PROJECT THESIS

ON

DESIGN OF A MICROPUMP

BY

AVADHESH UPADHYAY

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Prof. K.P.MAITY

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CERTIFICATE

This is to certify that the project thesis entitled “**DESIGN OF A MICROPUMP**” submitted by **Shri AVADHESH UPADHYAY** is based on bonafide work carried out by him under our guidance and supervision. This work has neither been published nor submitted to any other institution for the award of degree.

Prof. K.P.MAITY
Dept. Of Mechanical Engineering

SUBJECT APPROVED BY:

Prof. R.K.Sahoo
Professor & Head of the Department,
Department Of Mechanical Engineering,
NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA- 769008 (ORISSA)

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AVADHESH UPADHYAY

ABSTRACT

A micropump which can be produced using conventional production techniques and materials is presented. The micropump is capable of pumping both liquid and gas and is self-priming, which means that it can start pumping gas in a dry state and automatically fills with liquid. Basically, the micropump consists of two parts, a flat valve assembly with two passive membrane valves and an actuator placed on top. Two types of actuators have been applied to drive the pump; an electromagnetic actuator consisting of a magnet placed in a coil and secondly a disk. A disadvantage of the electromagnetic actuator was the relatively large volume occupied by the coil giving the micropump final dimensions of $10\times10\times8$ mm^3. Application of the piezoelectric actuator reduced these dimensions down to $12\times12\times2$ mm^3 with comparable performance.

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INTRODUCTION

Micro Total Analysis Systems (μTAS) are miniaturized chemical analyzers in which all necessary subsystems are combined. Besides sampling techniques, micro reactors and detectors, the handling of liquids and gases involved in an analysis forms an important part of the system. Fluid handling comprises the transport of fluids for sample intake, calibration of sensors and, for instance, the rinsing of the micro system by a washing solution. A micropump can be applied to propel these various fluids through the channel system. For this purpose, a number of micropumps have been designed and fabricated with different technologies.

The development of micropumps started in 1980 with the work of Smits and Wallmark at the University of Stanford with a peristaltic micropump using piezoelectric bimorphs [1]. In continuation of this work, at the University of Twente, by Van de Pol [2] and van Lintel et al. [3], a reciprocating displacement pump with piezoelectric monomorphs was realized with the intention to use the micropump in an insulin delivery system. In the work of Van de Pol, sputtering of piezoelectric films directly onto the silicon pump membrane was tried but these film showed a high temperature dependence and tendency for creep. As an alternative method for driving the membrane, a thermopneumatic driven micropump was manufactured [4]. Because of the thermal relaxation properties, the driving frequency can only be low. Also, micropumps with stack piezoelectric actuators were realized [5]. A disadvantage of this approach is the large piezo ceramic disc stack needed to reach a linear displacement large enough to open the valves and push out liquid. Another actuation principle is the electrostatic attraction of a thin membrane by a static counter electrode by the application of an electric field between them [6, 7].

Micromachining of silicon by anisotropic KOH wet etching was mostly applied in the work described above but other techniques have been applied also. One of them is the LIGA process [8], which enables the fabrication of microstructures with high aspect ratios in various materials. The process results in a metal mold insert that can be applied for the injection molding of plastics. Using this technique, a thermopneumatic actuated micropump for pumping gas was realized [9]. Valves were formed by a sandwich construction of the molded static valve parts with a thin polyimide membrane containing photolithographically patterned holes in between.

A major problem with almost all micropumps known in literature is that they have to be filled with liquid before use. Small gas bubbles inside the pump chamber act like mechanical springs and expand and compress during actuation of the chamber. If the pump stroke is small with respect to the gas volume in the pump chamber, the resulting maximum pressure reached in the chamber during a stroke is too low to open the valves, and no pumping action results. Only careful filling of the pump with incompressible liquid can make the pump to work. This priming of the pump imposes a serious problem on the operation of a microsystem.

Besides application in chemical microsystems, micropumps can be applied in medicine and in everyday consumer products. Two types were investigated: an electromagnetic and a piezoelectric membrane actuator. These actuator types were selected because they can be produced easily with conventional techniques. It is shown that both the electromagnetic actuator and the piezo actuator are capable of driving the pump but each has its own benefits regarding the input voltages and power consumption. A common feature of both types of pumps is that they are self-priming.

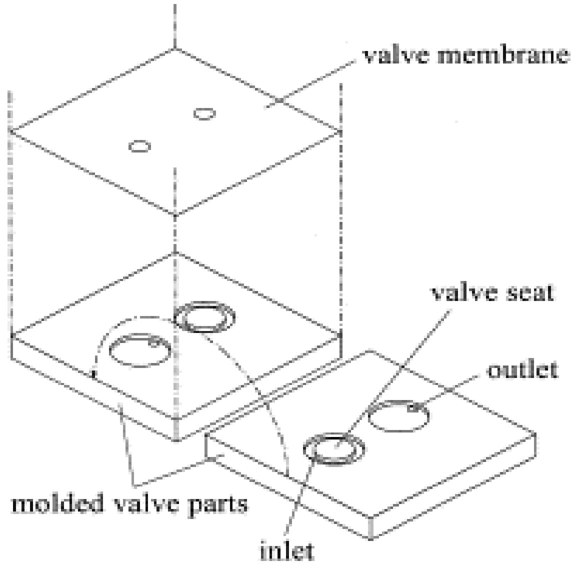
2. Description of the micropump

2.1. Pump construction

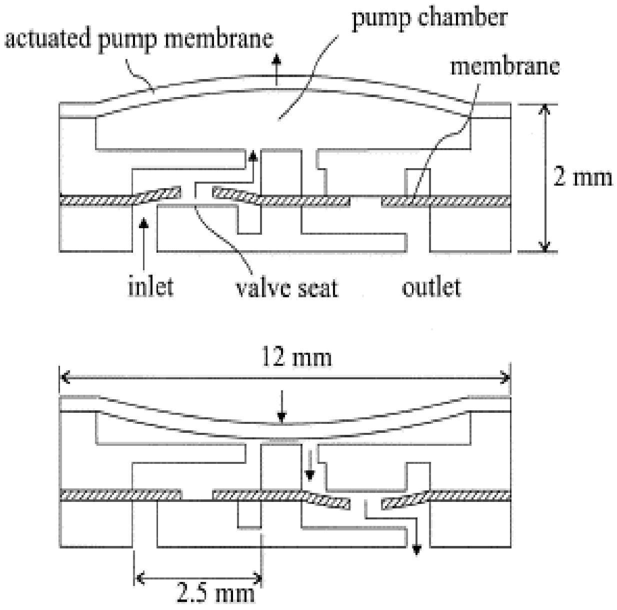
The micropump is a sandwich construction of two molded valve parts with a thin valve membrane in between. In each valve part a valve seat is present which in combination with the valve membrane results in a passive one-way membrane valve. The resulting two valves have opposite flow directions as can be seen in the cross-section . On the bottom of the pump are the inlet and outlet situated, while on top, the actuated pump membrane is placed. This configuration minimizes the dead volume of the pump chamber which is beneficial to allow the pump to be self-priming. If isothermal compression starting at atmospheric pressure p_{atm}, is assumed, the pumping of gas, which is a requirement for a self-priming pump, is achieved when:

$$\frac{V_{\mathrm{stroke}}}{V_{\mathrm{dead}} + V_{\mathrm{stroke}}} p_{\mathrm{atm}} \geq p_{\mathrm{min,gas}} \tag{1}$$

where V_{dead} is the dead volume of the pump chamber including the valves, V_{stroke} is the volume stroke of the actuator, and $P_{\mathrm{min,gas}}$ is the pressure at which a dry valve opens. If the pump is filled with water and the valves are wetted, a comparable relation can be derived for the maximal gas volume that is allowed in the pump chamber before pumping stops.



Sandwich construction of two molded plastic valve parts and a thin punched membrane in between.

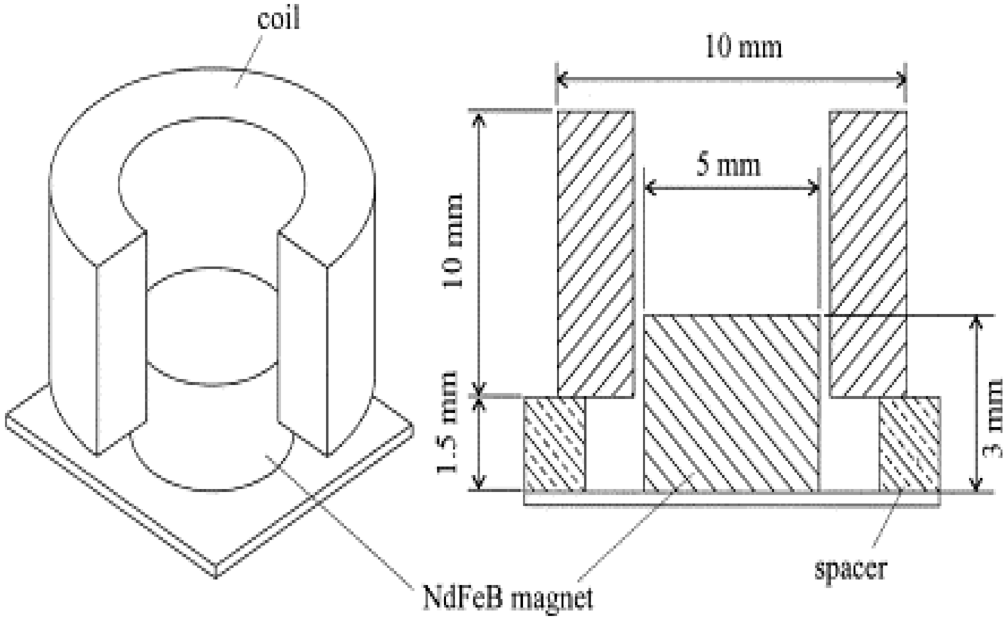


Cross-section of the pump showing the directions of flow for different actuating phases.

For the pump construction given , dead volume is in the order of 1 µl. This volume consists of the volume under the pump membrane and the upper halves of the valves.

2.2. Electromagnetic actuator

Two types of actuators were applied to drive the pump membrane. First, an electromagnetic actuator consisting of a permanent magnet placed in a coil was used in combination with a flexible pump membrane . In fact, this is the conventional construction of an electromagnetic loudspeaker. To investigate the forces that can be applied on the membrane, a two-dimensional finite element package for electromagnetic systems was used (Gemini v1.0, Infolytica, UK). A two-dimensional calculation could be used because of the cylindrical symmetry around the centerline.



Construction of the electromagnetic actuator. Dimensions are in millimeter.

The actuator that was calculated consisted of a permanent magnet (NdFeB) placed halfway into a coil. By the application of a current through the coil Lorenz' forces, up or down, are generated at the site of the coil which result in a force in the vertical direction depending on the current. For a current of 100 mA, the calculated force was 0.11 N. This force was linearly dependent on the current for practical ranges of 0–500 mA. The advantage of this construction is its simple design of driver electronics. A disadvantage is the rather large power consumption (5 V, 100 mA).

Because of the flexible rubber pump membrane used in this actuator, the stroke volume can be very large with respect to V_{dead}. Therefore, the actuator force divided by the surface area of the magnet gives the pressure that can be reached in the pump chamber which is 5.0×10^{3} Pa at a current of 100 mA and a magnet having a diameter of 5 mm. The opening pressure of the valves should be under this value for the pump to be self-priming.

2.3. Piezoelectric actuator

The second actuator consisted of a 10 mm diameter piezo ceramic disc 0.2 mm thick glued directly onto a 75 μm thick brass pump membrane. The stroke volume can be approximated using [10]:

$$V_{\mathrm{stroke}} = 8\times10^{-11}\frac{d^4}{h^2}U \tag{3}$$

with d the diameter of the piezo disc, h the thickness of the assembly and U the applied voltage (175 V). Substituting the parameters leads to a stroke volume of 3.5 μl. assuming that the pump chamber is completely filled with air bubbles, so that $V_{\mathrm{dead}}=V_{\mathrm{bubble}}=1$ μl, the valve opening pressure $p_{\mathrm{min,liq}}$ should not exceed 8.8×10^4 Pa to be self-filling. However, at this point, the flow is zero; therefore, the opening pressure should be as small as possible to maximize the pump rate.

The theoretical pressure that can be reached is given by [10]:

$$P = 8\frac{h}{d^3}U \tag{4}$$

For the applied system this theoretical pressure is 2.8×10^5 Pa.

Two major advantages with respect to the previous actuator are its simple construction and its very small size. However, for this actuator type, more sophisticated driver electronics are needed to generate the required voltage of around 175 V.

3. Conclusions

Self-priming plastic micropumps with excellent performance were made by adopting well-known conventional micro mechanical production methods and standard materials. Two types of actuators were chosen that also fulfill these requirements of easy fabrication, an electromagnetic actuator and a piezo actuator. A second reason for the selection of these two different actuators was that both could be mounted on top of the generic valve structure. This valve structure was produced ‘on wafer scale' by reaction molding of epoxy in a conventionally machined metal mold. By sandwiching a thin plastic membrane between two molded parts, planar passive membrane valves with low opening pressure results. The pump rates obtained with both actuators were far above rates that were presented earlier [1, 2, 3, 4, 5, 6, 7]. A major advantage of the presented approach is that expensive cleanroom and LIGA processes, which have their break-even point at large production volumes, can be avoided because the micrometer accuracy of these processes is not strictly necessary in micropumps. However, to enable large-scale production of micropumps using the described techniques, some research on manufacturing procedures is still needed to automate production completely. A first step can be made by using a more detailed mold that can be applied in injection molding machines for the manufacturing of the valve parts. This avoids the need for precise alignment under a microscope and the drilling of holes.

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