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Integrated Mass Flow Controller by Micromachining of Silicon

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Two integrated mass flow controllers were fabricated on a 20mm square silicon substrate by micromachining. The mass flow controller consists of a small thermal mass flow sensor and a normally close micro valve. The valve is driven by a couple of piezo actuators. The response of the integrated mass flow controller was less than 2msec, which is faster than that of previous ones by nearly thousand times. The small thermal capacity of the flow sensor gives high sensitivity and quick response. The integrated structure having negligible dead volume and the quick response gives rise to a precise flow control for advanced film deposition processes etc..

1. INTRODUCTION

Sophisticated device structures are fabricated by controlling gas flow precisely in advanced deposition processes as MOCVD, MOMBE, ALE etc. A flow control systems which contain mass flow controllers have been used for such purposes. The dead volume in the gas tube line as well as the slow response of a usual mass flow controller prevents from changing gas quickly.

The purposes of this study is to realize integrated flow control systems to improve the controllability of the gas system.

Semiconductor process technologies have been applied to fabricate sensors and actuators. By taking advantages of the micromachining, high sensitivity and quick response of a flow sensor, as well as a reduced dead volume in a flow path are given. The integrated control system is so small as to be equiped close by a reaction chamber and can reduce the dead volume in the gas tube line.

A normally open type integrated mass flow controller had been developed before.[1] This paper descrives a new integrated mass flow controller having a normally close micro valve.

2. PRINCIPLE AND STRUCTURE

The structure of the integrated mass flow controller is shown in Fig.1. Two mass flow

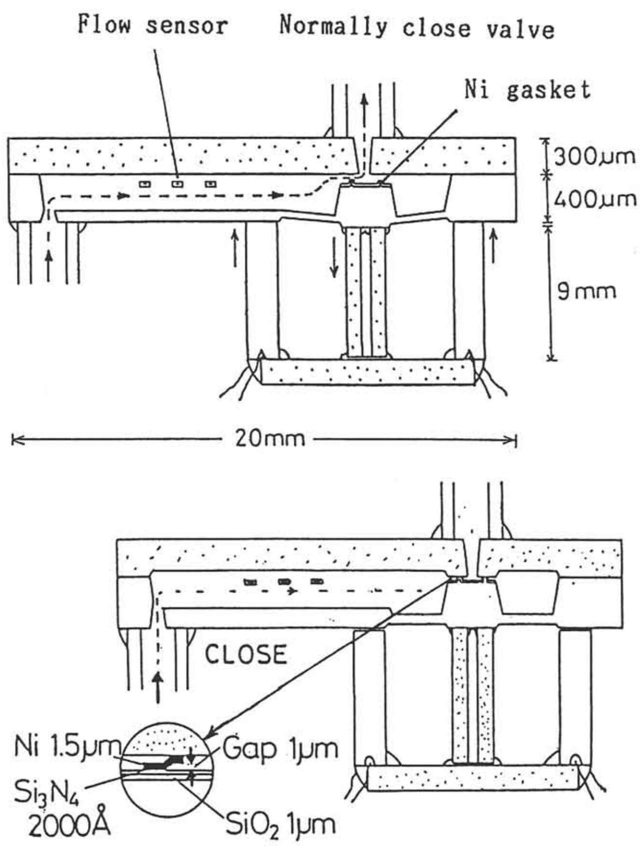

Fig.1 The structure of the integrated mass flow controller and the operation principle of the normally close valve.

controllers are fabricated on a 20mm square silicon sustrate. Silicon-to-glass anodic bonding was used for sealing the flow channel.

The mass flow controller consists of a micro flow sensor and a micro valve. Flow rate is sensed with a thermal mass flow sensor, which is a nickel micro heater in a gas channel, and the flow is controlled with a micro valve. Two small stacked piezo actuators were used to drive the micro valve and an external servo control circuit is used.

(1) Micro valve

If the control valve serves as a shut off valve, it could eliminate the dead volume between these valves connected serially.

The structure and the operation principle of the normally close micro valve are shown in Fig.1. The micro valve has a mesa suspended with a thin diaphragm. In order to shut off the gas flow, a gasket of a free standing nickel film was formed on the top of the mesa.

A couple of stacked piezo actuators of 3mm × 1.4mm ×9mm are used to open the valve. When these piezo actuators are expanded, it pulls down the mesa with the glass rod and the valve is opened. The gas flows between the gasket and the glass.

(2) Micro flow sensor

The principle of the thermal flow sensor is the heat dissipation by the gas flow. The structure of the thermal mass flow sensor is shown in Fig.2. A nickel heater covered with a silicon dioxide layer was fabricated as a bridge in the gas channel.

Nickel was used for the heater, because of its relatively large resistance temperature coefficient, good adhesion to silicon dioxide and the refractoriness. The nickel heater pattern has an angle with respect to the gas channel, in order that the silicon under the nickel heater should be etched out by the anisotropic silicon etching. The silicon dioxide layer supports the nickel film mechanically and besides prevents the nickel from the reaction with the gas. Since the micro heater is thermally isolated from the substrate and is exposed directly to the gas, fast response and high sensitivity of micro flow sensors are performed.

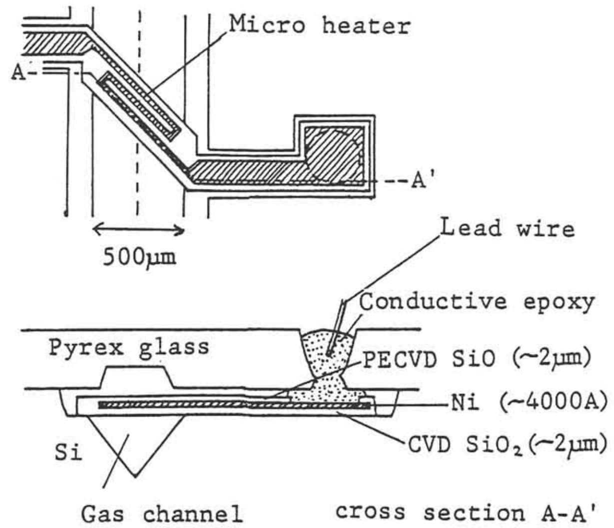

Fig.2 The structure of the micro flow sensor.

3. FABRICATION

The fabrication process are shown in Fig.3 and the assembly processes (g) and (h) are as follows.

A 300 μm thick Pyrex glass was drilled to make gas line holes and wire bonding holes using electrochemical discharge machining in a KOH solution. After aligning the silicon substrate with the glass, they were anodically bonded. The optimum temperature for stress free bonding was 390°C.

A glass rod was glued by epoxy to the center of the mesa. A small glass plate with two piezo actuators mounted on it was glued to the glass rod with epoxy. Bias voltage (10V) was applied to two piezo actuators during the curing process, which made about 1 μm gap between the glass and the actuators after removing the bias voltage. The epoxy resin was cured at room temperature to avoid a stress induced deformation which may causes valve seat leakage.

Fig.4 shows the wafer assembled.

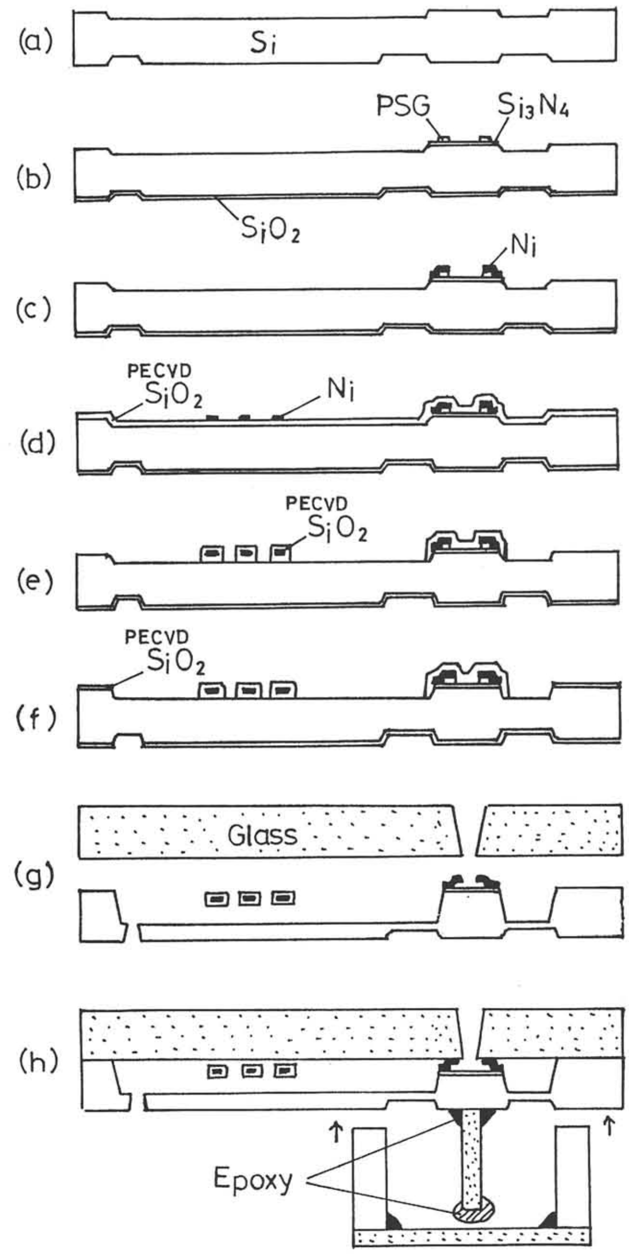

Fig.3 Fabrication process.

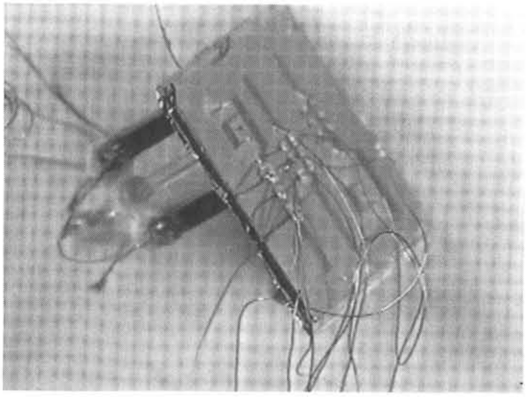

Fig.4 Assembled integrated mass flow controller.

4. CHARACTERISTICS AND DISCUSSION

(1) Micro valve

The characteristics of the normally close micro valve is shown in Fig.5. Maximum flow rate at 0.75 kgf/cm gas pressure was about 50 sccm. The valve closed at 0V and the leakage was less than 0.01 sccm by virtue of the nickel gasket. The detailed evaluation of the valve seat leakage and of the mechanical durability of the epoxy are remained for further study.

(b) Micro flow sensor

The circuit in Fig.6 supplies a power to the heater so as to keep the heater temperature constant, and the output coresponds to the flow rate. The characteristic of the flow sensor of which temperature was kept at 50 ℃ is shown in Fig.6.

Conductive epoxy used for the electrical feedthrough from this flow sensor is in contact with the gas in the channel. But an advanced flow sensor which can seal the gas channel harmetically with silicon and silicon dioxide was developed and was also used for the integrated mass flow controller.[2)]

The temperature compensation and improvements in flow sensitivity will be required.

(c) Integrated mass flow controller

The mass flow controller was evaluated with an external control circuit. It reads out a flow signal and supplies valve drive voltage corresponding to the difference between the flow sensor output and the flow set point.

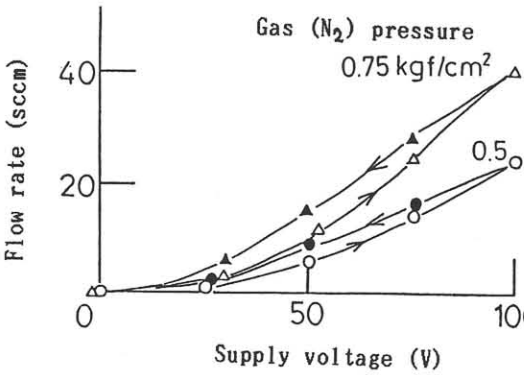

Fig.5 The characteristics of the normally close microvalve.

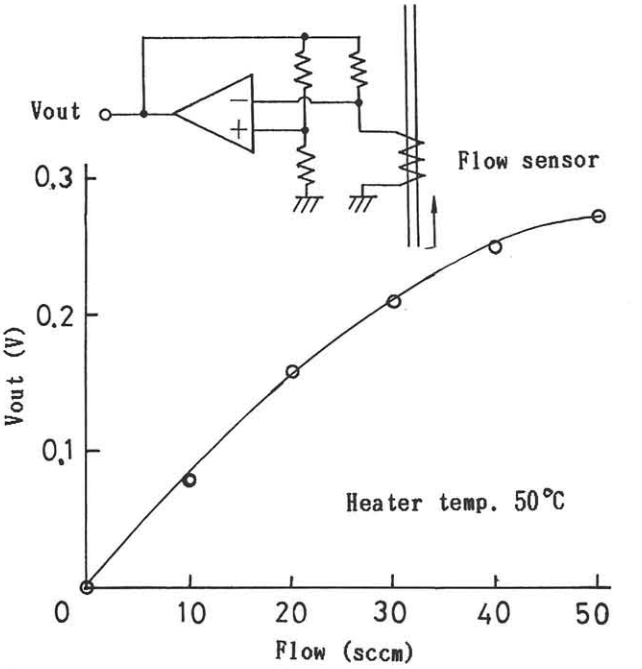

Fig.6 The characteristics of the flow sensor and the flow measurement circuit.

Fig.7 shows the flow rate versus the source gas pressure for different flow set points as parameter. The valve drive voltage is also plotted in it. Increasing the pressure, the valve voltage decreases and the valve is closed. Consequently the flow is kept constant. When the pressure is decreased, the flow is not kept constant and decreases due to the limitted conductance in the flow path.

Fig.8 shows a step response of the integrated mass flow controller. The response time measured was less than 2msec. This means the integrated mass flow controller is faster than that of previous ones by nearly thousand times. The connection of this system to a stainless steel pipe, durabilities to baking or to corrosive gases and an evaluation in application will be the future subjects.

5. CONCLUSION

Micro gas flow control systems for advanced semiconductor processes were integrated on a 20mm square silicon substrate by micromachining. The integrated structure and the quick response could introduce well controlled amount of molecules into a deposition chamber etc..

ACKNOWLEDGMENT

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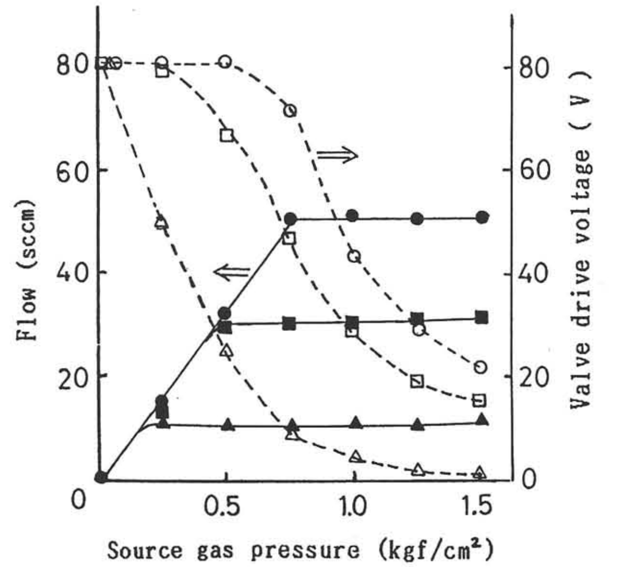

Fig.7 Flow rate and valve drive voltage versus source gas pressure for different set point as parameter.

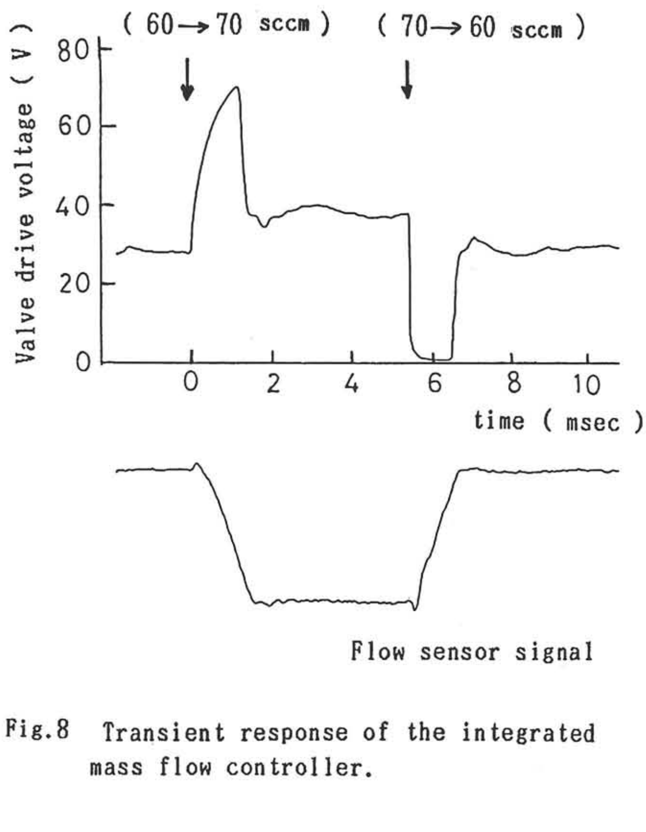

Fig.8 Transient response of the integrated mass flow controller.