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Piezoelectric dispenser based on a piezoelectric-metal-cavity actuator

K. H. Lam,[a] C. L. Sun, K. W. Kwok, and H. L. W Chan
Department of Applied Physics and Materials Research Centre, The Hong Kong Polytechnic University, Hunghom, Kowloon, Hong Kong

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A piezoelectric dispenser has been fabricated based on the idea of a piezoelectric-metal-cavity (PMC) actuator. The PMC actuator consists of a metal ring sandwiched between two identical piezoelectric unimorphs. The radial contraction of the piezoelectric ceramic is converted into a flextensional motion of the unimorph, causing a large flexural displacement in the center part of the actuator. With the PMC actuator as a fluid chamber, the large flexural actuation can be used to produce the displacement needed to eject fluid. By applying an appropriate voltage to the piezoelectric unimorphs, a drop-on-demand ejection of ink or water can be achieved. The efficiency of fluid ejection can be enhanced after installing a valve in the fluid chamber. With the simple PMC structure, the dispenser can be operated with a low driving voltage of 12–15 V. © *2009 American Institute of Physics.* [DOI: 10.1063/1.3187220]

I. INTRODUCTION

Over the century, fluid ejectors or dispensers were used in wide applications of biotechnology,[1–3] integrated circuit manufacturing,[4,5] and engineering.[6,7] In general, those devices are mainly classified into two types: the continuous jet and the drop-on-demand jet.[8] The continuous jet consists of a high pressure pump which is used to force a stream of ink out of a nozzle orifice. It is capable of producing drops at rates that are two orders of magnitudes faster than the drop-on-demand devices. For the drop-on-demand jet, it does not require a pump and a drop is ejected from the nozzle once the piezoelectric element is excited. In the literature, there are many different methods for generating microdrops in the form of either continuous fluid jets or individual droplets.[9–13]

Among various types of ejectors, a piezoelectrically actuated ejector is commonly used in both continuous and drop-on-demand applications because of the low cost of fabrication and support electronics.[14] The piezoelectric element is used to generate a pressure pulse so as to change the volume of the chamber to eject the fluid. There are several advantages of using the piezoelectric actuation. The time of ejection and the size of ejected drops can be optimized by tailoring the driving voltage of the piezoelectric element and the rise and fall times of the pressure pulse. Moreover, the fluid would not chemically alter using the pressure pulse actuation. Although the resolution and speed of ejection have been improved by some novel piezoelectric ejectors, the driving voltage of the piezoelectric system reported is quite high (32–200 V peak to peak) compared with that of the bubble system.[15,16]

In the past, many designs of fluid ejectors with different geometries have been studied. There are two major geometries: tubular design[17–19] and flat plate design.[20,21] Each of them has its corresponding merits and demerits. In this paper, the piezoelectric dispenser is based on the idea of a flat plate design. The piezoelectric-metal-cavity (PMC) actuator[22] has been used as the driving element and fluid chamber of the dispenser. The piezoelectric elements attached on the actuator would transfer a mechanical impulse to a fluid chamber through a flexible membrane in contact with the fluid. With the outstanding piezoelectric performance of the PMC actuator, the fluid can be ejected with a relatively low driving voltage.

II. DEVICE CONFIGURATION

A schematic diagram of the piezoelectric dispenser, divided into six parts, is shown in Fig. 1. The fluid is filled into part A via a soft tube and then ejected from a nozzle (part F as shown in Fig. 2) with an orifice of 0.2 mm diameter. Part A is connected to a large volume source of fluid (not shown in Fig. 1) for replenishing the expelled fluid. Part C is the PMC actuator which serves as the driving element and the fluid chamber. As shown in Fig. 3, the PMC actuator is the actuator in which the brass hollow cylinder is sandwiched between two piezoelectric unimorphs. The piezoelectric unimorphs of 20 mm diameter with 0.4 mm thickness act as a

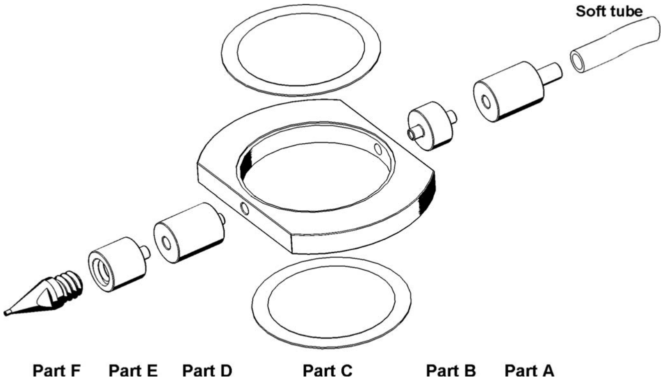

FIG. 1. A schematic of the piezoelectric dispenser with a PMC actuator.

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[a] FAX: +852-2333-7629. Electronic mail: kokokhlam@gmail.com.

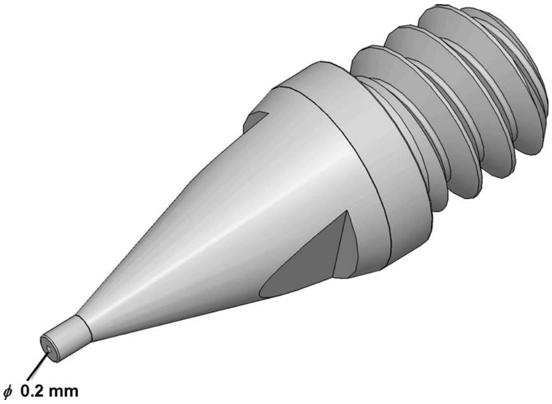

FIG. 2. A schematic (isometric view) of the nozzle (part F).

driving element of the actuator. The brass hollow cylinder of 6 mm thickness has the function of enlarging the displacement by a circumferential coupling of the unimorphs.[23] When the electric field was driven along the polarization direction of the unimorph, it would be bent depending on the lateral strain ($d_{31}E$) generated in the piezoelectric layer.[24] The brass hollow cylinder sandwiched between the unimorphs acts as a simply support medium, enlarging the bending curvature of the unimorphs. Since the hollow cylinder clamps the outer rim of the unimorphs, the displacement in the center of the actuator is the largest.[22] The fluid, mechanically coupled to the unimorphs, can be ejected from the fluid chamber by altering the fluid chamber volume with unimorphs. The fluid would be drawn from the external fluid source during the chamber expansion. While the chamber contracts to the smaller volume, the fluid inside the chamber may be squeezed out.

During the contraction of the fluid chamber, the fluid may be forced not only in the forward direction toward the nozzle but also in the backward direction away from the nozzle. The efficiency of the fluid ejection can be further improved by installing a simple valve, fabricated using a spring and a steel ball, in parts A and D, respectively. The valve is used to damp the backward movement of the fluid. Once the inertial force of the fluid is larger than the surface tension force (holds the fluid to the nozzle), droplets can be ejected from the nozzle.

III. CHARACTERIZATION OF THE DEVICE

Performance of the piezoelectric dispenser (shown in Fig. 4) can be evaluated by electrical and mechanical measurements. The resonance modes of the dispenser were measured by the Agilent 4294A impedance analyzer. In the mechanical measurement, the displacement of the actuator (fluid chamber) as a function of voltage at 0.1 Hz was measured by a photonic sensor (model: MTI-2000).

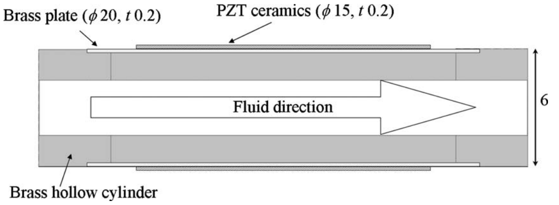

FIG. 3. A schematic (front view) of the PMC actuator (part C). (Dimension: mm.)

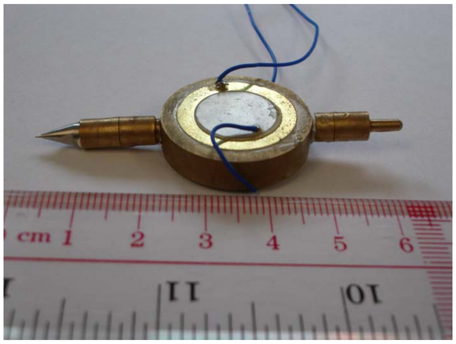

FIG. 4. (Color online) A photograph of the final product of the dispenser.

Figure 5 shows the variation of the impedance and phase of the piezoelectric dispenser before and after the water loading. As shown in the figure, the resonance signal of the dispenser becomes weaker after the fluid loading. It is a normal phenomenon because the water inside the chamber has damped the actuation of the PMC actuator. Since the dispenser is proposed to be used at low frequency range, there is

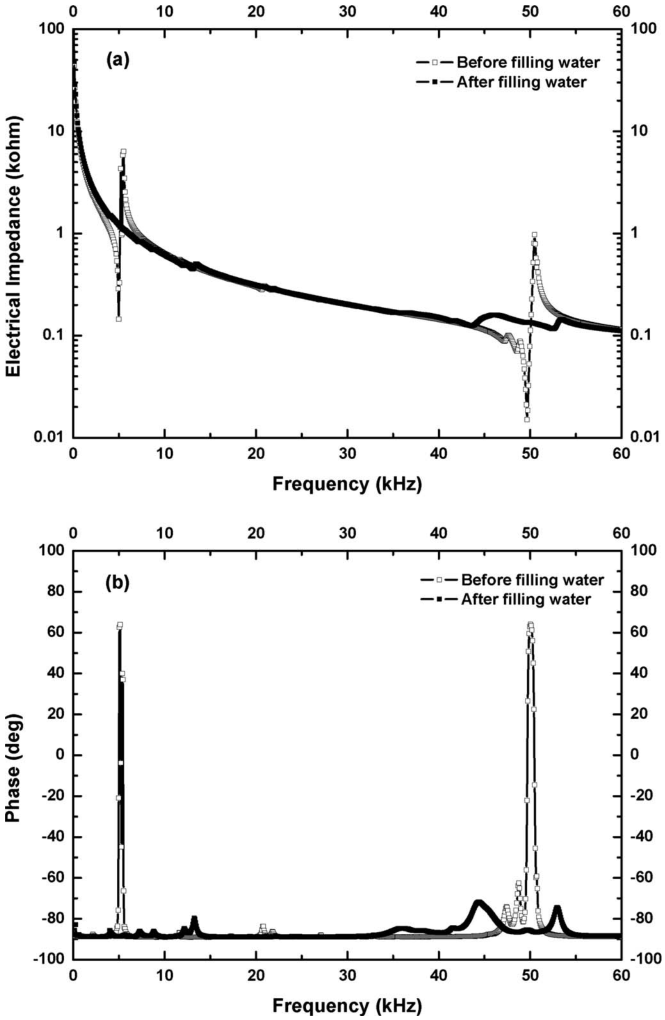

FIG. 5. The (a) impedance and (b) phase spectra of the piezoelectric dispenser before and after water loading.

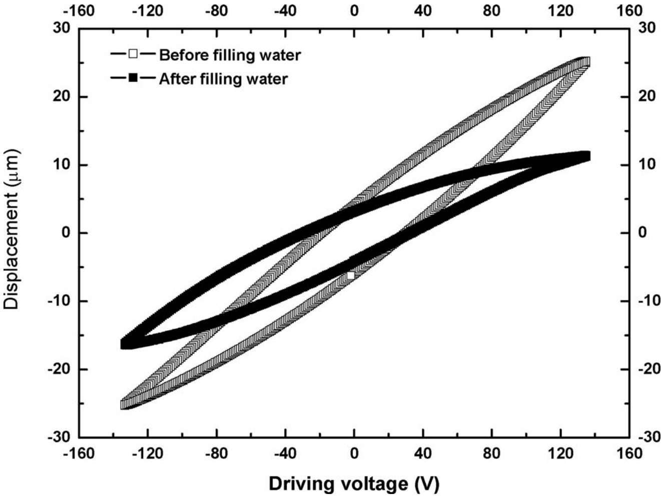

FIG. 6. The axial displacement of the piezoelectric dispenser as a function of driving voltage. (Frequency: 0.1 Hz; position: center of the actuator.)

no effect on the operation of the dispenser even with the significant damping of the resonance modes. Figure 6 compares the displacement induced by the actuator before and after the water loading. It is found that the displacement of the actuator can be still high, approaching 30 μm with a driving voltage of 150 $V_{p\text{-}p}$, even when water is filled inside the actuator.

Based on the high piezoelectric performance of the actuator, the dispenser may be operated in low driving voltage. Water and ink can be ejected with a driving voltage of 12–15 V at 0.1–10 Hz as shown in Fig. 7. The driving voltage is much lower than those reported in other literatures. Since the size of the droplet and its initial speed depend on the energy applied to the dispenser, the fluid can be jetted out if the driving voltage is high enough.

IV. CONCLUSION

This paper presents a novel piezoelectric dispenser based on a PMC actuator. A PMC actuator has been used as a fluid chamber to fabricate the dispenser. The electrical and mechanical performance of the dispenser has been studied. It is found that the displacement of the PMC actuator can be still high even when water is filled inside. Based on the ultrahigh piezoelectric performance, the dispenser can be operated at a very low voltage. Operation of the dispenser has been demonstrated using water and ink. The simple PMC-actuated dispenser shows good potential to be used in fluid ejectors.

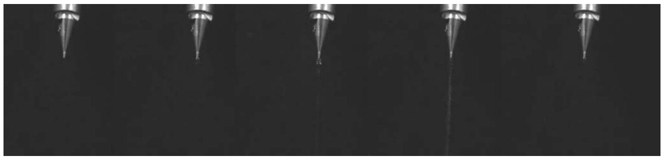

FIG. 7. Captured images of dispensing.

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