10-WAY MICRO SWITCHING VALVE CHIP FOR MULTI-DIRECTIONAL FLOW CONTROL

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Abstract

The world's first 10-way micro switching valve chip as one of Biochemical IC chip was developed successfully. This switching valve chip has a special rotary mechanism with the silicone rubber leak-preventions and the precise auto-positioning of outlets. This chip succeeded to switch 10 outlets from one inlet without dead volume under high leakage pressure (>700kPa). Since the micro fabrication was made by our original "Hybrid micro stereo lithography" (hybrid-IH process), the micro assembling and bonding are not needed. This chip is generally useful for various kinds of micro chemical devices.

Keywords: Micro switching valve, Multi-directional flow control, Hybrid-IH process, Biochemical IC chip

1. Introduction

The authors group have been developing module/versatile micro fluidic devices named "Biochemical IC Family [1-4]" proposed by Ikuta for these years. As shown in Fig.1, the biochemical IC chips contains different functional devices such as multiple connectors, pumps, one-way passive valves, reactors, switching valves, chemical concentrators. The total micro chemical system can be constructed by stacking various kinds of chips. To miniaturize total apparatus of micro-TAS and laboratory on a chip, the fluidic control apparatus such as micro pump and micro switching valve are needed. Our device is useful not only for micro-TAS but also "portable" or "wearable" micro chemical devices. In this paper, we investigated the multi-directional flow control device for the micro liquid sampling system (Fig.2).

2. Micro liquid sampling system

Fig.2 shows the micro liquid sampling system. This sampling system consists of the pump chip, the multi-directional switching valve chip, the liquid sampling chip, and the reservoir chip. To begin with, while the air is sucked by the micro pump, a reagent is introduced into the chamber through the one-way passive valve and stored to given quantity. Next, the air is pumped into the chamber by the micro pump and the measured reagent is supplied through the other one-way passive valve. Furthermore, by switching channels by

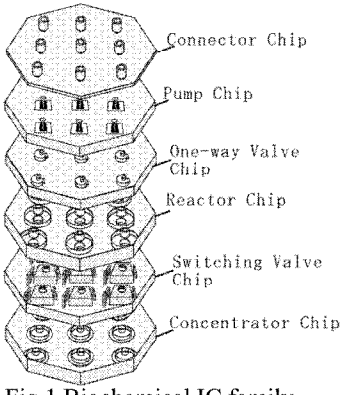

Fig.1 Biochemical IC family (Ikuta et al. [2])

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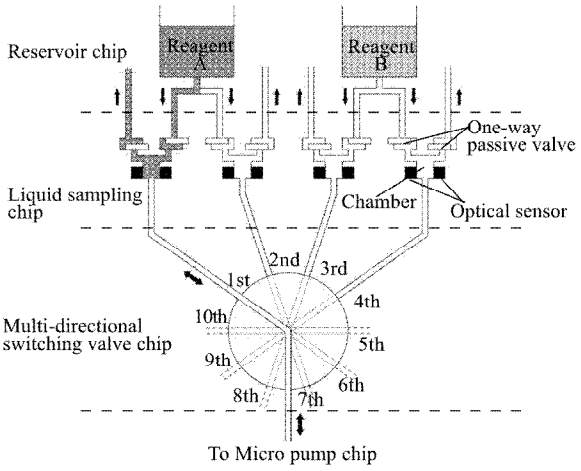

Fig.2 Schematic diagram of micro liquid sampling system with multi-directional switching valve

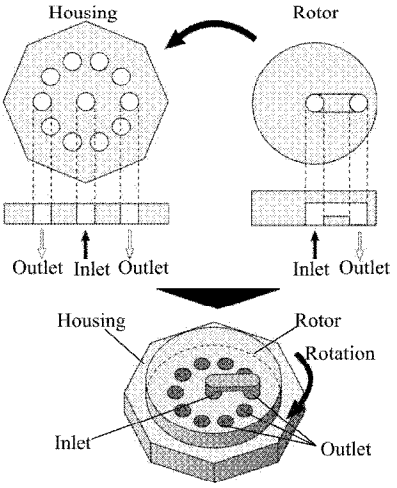

Fig.3 Operation principle of the micro valve with multiple outlets

the multi-directional switching valve, it is measurable in two or more reagents and amounts of reagents in one micro pump. Since the number of active devices can be stopped to the minimum extent, the size of this sampling system can miniaturize and its yield also becomes high.

3. Switching principle for multi-directional flow control

Some active valves have addressed to close the outlets by using the micro actuators. As switching multiple outlets, they have some disadvantages. The number of actuators increases in proportion to the number of the outlets and the chip size also becomes large. Furthermore, the leakage pressure is dependent on the power of the micro actuator. Thereby, it is difficult for leakage pressure to withstand about several 100 kPa. Therefore, the novel switching principle for multi-directional flow control was presented to solve the above problems drastically.

The switching principle of the micro valve with 10 outlets is shown in Fig.3. The housing with 10 outlets placed in circumference of the inlet and the rotor with the channel is utilized. By uniting and arranging their centers, the fluid is supplied to the outlets on the circumference from the inlet in the center of housing. When switching the outlets, the rotor is rotated and the channel of the rotor is united to another outlets. This switching principle enables to switch multiple outlets without dead volume. Moreover, since the leakage pressure is not dependent on the power of the micro actuator, this valve can withstand high pressure all the time.

4. Micro multi-directional switching valve chip

4.1. Design and fabrication

The design plans for making the above switching principle realize are summarized as follows;

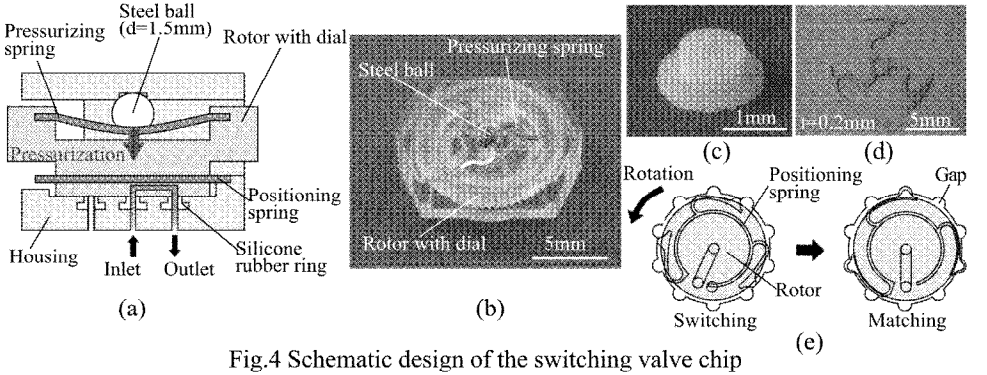

Fig.4 Schematic design of the switching valve chip
(a) Cross sectional view (b) prototype chip (c) Pressurizing spring
(d) Silicone rubber ring (e) Outlet auto-positioning

1) Leak-prevention between the rotor and the housing.
2) Smooth rotation of the rotor.
3) Precise positioning of the outlets.
4) Composite structure made of polymer and other materials (Hybrid IH process)

Fig.4(a) shows the cross sectional view of the micro switching valve chip. First, To prevent leakage between the rotor and the housing, the silicone rubber rings were integrated into the channel of the housing. Moreover, the pressurizing spring in the rotor upper part pushed the rotor into the housing and the leak-prevention between the rotor and the housing was realized. The fabrication process of the silicone rubber ring utilized the polymer mold fabricated by micro stereo lithography.

Secondly, to rotate the rotor smoothly, the steel ball (d=1.5mm) was incorporated between the rotor upper part and the housing. Thereby, while holding the rotation center of the rotor, the friction between the rotor and the housing was reduced and the smooth rotation of the rotor was enabled.

Thirdly, for precise positioning of outlets, the positioning spring was integrated into the rotor lower part. As shown in Fig.4(e), if the channel was in agreement, the positioning spring geared with the gap of the housing and the feeling of gearing is transmitted to a user. A user can recognize that the switching was completed.

Finally, the silicone rubber ring, the pressurizing spring, and the positioning spring were integrated into a photocurable polymeric structure by using the hybrid IH process [5]. Therefore, the packaging difficulty and leakage problem can be eliminated completely. This unique method to produce 3D hybrid structure is not possible by any other micro fabrication process.

4.2. Prototype

Fig.5 shows the multi-directional switching valve chip with the rotary mechanism. The size of this chip is 9x14mm. The design is one inlet-ten outlets connection valve. Since the micro switching valve was operated manually to verify the switching principle, the rotor with the dial

was fabricated. The following model becomes a micro actuator drive. Moreover, this novel valve design succeeded the leak-prevention between the rotor and the housing and the smooth rotation of the rotor. The positioning of the outlet was adjustable precisely without position sensor. The experimental results shown in Fig.6 suggests that the maximum leakage pressure of the switching valve was up to 700 kPa. This leakage pressure is sufficient for various biochemical experiments.

Unique features of this chip are summarized as follows;

1) To switch 10 outlets was succeeded.
2) The rotary mechanism was utilized for switching multiple outlets.
3) A good seal under high pressures was achieved between the rotor and the housing.
4) The leakage pressure is not dependent of the power of the micro actuator.
5) A dead volume of switching parts can minimize.
6) The positioning at the outlets was adjustable precisely without position sensor.

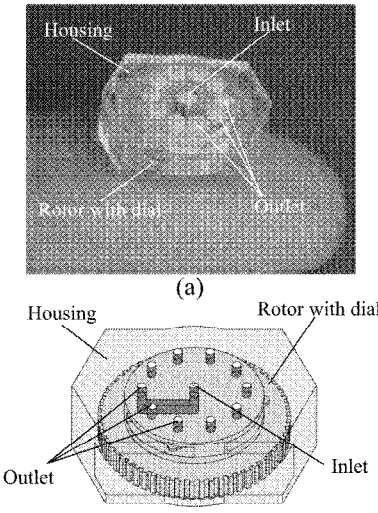

Fig.5 10-way micro switching valve chip with rotary mechanism
(a) upper surface on the finger
(b) basic design

5. Conclusions

The novel switching principle for multi-directional flow control was proposed and the prototype of the micro multi-directional switching valve chip with the rotary mechanism was fabricated. This micro valve succeeded to switch 10 outlets from one inlet without dead volume. Furthermore, the positioning mechanism of the outlets without sensor was realized, and this valve can withstand the water pressure up to 700 kPa without leakage. This pressure is sufficient for various biochemical experiments such as a cell-free protein synthesis. Further miniaturization and motorization of the switching valve is under going now..

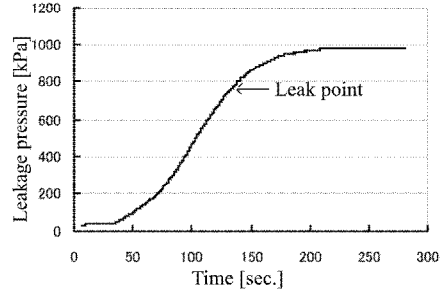

Fig.6 Measured maximum leakage pressure of micro switching valve chip

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