Syringe Based Automated Fluid Infusion System for Surface Plasmon Resonance Microfluidic Application

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Abstract. This paper presents the design, implementation and working of a syringe based automated fluid infusion system integrated with microchannel platforms for lab-on-a-chip application. Polymer based microchannels are fabricated and adhered to the silver coated glass substrates to direct the flow of the liquid at rates down to the value of 60 μL/min. The fluid infusion system integrated with the microfluidic platforms accounts for the precise and accurate monitoring of fluids at the micro-level presenting a scope for study of surface plasmon resonance based bio-sensing application.

Keywords: Lab-on-a-chip · Microfluidic · Surface plasmon resonance

1 Introduction

The field of microfluidics deals with the manipulation of the fluid flow to achieve steady flow, mixing of liquids etc. at micro, nano level [1, 2]. Recently Microfluidics devices are being used in diverse field or areas like bio-chemistry, food safety, pharmaceutics etc. for various bio-sensing, immune-sensing applications [3–5]. In such applications for many reasons detection of biomolecules like bacteria, proteins etc. are to be done at extremely small level and many a times presence of such target biomolecules in the sample is also very low [6]. Also point-of-care application demands for miniaturized devices that can integrate sensing and transducing element on same platform. The sensing devices in Lab-on-a-chip are to be exposed to the target sample at micro to nano levels. This demands the development of micfluidic devices that can allow precise manipulation of liquids at such extreme low volumes.

One of the specific applications of microfluidics is surface plasmon resonance (SPR) based biosensing which uses an optical transduction method for detection [7]. The measurement process requires the passage of the samples extremely precisely and accurately over the surface of the SPR sensor chip in order to produce extraordinary detection limits [8].The integration of microfluidics with SPR sensing provides the advantages of automation leading to precise control over reactions, fast processing with

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small sample volumes and better sensing efficiency [9–12]. The use of microfluidic integrated platforms allows for the utilization of SPR lab-on-a-chip application for point-of-care testing. The increasing popularity of the SPR technique is observed in fundamental biological studies, health care research, drug discovery and clinical diagnosis, environmental and agricultural research etc. [13]. In this direction, a miniaturized pumping system with a flow rate of 250 μL/min is reported by Liu et al. for injection test samples to a SPR sensor for the detection of lectin concanavalin A (Con A) and glycoprotein ribonuclease B (RNase B) [14]. Tee et al. designed an automated syringe based fluidic system for microfluidic application that can provide flow rate as low as 100 μL/min using a 5 ml syringe [15]. The authors also reported a syringe based system integrated with polyimide fabricated microfluidic device to allow flow of liquids at relatively high flow rate in the range 1000–5000 μL/min [16].

This paper presents the design and implementation of a syringe based automated fluid infusion system to pump liquid through microchannels. Polymer based microchannels were fabricated and later adhered to silver coated glass substrate for the construction of microfluidic platform. This allows directing liquid samples and reagents to the sensor surface at flow rates down to 60 μL/min. The developed system integrated with the microfluidic platforms thereby presents a scope for use in surface plasmon resonance (SPR) based biosensing and multichannel outlet systems for lab-on-a-chip applications.

2 Experimental Methods

2.1 Design of the Syringe Based Fluid Infusion System

The working of the infusion system is based on the displacement of a syringe piston through a program controlled bipolar stepper motor. The shaft of the stepper motor (4.2 kg cm) is coupled to a linear slider of length 300 mm which is connected to the plunger of the syringe with the help of a sliding support to convert the rotational motion of motor into linear movement of the piston. The microcontroller controlled program signals the motor driver to rotate the stepper motor which exerts a force on the slider thereby pushing the plunger of the syringe forward causing the infusion of fluids. The infusion system has a provision for mounting of two syringes of different volumes that allows fluid flow in different ranges. The 10 ml syringe provides flow rates as high as 3000 μL/min while the 1 ml syringe provides flow rates as low as 60 μL/min. A soft flexible tube of inner diameter and outer diameter 0.2 mm and 0.4 mm respectively is used to direct the flow of liquids to a microfluidic device made of epoxy resin.

A power supply (12 V, 2A) is used to feed the power to the microcontroller (Arduino) and the stepper motor driver (L293 N). A 4 × 4 keypad panel and a 20 × 4 Liquid Crystal Display are assigned to the input and output ports of the microcontroller

respectively from which they are powered for user interface purpose. Figure 1 shows the schematic representation of the syringe based fluid infusion system.

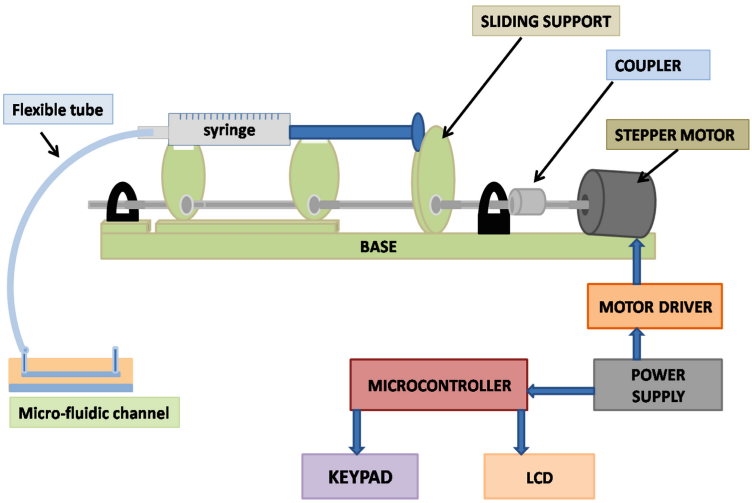

Fig. 1. Schematic representation of the syringe based fluid infusion system

The programming of the syringe based fluid infusion system is governed by a microcontroller to determine the step delay of the motor based on an algorithm. The library functions and the initialization of the input and output ports are defined in the program followed by the defining of step size of the bipolar motor (1.8˚) and the total number of steps (200) required for one revolution. The linear displacement of the slider (6 mm) due to one revolution of the motor is thereafter defined in the program. The volume of the syringe is calibrated with its length (length of 10 ml syringe = 5.25 cm) and defined in the program to determine the volume of fluid infused (1.14285714 ml for 10 ml syringe) per revolution of the motor. Thereafter the volume of fluid infused due to a unit step of the motor is determined (5.7143 µl). Finally, the step delay, which is the time required to move unit step of motor is defined by dividing the infused volume per revolution of the motor (5.7143 µL for the 10 ml syringe) with the desired flow rate. The developed low cost infusion system amounting to a sum of nearly rupees two rupees thus enables the variation of different flow rates using syringes of varied dimensions and volumes. Figure 2 shows the program flowchart.

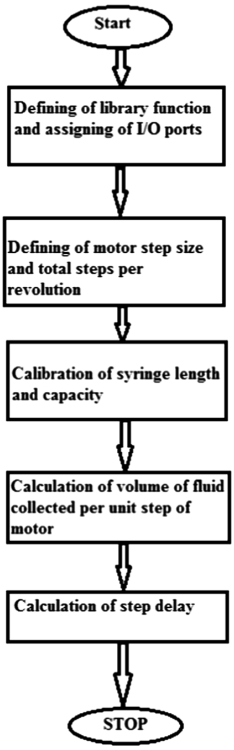

Fig. 2. Program flowchart

2.2 Fabrication of the Fluidic Microchannels

Polymer based fluidic microchannels were fabricated to direct the flow of the fluid infusion system through the microfluidic chambers. Figure 3 shows the schematic representation of the polymer based fluidic microchannels. High gloss epoxy resin clear coat was procured from Haksons containing the resin and the hardener. An epoxy resin flow cell was then fabricated by mixing the resin and the hardener in a solution of ratio 2:1. The solution was degassed for ten minutes in a water bath at a temperature of 50˚c before being stored for a duration of twelve hours at room temperature to undergo solidification. Multiple cylindrical shaped channels with radius measuring 0.5 mm and length measuring 30 mm (volume ~23.55 μl) were designed on the fabricated flow cell with separate inlets and outlets for the flow of fluids. The fabricated epoxy resin flow cell was then adhered to a silver film coated BK 7 glass substrate of thickness around 50 nm with the help of a suitable adhesive to prevent any leakage of liquid.

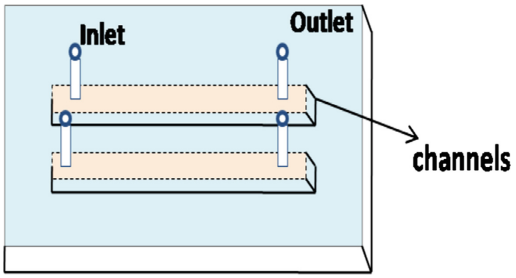

Fig. 3. Schematic representation of the polymer based fluidic microchannels

3 Results and Discussion

The syringe based fluid infusion system is experimentally tested by flowing fluids at different flow rates using two types of syringes of volume 1 ml and 10 ml.

Figure 4 shows the graph of the variation of the output flow rate with time at different values of set flow rates viz., 300 μL/min, 600 μL/min, 900 μL/min, 1000 μL/min, 2000 μL/min and 3000 μL/min using a 10 ml syringe filled with de-ionized water. The plots indicate a fluctuation in the output flow rate with time for the lower values of set flow rates viz., 300 μL/min–900 μL/min and a constant output flow rate with time for higher values of set flow rates viz., 1000 μL/min–3000 μL/min for various set of readings. Thus, the experimental results suggest that the 10 ml syringe based fluid infusion system provides a laminar flow of liquid only at the higher flow rates ranging from 1000 μL/min–3000 μL/min.

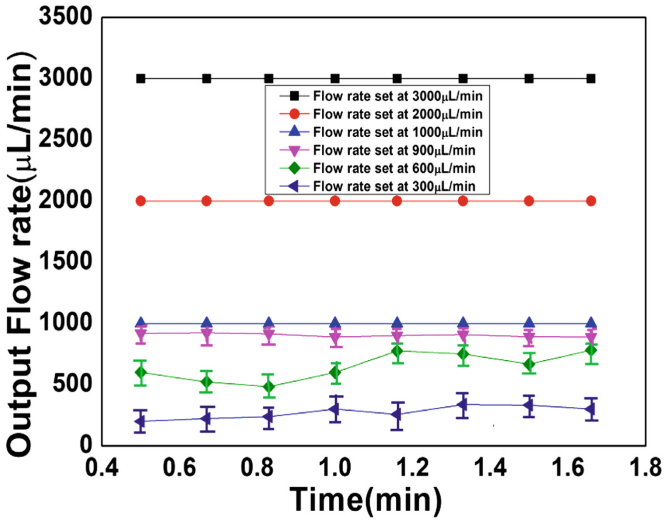

Fig. 4. Variation of the output flow rate of the infusion system with time at different values of set flow rates using a 10 ml syringe of DI water

Figure 5 shows the graph of the variation of the output flow rate with time at different values of set flow rates viz., 300 μL/min, 600 μL/min and 900 μL/min using a 1 ml insulin syringe filled with de-ionized water. The plots show a constant output flow rate with time for various set of readings. The results indicate that the 1 ml insulin syringe is more suited to be used at these flow rates in comparison to the 10 ml syringe owing to its small diameter as the minimal volume injected by the infusion system is proportional to the syringe diameter.

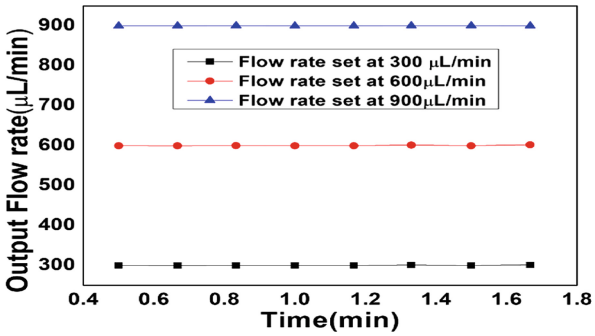

Fig. 5. Variation of the output flow rate of the infusion system with time at different values of set flow rates using a 1 ml syringe of DI water

Figure 6 shows the graph of the variation of the output flow rate with time at different values of set flow rates viz; 40 μL/min, 50 μL/min and 60 μL/min using a 1 ml insulin syringe filled with de-ionized water. The plots show a fluctuation in the output flow rate with time for the lower values of set flow rates viz., 40 μL/min and 50 μL/min while a constant output flow rate with time for a higher value of set flow rate of 60 μL/min for various set of readings. This is due to the fact that the stability in the fluid flow of a syringe based infusion system is governed by the rotation of the motor. Therefore, the pulses or oscillations appearing at the lower flow rates, represented by fluctuation in the data points on the graph, occur due to the mismatch of movement of the stepper motor in discrete steps with the diameter of the syringe. This mismatch can be improved upon with the use of a syringe of a lower diameter than a 1 ml syringe. Thus the experimental results indicate that the 1 ml syringe based fluid infusion system provides a stable, accurate and precise flow of liquid at a flow rate of 60 μL/min indicative of the minimum achievable flow rate of the fluid infusion system.

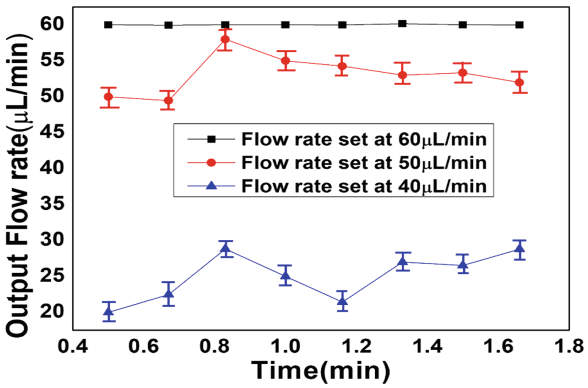

Fig. 6. Variation of the output flow rate of the infusion system with time (at low flow rate) using 1 ml syringe of DI water

4 Conclusion

This paper presents the design and working of a custom made syringe based automated fluid infusion system for precise monitoring of fluid flow at micro level. The system allows for the experimental variation of the flow rates down to the value of 60 μL/min using a 1 ml insulin syringe for use in microfluidics based application. The paper also presents the fabrication of polymer based microfluidic platforms to direct the fluidic flow at micro level without any leakage. The fluid infusion system integrated with the fabricated microfluidic platforms presents a future scope for use in surface plasmon resonance (SPR) based bio-sensing applications.

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