

Review on MEMS based Micropumps for Biomedical Applications

F. Rehana Munas¹, Y. W. Ranjith Amarasinghe², Dzung Dao³

Lecturer (Prob), Department of Mechanical Engineering, South Eastern University of Sri Lanka, Oluvil, Sri Lanka¹

Senior Lecturer, Department of Mechanical Engineering, University of Moratuwa, Moratuwa, Sri Lanka²

Senior Lecturer, Griffith School of Engineering, Griffith University, Gold Coast Campus, Australia³

ABSTRACT: In this 21st century biomedical industry is gaining popularity in manufacturing biomedical devices due to their growing market and great demand. In this paper, the development of MEMS based micropumps for biomedical applications has been addressed. The objective of this paper is to present the major features and issues such as applications, working principles, actuation techniques, design specifications and parameters etc... associated with micropumps. Based on the actuation principles, micropumps are classified into two main kinds such as mechanical and non-mechanical micropumps. The presented literature review on micropumps will provide widespread evidence for researchers working on design and development of micropumps for biomedical applications.

KEYWORDS: MEMS; Microfluidics; Micropump; Actuation principles; biomedical applications

NOMENCLATURE

A	Surface area of the electrodes
d	Counter electrode diameter
d	Tensor of the piezoelectric charge constant
E	Electric field
E	Bulk modulus of elasticity
F	Electrostatic force of attraction
h_{max}	Maximum back pressure
L	Distance separation between the two electrodes
P	Pressure
ΔP	The pressure change
$P_{actuator}$	Power of the actuator
P_{pump}	Power of the pump
Q_{max}	Maximum flow rate
S^E	Compliance tensor
ΔT	Temperature increase
U	Average velocity
V	Applied voltage
ΔV	Stroke volume of chamber
V_o	Dead volume of chamber including the valves
$\frac{\Delta V}{V}$	Volume change percentage
W	Stored energy
X	Electrode spacing
η_F	Fluidic diodicity
ϵ	Compression ratio
ϵ	Dielectric constant/Permittivity of the medium
σ	The stress
β	Thermal expansion coefficient

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 7, July 2015

η	The viscosity
γ	Pressure head
η	Pump efficiency
η_t	Total efficiency
η_m	Mechanical efficiency
η_v	Volumetric efficiency
η_h	Hydraulic efficiency
ζ	Pressure loss coefficient
ζ^-	Pressure loss coefficients negative flow directions
ζ^+	Pressure loss coefficients in positive flow directions

I. INTRODUCTION

In this 21st century Biomedical industry is gaining popularity in manufacturing biomedical devices like microneedles based transdermal devices, osmosis based devices, micropump based devices, microreservoir based devices due to their growing market and great demand. In recent years there has been an increased effort to improve the onsite rapid analysis of highly virally spreading diseases like Dengue and H1N1. Micro Electro Mechanical Systems (MEMS) technologies are the possible option to fabricate small size and high performance biomedical devices to meet critical aforementioned medical needs.

Micro Electro Mechanical Systems (MEMS) is a technology which is defined as miniaturized mechanical and electro-mechanical elements that are made using the techniques of microfabrication. Although the most notable and interesting elements of MEMS are micro sensors, microactuators and microsystems [1]. Owing to the diversity and demand of MEMS devices in wide range of applications, the design and manufacturing technologies are driving the extensive usage and rapid development of these devices. The first polysilicon surface micromachined device was developed by Howe and Muller in 1984[1].

In addition MEMS technologies have been applied to fulfil the requirement of biomedical industry in the emerging field called microfluidics. Microfluidics deals with design and development of miniature devices which can sense, pump, mix, monitor and control small volumes of fluids. Among these microfluidic devices, micropumps play a vital role in different applications of the biomedical devices since micropumps are very much essential to control and transport fluids in micro scale.

Micropumps are the scaled down versions of everyday macroscopic pumps. According to the MEMS technology, micropumps are defined as the miniaturized pumping devices fabricated by micromachining technologies [2,3] They are used in wide range of applications, such as automotive, aerospace, chemical processing and food & beverages, consumer products & printing, microelectronics and biomedical industries. The demand for micropumps in biomedical industries is widespread. Their characteristics of handling small and precise volumes of liquid make them able to serve medical and biomedical applications with great scientific and commercial potential. Therefore developing a MEMS based micropump will be a motivated research in biomedical applications.

This review expresses the novel classes of micropumps and their biomedical applications. The prominence of this review will be to explain significant features such as actuation methods, working principles, performance parameters and their medical applications reported wherever.

II. MICROPUMPS

Micropumps are designed to transmit fluids with high precision and they are developed for many reasons. Two primary reasons are reduction of weight and the ability to manipulate small volumes. These pumps are used for many kinds of functions such as circulate fluids, transfer fluids from one point to another, heating and cooling applications, mixing minuscule amount of fluids and dosages and safe handling of hazardous fluid and waste extraction. However the medical industry is taking great advantage in preparing samples for medical diagnoses & therapeutics and dispensing precise dosages of medications. A typical micropump consists of a pumping chamber with two valves (inlet & outlet) and a diaphragm. This diaphragm is actuated by a specific actuation technique during suction and pumping modes. The Figure II (a) illustrates the schematic diagram of such micropump.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 7, July 2015

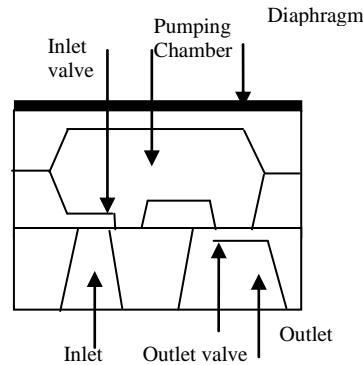


Fig II (a): Schematic illustration of a micropump[modified from 6]

Although the research and development work on micropumps started for more than two decades. In 1975, Thomas and Bessman patented the very first miniaturized micropump to implement into the human body and it was fabricated using conventional techniques [2]. Then in early 1980s Smith patented a peristaltic micropump for controlled insulin delivery system. The fabrication was done by using Silicon microfabrication technologies and the results were published in late 1990s [2,5].

Micropumps are categorized in to two main distinctive categories: Displacement/Mechanical micropumps and Non-mechanical/Dynamic micropumps. Displacement micropumps are commonly referred to as mechanically actuated pumps and these need a physical actuator. Dynamic micropumps are commonly used in micro devices in order to add energy to the working fluid to either increase its momentum. Eventhough in literature, Mechanical micropumps are categorized into several sub-categories based on their actuation techniques as well as their mechanisms like valve patterns, chamber configuration etc... The figure II (b) illustrates the classification of micropumps with their mechanisms.

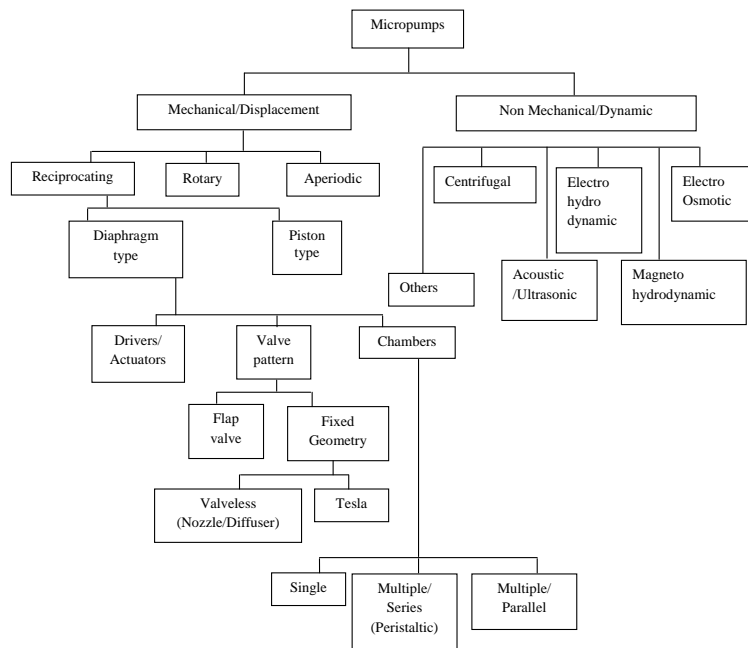


Figure II (b): classification of micropumps

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 7, July 2015

Design of micropumps plays an important role for practical applications of devices. To develop a suitable design of micropumps for real time applications, it is very much essential to understand terms like actuator, valves, chamber, nozzle diffuser mechanism and pumping parameters properly [5].

The actuator is the necessary and driving part of a micropump which converts energy into motion. It is used to provide force for fluid flow in micropumps. The actuator takes energy from electricity, heat, liquid pressure, air pressure and converts it into some kind of motion. In most micropumps reported in literature, the actuation disk is attached with membrane which is used to push the fluid. There are types of diaphragms which are fabricated in such a way that it produces energy itself to push the fluid. In peristaltic micropumps more than one actuator is fabricated sequentially.

In micropumps, valves are used to control the fluid flow by opening, closing and partially hindering passageways. In microfluidic systems, active and passive valves have been reported [8]. Actuation mechanisms are not applicable in passive valves since the control of fluid flow in liquid chamber is dependent on the pressure difference. The fluid flow is normally in one direction in such valves. In active valves, active elements are operated by an external actuation source for opening and closing phenomena. Mostly, separate components have been reported for active micro-valves in order to regulate the fluid flow in microfluidic systems. The first active valve was reported by van Lintel in 1988 [5]. Controlling the active valves is comparably easy. But they are more complicated in integrated microfluidic systems.

Chamber design is very critical in micro fluidic systems and it can significantly influence the volume stroke, pressure characteristics and nozzle-diffuser loss coefficients. Most of the micropumps reported in literature have a single chamber configuration. But in order to improve the performance, multiple chambers are arranged sequentially in such a way that series /parallel have also been reported [8]. These kinds of micropumps are known as peristaltic micropumps [11].

Nozzle/diffuser element is mostly used in valveless micropumps as a flow rectifier. The first nozzle/diffuser action in a valveless micropump was presented in 1993 by stemme and stemme [2,5]. Nozzle/diffuser element works in such a way that during supply mode more fluid enters in the chamber through an inlet than fluid that exiting the outlet. While reverse action will be directed during the pumping mode.

Various design parameters are very much essential to optimize the performance of micropumps such as maximum flow rate (Q_{max}), pump power (P_{pump}), maximum back pressure (h_{max}) and pump efficiency (η). Q_{max} is highest at zero h_{max} whereas Q_{max} is zero when highest value of h_{max} .

The pump efficiency η in the form of power can be expressed as:

$$\eta = \frac{P_{pump}}{P_{actuator}} \dots\dots\dots (1)$$

The total efficiency can be expressed as:

$$\eta_t = \eta_m \eta_v \eta_h \dots\dots\dots (2)$$

II.I Displacement /Mechanical Micropumps

Displacement micropumps are the minute versions of macroscopic mechanical pumps. These micropumps exploit a rotational or oscillatory movement of mechanical parts to move fluid from an inlet to an outlet. In these kinds of micropumps, the moving boundaries are diaphragms with fixed edges. These diaphragms are fabricated by using silicon, glass, PDMS. The principle which is most commonly applied involves a pumping chamber which is sealed with a flexible diaphragm on one side of the micropump. The actuation mechanisms are varied and they need a physical actuator with moving parts for the pumping. In these kinds of micropumps, the fluid flow is achieved by the oscillation of a diaphragm. Due to these oscillations, the pressure (ΔP) is created. The compression ratio (ϵ) is defined by the equation:

$$\epsilon = \frac{\Delta V}{V_o} \dots\dots\dots (3)$$

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 7, July 2015

II.I.I Actuation Principles

Electrostatic actuation principles are widely used in micropumps attached with microfluidic biomedical devices. Electrostatic actuation operates on the principle of coulomb attraction due to the application of a biased voltage between two plates. The electrostatic force applied on the electrostatic plates can be expressed by the equation [2,3,8,11]:

$$F = \frac{dW}{dX} = \frac{1}{2} \left(\epsilon A \frac{V^2}{X^2} \right) \dots\dots\dots (4)$$

Application of a high voltage to the capacitor electrodes provides an electrostatic attraction of the pump diaphragm, resulting in deflection of the membrane. This periodic motion of the membrane changes the volume and thus the pressure inside the micropump caused the fluid to propel in one direction through micro channels in the pump chamber. Utilizing this type of rapid actuation principle bidirectional fluid flow will be obtained at high operation frequencies. Capacitance between the diaphragm membrane and the electrode can be calculated as follows:

$$C = \frac{\epsilon \pi d^2}{4l} \dots\dots\dots (5)$$

Also the force being developed by the electrostatic actuation to achieve the attraction between the two electrodes is given by:

$$F = \frac{1}{2} \frac{\partial C}{\partial l} V^2 = - \frac{\epsilon \pi d^2}{8l^2} V^2 \dots\dots\dots (6)$$

A medium with appropriate high permittivity facilitates the usage of the electrostatic actuation even when the plates are far apart, due to the fact that force created will be sufficient to pump the fluid throughout the pumps entirety [11]. Fabrication of these mechanisms on an electronic chip is generally considered easy, but the electrostatic actuator has only a small stroke and the deflection of the diaphragm can be easily controlled by the applied voltage.

Piezoelectric actuation mechanism is the most commonly utilized in MEMS technology as well as in reciprocating mechanisms of biomedical applications [7,11]. This technique was the first to be tested due to its elegant characteristics. The piezoelectric effect is defined as the conversion of mechanical energy to electronic signal (voltage) and vice versa. A stress applied to such piezoelectric materials will alter the separation between the positive and the negative charges, causing surface net polarization. This piezoelectric actuation has a strain induced by an applied electric field on a piezoelectric crystal. These actuation principle provide a comparatively high stroke volume, a high actuation force, and a quick mechanical response as well as a simple structure. However, their fabrication is very complex as it is processing piezoelectric materials mounting the piezo to the surface of the micropump device. In addition to this it needs comparatively high actuation voltage [2,3,8,11].

The piezoelectric effect (ϵ) relates to the coupling between mechanical deformation and electrical polarization [8].

$$\epsilon = S^E \sigma + dE \dots\dots\dots (7)$$

In thermo-pneumatically actuated micropumps, a chamber full of air is periodically and alternately expanded and compressed by a pair of heater and cooler. The periodic change in the volume of the chamber gives the membrane a regular momentum so fluid can flow out. This type generates relatively large induced pressure and membrane displacement [2,3]. The pressure increase in liquids is expressed as [2,3].:

$$\Delta P = E \left(\beta \Delta T - \frac{\Delta V}{V} \right) \dots\dots\dots (8)$$

An advantage of thermo pneumatic micropumps is the capability of making a compact, small design, while generating displacements of the membrane up to several 100 micrometers resulting in high flow rates throughout the pump. Fabrication and integration in silicon technology is easily achievable [2]. One of the main disadvantages of thermo

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 7, July 2015

pneumatic actuation is the relatively long thermal time constant, which is especially crucial during the cooling process. This actuation exhibits a power consumption that is in the range of several watts. Operation and actuation at these power ranges cause a large amount of heating the transport medium that is problematic. So it is essential to maintain the driving power at a constant and specific level and also the response is very slow.

Electromagnetic actuation technology is in its early development stages and in most instances not very compatible with micropump technology [11]. A typical magnetically actuated micropump has a chamber with inlet and outlet valves, a flexible membrane, a permanent magnet and a set of drive coils. Either the magnet or the set of coils may be attached to the membrane. The strength of the magnet can be varied by changing the electric current flow through the coils. Current driven through the coils produces a magnetic field that creates attraction or repulsion between the coils and the permanent magnet which provides the actuation force. The electromagnetic actuation is realized by a solenoid plunger. The force developed by the actuator depends on the applied current and on the number of turns. This form of actuation requires voltages that are relatively low (~5V) and the actuator designs are simplistic as compared to previous actuation methods which could be a possible advantage. Their main features are high power consumption and heat dissipation. Their disadvantage is the difficulty in miniaturization, owing to the size of the required solenoid coil. Addressing the disadvantage is the integration of the magnets, the cores, or the micro coils, for compactness and smallness [8].

Shape memory alloy (SMA) actuated micropumps make use of the shape memory effect Shape memory alloys are special alloys such as Au/Cu, In /Ti, and Ni/Ti. The shape memory effect involves a phase transformation between two solid phases. These two phases are called the austenite phase at high temperature and martensite phase at low temperature. In SMA materials, the martensite is much more ductile than austenite and this low temperature state can undergo significant deformation by selective migration of variant boundaries in the multi variant grain structures. When heated to the austenite start temperature, the material starts to form single variant austenite. If the material is not mechanically constrained, it will return to predeformed shape, which it retains if cooled back to the martensite phase. These phase transitions result in mechanical deformation which is used for actuation. Main advantages of micro SMA pumps are high force-to-volume ratio, ability to recover large transformation stress and strain upon heating and cooling processes, high damping capacity, chemical resistance and biocompatibility. However the disadvantages are the need for specific SMA materials, relatively high power consumption and uncontrollable deformation of the SMA owing to temperature sensitivity [2,3,5,8,].

Bimetal refers to an object comprising of two different metals jointed together. The thermal expansion coefficients of these metals are different. The deflection of a diaphragm made of bimetallic materials induced against thermal alternation as long as the two chosen materials possess adequately discriminative thermal expansion factors. The implementation is extremely simple with large forces generated but the deflection of a diaphragm is only can be achieved by thermal alternation. The key advantage is that bimetallic micropumps require relatively low voltages than the other types of micropumps. Their main disadvantage is their unsuitability to high-frequency operation.

There were several research and development works had been carried out up to now on these actuation techniques for several applications. In addition, the valve type and the other required parameters also were mentioned. The table II.I illustrates the summary of these works with their specific features and applications reported wherever.

Table II.I: Details of micropump with different actuation principles

Reference	Actuation principle	Size	Valve type	Voltage (V)	Frequency (Hz)	Pressure (kPa)	Flow rate (µl/min)	Structure/Fabrication	Application reported
Judy et.al, 1991	Electrostatic	-	active valve	50	-	-	-	Selective etching deposition	-
Zengler et.al, 1992		-	Passive	170	1-100	25	70	Isotropic etching technique using lithography	-

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 7, July 2015

Zengerle et.al, 1995		-	passive	200	-	31	850	Bi directional silicon	-
Bourouinay et.al, 1997		-	-	10	-	-	0.01-0.1	-	Drug delivery
Cabuz et.al, 2001		-	-	160	30	-	30	Injection molding	Chemical & biological sensing
Yu Sun et.al, 2002		-	-	10.7 in X & 70.1 in Y	-	-	-	Deep Reactive Ion Etching (DRIE)	Micro manipulation and micro assembly
Teymori and Sani, 2005		7mmx4mmx1mm	-	-	-	-	9.1	-	medical applications
Machauf et.al, 2005		-	-	50	-	-	1	flip chip bonding	-
Podder et.al, 2011		1mmx1mmx50µm	Nozzle/Diffuser	-	-	-	0.167	-	Biomedical applications
Rosmani and Alabqari, 2013		-	-	0-20	-	-	-	-	-
Reference	Actuation principle	Size	Valve type	Voltage/(V)	Frequency/(Hz)	Pressure/(kPa)	Flow rate/(µl/min)	Structure/Fabrication	Application reported
Koch et.al, 1998	Piezoelectric	8mmx4mmx70µm	-	600	200	2	120	-	Drug delivery of insulin
Cao et.al, 2001		70 mm x 35 mm x 1 mm	Active	-	-	-	-	MEMS technology	-
Schabmueller et.al, 2002		12mmx12mmx0.85 mm	Passive	-	-	-	-	Bulk KOH etching	-
JUnwu et.al, 2005		-	-	-	-	-	27	-	-

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 7, July 2015

Feng and Kim, 2005		10 mm x 10 mm x 1.6 mm	-	80	-	0.12	3.2	fabrication with biocompatible materials	ideal for implantable micropump
Geipel et.al, 2006		-	Active	-	-	-	-	Bulk silicon process	Drug delivery
Suzuki et.al, 2007		-	-	-	-	-	336	-	-
Pham et.al, 2007		20 mm x 16 mm x 4 mm	-	-	-	1.8	900	fabrication with polydimethyl siloxane	-
Hsu et.al, 2008		24 mmx 75 mm	-	140	500	3.2	121.6	-	drug delivery
Dau et.al, 2008		-	valveless	-	-	-	-	conventional machining on PMMA material	gas jet for fluidic applications
Al-Hourani et.al, 2011		-	Nozzle/Diffuser	-	-	-	-	-	-
Johari et.al, 2011		14 mmx14 mmx2 mm	valveless	16	673	-	0.0048	two mask micromachining process	drug delivery
Reference	Actuation principle	Size	Valve type	Voltage/(V)	Frequency/(Hz)	Pressure/(kPa)	Flowrate/(μl/min)	Structure/Fabrication	Application reported
Elhashmi et.al, 2011	Piezoelectric	4mm x 4mm x 610 μ m	-	50	60	-	149.4	Deep Reactive Ion Etching (DRIE)	-
Gonzalez & Moussa, 2011		6000x6000x1000 μ m	-	-	-	-	-	Silicon Nitride	chemical & biomedical
Podder et.al, 2012		5mmx5mmx0.2mm	Nozzle/Diffuser	-	169.8	-	375	-	-
Yoshida et.al, 2012		20mmx13mmx18.5mm	-	-	-	-	-	-	-

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 7, July 2015

Ganesan and Palanisamy, 2012		-	-	-	-	-	100	MEMS fabrication	-
Shukur et.al, 2013		4mm x 4mm x 0.5mm	-	-	-	30	191.635	-	-
Zdelblich and Angell, 1987	Thermo-pneumatic	-	Passive	6	-	5	34	-	-
Jeong and Yang, 2000		-	Nozzle/Diffuser	8	4	2.5	14	n-type Si wafer	-
Zimmerman et.al, 2004		-	-	-	-	16	9	-	-
Hwang et.al, 2005		13mmx9mmx0.9mm	-	15/20	-	-	2/3.33	-	transdermal drug delivery
Kim et.al, 2005		-	nozzle/diffuser	20	2	-	21.6	-	micrototal analysis systems
Jeong et.al, 2005		-	-	-	-	-	-	PDMS elastomer	-
Reference	Actuation principle	Size	Valve type	Voltage/(V)	Frequency/(Hz)	Pressure/(kPa)	Flowrate/(μl/min)	Structure/Fabrication	Application reported
Baruah et.al, 2012	Thermo-pneumatic	-	-	-	-	-	60	-	micro/nanoliter level fluid control systems
OU et.al, 2012		-	-	10	1	-	0.1	-	-
Bohm et.al, 1999	Electromagnetic actuation	10mmx10mmx8mm	-	-	-	-	-	-	-
Geong et.al, 2000		-	-	-	125	-	70	-	-

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 7, July 2015

Yamahata et.al, 2005		-	Valveless	-	12 & 200	12	400	-	disposable lab on chip systems
Yamahata et.al, 2005		-	-	-	-	2.5	30	-	micromachining techniques
Pan et.al, 2005		-	ball check valves	0.013	-	-	774	-	-
Feldmann et.al, 2007		10mmx6mmx3mm	-	-	-	-	-	-	-
Shen et.al, 2007		-	ball valve	-	20	35	6000	-	micromachining techniques
Zordan et.al, 2009		-	nozzle/diffuser	-	45	-	119100	-	drug delivery
Chang et.al, 2013		-	valveless	-	-	-	470	-	-
Reference	Actuation principle	Size	Valve type	Voltage(V)	Frequency/(Hz)	Pressure(kPa)	Flowrate/(μl/min)	Structure/Fabrication	Application reported
Benard et.al, 1997	Shape memory alloy actuation	-	-	-	0.9	4.23	49	-	-
Xu et.al, 2001		6mmx5mmx1.5mm	-	-	-	100	340	-	-
Shuxiang and Fukuda, 2004		-	-	-	-	-	500-700	-	biomedical applications
Zhang and Qiu, 2006		8mmx8mmx1.8mm	-	-	80	-	235	-	-
Xia et.al, 2007		-	valveless	-	-	-	-	-	-
Pierce, 2011		-	-	-	-	-	-	66000	-

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 7, July 2015

Zhan et.al, 1996	Bimetallic actuation	6mmx6m mx1mm	-	5.5	0.5	12	45	-	-
Zou et.al, 1997		13mmx7 mmx2m m	check valves	-	-	0.5	336	-	-

II.II Dynamic/Non-Mechanical Micropumps

Dynamic micropumps make use of the physical properties fluids that can best be utilized when operating in the microscale or smaller. Dynamic micropumps are based on a direct transformation of mechanical or non-mechanical energy (electroosmotic, electro-hydrodynamic, magneto-hydrodynamic, electrowetting, etc.) into a kinetic momentum. It can be further categorized as being electrical, chemical, or magnetic. Since the pumping is continuous, the resulting flow is generally constant/steady in this case. Dynamic pumps do not usually have valves; they obtain directionality from the direction of the applied force [3,11]. These types of devices have been currently developed focusing on ultrasonic, magneto hydrodynamic (MHD), electro hydrodynamic (EHD), electro osmotic, or electrochemical actuation methods. The design principles being vastly different depend upon the respective physical or chemical principle [11]. The fabrications of these micropumps are relatively simple and easy. But these micropumps have certain limitations, such as the use of only low conductivity fluids and the actuation mechanisms interfere with the pumping liquids. A detailed description of non-mechanical micropumps is given in detail.

MHD refers to the flow of electrically conducting fluid in electric and magnetic fields. A typical MHD micropump structure is rather simple; microchannels, two walls bounded by electric-field-generating electrodes and two walls bounded by opposite-polarity magnetic-field-generating permanent magnets. The pressure and the flow rate of MHD micropump are:

Since these types of micro pumps can pump high-conductivity fluids, it is suitable for medical/biological applications. Their main disadvantage is the bubbles generated by ionization; it affects the flow rate. Bubble generation is reducible by reversing the direction of the applied voltage. An ac driving mechanism will improve their performance.

Electro Osmotic micropumps use the surface charge artificially developed via electrodes or spontaneously developed when a liquid comes in contact with a channel wall. Oppositely charged ions generated in fluid shield the surface charge. They can be manipulated by DC or AC electric fields. These kinds of pumps have certain advantages. An important one is that electro osmotic pumping does not involve any moving parts such as check valves. The major limitations of electro osmotic micropumps are high voltage required and electrically conductive solution [2,3]. Figure 2.3.2 represents the schematic diagram of such micropumps.

Electro Wetting micropump involves wettability change due to applied electric potential. In electro wetting, fluid is transported by surface tension, an interfacial force dominating at micro scale. Voltage is applied to the dielectric layer, decreasing the interfacial energy of the solid and liquid surfaces, causing fluid flow [3]. The major advantage of these micropumps are fast response and low power consumption. Also heating of the liquid is not required. These actuation techniques are mostly used in lab-on-a-chip applications.

The bubble type micropumps always need to be heated so that their application scope is limited in case heating process is not allowed or preferred [2]. The pumping effect in these is based on the periodic expansion and collapse of the bubbles generated in the micro channels. The volume of the bubbles are expanded and collapsed periodically by a controlled voltage input. The volume change in the chamber is achieved through a diffuser/nozzle mechanism that also determines the flow direction. The main advantage of this micropump type is the possible mixing of two or more kinds of doses during the expanding/collapsing cycles.

In Electrochemical Micropumps, the actuation force uses bubbles electrochemically generated in the microchannels. Application of a DC current electrolyzes the water between two platinum electrodes in a saline. The most common feature of electrochemical micropumps is the generation of bubbles by electrolysis in which water decomposes into hydrogen gas (H₂) and oxygen gas (O₂). This pump is very effective in pumping milliliter solution volumes. It also consumes little power [3].

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 7, July 2015

III. DISCUSSION

Micropumps are very much essential for the fluid transport in biomedical devices. Various factors are important during the selection of micropumps for particular bio medicinal applications. Operating voltage, pressure and flow rate of micropumps are critical issues to analyze the performance and suitability of micropumps for certain applications. Piezoelectric and electromagnetic mechanical micropumps have been reported extensively for microfluidic systems among the mechanical micropumps. The major limitation related to these types of micropumps is high operating voltage. On the other hand electrostatic micropumps are easy to fabricate on integrated microfluidic systems. Although it requires high operating voltage.

In case of non-mechanical micropumps, magneto hydro dynamic micropump has gained more attention since it is widely used in microfluidic applications. However, electrochemical micropumps are most appropriate for low voltage and high flow rate applications.

In literature it was reviewed that various types of micropump structures using different materials like Silicon, polymers...have been used for biomedical applications. Even though Si has been widely used for fabrication. On the other hand Si is brittle and always involves some risk for health care. Since biocompatibility is very much important for health, presently the tendency is moving towards polymeric materials. Most polymers, e.g., PGA, PDMS, PLA and PMMA, are very much suitable for micropumps like biomedical devices due to their low cost, good biocompatibility, ease of fabrication and excellent structural properties.

IV. CONCLUSION

The study on micropumps initiated in 1975 and the research and development on this device using fabrication technologies started in 1980s. In 1990s MEMS technologies have been applied in order to fulfil the necessity in biomedical industry on developing micropumps for various onsite applications. As a result of these, the performance of specific micropumps for specific applications has been consistently increased.

In most of the biomedical applications including drug delivery systems, insulin injectors, artificial prostheses etc... reported in literature, micropumps have been proposed as stand-alone devices with specific actuation techniques. Although nowadays the demand for the onsite blood analysis of highly virally diseases is very high. Therefore it is very much essential to develop a micropump for the particular application. However, developing a suitable micropump for the particular application is a challenge and this will continue to persuade research on developing micropumps in biomedical systems.

REFERENCES

- [1]. J. W. Judy, "Microelectromechanical systems (MEMS): fabrication , design and applications," vol. 10, pp. 1115–1134, 2001.
- [2]. A. Nisar, N. Afzulpurkar, B. Mahaisavariya, and A. Tuantranont, "MEMS-based micropumps in drug delivery and biomedical applications," *Sensors Actuators B Chem.*, vol. 130, no. 2, pp. 917–942, 2008.
- [3]. F. Abhari, H. Jaafar, and N. A. Yunus, "A Comprehensive Study of Micropumps Technologies," vol. 7, pp. 9765–9780, 2012.
- [4]. E. M. Garcell, "Analysis and Simulation of MEMS Comb-Actuators Author :," 2012.
- [5]. D. J. Laser and J. G. Santiago, "A review of micropumps," *J. Micromechanics Microengineering*, vol. 14, no. 6, pp. R35–R64, 2004.
- [6]. A. F. M. Shukur , N. Sabani , B. N. Taib, M.A.M Azidin and M.M. Shahimin, "Performance characteristics of valveless and cantilever-valve micropump," *Proc. SPIE 8923, Micro/Nano Mater. Devices, Syst.*, vol. 89234B, 2013.
- [7]. K. Mahija, B.G. Pushpalatha and J.J.Jijesh "MEMS based drug delivery system," pp. 91–95, 2012.
- [8]. M. W. Ashraf, S. Tayyaba, and N. Afzulpurkar, "Micro Electromechanical Systems (MEMS) Based Microfluidic Devices for Biomedical Applications.," *Int. J. Mol. Sci.*, vol. 12, no. 6, pp. 3648–704, 2011.
- [9]. S. K. Jha and V. C. Jha, "Design and fabrication of a three dimensional valveless micropump with Shape Deposition manufacturing Process (SDM) IJREAS," vol. 2, no. 2, pp. 805–824, 2012.
- [10]. K. Yoshida, T. Muto, J. Kim, and S. Yokota, "An ER Microactuator with Built-in Pump and Valve," *Int. J. of Automation Tech.*, vol. 6, no. 4, pp. 468–469, 2012.
- [11]. C. P. Cartin, "Design, Fabrication, and Testing of a PDMS micro pump with moving membranes," Ph.D. dissertation, Dept. Mec. Eng, Virgi. Comm. Univ, Richmond, Virginia, 2012.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 7, July 2015

- [12]. J. M. Anderson and J. J. Langone, "Issues and perspectives on the biocompatibility and immunotoxicity evaluation of implanted controlled release systems," *J. Control release* 57 pp. 107–113, 1999.
- [13]. J. W. Judy, T. Tamagawa, D. L. Polla, "Surface micromachined micropump," *Proc.MEMS 91*, pp. 182–186, 1991.
- [14]. R. Zengerle, M. Richter and H. Sandmaier, "A micro membrane pump with electrostatic actuation," *Proc. IEEE, Microelectromechanical Syst.*, pp. 19–24, 1992.
- [15]. R.Zengerle, J. Ulrich, S. Kluge, M.Richter, A.Richter, "A bidirectional silicon micropump," *Sens. Actuators*, vol. A50, pp. 81–86, 1995.
- [16]. T. Bourouinay, B. Alain, J.P. Grandchamp, "Design and simulation of an electrostatic micropump for drug delivery applications," *J. Micromechanics Microengineering*, vol. 7, pp. 186–188, 1997.
- [17]. C. Cabuz, W. R. Herb, E. I. Cabuz, S. T. Lu "The dual diaphragm pump," *Proc. IEEE, Microelectromechanical Syst.*, vol. 117, pp. 222–229, 2001.
- [18]. Y. Sun, D. Piyabongkarn, A. Sezen, B. J Nelson, R. Rajamani, R. Schoch, D. P. Potasek "A Novel Dual-Axis Electrostatic Microactuation System for Micromanipulation," *Proc. IEEE, Intl. Conf. Intell. Robot. Syst.*, pp. 1796–1801, 2002.
- [19]. M. M. Teymoori, E. A. Sani, "Design and simulation of a novel electrostatic peristaltic micromachined pump for drug delivery applications," *Sensors and Actuators A:Physical*, vol. 117, pp. 222–229, 2005.
- [20]. A. Machauf, Y. Nemirovsky, U. Dinnar, "A membrane micropump electrostatically actuated across the working fluid," *J. Micromechanics Microengineering*, vol. 15, pp. 2309–2316, 2005.
- [21]. B. Sahu, C. R. Taylor, and K. K. Leang, "Emerging Challenges of Microactuators for Nanoscale Positioning, Assembly, and Manipulation," *J. Manuf. Sci. Eng.*, vol. 132, no. 3, pp. 030917, 2010.
- [22]. P. K. Podder, D. Mallick, D. P. Samajdar, and A. Bhattacharyya, "Design , Simulation and Study of MEMS Based Micro-needles and Micro-pump for Biomedical Applications," *Proc. Comsol. Conf.*, 2011.
- [23]. R. Rosmani, M. R. A. Alabqari, "Electrostatic Pull-in Characteristic of Silicon Diaphragm for MEMS Micropump Design," *procedia Eng.*, vol. 53, pp. 362–367, 2013.
- [24]. H. T. G. Van Lintel, F. C. M. Van De Pol, S. Bouwstra, "A piezoelectric micropump based on micromachining of silicon," *Sens. Actuators*, vol. 15, pp. 153–167, 1988.
- [25]. L. Cao, S. Mantell, D. Polla "Design and simulation of an implantable medical drug delivery system using microelectromechanical systems technology," *Sensors and Actuators A:Physical*, vol. 94, pp. 117–125, 2001.
- [26]. C. G.J. Schabmueller, M. Koch, M. E. Mokhtari, A. G. R. Evans, N. M. White, A. Brunnschweiler, H. Sehr, "Self-aligning gas/liquid micropump," *J. Micromechanics Microengineering*, vol. 12, pp. 420–424, 2002.
- [27]. K. JUNWU, Y. ZHIGANG, P. TAIJIANG, C. GUANGMING, W. BODA, "Design and test of a high performance piezoelectric micropump for drug delivery," *Sensors and Actuators A:Physical*, vol. 121, pp. 156–161, 2005.
- [28]. G. H. Feng, E. S. Kim, "Piezoelectrically actuated dome - shaped diaphragm micropump," *J. microelectromechanical Syst.*, vol. 14, pp. 192–199, 2005.
- [29]. A. Geipel, A. Doll, F. Goldschmidtboing, P. Jantschkeff, N. Esser, U. Massing, P. Woias, "Pressure independent micropump with piezoelectric valves for low flow drug delivery systems," *MEMS, Istanbul, Turkey*, pp. 22–26, 2006.
- [30]. T. Suzuki, Y. Teramura, H. Hata, K. Inokuma, I. Kanno, H. Iwata, H. Kotera, "Development of a micro biochip integrated travelling wave micropumps and surface plasmon resonance imaging sensors," *Microsyst. Technol. Springer-Verlag*, vol. 13, pp. 1391–1396, 2007.
- [31]. M. Pham, T. T. Nguyen, N. S. Goo, "Development of a peristaltic micropump for bio-medical applications based on mini LIPCA," *Artificial muscle research center, South Korea*, pp. 126–131, 2007.
- [32]. Y. C. Hsu, S. J. Lin, C. C. Hou, "Development of peristaltic antithrombogenic micropumps for invitro exvivo blood transportation tests," *Microsyst. Technol. Springer-Verlag*, vol. 14, pp. 31–41, 2008.
- [33]. V. T. Dau, T. X. Dinh, R. Sakamoto, O. Tomonori, K. Tanaka, S. Sugiyama "A Valve-less micropump with PZT diaphragm," in *Twelfth International Conference on Miniaturized Systems for Chemistry and Life Sciences, California, USA*, pp. 1369–1371, Oct 2008.
- [34]. S. Al-Hourani, M. N. Hamdan, A. A. Al-Qaisia, M. S. Ashhab, "Fabrication and Analysis of Valve-less Micropumps," *Jordan J. Mech. Ind. Eng.*, vol. 5, pp. 145–148, 2011.
- [35]. J. Johari, J. Yunas, A. A. Hamzah, B. Y. Majlis, "Piezoelectric Micropump with Nanoliter Per Minute Flow for Drug Delivery Systems," *Sains Malaysiana*, vol. 40, no. 3, pp. 275–281, 2011.
- [36]. A. Elhashmi, S. Al-Zghoul, X. Xiong, "Design and Simulation of a MEMS Piezoelectric Micropump," in *Pro .ASEE - NE Section Conference* , 2011.
- [37]. U. F. Gonzalez & W. A. Moussa, Simulation of MEMS piezoelectric micropump for biomedical applications, 2011, Available: http://www.algor.com/news_pub/tec_white_papers/mems_micropump
- [38]. P. K. Podder, D. P. Samajdar, D. Mallick and A. Bhattacharyya, "Design and Simulation of Micropump, microvalve, microneedle for biomedical applications," in *5th International Conference on Computers and Devices for Communications*, 2012.
- [39]. K. Ganesan, V. Palanisamy, "Analysis and Experiment of MEMS based micropump for microfluidic application," *Int. J. Adv. Res. Comput. Eng. Technol.*, vol. 1, no. 10, pp. 259–264.
- [40]. M. J. Zdelblich, J. B. Angell "A microminiature electric to fluidic valve," in *Proceedings of the 4th International Conference Solid State Sensors and Actuators, Tokyo, Japan*, 1987, pp. 827.
- [41]. F. C. M. Van De Pol, H. T. G. Van Lintel, M. Elwenspoek, J. H. J. Fluitman, "A thermopneumatic micropump based on microengineering techniques," *J.Sens. Actuators A:Phys*, vol. 21, pp. 198–202, 1990.
- [42]. O. C. Jeong, S. S. Yang, "Fabrication and test of a thermopneumatic micropump with a corrugated P+ diaphragm," *Sensors and Actuators A:Physical*, vol. 83, pp. 249–255, 2000.
- [43]. S. Zimmermann, J. A. Frank, D. Liepmann, A. P. Pisano, "A planar micropump utilizing thermopneumatic actuation and in-plane flap valves," in *Proceedings of the 17th IEEE International Conference on Micro Electro Mechanical Systems (MEMS): MEMS Technical Digest, Maastricht*, pp. 462–465, 2004.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 7, July 2015

- [44]. S. R. Hwang, W. Y. Sim, D. H. Jeon, G. Y. Kim, S.S. Yang, J. J. Pak, "Fabrication and test of a submicroliter level thermopneumatic micropump for transdermal drug delivery," in *Proceedings of the 3rd Annual International IEEE EMBS Special Topic Conference on Microtechnologies in Medicine and Biology, Kahuku, Oahu, Hawaii*, 2005.
- [45]. J. H. Kim, K. H. Na, C. J. Kang, Y. S. Kima, "A disposable thermopneumatic actuated micropump stacked with PDMS layers and ITO coated glass," *Sensors and Actuators A:Physical*, vol. 120, pp. 365–369, 2005.
- [46]. O. C. Jeong, S. W. Park, S. S. Yang, J. J. Park, "Fabrication of a peristaltic PDMS micropump," *Sensors and Actuators A:Physical*, vol. 123/124, pp. 453–458, 2005.
- [47]. A. K. R. Baruah, G. Talukdar, B. Mondal, "Design of MEMS based diaphragm for micropump in drug delivery and biomedical application," in *International conference on Biomedical Engineering and Assistive Technologies (BEATS)*, 2012.
- [48]. A. K. R. Baruah, B. Mondal, "Thermally actuated MEMS based silicon micropump," in *2012 International Conference on Communications, Devices and Intelligent Systems(CODIS)*, 2012, pp. 176–179.
- [49]. Y. C. OU, C. H. Yu, C. C. Yang, C. M. Chang, Y. H. Tang, Y. H. Lin, "Biomimic PDMS Valve Applied in Thermopneumatic Micropump," *J. Appl. Sci. Eng.*, vol. 15, pp. 317–322, 2012.
- [50]. S. Bohm, W. Olthuis, P. Bergveld, "A plastic micropump constructed with conventional techniques and materials," *Sensors and Actuators A:Physical*, vol. 77, pp. 223–228, 1999.
- [51]. Q. Geong, Z. Zhou, Y. Yang, X. Wang, "Design, optimization and simulation on microelectromagnetic pump," *Sensors and Actuators A:Physical*, vol. 83, pp. 200–207, 2000.
- [52]. C. Yamahata, C. Lotto, E. Al Assaf, M. A. M. Gijs, "A PMMA valveless micropump using electromagnetic actuation," *Microfluid Nanofluid*, vol. 1, pp. 197–207, 2005.
- [53]. C. Yamahata, M. Chastellain, V.K. Parashar, A. Petri, H. Hofmann, M. A. M. Gijs, "Plastic micropump with ferrofluidic actuation," *J. microelectromechanical Syst.*, vol. 14, pp. 96–102, 2005.
- [54]. T. Pan, S. J. McDonald, E. M. Kail, B. Ziaiel, "A magnetically driven PDMS micropump with ball check valves," *J. Micromechanics Microengineering*, vol. 15, pp. 1021–1026, 2005.
- [55]. M. Feldmann, S. Demming, C. Lesche, S. Buttgenbach, "Novel electromagnetic micropump," in *proc. SPIE 6799, BioMEMS and Nanotechnology iii*, Dec 2007.
- [56]. M. Shen, C. Yamahata, M. A. M. Gijs, "Miniaturized PMMA ball-valve micropump with cylindrical electromagnetic actuator," *Microelectron. Eng.*, vol. 85, no. 5–6, pp. 1104–1107, 2007.
- [57]. E. Zordan, F. Amirouche, Y. Zhou, "Principle design and actuation of a dual chamber electromagnetic micropump with coaxial cantilever valves," *Biomed. Microdevices*, vol. 12, pp. 55–62, 2009.
- [58]. Y. J. Chang, Y. W. Chung, T. A. Chou, M. F. Huang, "Vave-less Diaphragm Micropump with Electromagnetic Actuation," *Adv. Mater. Res.*, vol. 647, pp. 929–934, 2013.
- [59]. W. L. Benard, H. Kahn, A. H. Heuer, M. A. Huff, "A titanium-nickel shape memory alloy actuated micropump," *Sens. Actuators*, vol. 1, pp. 361–364, 1997.
- [60]. W. L. Benard, H. Kahn, A. H. Heuer, M. A. Huff, "Thin film shape memory alloy actuated micropump," *J. microelectromechanical Syst.*, vol. 7, pp. 245–251, 1998.
- [61]. D. Xu, L. Wang, G. Ding, Y. Zhou, A. Yu, B. Cai, "Characteristics and fabrication of NiTi/Si diaphragm micropump," *Sensors and Actuators A:Physical*, vol. 93, pp. 87–92, 2001.
- [62]. G. Shuxiang, T. Fukuda, "SMA actuator based novel type of micropump for biomedical applications," in *IEEE international Conference, Vol 2*, pp. 1616–1621, 2004.
- [63]. H. J. Zhang, C. J. Qiu, "A TiNiCu Thin Film Micropump Made by Magnetron Co-Sputtered Method," vol. 47, no. 3, pp. 532–535, 2006.
- [64]. L. Xia, F. Wang, J. Lu, "A valveless micropump driven by differential SMA actuator," in *Proc. SPIE International Conference on Smart Materials and Nanotechnology in Engineering*, vol 6423, 2007 doi:10.1117/12.779366
- [65]. M. D. Pierce, "Design and optimization of a shape memory alloy actuated pump with thermofluidic feedback", M. S. thesis, Dept. Mech. Eng., Univ. Utah., 2011.
- [66]. C. Zhan, T. Lo, L. P. Liu, "A silicon membrane micropump with integrated bimetallic actuator," *Chinese J. Electron.*, vol. 5, pp. 29–35, 1996.
- [67]. J. X. Zou, Y. Z. Ye, Y. Zhou, Y. Yang, "A novel thermally actuated silicon micropump," in *Proceedings of the 1997 International Symposium on Micromechatronics and Human Science*, pp. 231–234, 1997.
- [68]. W. Y. Sim, H. J. Yoon, O. C. Jeong, S. S. Yang, "A phase change type of micropump with aluminium flap valves," *J. Micromechanics Microengineering*, vol. 13, pp. 286–294, 2003.