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Manufacture of three-dimensional valveless micropump

Yih-Lin Cheng *, Jiang-Hong Lin

Department of Mechanical Engineering, National Taiwan University of Science and Technology, 43 Keelung Road, Section 4, Taipei, Taiwan

Abstract

Up to the present, the manufacture of the micropump generally used MEMS processes to obtain micro scale channels. However, the geometry of the channels is usually 2.5D and the cost is relatively high due to the characteristics of the most micro fabrication techniques. In this research, we focused on manufacture of three-dimensional valveless micropumps in inexpensive approach. The design of the micropump consists of three horizontal inlet channels and one vertical outlet channel. The 3D geometry of the channels with minimum width of 80 μm gives great challenges in fabrication and is difficult to be achieved by traditional micro fabrication techniques. Shape deposition manufacturing (SDM) process, a layered manufacturing technique involving repeated material deposition and removal, was used to manufacture the chamber and channels of the micropump. CAD/CAM software was applied to slice the 3D model and plan the manufacturing sequences. The piezoelectric buzzer was attached to the fabricated valveless micropump chamber to test the performance. Three different channel width designs were manufactured successfully and tested at various piezo-triggered frequencies. This research provides a solution to manufacture the three-dimensional micropump geometry inexpensively. SDM process was proved to be a suitable approach to generate pre-assembled valveless micropump structure with micro channels, and is applicable to other similar applications.
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Keywords: Micropump; Valveless; Microchannel; Layered manufacturing; Shape deposition manufacturing (SDM); Piezoelectric

1. Introduction

Micropumps have been developed for more than two decades. Their characteristic of handling small and precise volumes of liquid and/or gas makes them able to serve chemical, medical, and biomedical applications with great scientific and commercial potential. Fuel delivery in a fuel cell system [1], drug delivery [2], and integration with miniaturized chemical analyzers as a “Micro total analysis system (μTAS)”[3] are some of the examples. The design of micropumps can be divided into valve-based and velveless. In valve-based pumps, mechanical check valves in terms of membranes or flaps are used. Wear, fatigue, and valve blocking are issues concerned in this type and limit its applications. Valveless micropumps, first introduced by Stemme and Stemme [4], use diffuser/nozzle elements to perform as a check valve. The construction of valveless micropumps is relatively simple compared to check valves and can avoid the problems mentioned above. Most common actuation methods in micropumps include electromagnetic [5], electrostatic [6], shape memory alloy [7], thermopneumatic [8], and piezoelectric [4,9–12]. Piezoelectric actuation can provide relatively a high actuation force and a fast mechanical response, therefore, is widely used in micropump development.

Micro-electro-mechanical system (MEMS) technologies are the major manufacturing approach to build micropumps in recent researches. Silicon micromachining and polymer-based micromachining techniques are the main categories. Silicon moving parts can avoid wear and fatigue problems in the long-run tests, but the material choice is limited and fabrication cost is relatively high. In polymer microfabrication, such as thick-resist lithography, soft lithography, micro stereolithography, and micro injection molding, the advantage is the possibility of using different polymeric materials to meet biocompatibility and chemical resistance for its potential applications. However, the limited material lifetime can be an issue and the goal of true low-cost micropump is still not achieved yet. Besides, most of the MEMS techniques can only build 2.5-dimensional geometry rather than a true three-dimensional one. The microchannel geometry was hence limited in the most designs. Therefore, there is a need to develop some manufacturing alternatives which are capable of building true 3D geometry at lower cost.

In this research, we focused on manufacture of three-dimensional valveless micropumps in inexpensive approach. A special micropump design with vertical and horizontal diffusers/nozzles is proposed initially as a micro-submarine’s propulsion system, but is not limited to this specific application.

* Corresponding author. Tel.: +886 2 2737 6450; fax: +886 2 2737 6460.
E-mail address: ylcheng@mail.ntust.edu.tw (Y.-L. Cheng).

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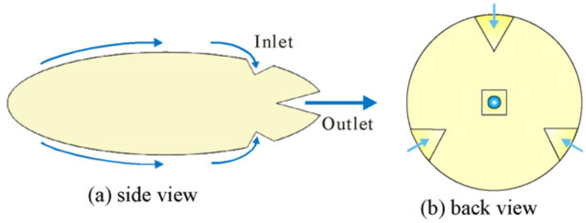

Fig. 1. Schematic drawings of a valveless micropump placed at the end of a micro-submarine with three inlets and one outlet.

A manufacturing alternative, shape deposition manufacturing (SDM) process, which can build true 3D geometry, was applied to fabricate pre-assembled chamber with inlet and outlet channels. Moreover, three valveless micropump designs with different channel width were fabricated and tested.

2. Design of the valveless micropump

The micropump developed in this research is a piezoelectric-actuated valveless pump. This pump consists of a chamber, three horizontal inlet channels, and one vertical outlet channel. This was originally designed for propelling a micro-submarine with the configuration of inlets from the side perpendicular to one outlet in the back as shown in Fig. 1.

2.1. Diffuser design

In the traditional valveless micropump, the working theory can be illustrated in Fig. 2. The dimension difference at the both ends of the diffuser causes the pressure difference and drives the

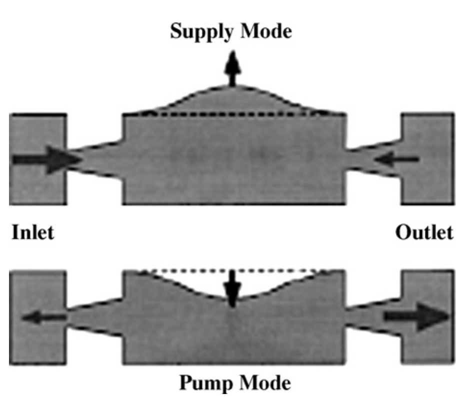

Fig. 2. The working theory of a traditional valveless micropump [13].

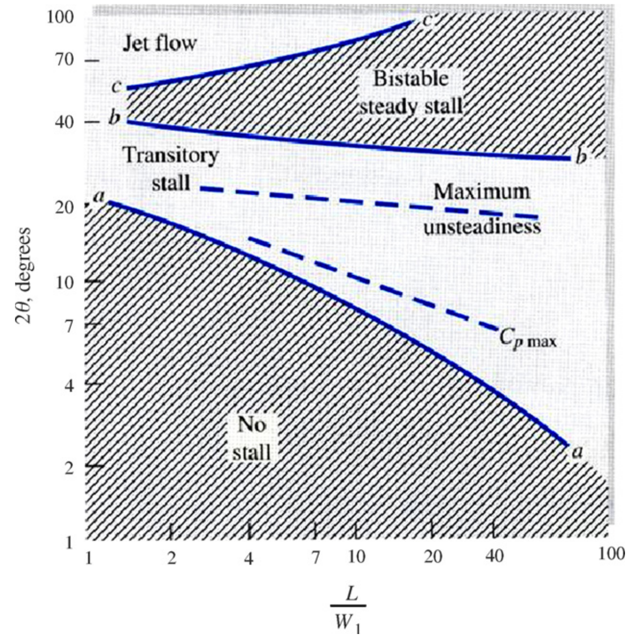

Fig. 4. The stability map of a diffuser [15].

fluid. In the supply mode, the actuator increases the chamber volume, resulting in a lower pressure inside the chamber. In this situation, the inlet flow is greater than the outlet flow; therefore, the fluid is supplied into the chamber. Reversely, in the pump mode, the decrease in the chamber volume increases the chamber pressure and, as a result, the outlet flow is greater than the inlet flow.

The diffuser/nozzle design determines the performance of the micropump. Diffusers can be categorized as conical and flat-walled with circular and rectangular cross-section, respectively (Fig. 3). According to the literature [15], the length of the flat-walled diffuser will be 10–80% shorter than that of the conical one under the same flow performance. Therefore, flat-walled diffuser design was chosen in this research. The major dimensions of a diffuser with the same channel height b include throat width W_1, exit width W_2, length L, and total included diffuser angle 2θ.

According to the stability map of a diffuser (Fig. 4), the diffuser operates in four different regions depending on the diffuser geometry. In the bistable steady stall (between b–b and c–c lines) and jet flow (above c–c line) regions, the flow performance is poor to extremely poor. Under the line a–a, the no stall region, the flow is steady viscous without separation at the diffuser walls

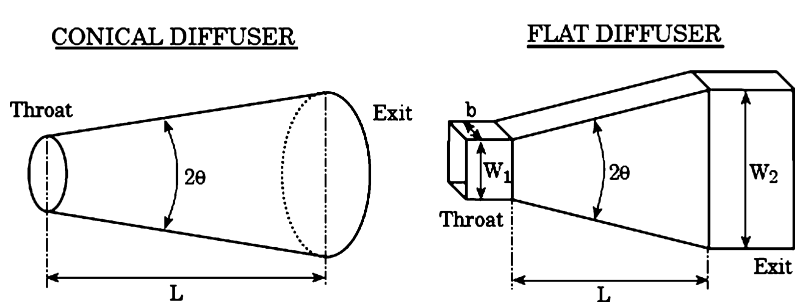

Fig. 3. Conical and flat-walled diffusers [14].

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