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Invited

Micro Systems by Bulk Silicon Micromachining

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Micro systems which are small sized but relatively complicated intelligent systems were fabricated based on bulk silicon micromachining. Extremely sensitive sensors with thin beam structure, packaged micromechanical sensors for inertia measurement, microactuators as microvalve and optical scanner and active catheter which moves flexibly like a snake in a blood vessel were developed. Silicon nano-wire growth by electric field evaporation using UHV STM and novel three-dimensional micromachining as deep RIE were developed for the fabrication of the microsystems.

1. INTRODUCTION

Advanced principles of IC fabrication can be applied for three-dimensional microstructures. By using a silicon wafer as a principal material, intelligent micro systems which have sensors, actuators and electronic circuits can be fabricated. The technology based on photofabrication, bulk silicon etching, interfacial bonding and other three-dimensional microfabrication are called bulk micromachining. On the other hand, so called surface micromachining which uses deposited multiple layers as a structural and a sacrificial material has been also used. This paper deals with the micro systems by the bulk silicon micromachining.

2. EXTREMELY SENSITIVE SENSORS

AFM probe is an example of extremely sensitive sensors which detect small atomic forces with fast response. To improve the performance of the probe, thin single crystalline silicon cantilever attached on a metallized glass plate with narrow gap was fabricated (Fig.1)[1]. The thickness and the gap were less than 1μm. Distortion free thin silicon cantilever fabricated by etching a silicon wafer was anodically bonded to a metallized glass. Rinsing and drying method using small surface tension liquid (Fluorinert (3M Inc.)) and improved wafer holder was used to prevent stiction and collapse. This structure and the following nano-wire are being applied for capacitive AFM probes.

Silicon nano-wire was grown at the tip of the cantilever by electric field evaporation from substrate in UHV STM (Fig.1)[2]. The silicon substrate with gold surface was heated at 700°C. The diameter of the nano-wire was less than 50nm and the growth rate was approximately 200nm/min.

An extremely sensitive capacitive pressure sensor which has thin silicon diaphragm was developed for vacuum measurement[3]. A resonant infrared sensor of which resonant frequency is modulated by radiation-induced thermal strain variation was also developed[4]. High vacuum inside a cavity is required for these sensors in order to keep a reference vacuum pressure and to reduce a dumping of the resonator respectively. Nonevaporable getter was accomodated inside the cavity to achieve the high vacuum sealing[3].

Thin silicon for these sensors could be made using in-situ thickness monitoring during anisotropic silicon wet etching[5]. The principle of the thickness measurement is multiple interference of the near-infrared light.

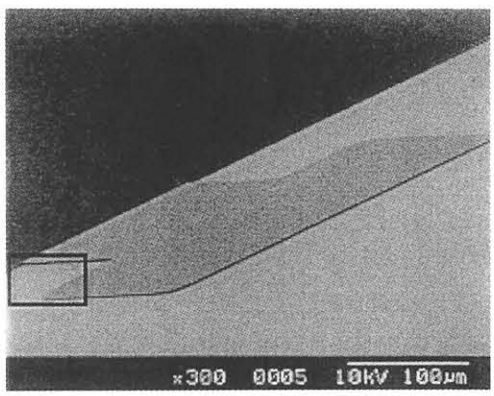

Fig.1 Thin silicon cantilever attached on a metallized glass plate with narrow gap

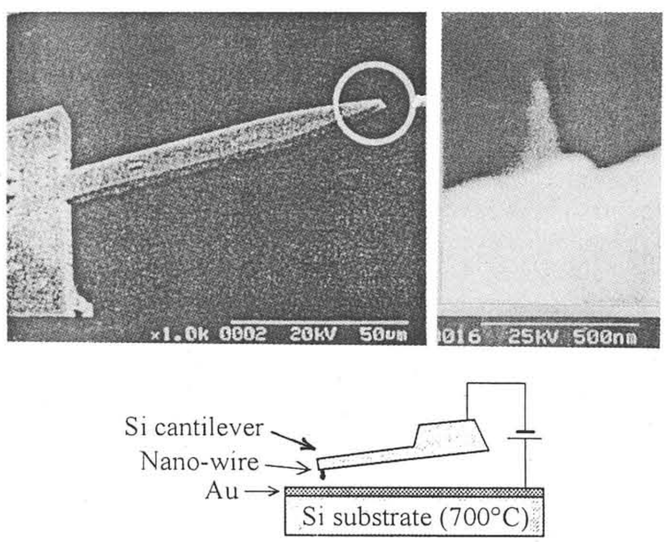

Fig.2 Silicon nanowire grown at the tip of a cantilever

3. INERTIA MEASUREMENT SYSTEMS

Accelerometers and angular rate sensors are required for advanced motion control in automobiles and other systems. Glass-to-silicon anodic bonding has been applied for packaged micromechanical sensors[6]. Parallel plates made of silicon and metal on the glass has been applied for capacitive sensors and electrostatic actuators.

Integrated capacitive servo accelerometer which has a capacitive displacement sensor, an integrated capacitance detection circuit and an electrostatic force balancing actuator was fabricated[7].

A three-axis electrostatic force-balancing accelerometer was developed[8]. Tilt of the mass by X or Y axis acceleration and movement by Z axis acceleration are detected capacitively and the feedback voltage for force balancing are superimposed on the signal voltage for the capacitive sensing.

Cavity pressure of the packaged accelerometer must be adjusted to achieve wide frequency response at critical dumping condition. A packaging scheme based on the built-in nonevaporable getter and inert gas in a cavity in anodically bonded glass-silicon structure was successfully applied for accelerometers[9].

Silicon resonant angular rate sensor was developed (Fig.3)[10]. A tuning fork structure suspended by a torsion bar is driven electromagnetically with an alternating current in the silicon resonator and external permanent magnet. The applied angular rate generates the Coriolis' force and the resonator shows torsional vibration around the torsion bar. This torsional vibration is detected capacitively. The monolithic silicon tuning fork was fabricated by deep reactive ion etching through the silicon wafer thickness as shown in Fig.3[11].

4. MICROACTUATORS

A new bakable silicon pneumatic microvalve was developed for advanced semiconductor processes (Fig.4)[12]. Since valves are installed close to the wafer inside the deposition chamber, dead space in the flow channel is minimized and gas flow can be precisely controlled. To apply such valve for reactive gases, baking out the valve is necessary to remove adsorbed water. Glass-silicon-glass structure was anodically bonded to a Kover block which has welded tubes.

Integrated mass-flow controller consisting of a microvalve and a thermal mass-flow sensor was developed for precise gas control[13]. The response time was 2ms.

A two-dimensional electromagnetic optical scanner was also developed[14]. To realize two-dimensional scanning, mirror and driving coils were fabricated on a silicon micromachined gimbal structure. Closed loop operation is feasible by using a built-in deflection sensor.

5. ACTIVE CATHETERS

Multi-link active catheter which moves flexibly like a snake was developed (Fig.5)[15]. Links were fabricated by silicon bulk micromachining and were connected with joints made of shape memory alloy (SMA) coil actuators. Built-in integrated circuits for its communication and control were developed[16]. Laser CVD processes for micro assembly was developed for the smart catheter[17].

This active catheter is intended for instrumental navigation in blood vessel. Potential applications include not only medical tools for minimal invasive diagnosis and therapy but also other distributed microsystems used in narrow spaces for .maintaining complicated systems without disassembling.

6. CONCLUSIONS

Extremely sensitive sensors, inertia measurement systems as accelerometers and anguler rate sensors in packaged glass-silicon structures, microactuator systems as microvalve and optical scanner and active catheter which moves flexibly like a snake in a blood vessel were developed using bulk silicon micromachining.

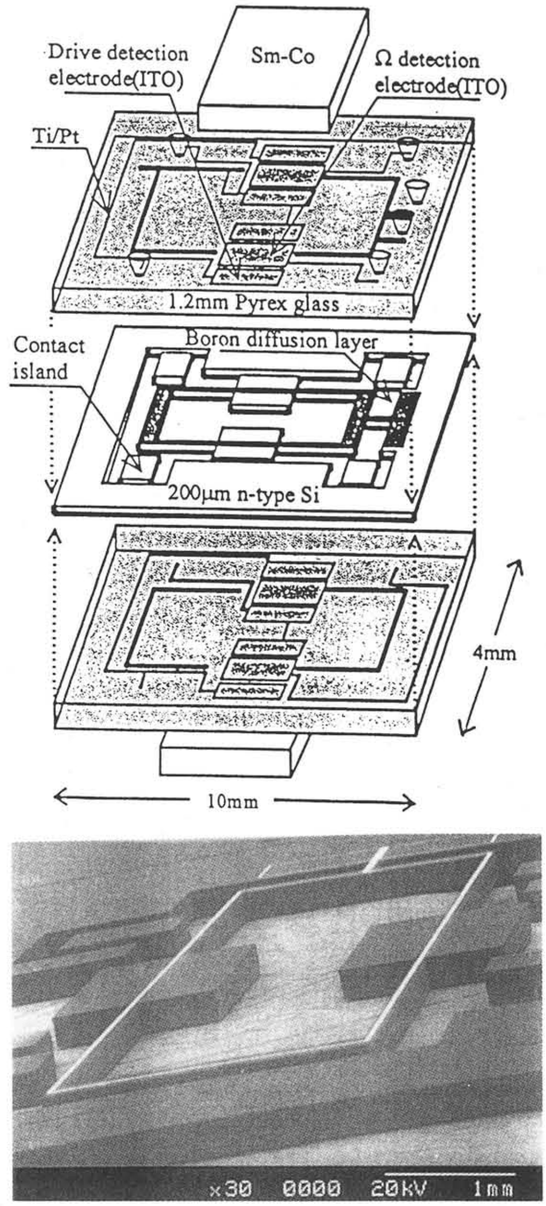

Fig.3 Silicon resonant angular rate sensor and silicon tuning fork formed by deep RIE

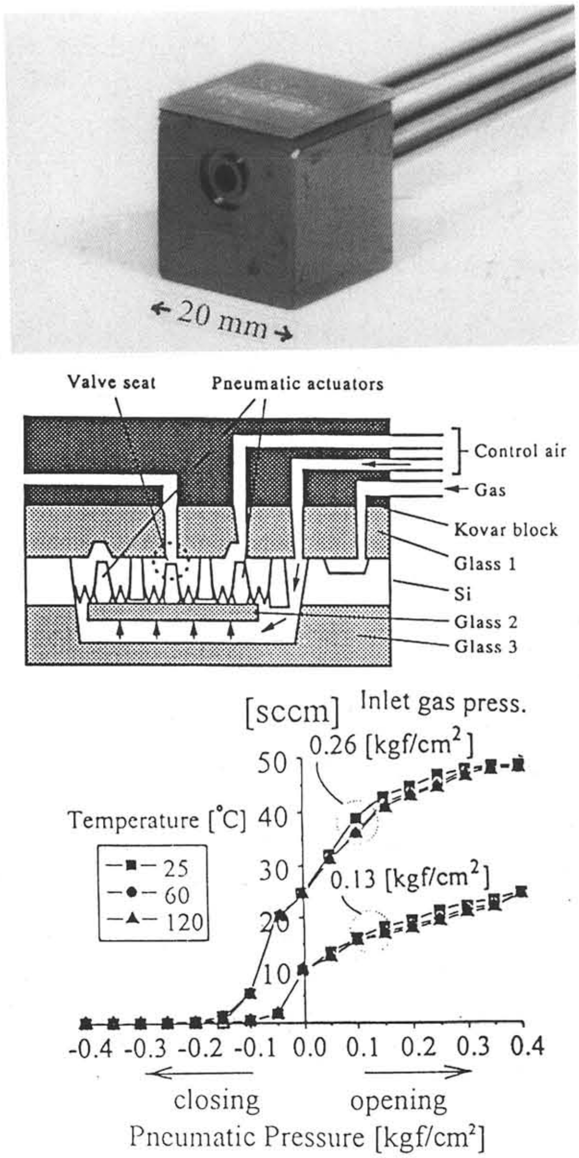

Fig.4 Bakable silicon pneumatic microvalve

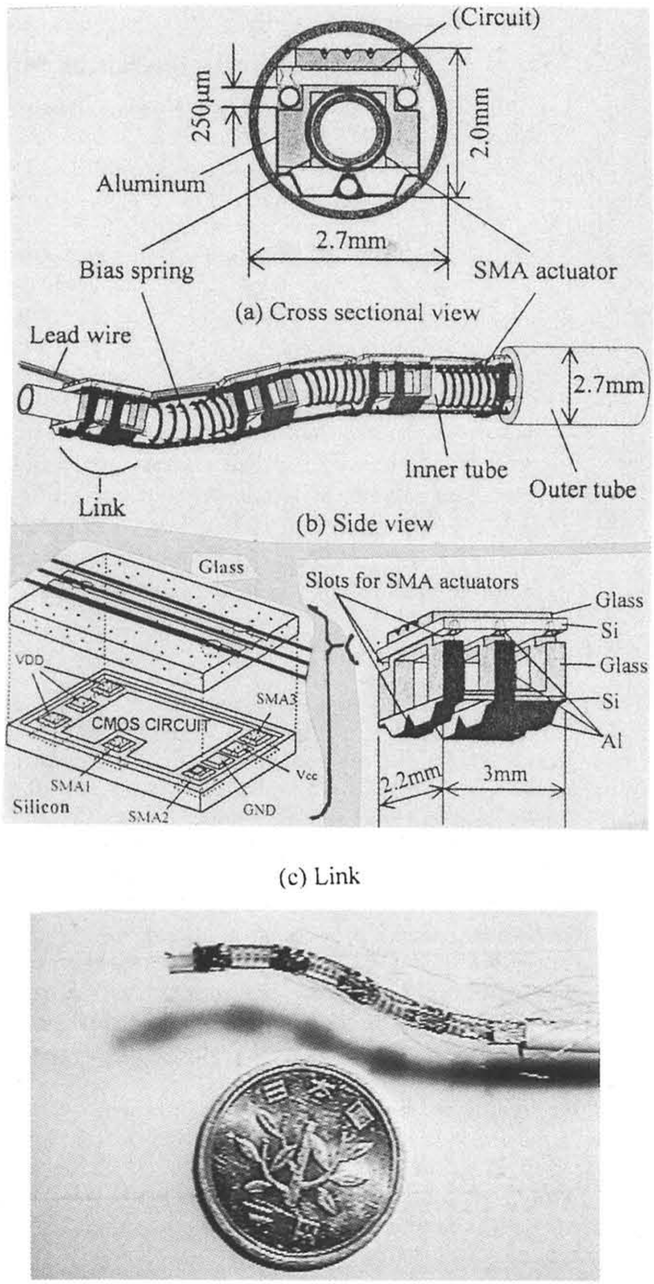

Fig.5 Active catheter

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