided portable reservoirs that can be integrated in small areas of the chip. The main problem in these cases is related to packaging, since pressure sealing increases drastically its cost [10]. So, an important requirement of our design was low cost fabrication. A convenient solution in order to solve this problem is using PCB as a substrate. Moreover, its versatility for integration with electronics and polymers makes it very beneficial. Many devices have been reported in this field using PCBMEMS technology [11–15].

The starting point of this method was a previous work [16] related to the fabrication of pressurized chambers. It was based on the injection of SU-8 through a long channel connected to a chamber to compress the air in the chamber. The dimensions of the channel and the chamber are calculated to achieve the desired pressure in the chamber. When the desired pressure is reached, the SU-8 is crosslinked blocking the chambers. However, the complex set-up made quite difficult the control of pressure in most cases, a syringe pump is needed with a rough connection to the device to avoid any leakage. So, an important aim is to minimize the required set-up.

In this paper, an improvement of this method is proposed in order to construct chambers at pressures over atmospheric one. If it is compared with the previous work, the current setup does not need syringe pumps, external tubes and pressure sources, avoiding possible leakages of the system. In addition, it reduces significantly the dimension of the microfluidic circuit because the auxiliary circuit for pressurization is reduced. Moreover, the method presented in this paper can be easily parallelized in order to pressurize several chambers at different pressures to move different volumes of fluids. This is an important issue if taking into account the mass-production of devices. An SU-8 general purpose microfluidic circuit is fabricated to demonstrate the working of the proposed method. However, this method does not depend on the fabrication material and process. For testing the working of the system, a SU-8 microfluidic circuit will be performed. Also, a study of the

* Corresponding author.
E-mail address: gflores@zipi.us.es (G. Flores).

http://dx.doi.org/10.1016/j.mee.2015.05.002

permeability of this pressurization method for SU-8 based microfluidic platform is carried out.

The rest of the paper is structured as follows. In Section 2, the concept of the pressurization is commented. In Section 3, the fabrication process to construct the microfluidic circuit is described. In Section 4, the experimental results are reported and discussed. Finally, the conclusion of this research is commented in Section 5.

2. Pressurization system

The concept of pressurization is based on the Boyle's Law

$$P_1V_1 = P_2V_2 = \text{constant}. \quad (1)$$

This expression states that, at constant number of moles and temperature, pressure and volume are inversely proportional. Where P_1 and V_1 are the initial pressure and volume, and P_2 and V_2 are the pressure and volume in final conditions. Boyle's Law explains how the volume of a gas varies with the surrounding pressure.

Applying this concept, the difference of initial volume and final volume brings about a change of pressure. So, the pressure of a chamber can be controlled by means of the change of volume. The impulsion system is based on the use of an auxiliary chamber, where the gas is compressed when a deformable material is inserted. The part of the microfluidic circuit to be pressurized will be connected to the auxiliary chamber through a small microchannel. When the pressure of this chamber is released, by means of an actuator, the impulsed volume is the same than the injected one. Therefore, the proposed system could be completed with a microvalve to activate the system in a controllable manner. This method is designed to be single-use. Even though the advantages of continuous operation devices are wider in general applications, single-use devices provide interesting advantages on biological and chemical applications. These are disposables, low-cost and highly integrable due to the fact that these do not need a cleaning circuit that assures its sterilization. The generic system can be seen in Fig. 1.

The method is summarized in Fig. 2, where a cross view from Fig. 1 is detailed. The initial pressure in the chamber is atmospheric one (P_1) (step a). The procedure consists in inserting a putty-like modeling material as a filler in the auxiliary chamber through the hole of the substrate. In this case we used plasticine, however any material with similar properties can be used. During the process the pressure increases meanwhile the material is being inserted (step b). Finally, the auxiliary chamber is filled in and the final pressure is reached (step c). The microchannel acts as a filter defining the amount of putty injected. As it was commented before, the pressure on the pressurized chambers depends on the volume of those chambers, and the injected material following Eq. (1), where P_1, P_2, V_1 and V_2 are the atmospheric pressure, the final pressure on the pressurized chamber, the initial volume (auxiliary chamber, pressurized chamber, microchannel and hole

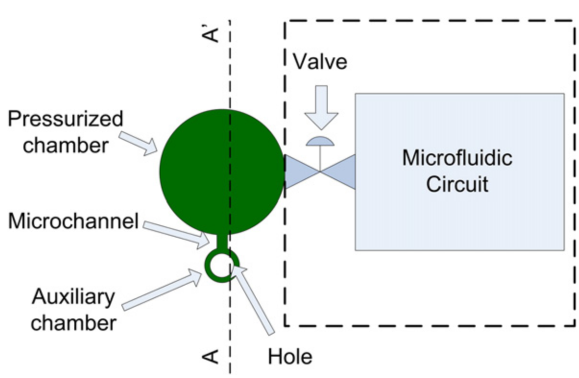

Fig. 1. Microfluidic structure. The parts of the microfluidic structure can be seen.

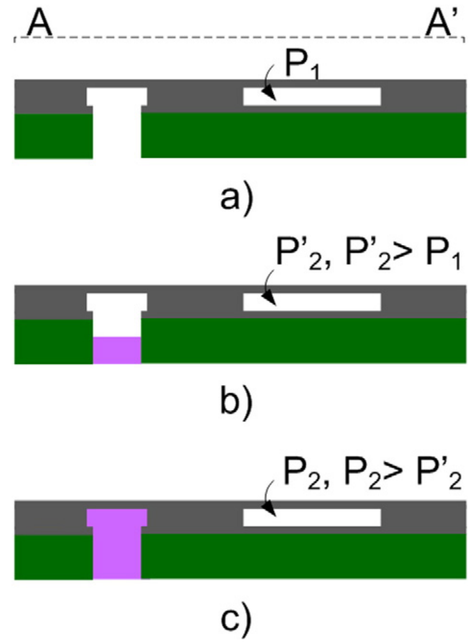

Fig. 2. Pressurization method, step by step, from the cross view AA′ of Fig. 1.

substrate) and pressurized chamber volume, respectively. The theoretical inserted volume V_{ha} is the sum of the volumes of hole substrate and the auxiliary chamber, that will be the impulsed volume after the activation.

Therefore, the design parameters are the diameter of the hole, the substrate thickness and the chamber dimensions because the volume of the microchannel is designed to be negligible if compared with V_{ha}. Finally, the expressions of V_{ha} and P_2 can be written as a function of the chambers and hole dimensions as follows:

$$V_{ha} = \frac{\pi D^2 H_{substrate}}{4} + V_{aux} \quad (2)$$

$$P_2 = P_1\frac{V_1}{V_2} = P_1\frac{V_{ha} + V_{pc}}{V_{pc}} \quad (3)$$

where D is the diameter of the substrate hole, $H_{substrate}$ is the substrate thickness, V_{aux} is the auxiliary chamber volume and V_{pc} is the pressurized chamber one. The volume of the microchannel has been neglected.

The ratio (inserted volume/total volume) has to be less than one because the inserted one has to be always smaller than the volume of the circuit. Otherwise, the samples would be transported out the device. The inserted volume has to be designed as a function of the volume to be moved, in order to transport the samples towards the desired place in the device. Therefore, this ratio depends on the designer.

The minimum inserted volume depends on the machining of the substrate, that is, on the diameter of the drilling tool used to perform the hole through a PCB substrate of 1.5 mm. The diameter has to be large enough to insert the filler material manually filling the chamber and to avoid the tool breaking. In our case, the minimum drilling tool has a diameter of 600 μm, to fulfill these issues. Therefore, the minimum volume is 0.42 μL, if the volume of the auxiliary chamber is reduced to zero.

Regarding the minimum pressure, it has to be enough to move the samples, that is, higher than the one due to the friction with the walls. In the proposed approach, the sample is colored water and the material is SU-8. The friction on the circuit can be considered negligible due to the hydrophobic nature of the SU-8.