BISTABLE, TUBULAR PHASE CHANGE ACTUATORS FOR A LARGE SCALE MICROFLUIDIC MEMBRANE ACTUATOR PLATFORM

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ABSTRACT

We present an integrated platform with up to 200 bistable, individually controllable, thermally driven microactuators, that can be used as valves or pumps. In our setup the electronic control layer is completely separated from the fluidic actuators. This allows higher integration then achieved using commercially available surface mounted devices (SMD). The three-dimensional heating structure of our tubular actuators ensures optimum heat transfer, which significantly reduces the switching times. Using a demonstrator with six actuators we applied such actuators as microfluidic valves. The platform may also be used for various other applications such as micropipettes, micropumps and refreshable Braille displays.

KEYWORDS: Large Scale, Microfluidic Actuator, Valve, Refreshable Braille Display

INTRODUCTION

In microfluidics a lot of devices are disposable. Thus expensive sterilization of health care products is avoided. In order to be financially worthwhile the production costs of such disposable devices must be kept at a minimum. Thus the integration of actuators such as valves or pumps, that are used for microfluidic flow control, is often impossible. However, there are a lot of biological and chemical assays that can only be carried out if the fluid flow within the device is controlled precisely. For these applications external actuator arrays, e.g., refreshable Braille displays have been used in the past [1]. These displays are commercially available and consist of an array of pins that can be moved up and down. If a chip with a flexible membrane is pressed on such a device the pins can be used as propellant for a microfluidic membrane actuator. After usage the chip, which is the only part to come in contact with the sample volume, is disposed while the actuator array can be reused without any additional cleaning steps. However, the displays, which are based on piezo-electric actuators, are rather expensive. Besides, the refreshable Braille displays are designed for displaying one line of Braille text. Thus the actuator array is divided into several matrices of 3×2 actuators, each of which represents a Braille character. For chip design it would be easier to use an array with evenly spread actuators. Such systems are typically setup using pneumatic [2] or hydraulic [3] actuators. However, both actuator types consume energy constantly while the valve remains in the closed state. Thus these Lab-On-Chip systems either need a pressurized air-line or constant electric power supply and can therefore not be fabricated as portable devices. However, for many applications, e.g., point of care diagnostics portability is preferable. Therefore latched actuators based on the phase change of paraffin have been developed [4]. These actuators are often integrated directly into the microfluidic channels which may result in contamination of the reactants or even inhibit the reaction the system was designed for. Actuators that overcome this problem are based on the combination of inline membrane-based microfluidic valves actuated via a phase-change. However, these actuators tend to be rather bulky and have switching times in the range of several minutes [5]. To overcome this problem we propose a three dimensional actuator design which allows optimum heat transfer and thereby reduces the switching time to tens of seconds. By integrating several of these actuators into a microfluidic chip we designed a reusable platform for valving, pipetting and displaying Braille characters.

THEORY

To reduce the switching times of the thermally controlled phase change actuators we developed three dimensional heating elements, which consist of a heating wire that is wound around a commercial available tube forming a coil. The phase change material (PCM) used for these actuators is standard soft paraffin. To switch the actuator state, the PCM is melted and then shifted using pressure which is applied through a microfluidic channel network (control channels, see Fig. 1). Once shifted the state can be stabilized by turning off the heating thus resulting in valves with stable on- and off-states. Furthermore, in contrast to the concepts presented in literature this pressure is not created by a pressurized airline but provided by a small simple syringe pump integrated into the portable platform. In our design, the actuators are integrated in a matrix array with a pitch of 2.5 mm. By using a diode matrix each actuator tube can be heated and therefore controlled individually.

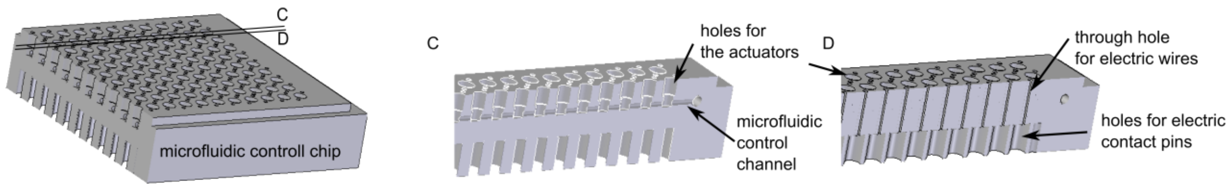

Figure 1: 3D-CAD drawing of the fluidic control chip containing 200 actuators. Sectional drawing C shows the microfluidic channel structure which allows to connect all actuators to the same pump. The electric wires that are used for heating the actuator are connected to electric contact pins using the holes depicted in sectional drawing D. These pins are then connected to a diode matrix which enables individual control of the actuators.

EXPERIMENTAL

For building up the tubular actuator setup the tube was cut into pieces of equally length. Then the tube pieces were filled with the PCM, e.g., soft paraffin. Therefore the tube pieces were dispersed in the liquid PCM. Afterwards the PCM was cooled down at room temperature. Then approximately 1 m of an electric resistor wire was wound in bifilar manner around each tube. When the wire has been wound around the tube, the actuator was glued to a microfluidic chip (see Fig. 1) that contains the channel network using PDMS. In order to connect the actuator to the electric board both ends of the heating resistor wire were connected to electric pins using a wire wrap tool. Using this technology the actuators were completely decoupled from the electric components on the circuit board. This allows higher integration in comparison to systems that rely on commercially available SMD resistors [5].

RESULTS AND DISCUSSION

For demonstrating bistability of the actuator concept we used a simple prototype as depicted in Fig. 2a. This Prototype consist of a silicon tube (inner diameter 2 mm). A PDMS membrane is bonded directly on top of the tube. For the first tests pressure was applied to the setup using a manually driven syringe. Later we integrated six of these actuators into an actuator array (Fig. 2b+c). In these array the actuators were controlled by switches. By connecting the actuator array to a chip with a microfluidic channel we could prove its usability as valve platform. However, for demonstration purpose the actuators of this array were rather big (inner diameter of tubes: 2 mm). For the actuator array consisting of 200 actuators tubes with an inner diameter of 1.4 mm are required. These actuators have a PCM volume of 15.4 mm³. For these actuators we experimentally determined the actuation time. The time for a whole actuation cycle consists of the time for melting the PCM, the time for displacing the melted PCM and the time required for PCM to solidify again. The time that is required for closing the channel is determined by the melting time of the PCM which was determined to be 11 s ± 1 s for the small actuators. Shifting the PCM can be done in less than 1 s. Then the channel is closed. For stabilizing the actuation state the wax needs to solidify again. In our experiments the time the PCM within the small actuators needed for solidification was 12,3 s ± 0,6 s. Thus the time required for a complete actuation cycle is approximately 24 s.

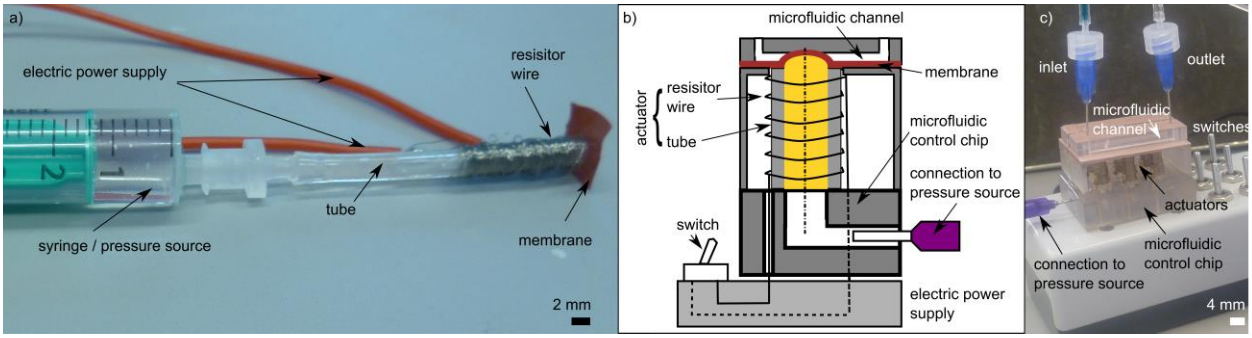

Figure 2: Implementation of the tubular actuators. a) First prototype for proofing bistability of the actuator concept. The actuator consists of a silicon tube onto which a membrane made of polydimethylsiloxane (PDMS) is bonded. The wire that is wound around the actuator can be heated thereby melting the PCM that is filled into the actuator. If the PCM inside the tube is melted and pressure is applied to the channel using a 5 ml syringe, the membrane will bulge. Then the electric power is disconnected and the PCM solidifies thereby stabilizing the current state. b) Schematic of the actuators of the demonstrator. The tube is now integrated into a rigid housing. A microfluidic control chip allows to address several tubes with the same syringe. On top of the actuators a microfluidic channel is located. The actuators can be used to control the flow within these channel. The electric wires of the actuators are connected to an electronic control which allows individual control of the actuators by means of switches. c) Implementation of an array containing six actuators. This array was connected to a device with a microfluidic channel in order to demonstrate its application as microfluidic valve.

CONCLUSION

In this paper we present a three dimensional PCM actuator design. Using this concept we were able to fabricate arrays with fast switching, latchable PCM actuators. By integrating hundreds of actuators to the same microfluidic chip we will provide a reusable actuator platform that can be used for valving as well as other applications, e.g., pumping or displaying Braille characters.

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