MEMS Technologies in MEMSat-1

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ABSTRACT

MEMSat-1 is a small satellite which integrates some MEMS devices such as micro thruster, micro magnetometer and micro Inertial Measurement Unit (MIMU). The micro thruster is a 6×6 array with the solid propellant. It is used for the attitude control of MEMSat-1. The MIMU integrates three micro gyroscopes and three micro accelerometers. The three-axis micro magnetometer and the MIMU are used for the attitude determination of MEMSat-1. MEMSat-1 is designed for testing the space capability of the MEMS devices, and MEMS technologies in MEMSat-1 make it small size, small volume and low power consumption. It is believed that MEMS technologies and space technologies will promote each other greatly.

INTRODUCTION

MEMSat-1 is a small satellite which is designed to test the space capacity of some key MEMS devices and to develop corresponding all-for-one design and system integration technology. The satellite is a 3-axis stable satellite which weighs about 5kg. Its size is about 180mm×180mm×220mm. Fig.1 is the system structure of the satellite, and Fig.2 illustrates the components of the satellite.

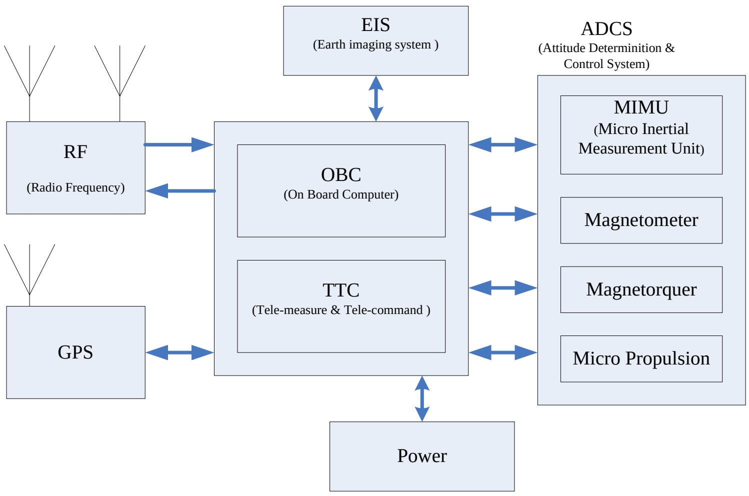

Fig.1. MEMSat-1 system structure

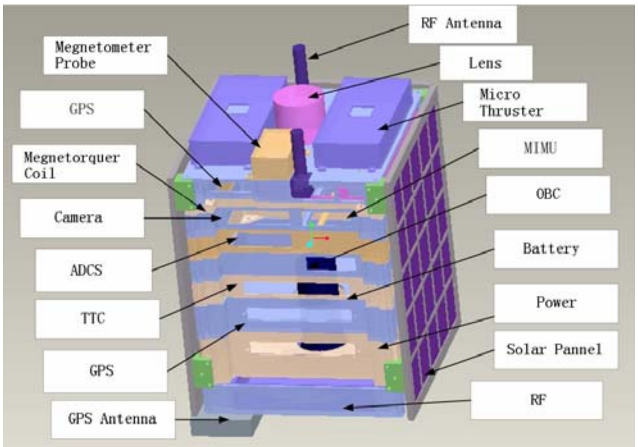

Fig.2. components and structure of MEMSat-1 prototype

The MEMS technologies are mainly applied in the key devices of the ADCS (Attitude determination and Control System), such as micro thrusters, micro magnetometers, and MIMU. The MEMS technologies have greatly promoted the miniaturization of these sensors and actuators, and have greatly reduced the size, energy consumption and weight of the entire satellite.

MICRO THRUSTER

Spatial thruster is an important component for orbit maintenance, station keeping as well as special attitude control of the micro satellite. In order to adapt for the requirement of miniaturization, a MEMS-based thruster array [1][2] with solid propellant was developed in Tsinghua University.

The structure of a single thruster unit is illustrated in Fig.3. The micro thruster is composed of three layers: the igniter layer, the chamber layer, and the nozzle layer.

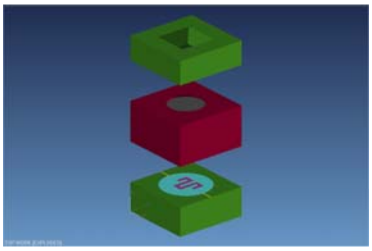

Fig.3. structure of high accurate impulsion unit

The igniter layer consists of an igniter array on the surface of the chip and the addressing circuits integrated inside the silicon chip. Fig.4. is the SEM photograph of one igniter unit. The igniter is made up with addressable Pt resisters, and the underlay is Pyrex7740 glass.

Fabrication process of the igniter layer starts with patterning of resisters, circuits, and bond pads on the glass with a lithography operation, then sputter Cr, Pt and Au successively. Lift off the metal to form lead wires and bond pads. Again pattern the resisters with Lithography operation on the Au membrane, and the Pt igniter array would be finally formed.

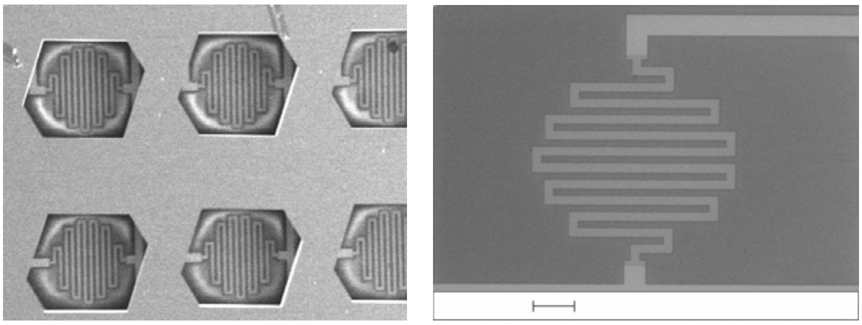

Fig.4. SEM photograph of igniter array and single igniter unit (Pt resister)

The chamber layer is made up of an array of combustion cavities. In the middle of a chamber unit there is a main hole, which is the chamber where the fuel combusts. The main hole also serves as a cavity to deposit fuel. Such ingenious design makes good use of the room. Around the main hole, four auxiliary small holes are arranged, serving as passageways for the gas produced by fuel combustion, which could improve the combustion character of the fuel. Fig.5. is an SEM photograph of the combustion cavity array.

Fabrication process of the igniter layer is as follows: first, deposit SiO_2 and Si_3N_4 as etching masks on the surface of P-type (100) silicon substrate through LPVCD. Pattern the array with Lithography operation and diffuse Sb on the P-silicon substrate to form the N-silicon region. Thus the N-silicon regions get insulated as inverse P-N's formed. Finally, etch the main hole and gas passageways with ICP technology.

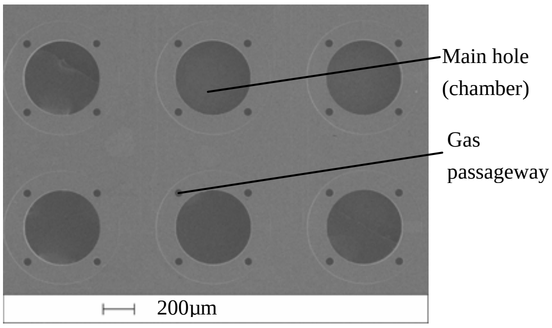

Fig.5. SEM photograph of combustion cavity array

Naturally, the nozzle layer is made up of nozzle array. When combustion gas comes through the nozzle, due to the specially designed configuration of the nozzle passage, the gas would expand and get greatly accelerated, giving out a strong propulsion force. The nozzle layer is processed from P-type silicon substrate. First, deposit SiO_2 and Si_3N_4 as etching masks on top and bottom surfaces, then pattern the nozzle array with Lithography operation. Finally, the nozzle shape is formed with wet etching operation on the substrate in KOH.

To assemble the layers, first bond the igniter layer and chamber layer, then inject the fuel AT/HTPB, and solidify the fuel in the constant temperature case. Finally, paste the nozzle layer upon the chamber layer. Fig.6. illustrates the section of a micro thruster unit.

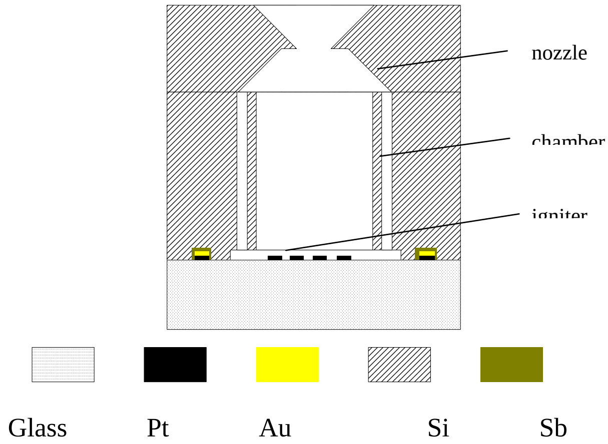

Fig.6. section of a micro thruster unit

Such structure leaves out the fuel tins, pipes, and valves of traditional thrusters, and greatly promotes the integration. Fig.7. is the photograph of the prototype chip, which is a 6×6 unit array. As the technology develops, it is possible that millions of units could be integrated in the same area.

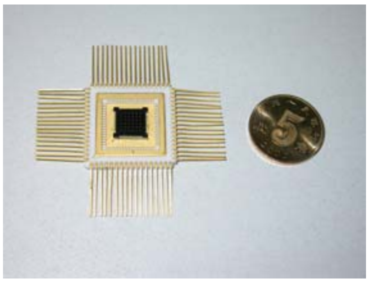

Fig.7. prototype of a 6×6 micro thruster

The prediction and ignition test of the 6×6 array micro thruster prototype was done. The ignition instantaneous power of each unit is lower than 1W, the mean ignition voltage is less than 40V, and the theoretical propulsion is about 1.7mN. Its working voltage is far less than that of the electrical thruster with the same propulsion. As the micro thruster has low power, energy thresholds for ignition and has no moving parts, it is highly reliable. In the ignition test 94% of the units were ignited successfully.

MICRO MAGNETOMETER

The magnetometer has very good perspectives in the applications for small satellites due to its small size, low energy consumption, high reliability and fairly well accuracy. There are many ways to sense magnetic fields, most of them are based on the intimate connection between magnetic and electric phenomena [3]. Three types of magnetometers are researched and they are the candidates for MEMSat-1.

The first type of magnetometer is based on magneto resistive sensors. A prototype of MEMSat-1 integrated Honeywell’s HMC1001/1002 magnetic sensors [4]. The product is designed with Anisotropic

Magneto Resistive (AMR) technology, providing extreme sensitivity and reliability for high performance applications. They are an ideal solution for linear, low-field magnetic sensing due to its capabilities to convert magnetic field strengths into a differential output voltage. In the prototype, a 1-axis and a 2-axis MR-chips are integrated together with conditioning circuits to form the magnetometer probe. Hence the entire magnetometer probe takes only a volume of 60mm×45mm×25mm, while its revolution could be 100nT ~ 10nT. Fig.8. is the photograph of the integrated system.

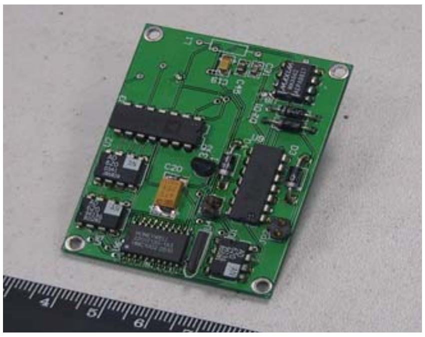

Fig.8. integrated magnetometer basing on MR magneto sensors

Another type is tunneling magnetometer, which is based on tunnel effect in quantum mechanics, and is characterized by its high sensitivity comparing with other transducers made by other technique.

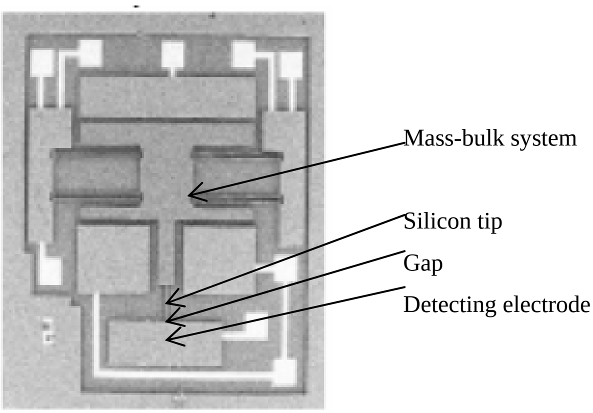

Fig. 9. SEM photo of the magnetometer

Tsinghua University has developed a horizontal tunneling magnetometer[5], which is a kind of oscillating magnetometers. Fig. 9 is the SEM photo of the magnetometer prototype. Fig.10. (A) and (B) illustrate the two general parts of the magnetometer: the upper part which is the main structure of the device, and the bottom part which is a properly placed glass substrate with all the electrodes the magnetometer needs to lead out from.

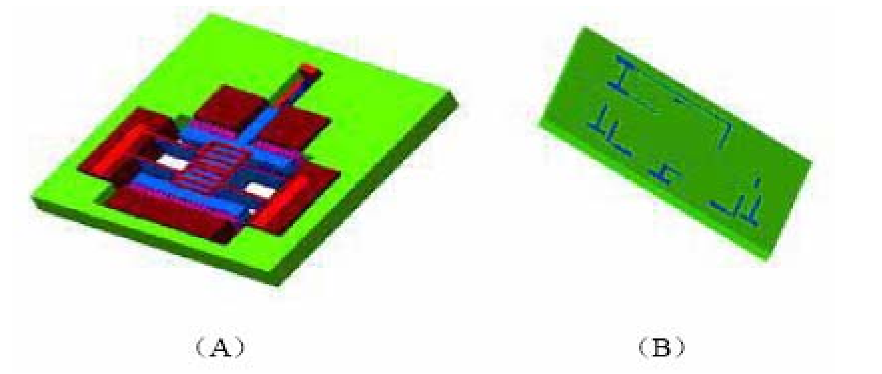

Fig.10. Structure charts of the magnetometer

As illustrated in Fig. 9, the main structure is an elastically supported mass bulk system with a silicon tip which acts as the probe tip of a STM. When the gap between the tip and the fixed detecting electrode gets close enough at about 10Å, because of the tunnel effect in quantum mechanics, a tunneling current would arise and run through the tunnel. The mass bulk system is designed to be driven by the comb electrode. The magnetometer start to work with the comb electrode drawing the elastically supported mass bulk towards the silicon tip with an expected displacement, about 4μm, so that the gap between the silicon tip and the detecting electrode may close to 10Å. At the same time, a driving voltage is applied, and then a tunneling current about 1.4nA arises. When the environment magnet field changes, an alternative current would be induced into the circuits, and the alternative current would induce a Lorentz force which brings the mass bulk to oscillate, thus the original gap is affected and the tunneling current is changed. By tracing the time-domain signal of the tunneling current, we can detect the magnitude of the magnetic field where the instrument is placed in. The horizontal tunneling magnetometer is fabricated by MEMS bulk process and the detail flow chart is illustrated in Fig.11. At present, we have manufactured two types of magnetometers and finished the primary tests, and more related tests are underway.

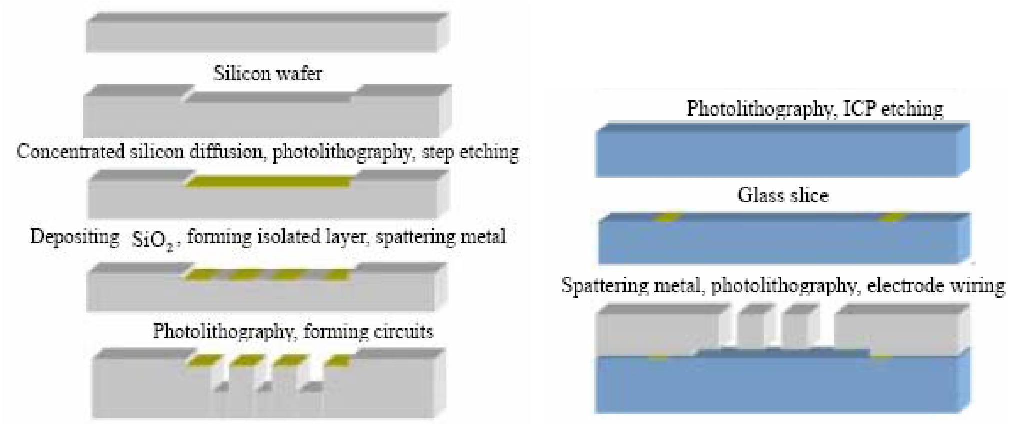

Fig.11. Process flow charts of the tunneling magnetometers

The third type magnetometer is based on fluxgate magneto sensors. In space missions that ruggedness, stability and reliability are important factors, the demand for a small, simple magnetometer seems to be met more frequently by the fluxgate instrument than by other types of magnetometer. A prototype of fluxgate magnetometer has been developed in Tsinghua University, which would be discussed specially in another paper [6].

MICRO INERTIAL MEASUREMENT UNIT (MIMU)

Inertial measurement devices like gyroscopes and accelerometers are widely used in the guidance and ADCS technologies. Traditional Inertial Measurement Unit (IMU) is usually a ponderous component that seems too big for a micro satellite. The applications of MEMS technologies have successfully accomplished the miniaturization of these devices, and give birth to Micro IMU (MIMU). And the MIMU has such a small size that it could even be integrated into a satellite weighting only several kilograms as MEMSat-1.

The MIMU integrates three MEMS gyroscopes and three MEMS accelerometers. They are arranged perpendicular to each other to measure the angular velocity and acceleration of 3 axes. Hence it could offer the satellite's orbit and attitude information like position, attitude angles by the integral of corresponding parameters.

The prototype of MIMU for MEMSat-1 has integrated the QRS14 [7] produced by BEI Technologies Inc, and the 3140 [8] accelerometer produced by EG&G. The QRS14 Gyro Chip utilizes a one piece, micro machined, vibrating quartz tuning fork sensing element (Fig.12.). Applying the Coriolis Effect, a rotational motion about the sensor's input axis produces a DC voltage proportional to the rate of rotation. The piezoelectric quartz material simplifies the active element, resulting in exceptional stability over temperature and product life. While the 3140 accelerometer's sensing element is a micro machined silicon mass suspended by multiple beams from a silicon frame. Piezoresistors located in the beams change their resistance as the motion of the suspended mass changes the strain in the beams. Silicon caps on the top and bottom of the device are added to provide over range stops. This design provides a very low profile, high shock resistance, durability and built-in damping over a wide usable bandwidth. Fig.13. is the prototype of the MIMU, with the general size of 74mm×50mm×70mm.

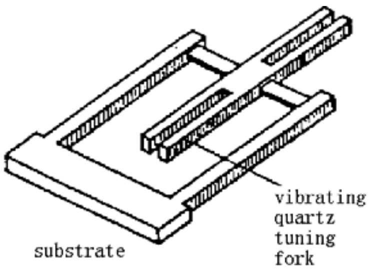

Fig.12. vibrating quartz tuning fork sensing element of the gyroscope

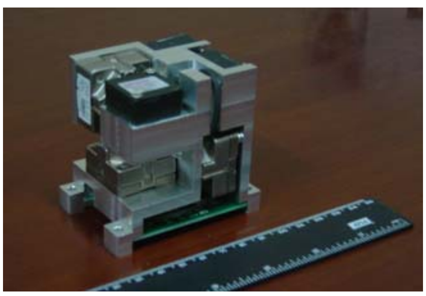

Fig.13. the MIMU prototype

Currently a new prototype is being developed in Tsinghua University as illustrated in Fig.14. The new prototype integrates gyroscopes designed by the Guidance and Control lab of Tsinghua University and accelerometers produced by CETC (China Electronics Technology Group Corporation).

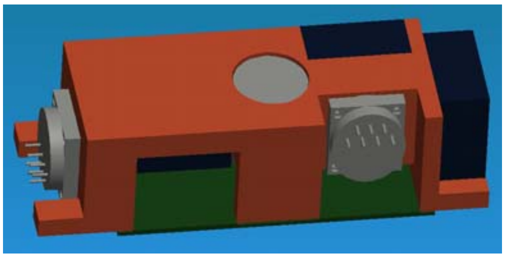

Fig.14. new MIMU prototype

CONCLUSION

The MEMSat-1 exhibits such perspectives that a satellite weighing only several kilograms would soon enjoy complete guidance, attitude maneuver and stabilization capabilities, though such capabilities have long been the priority of much larger satellites. Though some MEMS-based devices could not be so precise compared with their larger congeners, they are fairly enough for the small satellite to complete quite a range of space missions. Furthermore, MEMS-based devices have the advantages of miniaturization, low cost and agility. As MEMS and correlative technologies develop, better devices would be developed and better capabilities would be achieved. It is believed that MEMS technologies and space technologies will promote each other greatly.

REFERENCES

[1] You Zheng, Zhang Gaofei, Ren Dahai, “Study on MEMS Micro-thruster Technology”, *Nano Technology and Precision Engineering*, Vol.2, No.2, pp.98-105, June 2004

[2] ZHANG Gaofei, YOU Zheng, HU Songqi, LI Baoxuan, WANG Boxiong, “ MEMS-Based Propulsion Arrays with Solid Propellant”, *Tsinghua Science and Technology*, Vol.44, No.11,pp.1489-1492,2004

[3]James E.Lenz, “A Review of Magnetic Sensors”, *Proceedings of the IEEE*, Vol.78, No.6, pp.973-989, June 1990

[4] *Honeywell Magnetic Sensors Product Catalog*

[5] Tang Xue-hua, Zhang Gao-fei, You Zheng, Yang Yong-jun, He Hong-tao, Lin Hai-feng, “Design and fabrication of horizontal tunneling magnetometer”, *Proceedings the 4th International Workshop on Microfactories (IWMF'04)*,p5-3,October,2004

[6] Yang Jianzhong, You Zheng, Li Bin, Zhang Gaofei, “Study on Micro Fluxgate Magnetic Sensor”, *5th Round Table on Micro/Nano Technologies for Space*.

[7] BEI Technologies, Inc, “BEI Gyro Chip II Micromachined Angular Rate Sensor”, 1998

[8] Measurement Specialties, Inc, “Model 3140”, *Pressure Sensors, Accelerometers, and Custom Microstructures IC SENSORS Products Data Book*, pp.2.28-2.29, 2003