文章编号 1004-924X(2002)06-0608-06

Micro-nano electromechanical system by bulk silicon micromachining

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1 Introduction

MEMS (Micro ElectroMechanical System) based on semiconductor microfabrication plays important roles for example in the periphery of IT systems. NEMS (Nano ElectroMechanical System) contains nano-scale structures. Sophisticated and high performance systems based on the MEMS and the NEMS have been developed. Packaging and electrical interconnection play an important role in realizing practically applicable systems[1].

2 Electrostatically levitated rotational gyroscope

Electrostatically levitated rotational gyroscopes have been developed by Tokimec Inc. and Tohoku University[2]. The levitation is actively controlled by force balancing in all directions based on a capacitive displacement sensing and an electrostatic actuation[3]. This principle has been applied to an electrostatically levitated spherical 3-axis accelerometer developed in Ball Semiconductor Inc. collaborating with Tokimec Inc. and Tohoku Univ. [4]. The structure of the electrostatically levitated rotational gyroscope is shown in Fig. 1. A 4mm diameter silicon ring rotor is electrostatically levitated and rotated at 12000rpm[5]. This has been used as a two - axis rotational gyro - scope for

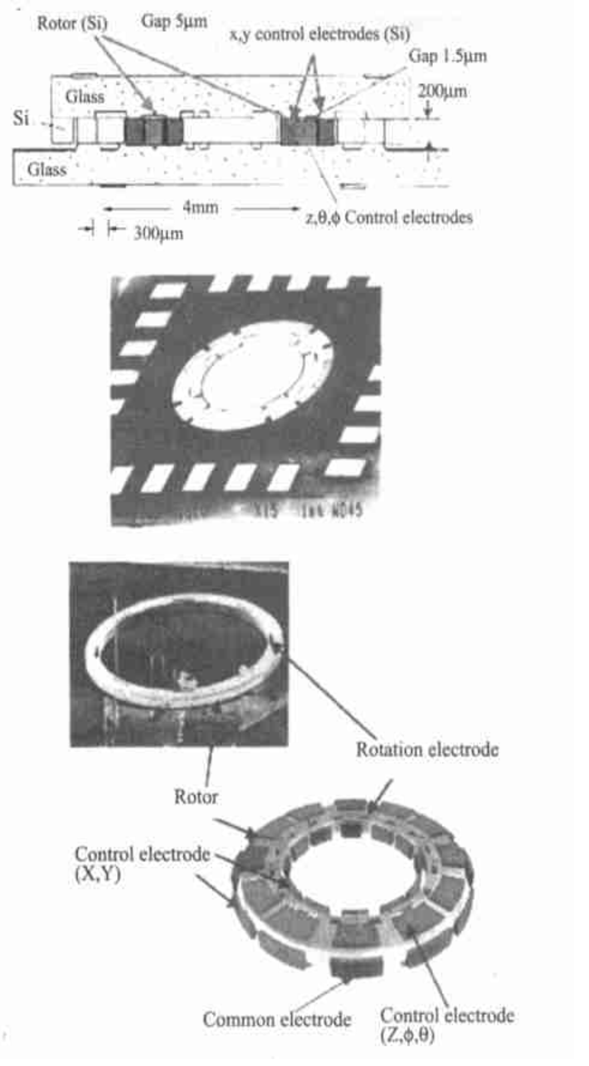

Fig. 1 Electrostatically levitated rotational gyroscope.

收稿日期:2002-10-17;修订日期:2002-11-16

navigation control system and additionally used as a three-axis accelerometer. The rotation is based on the principle of the variable capacitance motor. The ring rotor is electrostatically balanced by the x , y control electrodes and z , θ , φ control electrode shown in Fig. 1. A 5μm radial gap between the ring rotor and the x , y electrodes are formed using deep RIE (Reactive Ion Etching) and the rotor is held between two glasses which have z ,θ,φ control electrodes. The function as a high performance gyroscope and an accelerometer are successfully demonstrated , as shown in Fig. 2.

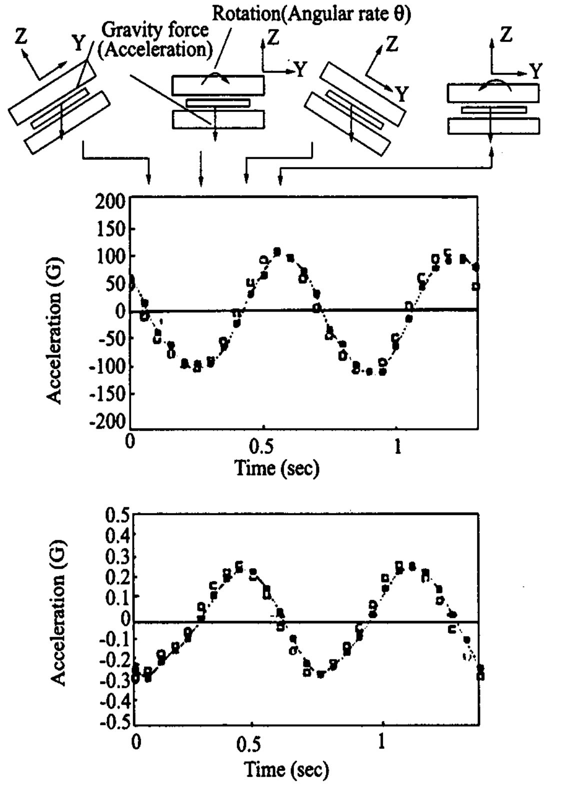

Fig. 2 Measurement of angular rate acceleration using the electrostically levitated rotational gyroscope of ring rotor type.

3 Multiprobe Data Storage

Multiprobe data storage has been developed[6]. The structures of the multiprobe data storage system and the probe are shown in Fig. 3. High density electrical feedthrough is made in a

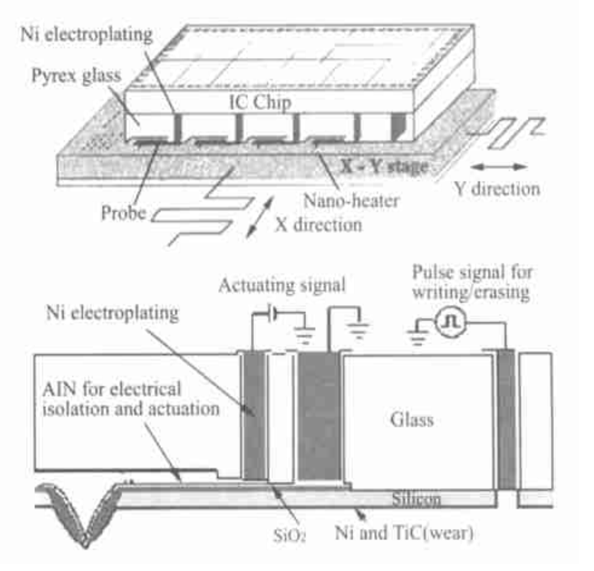

Fig. 3 Structures of the multiprobe data storage system and probe.

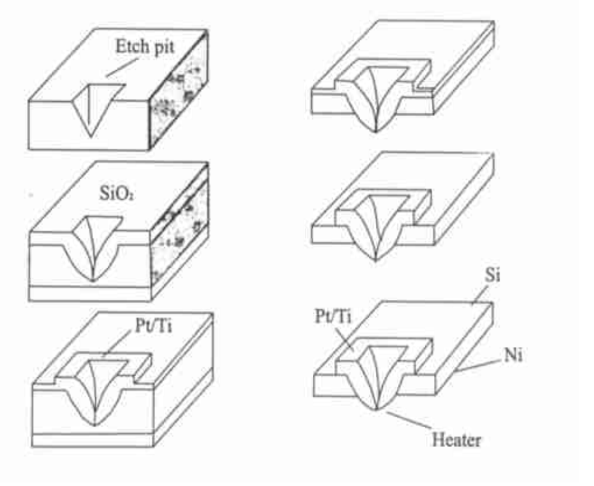

Fig. 4 Fabrication process and a photograph of the nano-heater.

Pyrex glass using deep RIE and electroplating of nickel. It is used to make an electrical connection between each probe and the backside IC chip[7]. The control circuit and MEMS devices can be fabricated separately and connected by flip chip bonding. A nanoprobe which has a heater with 30 nm metal junction was fabricated at the apex of a SiO_2 tip shown in Fig. 4[8]. Not only high spatial resolution but also quick response can be achieved owing to the extremely small tip-size. Thermal pro -

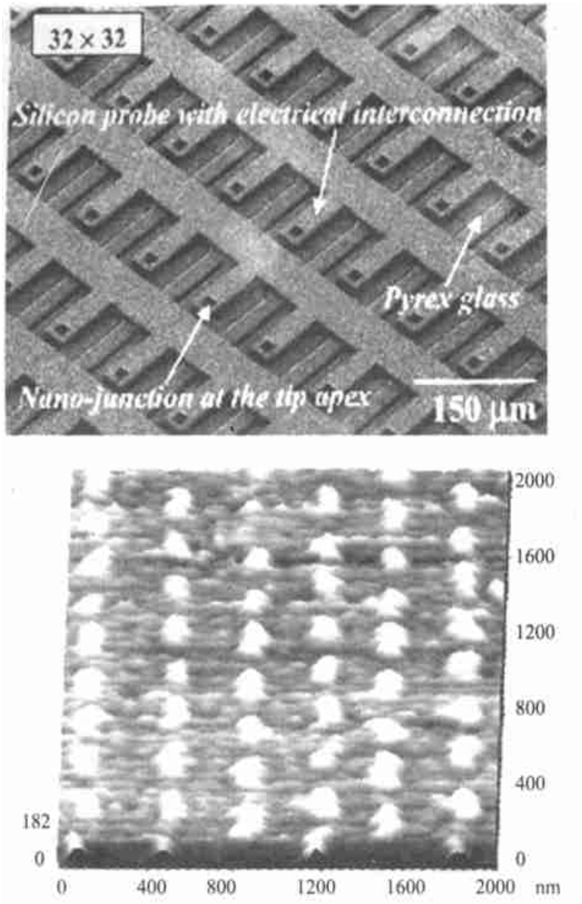

Fig. 5 32 ×32 probe array and conductance image of the recorded bits on thin GeSbTe (2μm ×2μm) .

cessing for writing and electrical resistance measurement for reading is adopted for the multiprobe data storage. This thermal nanoprobe could be successfully used for recording data to the GeSbTe phase change media which is used for DVD RAM. The 32 ×32 probe array and the conductance image of the recorded pattern are shown in Fig. 5. Conductance modification of approximately ten times is caused by the phase change. Owing to the small (30nm) tip-size , the bit density can be Tbit/inch^2 order which is about 100 times higher than the conventional data storage. The recording could be made on the ferroelectric recording media as PZT as well using the nanoprobe[9]. To prevent wear of the contacting probes , a nanoprobe was fabricated using a doped diamond[10]. A XY stage for the recording media has been developed (Fig. 6)[11]. Two multiplayer piezoelectric actuators were fabricated on a PZT plate as follows. Grooves are made in a PZT (lead zirconium titanate) plate by dicing and then filled with a metal , using electroplating of nickel. The metal electrodes are connected alternately[12].

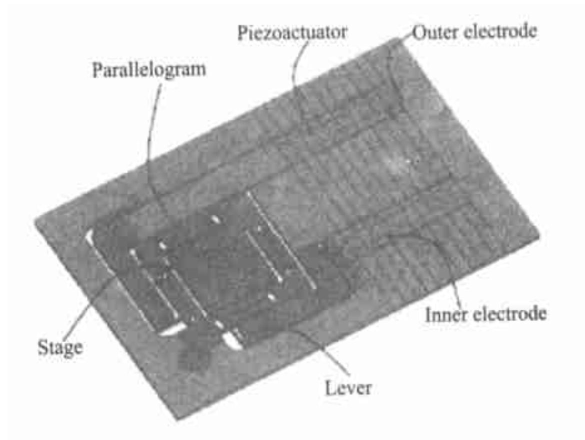

Fig. 6 XY-stage fabricated from PZT plate.

4 Multi-Beam Electron Sources

An electron field emitter array has been deve -

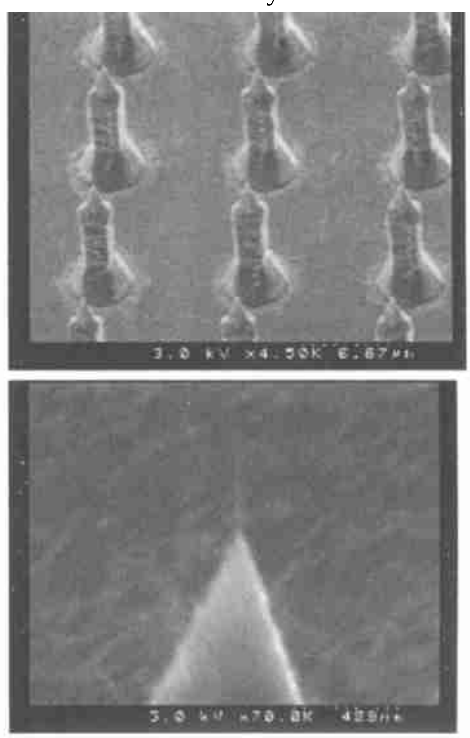

Fig. 7 Electron field emitter array having CNT at the apex.

loped for multi-beam electron source. Carbon nano tubes (CNT) are grown at the apex of each silicon tip as shown in Fig. 7[13]. The fabrication process is shown in Fig. 8. After forming silicon tips 4 nm Fe film was deposited for catalyst and CNTs were grown using hot-filament CVD. High electric field by applying negative substrate bias was necessary for enhancing the growth of CNTs at the apex[14]. The emission current versus voltage is shown in Fig. 9. A small threshold voltage for field emission was achieved and the CNT emitter has along life, in principle.

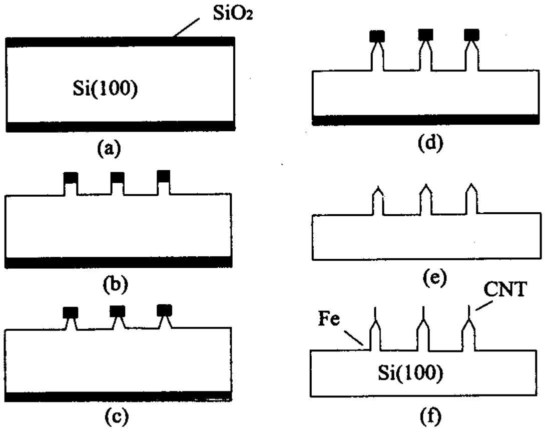

Fig. 8 Fabrication process of electron field emitter array.

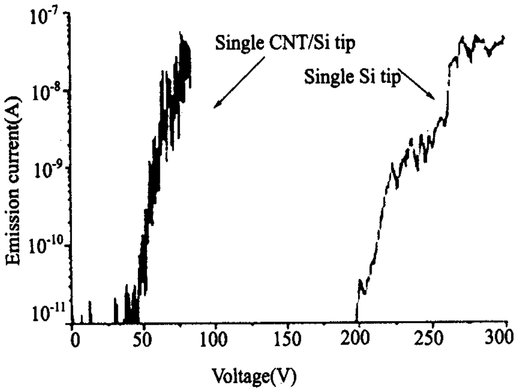

Fig. 9 Electron field emission characteristics of a single electron emitter.

A novel field emission device with an integrated electrostatic lens array for electron extraction and focusing has been developed[15]. The structure and photographs are shown in Fig. 10. A result of focusing simulation showed 40nm beam spot size. Field emission device provides a noncontact multi probe data storage, and a high throughput multi-electron beam lithography system as shown in Fig. 11.

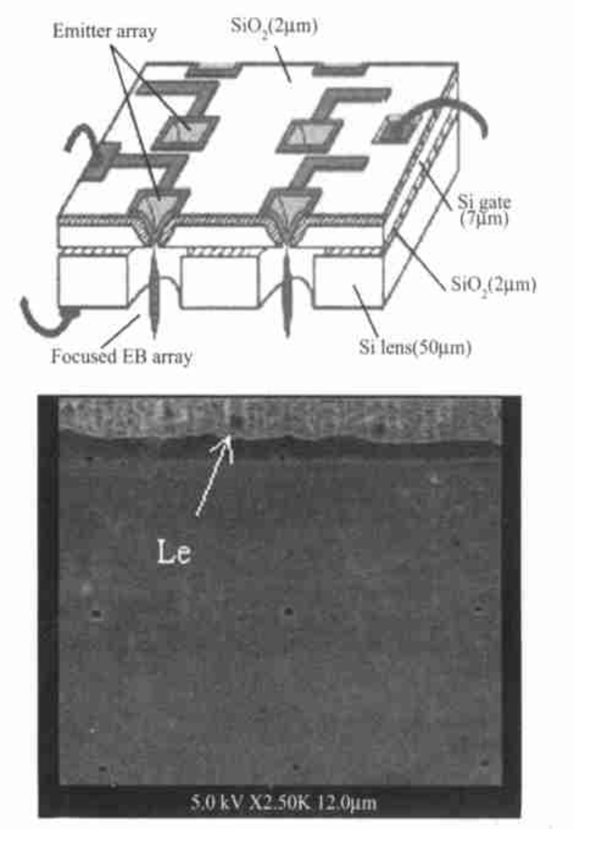

Fig. 10 Structure and photographs of the lens integrated electron field emitter.

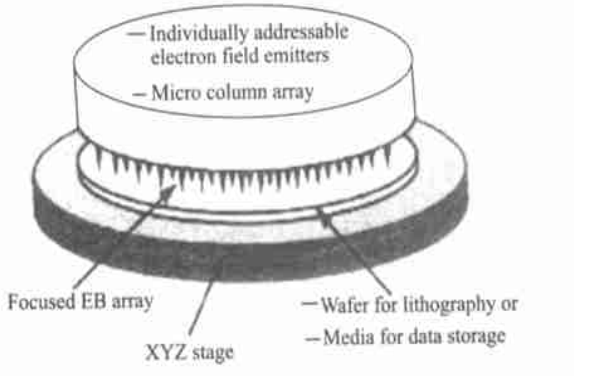

Fig. 11 Concept of multi-electron beam lithography.

5 Measurement of hydrogen storage capacity of carbon nanotube using resonant frequency change of thin silicon cantilever

A thin silicon cantilever resonator can have high Q (250 ,000) by heating in ultra high vacuum[15]. Using the thin silicon resonator with high Q , the hydrogen storage capacity of the carbon nanotube was measured. Hydrogen storage is needed for polymer electrolyte fuel cell systems. The carbon nanotube bundle was attached to a 170nm thick silicon cantilever (Fig. 12) and the frequency changes of the cantilever after loading the carbon nanotube and hydrogen adsorption were measured as shown in Fig. 13[16]. Hydrogen storage capacity against the carbon nanotube weight was calculated from the experimental frequency change and it was 6 wt %.

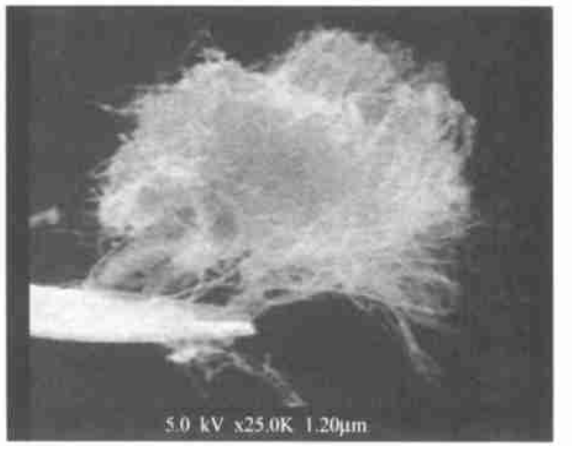

Fig. 12 Carbon nanotube bundle was attached on a 170nm thick silicon cantlever.

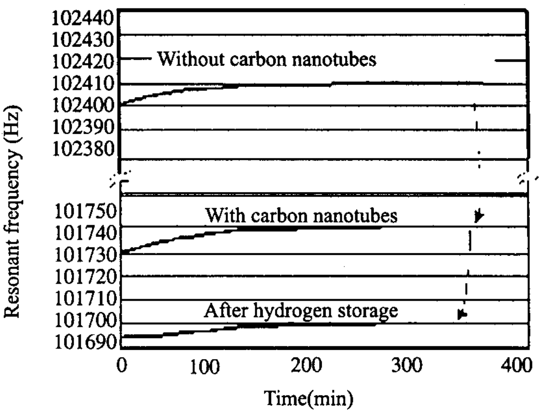

Fig. 13 Frequency change of a thin silicon cantlever on which carbon nanotube bundle is attached.

6 Conclusions

Micro-nano structures and electromechanical systems have been studied, based on bulk micromachining. High density electrical feedthrough in glass plays important roles in array MEMS as multi probe data storage. The high density electrical feedthrough in glass can separate IC chip from array MEMS devices and therefore simplify the MEMS fabrication. Nanometric structures could be used for high density data storage and electron field emitter. Sophisticated MEMS uses electrostatic levitation. Application of functional materials as CNT (carbon nano tube) to the MEMS/ NEMS was studied.

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