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Sensors and Actuators A 136 (2007) 434–440
SENSORS AND ACTUATORS A PHYSICAL
www.elsevier.com/locate/sna

PZT bimorph actuated atomizer based on higher order harmonic resonance and reduced operating pressure

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Received 8 March 2006; received in revised form 30 November 2006; accepted 4 December 2006
Available online 5 January 2007

Abstract

This paper presents the design, fabrication and testing of a PZT bimorph actuated atomizer. The atomizer with the size of 43 mm × 37 mm × 7 mm is composed of a PZT bimorph actuator, which is sandwiched by top and bottom flow channel plates and cover shields. The micronozzle plate is attached onto the top cover shield. UV laser machining and micro electrical discharge machining (μEDM) are applied to fabricate the micronozzles with different geometry. The experimental results indicate that we can justify the frequency response of flow rate by acoustic pressure analysis. The peak flow rates occur at higher order resonances, and the operating pressure is less than 0.1 MPa, which is much lower than that of existing atomizers. Also, the influence of flow rate by changing the distance between the PZT bimorph and the nozzle plate, as well as the flat plate on the bottom cover shield are discussed. The maximum flow rate of 8 ml/min is obtained by using the μEDM-made micronozzle plate, when the atomizer is driven with square pulses at 7 kHz with 50% duty cycle and 27 V peak-to-peak.

Keywords: PZT bimorph; Atomizer; μEDM; Micronozzle

1. Introduction

Atomization of liquid can cause bulk liquid into fine spray. For many applications, such as electronic component cooling, lubrication, drug delivery, and fuel injection, atomizer can effectively shorten the reaction time. Ultrasonic [1–4] and pressure-driven [5,6] methods for atomization are commonly used. Usually, ultrasonic atomizers can be classified into two driving mechanisms: capillary waves and Rayleigh wave. One representative of pressure-driven atomizer is the fuel ejector used in the fuel injection system of vehicles. Atomization is generated by high-pressure liquid passing through a single nozzle.

With recent progress in MEMS technology, atomizers fabricated by micromachining have achieved even better performance [7,8]. Among different driving schemes of atomizers, piezoelectric actuation is one of the popular selections, since it has faster response, low power consumption and simpler driving structure than thermopneumatic, and electrostatic actuation, which MEMS devices commonly used [9].

In this paper, we will report a PZT bimorph actuated atomizer with a micromachined nozzle plate [10]. The atomizer uses higher order harmonic resonances of a PZT bimorph to acquire large flow rate, and ejecting/atomizing the liquid with relative low acoustic pressure. The packaged device is tested through an experimental setup of a fuel injection system. The results show the flow rate of 2.5 ml/min can be obtained less than the operating pressure of 25 kPa.

2. Device fabrication

The atomizer is composed of a PZT bimorph, two flow channel plates, and two cover shields, which we have described in the previous section. The PZT is sandwiched by the top and bottom flow channel plates and cover shields. Openings are made on the cover shields, and a micronozzle plate, and a flat steel plate are attached onto the cover shields to seal the top and bottom openings, respectively.

Two major micromachining technologies are exploited to fabricate the array-type micronozzles plates for our fuel atomizer.

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doi:10.1016/j.sna.2006.12.004

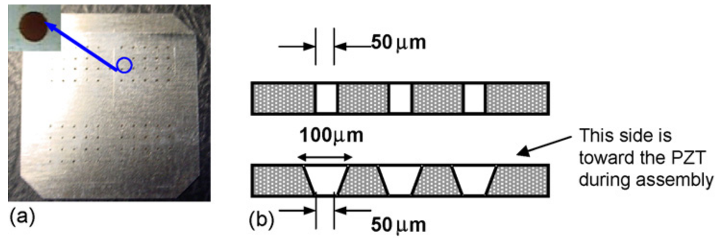

Fig. 1. (a) Micromachined nozzle plate: the array of 80 micronozzles made by UV laser machining. (b) The cross-sectional dimension of the micronozzle plate. *Top*: Fabricated by UV laser machining. *Bottom*: Fabricated by μEDM.

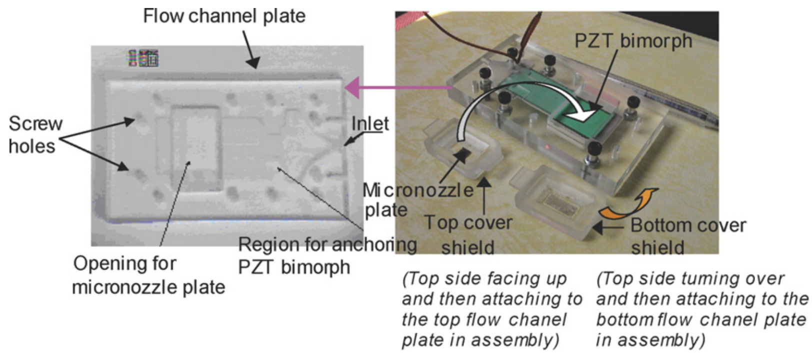

Fig. 2. Assembly of PZT bimorph actuated atomizer.

A 200 μm thick stainless steel is used as a substrate since it is readily available and convenient to be further machined, such as drilling, and cutting by computer numerical control (CNC) machine for assembly later. First, UV laser machining with the wavelength of 266 nm, 1 kHz pulse frequency and 7 ns pulse duration is applied to the stainless steel substrate to make the array of 80 micronozzles (Fig. 1a). The laser machining could directly make round shape thru holes on the steel substrate with low cost. Micro electrical discharge machining (μEDM) is the second technique for making micronozzles with designated shapes. This method is applied to the micromachined nozzles after laser machining. The taper-shaped electrode with designed taper ratio is used for this process. Fig. 1b illustrates the fabricated cross-sectional geometry. In this case, the diameters of nozzles made by μEDM are 50 and 100 μm on the two ends of nozzles (area ratio is 1 to 4), respectively. The orientation of the tapered micronozzles in the assembled device is also denoted.

Another component is the flow channel plate. Through the channel on the plate, the liquid can be continuously supplied from the main tank. The flow channel plate and cover shield are made of acrylic by CNC machining. Fig. 2 shows the assembly of the designed atomizer. The PZT plate is fastened by top and bottom flow channel plates. Two cover shields (top shield with micronozzles, and bottom shield with a flat plate) are sandwiched to form the atomizer. O-rings are placed into the grooves between the cover shields and flow channel plates. Precision screws are used to give pressure to make a good seal. We could precisely adjust the distance between the PZT bimorph and top/bottom cover shields for the experiments later by turning the screws and counting the rotating angle.

3. Design principle and background study

Fig. 3 illustrates the configuration of our developed atomizer. The condition for ejecting the fuel droplets out from the nozzles is [11]

$$P_a > \frac{2T}{R} - P_p$$

where P_a is the acoustic pressure, T the surface tension, R the radius of curvature of the liquid surface around the nozzle, and P_p is the negative pressure caused by the pump connected to the main fuel tank. The acoustic pressure P_a can be calculated as [12]

$$P_a = Z_0 V$$

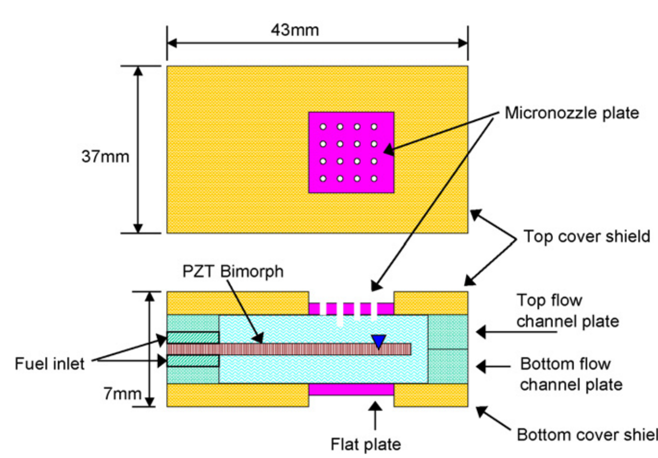

Fig. 3. Illustration of PZT bimorph actuated fuel atomizer. *Top*: Top view. *Bottom*: cross-sectional view. The triangular mark on the PZT is the measured point for the data shown in Fig. 4.