# MICROPUMPS FOR MEDICAL APPLICATIONS

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*Much effort is being applied to the development of autonomous Micro Electro Mechanical Systems (MEMS). In their full and total configuration, Microsystems consist of sensor part, data processing part and actuator part. One kind of actuator devices, these are Microfluidic Pumps. Nowadays, they find very large applications in different areas of life, science and techniques. Contemporary microelectronics and microelectronic technologies give the possibility to design and to produce Microfluidic Pumps, with very small dimensions and weight, low power consumption and very high reliability. In the present paper, an explanation of the principles of operation, technological ways of production and application are given. A Piezoelectric-driven Microfluidic Pump is designed and presented.*

**Keywords:** Microfluidic Pump, Microsystems, MEMS, Micropump Design

## 1. INTRODUCTION

From biology and medicine to space exploration and microelectronics cooling, fluid volumes, on the order of a milliliter - the volume contained in a cube 1 cm on a side and below, figure prominently in an increasing number of engineering systems. The small fluid volumes in these systems are often pumped, controlled or otherwise manipulated during operation. For example, biological samples must be moved through the components of miniature assay systems, or coolant must be forced through micro heat exchangers. Microfluidic transport requirements such as these can sometimes be met by taking advantage of passive mechanisms, most notably surface tension. For other applications, macroscale pumps, pressure/vacuum chambers and valves provide adequate microfluidic transport capabilities. Yet for many microfluidic systems, a self-contained, active pump, the package size of which is comparable to the volume of fluid to be pumped, is necessary or highly desirable.

Space exploration is one of the exciting areas for micropump technologies. Miniature roughing pumps are needed for use in mass spectrometer systems to be transported on lightweight spacecraft. Such a pump would likely be required to achieve a vacuum of approximately 0.1 Pa, the level at which high vacuum pumps typically become effective. Miniature roughing pumps have been sought for other applications as well. Micropropulsion is another potential application of micropumps in space. For example, ion-based propulsion systems proposed for future 1–5 kg "microspacecraft" may require delivery of compressed gases at 1 $ml.min^{-1}$ flow rates. Larger stroke volumes are generally required for pumping gases than for pumping liquids, making these space exploration applications particularly challenging.

Dispensing therapeutic agents into the body has long been a goal of micropump designers. Among the first micropumps, those developed by Jan Smits in the early 1980s were intended for use in controlled insulin delivery systems for maintaining diabetics' blood sugar levels without frequent needle injections. Micropumps might also be used to dispense engineered macromolecules into tumors or the bloodstream. High volumetric flow rates are not likely to be required of implanted micropumps (the amount of insulin required by a diabetic per day, for example, is less than a milliliter), but precise metering is of great importance. The pressure generation requirements for implantable micropumps are not insignificant, as the back pressure encountered *in vivo* can be as high as 25 kPa. Reliability, power consumption, cost and biocompatibility are critical. To date, deficiencies in these areas have precluded widespread implantation of micropumps. For example, currently available implanted insulin delivery systems employ static pressure reservoirs metered by solenoid-driven valves and are over 50 $cm^3$ in size.

## 2. Classification Of Micropumps

An example of a categorization of micropumps, according to the manner and means by which they produce fluid flow and pressure, is presented in Chart 1.

This classification is applicable to pumps generally and is essentially an extension of the system set forth by Krutzch and Cooper for traditional pumps. Pumps generally fall into one of two major categories: (1) *displacement pumps*, which exert pressure forces on the working fluid through one or more moving boundaries and (2) *dynamic pumps*, which continuously add energy to the working fluid in a manner that increases either its momentum (as in the case of centrifugal pumps) or its pressure directly (as in the case of electroosmotic and electrohydrodynamic pumps). Momentum added to the fluid in a displacement pump is subsequently converted into pressure by the action of an external fluidic resistance. Many displacement pumps operate in a periodic manner, incorporating some means of rectifying periodic fluid motion to produce net flow. Such periodic displacement pumps can be further broken down into pumps that are based on reciprocating motion, as of a piston or a diaphragm, and pumps that are based on rotary elements such as gears or vanes. The majority of existing micropumps are reciprocating displacement pumps in which the moving surface is a **diaphragm**. These are sometimes called membrane pumps or diaphragm pumps. Another subcategory of displacement pumps are aperiodic displacement pumps, the operation of which does not inherently depend on periodic movement of the pressure-exerting boundary. A periodic displacement pumps typically pump only a limited volume of working fluid; a syringe pump is a common macroscale example.

Dynamic pumps include centrifugal pumps, which are typically ineffective at low Reynolds numbers and have only been miniaturized to a limited extent, as well as pumps in which an electromagnetic field interacts directly with the working fluid to produce pressure and flow (electrohydrodynamic pumps, electroosmotic pumps and magnetohydrodynamic pumps) and acoustic-wave micropumps.

In Table 1, colored boxes represent pump categories of which operational micropumps have been reported. In the use of the term micropump the prefix micro is

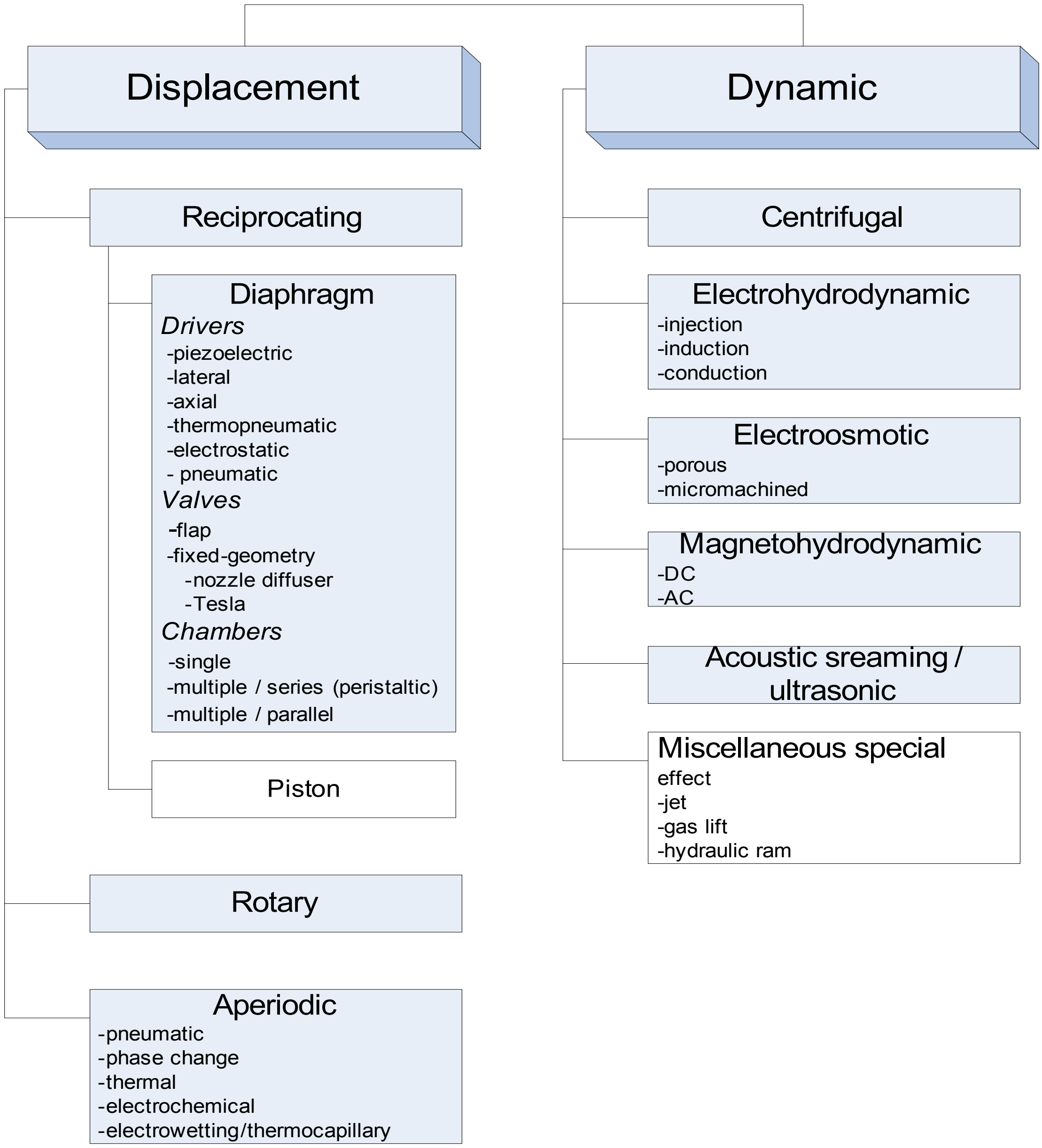


**Table 1** Classification of pumps and micropumps after Krutzch and Cooper. Colored boxes are pump categories of which operational micropumps have been reported.

considered to be appropriate for devices with prominent features having length scales of order 100 μm or smaller.

## 3. Principle of Operation of Reciprocating Displacement Micropumps

The vast majority of existing micropumps are reciprocating displacement micropumps - micropumps in which, moving boundaries or surfaces do pressure work on the working fluid in a periodic manner. (Pistons are the moving boundaries in many macroscale reciprocating displacement pumps, but traditional, sealed piston structures have not been used in micropumps.).

In most reciprocating displacement micropumps, the force applying moving surface is instead a deformable plate - the pump diaphragm - with fixed edges. Common pump diaphragm materials include silicon, glass, and plastic. Figure 1 shows the structure and operation of a **generic diaphragm-based reciprocating displacement micropump**.

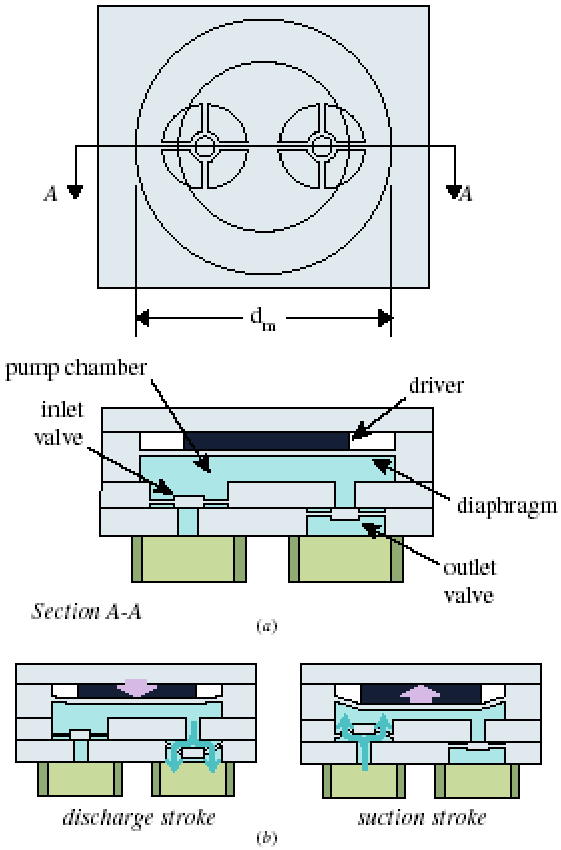


**Figure 1.** Structure and operation of a typical reciprocating displacement micropump

During the discharge stroke, the driver acts to reduce the pump chamber volume, expelling working fluid through the outlet valve. During the suction stroke, the pump chamber is expanded, drawing working fluid in through the inlet valve.

The basic components are a **pump chamber** (bounded on one side by the pump diaphragm), an **actuator mechanism or driver** and two passive **check valves**—one at the **inlet** (or suction side) and one at the **outlet** (or discharge side). The generic reciprocating displacement micropump shown in Figure 1 is constructed from four layers of material. There are micropumps made from as few as two and as many as seven layers of material.

During operation, the driver acts on the pump diaphragm to alternately increase and decrease the pump chamber volume. Fluid is drawn into the pump chamber during the chamber expansion/suction stroke and forced out of the pump chamber during the contraction/discharge stroke. The check valves at the inlet and outlet are oriented to favor flow into and out of the pump chamber, respectively, rectifying the flow over a two-stroke pump cycle.

While most micropump designs have a single pump chamber, a few micropumps have multiple pump chambers arranged either in series or in parallel. Driver types and configurations vary widely; reciprocating displacement micropumps with piezoelectric, electrostatic, thermopneumatic and pneumatic drivers.

Most reported reciprocating displacement micropumps have a **single pump chamber**, like the design shown in figure 1.

Most reported reciprocating displacement micropumps are roughly planar structures between 1 mm and 4 mm thick. The overall size of the micropump depends heavily on the in-plane dimensions, which must be large enough to accommodate the pump diaphragm. To estimate the effects of reducing diaphragm diameter, we consider a generic reciprocating displacement micropump with ideal check valves and a **circular, planar diaphragm**.

There are different common reciprocating displacement micropump driver designs. The most commonly used are **piezoelectric drivers** in lateral and axial configurations. The free strain that can be produced in the driver places an upper limit on the stroke volume of a **piezoelectric-driven micropump**.

The use of piezoelectrics to drive micropumps can be traced to a class of ink jet printheads. Applying an axial electric field across the piezoelectric disk produces both a lateral and an axial response in the disk, described by the $d_{31}$ and $d_{33}$ piezoelectric strain coefficients, respectively. For this configuration, the chamber diaphragm bows to balance the lateral stress in the piezoelectric disk. If the induced lateral stress in the disk is compressive, the diaphragm bows into the chamber; if tensile, it bows away from the chamber.

The performance of check valves at the inlet and outlet of the pump chamber is critical to the operation of reciprocating displacement micropumps. In general, these devices have stationary valve seat with inlet and outlet and a deflectable membrane. Deflection of the membrane opens or closes the valve according to its initial configuration which can be normally open or closed.

Most of the micro-valves have been micromachined from silicon. Silicon has many advantages for MEMS applications. It is one of very few materials that can be economically manufactured in single crystal substrates. Its crystalline nature provides significant electrical and mechanical advantages. Besides, silicon is abundant and can be produced in high purity. It is an elastic and robust material. Good sealing properties make it the most used material for micro-valve applications. Glass, polymers and thin metal films such as Ni, Ti, Fe, Cu are also used in micro-valve fabrication.

## 4. DESIGN OF A DRUG-DELIVERY PIEZOELECTRIC MICROPUMP

The impressive **wafer bonding technology** is a technological process of great importance in the production of micropumps. During operation, the structures produced by wafer bonding can withstand very high pressures without breaking or decreasing reliability.

The general draft of the micropump is shown in Figure 2.

The pump consists of **five** Silicon wafers, one of which will be attached to the driver and will act as a membrane, and will be responsible for the volume changes in

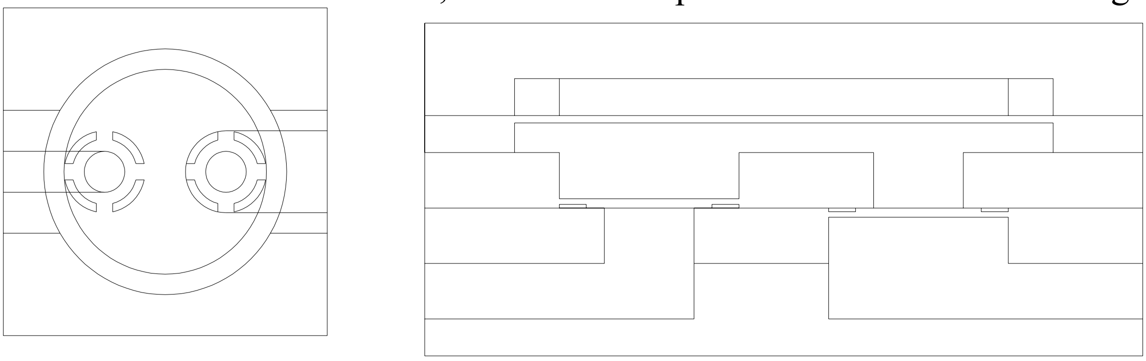

**Figure 2** General draft of the micropump

the pump chamber and for providing the pressure, which opens and closes the inlet and outlet valves.

The piezoelectric actuator will have a disc form, will be made from one of the most widely used piezoceramic materials, lead zirconate titanate, PZT-5H2 and will have the following dimensions:

*Diameter,* $D_a = 5000\ \mu m = 5\ mm$, and *Thickness,* $t_a = 200\ \mu m = 0{,}2\ mm$.

## 5. Fabrication Procedure For The Piezoelectric Micropump

Wafer 1 (bottom wafer) – the shape and configuration of **inlet** and **outlet channels**.

Wafer 2 - the shape and configuration of **outlet valve**.

Wafer 3 - the shape and configuration of **inlet valve**, bottom part of the chamber.

Wafer 4 - the shape and configuration of **membrane**, upper part of the chamber.

Wafer 4 - the shape and configuration of the **compartment for the piezoelectric**.

All these wafers are prepared by **anisotropic wet etching of Silicon**, one of the most important processes in so called **Bulk Micromachining**.

After preparing of all five wafers, there are **wafer bonding** procedures:

1. Wafer bonding - wafer 1 to wafer 2.
2. Wafer bonding - wafer 3 to wafer 2; wafer 3 is rotated at 180°.
3. Wafer bonding - wafer 4 to wafer 3.
4. Bonding of the piezoelectric to wafer 5 – 2 droplets of conducting resin.
5. Wafer bonding, wafer 5 (with the piezoelectric) to wafer 4.

## 6. Conclusions

The explanation of the action of piezoelectric-driven micropump is studied, systematized and formulated. A specialized design procedure is proposed and successfully done. The technological sequence and procedure are presented. The results are in good accordance with the expectations and the initial specification.

## 7. References

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