적층형 압전 엑츄에이터를 이용한 고성능 마이크로 밸브의 제작과 그 특성

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Fabrication of a high performance microvalve using a multilayer piezoelectric actuator and its characteristics

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Abstract : This paper describes the design, fabrication and characteristics of a micromachined piezoelectric valve utilizing a multilayer ceramic actuator (MCA). The micromachined MCA valve, which uses a buckling effect, consists of three separate structures: the MCA, the valve actuator die and the seat die. The valve seat die with 6 trenches was made, and the actuator die, which is driven by the MCA under optimized conditions, was also fabricated. After Si wafer direct bonding between the seat die and the actuator die, the MCA was also anodically bonded to the seat/actuator die structure. A polydimethylsiloxane (PDMS) sealing pad was fabricated to minimize the leak rate. Finally, the PDMS sealing pad was also bonded to the seat die and the stainless steel package. The MCA valve shows a flow rate of 9.13 sccm at an applied DC voltage of 100 V with a 50% duty cycle and a maximum non-linearity of 2.24% FS. Therefore, the fabricated MCA valve is suitable for a variety of flow control equipment, as a medical bio-system and in the automobile industry.

Keywords : Microvalve, multilayer ceramic actuator, piezoelectric, buckling effect, flow rate

1. Introduction

Fluidic devices are used in many fields, including industrial gas and liquid control, bio-medical instruments, semiconductor processes and automotive applications. In particular, different components for microfluidics have been fabricated including channels, passive and active valves, actuators for active valves and pumps, flow sensors, reaction chambers, filters and mixers [3]. Recently, there has been a growing interest in using the various components to implement microflow handling systems for applications such as ink jet printing nozzles, fluid injection analysis, electrophoresis systems, microdosage systems and systems for counting red blood cells. .

Among these systems, microvalves are especially important in various fluidic applications to control gas or liquid flow. In general, a valve can be categorized by its actuation type. Conventional valves employ solenoids for magnetic actuation. On the microscale, however, induced magnetic forces are usually too weak to act against high pressure flows. Microvalves using bimetallic and thermopneumatic driving techniques often operate under relatively low temperatures (below 60°C)[6]. Piezoelectric and electrostatic actuation has been widely used in design because of their low power consumption, but such drives require high voltage input and small deflections in order to produce large actuation forces. Other actuation techniques include electrolysis-bubble actuation and shape memory alloys.

Piezoelectric ceramics are widely used to fabricate MEMSs with high performance, as well as electronic devices. They have several advantages, such as a larger generative force, quick response, and smaller driving voltage than electrostatic, electromagnetic, shape memory alloy or pneumatic methods [1]. However, piezoelectric thin film ceramics also have some problems such as a slow response, insufficient driving forces and low resonance frequency [2]. Therefore, in the future it is expected that multilayer ceramic actuators (MCA) can be substituted for piezoelectric thin film ceramics for use asactuating parts of MEMS devices with accurate control and low power consumption [3-4].

The aim of this work is to describe the design and fabrication process used to make the micromachined piezoelectric valve with the MCA and to evaluate its characteristics. The MCA valve was fabricated using micromachining technologies, such as anodic bonding of MCA/Si and Si selective bonding.

2. Fabrication

Fig. 1 shows the fabrication process sequence for the MCA valve. We used two boron-doped Si wafers with <100> orientation and 22 cm^2 dimensions. Firstly, a seat die with an inlet andan outlet with 430430 μm^2 dimensions and a seat with 6 trenches were fabricated using anisotropic wet etching. A 500 Å-thick Si_3N_4 film was deposited onto the seat die using PECVD and then removed, with the exception of the seat area, for selective bonding. After pre-treatment, the fabricated seat die was directly bonded to the 510 μm thick actuator die to form a channel. The 1010 mm^2 Si diaphragm with 200 μm thickness was fabricated from the perfectly bonded actuator die using an anisotropic wet etch TMAH 20 wt% solution for optimized control of the MCA. Then anodic bonding between the actuator die and the MCA was also performed. Pyrex glass #7740 thin films were deposited on the MCA under optimum RF magneto conditions (Ar 100%, input power 1 W/cm^2). After annealing at 450°C for 1 hr, the anodic bonding of the MCA and Si substrate was successfully completed at 600 V and 400°C for 1 hr in a vacuum chamber at 110^{-6} Torr. After polarizationof the bonded MCA, a polydimethyl siloxane sealing pad, which has an inlet and an outlet, was also fabricated and bonded to the seat die for electrical isolation and to prevent leakage. Finally, the MCA and the valve holder were packaged with stainless steel (303L) to interface with other fluid control systems.

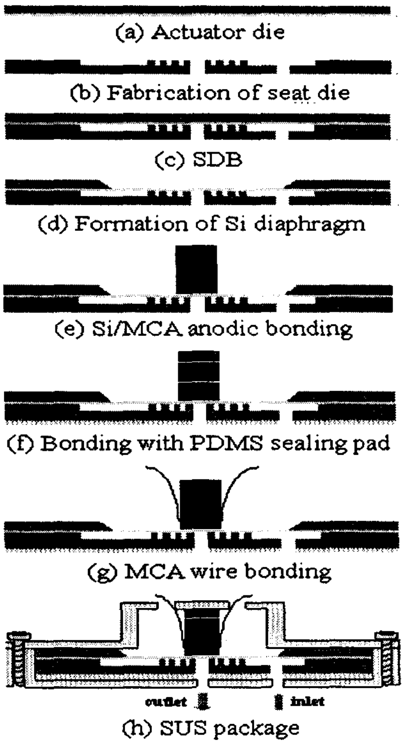

Fig. 1. Fabrication process sequence of the micromachined MCA valve.

3. Characteristics

Fig. 2 shows the flow characteristics of the MCA valve as a function of the applied pressure at a duty cycle of 50%. The maximum flow rate was 9.13 sccm, and the maximum non-linearity was 2.24%, which was greater than the 2.5% of the AFC valves. From this result, it is confirmed that measured values are always smaller than expected values, because the MCA deflection is continually changing with electric charge and discharge.

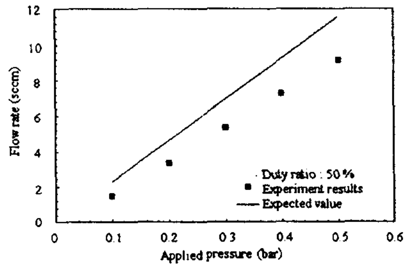

Fig. 2. Flow rate characteristics of the fabricated MCA valve as a function of applied ressure (duty cycle: 50%)

Fig. 3 shows the flow rate characteristics of the fabricated MCA valve as a function of a duty cycle at 0.2 bars applied pressure. By increasing the duty ratio to 50%, the flow rate gradually increasedto 3.28 sccm. However, when the duty cycle was increased to 90%, the flow rate dramatically decreased, owing to difficulty of electrical discharge to the MCA. Thus, a duty cycle of 50% yielded the maximum flow rate, and it is possible to control fluids into the MCA valve using duty cycle control.

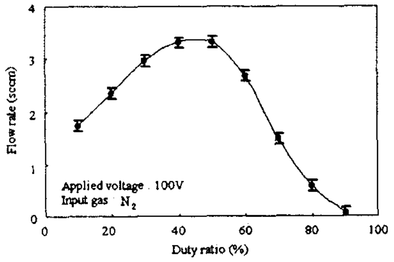

Fig. 3. Flow rate characteristics of the fabricated MCA valve as a function of duty cycle (applied pressure: 0.2 bars).

4. Conclusion

In this work, the micromachined piezoelectric valve using MCA was designed, fabricated and analyzed forflow control system applications. The MCA valve is composed of an actuator die, a seat die, and a multilayer ceramic actuator and has the advantages of high non-linearity (2.24% FS), high reliability (0.092% FS), and low leak rate (1.1910^{-8} pa·m^3/cm^2). From these results, the fabricated MCA valve is suitable for a variety of flow control equipment, medical biosystems, semiconductor fabrication processes, and in the automobile and air transportation industries.

REFERENCES

[1] N. T. Nguyen et al., Sensors &. Actuators A 69, 85 (1988).
[2] M. Elwenspoek et al. J. of Micromechanics & Microeng. 4, 227(1994).
[3] P. Gravesen et al., J. of Micromechanics & Microeng. 3, 168(1993).
[4] J. Collier et al., J. of Microelectromechanical systems, 13, 912(2004).