FABRICATION OF A MEMS-BASED ER MICROGRIPPER WITH ALTERNATING-PRESSURE SOURCE

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ABSTRACT

We propose and develop a MEMS-based ER microgripper system using an alternating-pressure source, which has high power density and is space-saving for in-pipe working micromachines, medical microrobots, and so on. The proposed system utilizes an electro-rheological fluid (ERF) flow induced by synchronizing ER microvalves and an alternating-pressure source. The ER microvalve controls the ERF flow through its apparent viscosity change due to the applied electric field. Each ER microfinger has only one pipe for supply and return with small diameter by transmitting alternating-pressure with low viscosity water. An ER microfinger having 1-mm long PDMS finger part with high-aspect-ratio was fabricated by a newly developed MEMS process, then the ER microgripper was experimentally characterized.

KEY WORDS

Microactuator, Electro-Rheological Fluid (ERF), Alternating Pressure, MEMS, Multiple Actuators System

INTRODUCTION

For micromachines working in narrow space such as tiny pipelines of industrial plants, human body inside for medical use and so on, high power multiple microactuators systems are required because they need to travel in narrow but long space and to manipulate some objects by microgrippers in micro area. We have proposed and been developing microactuators using homogeneous electro-rheological fluid (ERF) as the working fluid, which can utilize high power density of hydraulic actuators. Homogeneous ERFs have controllable apparent viscosity by the applied electric field strength (ER effect) and are usable in micro channels because they have no particles in them [1]. A flow channel having a pair of parallel plate electrodes can control the ERF flow by applying electric field as shown in Fig. 1, and it is called the ER microvalve. An ER microactuator is a combination of an ER microvalve and a hydraulic microactuator [2]. However, conventional ER microactuators systems are not suitable for multiple microactuators systems due to the large pipes space, because each ER microactuator needs two pipes for supply and return and large diameter pipes for the high base viscosity of ERF. To overcome the problem, we have proposed an ER microfinger system using an alternating-pressure source and confirmed its validity through experiments on a large model [3].
In this paper, for miniaturization of the system a MEMS-based ER microfinger system is proposed for microgrippers and an ER microfinger with 1-mm long finger part is developed.

PROPOSAL OF MEMS-BASED ER MICROFINGER WITH ALTERNATING-PRESSURE SOURCE

Figure 2 illustrates the ER microfinger system using an alternating-pressure source. In the proposed system, multiple ER microfingers are connected to one pressure source. The ER microfinger consists of a finger part, two ER microvalves, and a pressure transmitter, and is fabricated by MEMS processes. Working principle of the system is based on rectifying alternating flow by ER microvalves. In the outflow period (Fig. 2a), the ER microvalve B is closed by applying voltage; ERF discharged from the pressure source flows in the upper chamber of finger part through the ER microvalve A; the finger bends downward. In the successive inflow period (Fig. 2b), the ER microvalve A is closed; ERF sucked by the pressure source flows from the lower chamber of finger part through the ER microvalve B; the finger bends downward. In addition, the finger can bend upward and stand still by changing the waveforms of voltages to the ER microvalves.

The ER microfinger has only one pipe for supply and return with small diameter due to low viscosity water, which is suitable for multiple microactuators system. To realize the ER microfinger in micro size, conventional machining are insufficient. In this paper, MEMS fabrication processes are proposed and utilized, which features micro fabrication, high precision, and high reproducibility.

FABRICATION

Figure 3 shows the schematics of MEMS-based ER microfinger having 1-mm long poly(dimethylsiloxane) (PDMS) finger part and two ER microvalves fabricated by MEMS technologies.

The ER microvalve is composed of an anisotropic etched silicon substrate and an electrode sputtered Pyrex glass. The silicon substrate and the Pyrex glass were assembled by anodic bonding and the microvalve has trapezoidal cross-section microchannel as shown in Fig. 4. A nematic liquid crystal (JD-5036XX, JNC Corp., base viscosity: 103 mPa-s) was used in the system as the ERF. Static and dynamic properties of the JD-5036XX between the differential pressure and the flow rate have been characterized. We confirmed the ER effect with the ER effect index \( \kappa_{ER} = 3.3 \), and the rise times 44 ms at step-up and 29 ms at step-down. Fabricated ER microvalves are shown in Fig. 5. Two ER microvalves
are installed for each finger part and ERF is supplied through the hole of the glass. As shown in Fig. 6, the finger part has high-aspect-ratio reinforcing walls in its two square cross-section chambers. The reinforcing walls restrain the lateral expansion of pressurized chambers and transform the applied pressure to the tip displacement of the finger part efficiently.

The PDMS finger part was fabricated by newly developed molding process for high-aspect-ratio PDMS 3-D structure as shown in Fig. 7. A pair of negative photoresist molds for the lower part of the finger is fabricated on glass substrates by photolithography technique for casting of PDMS (Fig. 7a). SU-8 3035 (Microchem, Corp.) is used in this process for high-aspect-ratio and thick structure due to its suitable chemical and mechanical properties. For the mold release process, Poly (vinyl alcohol) (PVA) layer is formed on the mold by spin coating of 2 wt% PVA water solution. PVA is water-dissolvable polymer [4]. A 15:1 mixture of PDMS (SIM-260, Shin-Etsu Chemical Co., Ltd.) prepolymer and curing agent are casted and cured in two SU-8 molds at 95 °C for 90 min (Fig. 7b). Then the PVA film covered mold is released by ultrasonication in DI water by dissolving PVA into water (Fig. 7c). In the release process, thin brass c-shaped spring are inserted between glass substrates for acceleration of water penetration into the boundary between PDMS and the mold.

The center part of the finger is also fabricated by photoresist molding process but two release agents are used for selective release of the molds. PVA and positive photoresist (S1805, Shipley Co., L.L.C) films are formed on the molds, respectively. The positive photoresist film covered mold is released by ultrasonication in acetone bath by dissolving the positive photoresist into acetone using thin brass c-shaped spring.

Each finger parts are assembled by PDMS-PDMS bonding with surface activation using O₂ plasma. The surfaces of two PDMS finger parts are activated by O₂ plasma (10 W, 300 mTorr, 20 sccm, 25 s) (Fig. 7d), and they are stacked and bonded using mask aligner (MA-10, Mikasa Co., Ltd.) (Fig. 7e). After bonding process, the center part mold is released by ultrasonic water bath. The upper part of the finger is fabricated as well as the lower part and is bonded to assembled lower part by O₂ plasma, and the residual molds are removed (Fig. 7f).

The PDMS-PDMS bonding strength of the fabricated finger part was characterized by air pressure test, and airtight of the finger was confirmed up to 110 kPa. An ER microfinger was assembled by bonding three parts together as shown in Fig. 8. A pressure transmitter which has 40 μm thick silicon diaphragm with a
EXPERIMENTS

The schematic view of the experimental apparatus for the ER microfinger system is shown in Fig. 10. We used a large model of alternating-pressure source using a voice coil motor [3] in this experiment. The ER microvalves in the ER microfinger are connected electrically with high voltage power supplies, and the alternating-pressure source and the power supplies are controlled by a personal computer. Experiments were conducted with sinusoidal pressure by the alternating-pressure source. The driving frequency of the alternating-pressure source was 5 Hz, and the peak-to-peak value of pressure amplitude was 50 kPa. The voltage applied to the each ER microvalves has amplitude of 200 V. Under the above-mentioned conditions, we conducted characteristic experiments. As shown in Figure 11, the movement of ER microfinger was confirmed, but bending motion of the finger was slower and the displacement was smaller than the designed values. It will be improved by changing the design and the method to fill the ER microfinger with ERF.

REFERENCES