行政院國家科學委員會專題研究計畫成果報告

極高壓力振幅驅動器之設計 (1/3)

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國立台灣大學應用力學研究所

主持人: 胡文聰

中文摘要

本進度報告說明三年計劃之第一年進度。三年計劃總目的為設計及製造高壓驅動器，應用於微流體流動所需要之之泵及閥。

第一年重點在於驅動器之設計及評估。目前考慮以下幾種設計: RMS 設計，Helmholtz resonator 設計, tuned resonator 設計, 及 electrostatic 設計。文中討論各設計之等點及最近兩年多所提倡之 soft lithography fabrication – poly(dimethylsiloxane) (PDMS).

Abstract

This interim report outlines work done on the first year of this three-year project with the overall aim to study and fabricate a high-pressure amplitude device for micro device pumping and valve applications.

The first year effect has been focused on the preliminary study and design of a resonator chamber to amplify the initial pressure fluctuation. Several designs are current under serious considerations. Concepts studied include Resonate macrosonic synthesis (RMS), Helmholtz resonator design, tuned resonator design, electrostatic actuation. Pros and cons are discussed. The design will be fabricated using an elastomer material, poly(dimethylsiloxane) (PDMS), which offers substantial advantages over traditional silicon-based processes.

Introduction

MEMS based micro fluidic applications will be vital to success in micro total analysis systems (mTAS). Traditional approach calls for fabrication to be made in silicon processes, as is well known. There are disadvantages to this well-beaten approach, namely, planar surface profile (hard to implement 3D applications), long turn-around time, and expensive.

Current, there is a new class of fabrication method which is coined under the general class of “soft lithography.” [1-2] The process utilizes polymer material, which after heat cure, can be made to exhibit great MEMS fluidic devices. Device dimension can be a few nanometers. The technology has been invested only for the last five years and has gained tremendous interest since then. The fabrication time is another of its great attraction. With some experience, one can manufacture a micro-fluidic device in about a day, which takes weeks for traditional silicon based processing. The technology has already been applied in many applications [3-10].

Several high amplitude devices are being considered. They are the resonant macrosonic synthesis (RMS), Helmholtz resonator design (HRD), tuned resonator design (TRD), and electrostatic membrane design (EMD). Details are provided below.

Resonant Macrosonic Synthesis (RMS)

RMS method [11] tests a special resonator cavity which allows amplification of non-linear acoustic wave, thus producing large pressure fluctuation. Application of this technology will be explored in the present application. However, it is not clear whether the decreased scale will decrease the pressure amplitude to sufficient degree that hampers this potentially useful technology. A performance prediction code is being developed.

Helmholtz Resonator Design (HRD)

The HRD takes the traditional approach of using a Helmholtz resonator to establish a fundamental frequency for the device, as shown in Fig. 1.

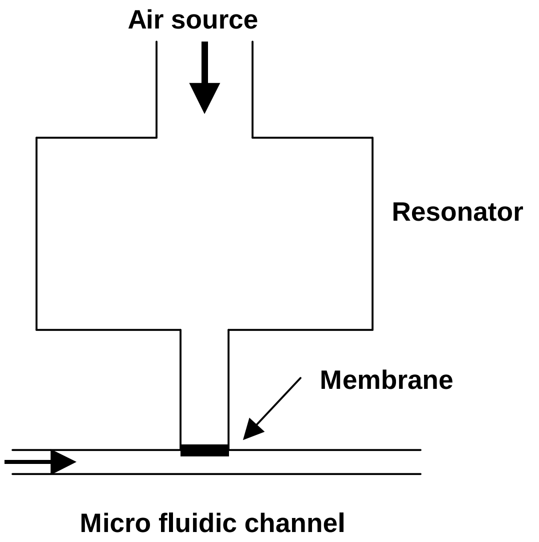

Fig. 1 The Helmholtz resonator design (HRD) which consists of the inlet duct, the resonator chamber, outlet duct with a vibrating membrane at its end. The membrane acts as a pump or a valve for the micro fluidic channel.

The basic idea for the HRD is as follows. An air source blows air into the inlet duct, which will compress the air in the resonator chamber. As the air expands, the springy action forces air back through the inlet tube, and set the frequency for the device – forms a Helmholtz resonator. The outlet tube has a small volume compared to the resonator chamber. The pressure fluctuation in the resonator is amplified when passing through the outlet duct at the frequency of the resonator. The pressure difference between the two sides of the membrane acts to pump fluid through the micro channel, or acts as a valve. (Fluid pumping will require more than one membrane, which should not be difficult to fabricate as an extension of a single-membrane device.)

The draw back of a HRD is as follows. Calculation of the classical Helmholtz resonator frequency shows that an excessive volume is needed to achieve low frequency (about 100Hz.) for membrane actuation. At higher frequency, would not have time to response [1]. For a micro channel configuration, volume of about $1000mm^3$ is needed, with inlet duct cross-sectional area minimized and a compatible duct length. This has several consequences. First, this almost forbiddingly large volume suggests only one "central" volume is allowed for adjacent membrane outlet tubes. (For multiple membrane configuration, phasing of the membranes can be achieved needs to be overcome.) Second, fabrication of such large volume using the PDMS might posses unique problem.

Tuned Resonator Design (TRD)

The Helmholtz resonator design suffers from a large volume required primarily due to that compression of air demands a large void space to achieve low actuation frequency. This is overcome by the TRD design. The basic idea is shown in Fig. 2. The design is very similar as that of Fig. 1 except of a tuned membrane without the resonator cavity. The spring constant of the membrane is much less than that of air so the tuned membrane substantially reduce the frequency of the device with a given volume. An analysis is underway to predict the resonant frequency of such device.

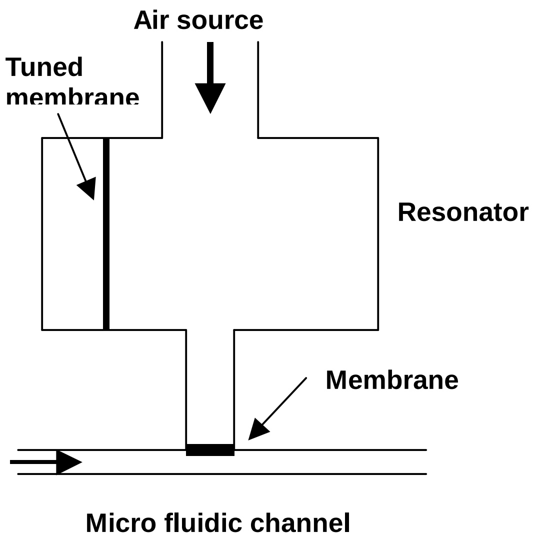

Fig. 2 The tuned resonator design (TRD) utilizes a flexible membrane within the resonator chamber. The tuned membrane has a lower spring constant than air thus decreasing the resonating frequency of that device.

Electrostatic Membrane Design (EMD)

Electrostatic actuation is an important form of drive mechanism in the MEMS world. In this work, we will consider the feasibility of electrostatic actuation in the context of pumps and valves.

Electrostatic actuation can be used to charge two electrodes in a capacitor. The charged surface will be mutually attracted to each other due to electrostatic force, and, if sufficient force, actuation results. The manner in which PDMS material can be used with electrical properties has been studied before [8,10]. Thus, implementation of the design should not be too difficult. However, it remains to be seen whether sufficient electrostatic force can be generated to close the valves. Further study is underway.

Soft Lithography – PDMS Processing

Fabrication of the device will use soft lithographic approach. Dr. Whitesides clearly states the advantages and disadvantages of soft lithography using polymer material – PDMS [2]. Since the article was published in Scientific American and intended for the general public, it is very easily understood, thus a portion is quoted below.

“To carry out reproduction using soft lithography, one first makes a mold or a stamp. The most prevalent procedure is to use photolithography or electron-beam lithography to produce a pattern in a layer of photoresist on the surface of a silicon wafer. This process generates a bas-relief master in which islands of photoresist stand out from the silicon [see top illustration on opposite page]. Then a chemical precursor to PDMS--a free-flowing liquid--is poured over the bas-relief master and cured into the rubbery solid. The result is a PDMS stamp that matches the original pattern with astonishing fidelity: the stamp reproduces features from the master as small as a few nanometers. Although the creation of a finely detailed bas-relief master is expensive because it requires electron-beam lithography or other advanced techniques, copying the pattern on PDMS stamps is cheap and easy. And once a stamp is in hand, it can be used in various inexpensive ways to make nanostructures.

The first method--originally developed by Amit Kumar, a postdoctoral student in our group at Harvard University--is called microcontact printing. The PDMS stamp is "inked" with a reagent solution consisting of organic molecules called thiols [see middle illustration on opposite page]. The stamp is then brought into contact with an appropriate sheet of "paper"--a thin film of gold on a glass, silicon or polymer plate. The thiols react with the gold surface, forming a highly ordered film (called a self-assembled monolayer, or SAM) that replicates the stamp's pattern. Because the thiol ink spreads a bit after it contacts the surface, the resolution of the monolayer cannot be quite as high as that of the PDMS stamp. But when used correctly, microcontact printing can produce patterns with features as small as 50 nanometers.

Another method of soft lithography, called micromolding in capillaries, involves using the PDMS stamp to mold patterns. The stamp is placed on a hard surface, and a liquid polymer flows by capillary action into the recesses between the surface and the stamp [see bottom illustration on opposite page]. The polymer then solidifies into the desired pattern. This technique can replicate structures smaller than 10 nanometers. It is particularly well suited for producing subwavelength optical devices, waveguides and optical polarizers, all of which could be used in optical fiber networks and eventually perhaps in optical computers. Other possible applications are in the field of nanofluidics, an extension of microfluidics that would involve producing chips for biochemical research with channels only a few nanometers wide. At that scale, fluid dynamics may allow new ways to separate materials such as fragments of DNA.

These methods require no special equipment and in fact can be carried out by hand in an ordinary laboratory. Conventional photolithography must take place in a clean-room facility devoid of dust and dirt; if a piece of dust lands on the mask, it will create an unwanted spot on the pattern. As a result, the device being fabricated (and sometimes neighboring devices) may fail. Soft lithography is generally more forgiving because the PDMS stamp is elastic. If a piece of dust gets trapped between the stamp and the surface, the stamp will compress over the top of the particle but maintain contact with the rest of the surface. Thus, the pattern will be reproduced correctly except for where the contaminant is trapped.

Moreover, soft lithography can produce nanostructures in a wide range of materials, including the complex organic molecules needed for biological studies. And the technique can print or mold patterns on curved as well as planar surfaces. But the technology is not ideal for making the structures required for complex nanoelectronics. Currently all integrated circuits consist of stacked layers of different materials. Deformations and distortions of the soft PDMS stamp can produce small errors in the replicated pattern and a misalignment of the pattern with any underlying patterns previously fabricated. Even the tiniest distortions or misalignments can destroy a multilayered nanoelectronic device. Therefore, soft lithography is not well suited for fabricating structures with multiple layers that must stack precisely on top of one another."

Concluding Remarks

The first year effort was spent in evaluating several promising approaches for a driver for pump and valves for microfuidic applications. Efforts are underway to finalize the candidate and fabrication procedure will be studied in the next few months.

Acknowledgement

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