A THEORETICAL STUDY ON USING PVDF IN THE ACOUSTIC MICROPUMP FOR BIOMEDICAL APPLICATIONS

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1. INTRODUCTION

In the recent years micropumps have been extensively developed to manipulate fluids in a small scale. With the increasing demand of the medical fields, micropumps have been applied to biomedical applications[1,2]. Various micropumps with different actuation principles, such as piezoelectrics, shape memory alloys, electrostatics, thermal actuation and magnetics, have been investigated in the last decad[3]. For biomedical applications, micropumps are predestinated due to their small size, small power consumption, no moving parts, no frictional losses, no lubrication required, perfect isolation of the fluid from the outside environment, no chance of fluid contamination and consequently, better biocompatibility.

Acoustic standing wave micropump which achieves a pumping action using the properties of standing waves is a new type of micropump. A standing wave micropump consists of a chamber and an acoustic driver (see Fig. 1). The chamber has a fluid inlet and outlet through which the pumped fluid enters and exits. The excitation driver provides excitation energy to establish a standing wave in the chamber. The excitation source is matched with the pumped fluid and with the length of the excitation chamber so that a traveling wave generated by the excitation source is reflected upon itself within the chamber to create the standing wave. The frequency of oscillation of the excitation source and the length of the pump chamber are configured together so that this arrangement forms a resonant cavity where acoustic standing waves are established in the fluid. The length of the pump chamber should be equal to an integer times half the wavelength of the acoustic wave and the pump housing acts as a resonant cavity having a standing wave pattern set up inside. The standing wave results in one or more pressure nodes and pressure anti-nodes within the chamber. The number of nodes and anti-nodes depends upon the length of the chamber and the frequency of oscillation of the excitation source. Generally, the pressure at a pressure node is relatively constant at approximately the same level as the undisturbed pressure of the fluid while the pressure at a pressure anti-node fluctuates above and below the undisturbed pressure level. The inlet and outlet may be placed proximate to the pressure nodes and anti-nodes of the chamber, respectively. Due to significantly large pressure inside the cavity at the pressure anti-node, the fluid is discharged through the outlet. As the fluid discharges, there is a reduction in the fluid mass inside the tube which will cause a reduction in the static pressure.

The pressure will now be lower than the pressure of the inlet fluid. As a result the fluid will be sucked into the tube. A check valve must be placed at the outlet to prevent the pumped fluid from re-entering the chamber during low pressure portions of the cycle at the pressure anti-node. However, a valveless version of this micropump is also capable of pumping fluid.

Among different actuation methods, PZT actuation is promising due to its simple structure, high output power density and high actuation strength. However, lack of biocompatibility is the main drawback of PZT for biomedical applications. Whereas PVDF (Polyvinylidene fluoride) is a medical grade material and compatible with the biofluids. The aim in this paper is to theoretically show that PVDF in bimorph configuration is an appropriate material as an actuator in the acoustic micropump.

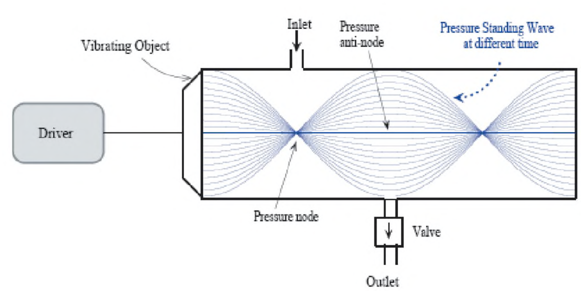

Figure 1: The schematic of the standing wave micropump.

2. BIMORPH PVDF ACTUATOR

The pumping action of the acoustic micropump is related to the maximum pressure fluctuation inside the pump chamber.
The larger pressure fluctuation, the higher flow rate of the micropump. To achieve higher pressure fluctuation we need larger value of maximum vibrational displacement (u_0). Typically the value of u_0 between 10 to 100 μm is required. In the following we have shown that this value of u_0 can be achieved using an appropriate configuration of PVDF film as an actuator.

The values of length change (δl) and width change (δt) of a PVDF film can be obtained using $\delta l = d_{31} l V/t$, $\delta t = d_{33} V$, where V is excitation voltage, l and t are length and thickness of the PVDF film, respectively, and d_{31} and d_{33} are piezoelectric strain coefficients for the drawn and thickness directions, respectively. Typical value for these parameters is about 2×10^{-11} m/V. The maximum thickness of commercially available PVDF films is limited to 110 μm. Obviously, even for large value of excitation voltage the change in thickness of a single layer of PVDF film is not sufficiently large to produce enough vibrational displacement to excite high-amplitude standing wave inside the micropump chamber. Therefore, a two-layer bimorph PVDF actuator is considered for actuation of the micropump, as shown in Fig. 2. The layer A and B are glued together using a low viscosity epoxy and a parallel electrical connection is made in order to form a bimorph actuator configuration to increase the vibrational displacement. In the bimorph configuration, an applied voltage causes one PVDF film to expand, whereas the other unit contracts causing the entire multi-layer PVDF film to deflect in one direction or the other. The bimorph configuration converts small length changes into sizable transverse deflection.

As a feasibility study, mathematical calculations of the maximum vibrational displacement have been performed with the bimorph PVDF actuator for V=1000 V, l=2 cm and t=110 μm. The resultant values of δl and δt are 3.64 and 0.02 μm, respectively. Referring to Fig. 3, in bimorph configuration the values of α, R and x can be calculated, $\alpha=\delta l/t$=0.033 rad, $R=(l-\delta l)/\alpha$=604.89 mm, $x=R\cos(\alpha/2)$= 604.807 mm. The maximum vibrational displacement of the bimorph PVDF actuator is obtained using $u_0=R-x$=82.6 μm. It is observed that sufficiently large vibrational displacement can be obtained using the bimorph PVDF configuration.

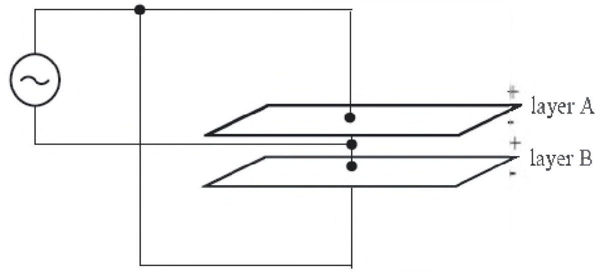

Figure 2: Configuration of a bimorph PVDF actuator.

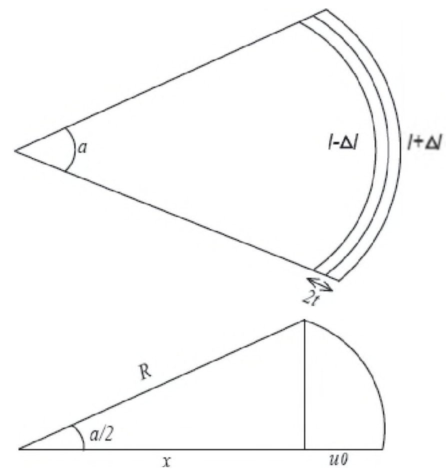

Figure 3: Deflection of the bimorph PVDF actuator in the thickness direction.

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