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A novel piezo actuated high stroke membrane for micropumps

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ABSTRACT

Piezo micropumps traditionally use a piezoelectric bimorph actuation method, which is a piezo material mounted on top of a membrane. By applying a voltage difference on the two electrodes of the piezo material, it bends and therefore the membrane will deflect, leading to a displacement of fluid. While these actuators can produce a rather high force, they are unable to create a very large deflection. The first reason is due to the intrinsic characteristics of the piezo material itself. On one hand it has usually a high Young's modulus and therefore resists the deflection. On the other hand, due to its brittle nature, it will break if it undergoes very large deflections. This paper presents a novel method to achieve very high strokes in membranes using piezo actuators. With a new configuration, the bending piezo is eliminated from the centre of the membrane, where there is the maximum displacement. Instead, a piezo ring is mounted around the membrane to change the mechanical actuation regime from bending to buckling. Hence, the energy that we are putting into the system by our piezo material is focused to deform the membrane, instead of being used in terms of strain energy and damping in the stiff piezo material itself. The whole system is analyzed using finite element simulation and the promising simulation results and achieved experimental results with this new actuation method are compared. When using a 50 μm thick steel membrane with 22 mm diameter actuated with piezo actuators of 250 μm thickness, we have achieved deflections up to an average of 197 μm, which fits well to our simulated deflection of 180 μm. Using a 100 μm Rigid-PVC membrane results in an average of 177 μm, which again corresponds very well to our simulated deflection of 170 μm. This tremendously high deflection can be compared to the one of a traditional piezo bimorph actuator which can be up to 24 μm, with the same parameters.

1. Introduction

Micropumps are the beating heart in fluid handling, such as fluid transportation, metering, dosing and manipulation [1]. Hence, they are vastly desired in a large variety of industries such as biotechnology, micro-total analysis systems μ-TAS, aerospace industry, cooling of micro devices, etc. [2–4]. Meeting specifications such as high flow rate and high back pressure within a small size and low consumption of power is a perpetual challenge in this field. Piezo membrane actuators are among the most reported actuation methods used in the micropump field [5]. Having large deflections is of vital importance in these devices, especially in active valves [6]. While piezo actuators are able to exert high forces, they cannot achieve very large deflections. Therefore, we developed a new actuation method to achieve very high deflections. In the following, first we describe the working principle of this innovative method. After explaining the manufacturing and experimental setup, we describe our finite element simulation setup. At the end, we will provide the achieved experimental data together with simulation results to fully verify the advantages of this actuation method.

2. Methods

2.1. Working principle

Our proposed configuration consists of a membrane sandwiched between two piezo rings which are polarized axially with the opposite polarization direction as shown schematically in Fig. 1(a). We have used two types of membranes (50 μm thick steel and 100 μm thick Hard-PVC) for our actuators and we have compared the results. Fig. 1(b) shows the simplified model outside of the experimental setup, with free-free edge boundary conditions. If a piezo ring sees a voltage in the direction of its polarization, it contracts radially due to the d_{31}-effect. In the same manner, if a piezo ring sees a voltage in the opposite direction of its polarization, it expands radially. Therefore, if piezo ring 2 contracts radially by seeing the voltage V_2 (in the direction of its polarization) while piezo ring 1 expands by seeing the voltage $V_1 = -V_2$ (in opposite direction of its polarization) a bending moment will be created which bends the membrane in the upward direction, Fig. 1(c). Having this initial deflection, switching the voltage on both

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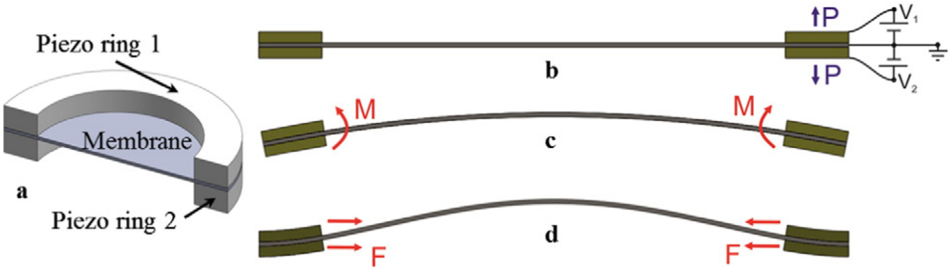

Fig. 1. (a) Schematic of the sandwich configuration; (b) simplified model, showing the polarization and voltage directions; (c) expanding the piezo ring 1 and contracting piezo ring 2 bends the membrane upward; (d) contracting both piezo rings leads to buckling in the already bent direction.

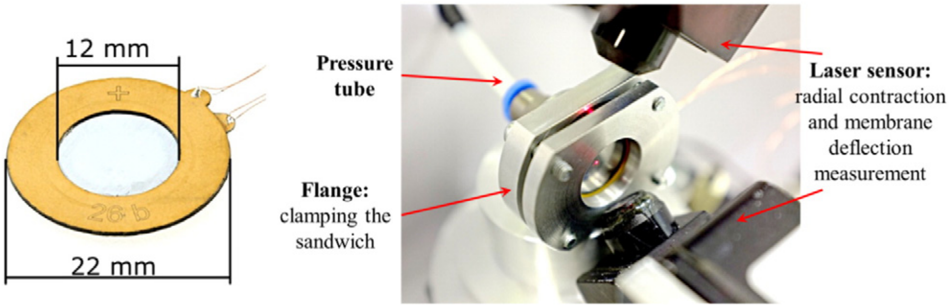

Fig. 2. Left: sandwich configuration; Right: experimental setup with detailed schematic shown in Fig. 3 left.

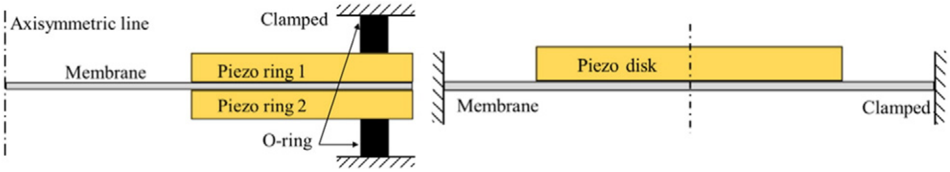

Fig. 3. The model used in finite element simulation for Left: our sandwich configuration, Right: traditional bimorph configuration.

sides of piezo ring 1 ($V_1 = V_2$) contracts this piezo radially as well. Therefore, a radially contracting force will be equally applied by the two piezo rings. Hence the pre-bent membrane buckles in the desired direction and further increases the deflection, Fig. 1(d). If the voltages have opposite signs and the magnitude of the positive voltage is bigger than the negative voltage ($V_1 \times V_2 < 0 \,\&\, V_1 + V_2 > 0$), we have a bending moment together with a net radially compressive load. Therefore, we have a combination of bending and buckling.

2.2. Manufacturing and experimental setup

In order to produce the sandwich setup (Fig. 2, left), first a laser cutter is used to cut the piezo rings and membranes in the desired shape. Our piezo material is M1876 from Johnson Matthey©, our PVC membrane is a Hard-PVC from Puetz GmbH + Co. Folien KG© and our steel membrane is a c-steel from h + s Praziosions-Folien©. Our three-layered structure is glued together using EPO-TEK® 301-2 optical

Table 1
The geometric and material properties used in the finite element simulation.

	Young's modulus [Gpa]	Poisson's ratio	Density [kg/m^3]	Thickness [μm]	Inner radius [mm]	Outer radius [mm]
PVC membrane	3	0.4	1780	100	–	11
Steel membrane	210	0.3	7800	50	–	11
O-ring (FKM)	0.01	0.48	1780	1000	9.625	10.375
Piezo	63	0.3	8000	250	6	11

Dielectric constants		Elasticity coefficients [10^{12} m^2/N]					Charge constants [10^{12} m^2/N]		
$\varepsilon r^T{}_{11}$	$\varepsilon r^T{}_{33}$	$S^E{}_{11}$	$S^E{}_{12}$	$S^E{}_{13}$	$S^E{}_{13}$	$S^E{}_{55}$	d_{31}	d_{33}	d_{15}
6500	700	15.8	−5.6	−8	20.5	57.8	−385	860	1160