Fabrication of MEMS-based Micro-fluxgate Sensor with Runway-shaped Co-based Amorphous Alloy Core

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Abstract. High-precision magnetic micro-sensor is an interdisciplinary subject of magnetic field measurement techniques and micro-electromechanical systems (MEMS) technology. A micro-fluxgate magnetic sensor based MEMS technology was designed and fabricated in this paper. This device is a micro-magnetic sensor with a symmetric construction, closed magnetic circuits and differential form. A 25μm thick Fluxgate core of runway model, made by Co-based amorphous alloy, was etched by laser and pasted on the substrate accurately. Excitation coil and sensing coil of 3D solenoid structure were prepared by RF magnetron sputtering and UV-lithography. The minimum line width of the coil is 50 μm. The experimental result shows that micro-fluxgate devices with the size of 5.7mm×7.1mm×60μm had a stable structure.

1. Introduction
Fluxgate magnetic sensor is a measurement device which are widely used in various fields. It has the features of high resolution (up to 10-11T), wide range of measuring weak magnetic fields (in the 10-8T or less), low power consumption, being able to measure the magnetic field component directly and suitable for using in high speed motion systems [1]. Micro-FluxGate is an interdisciplinary subject of magnetic field measurement techniques and micro-electromechanical MEMS technology. With the development of fluxgate sensor, micro-fluxgate sensor produced by micro-mechanical technologies such as anisotropic etching and LIGA technology, has become an inevitable development trend of fluxgate sensor.
[2]. Because of the characteristic of micro-fluxgate, such as light weight, small size, high sensitivity, high resolution and good temperature stability and other remarkable features, it was used to be weak magnetic field measurement [3]. Micro-FluxGate sensor has important application in aerospace field, particularly in satellite technology. Fluxgate sensor is composed with the probe and interface circuits. Probe typically includes magnetic core, excitation coil and sensing coil. Magnetic Core is generally made of soft magnetic materials with high permeability and low coercivity. Excitation coils and sensing coils are in the form of solenoid around the core, the coil material is copper [4]. For the micro-fluxgate, the core thickness and width of copper coils was tens of microns. It is difficult to electroplate the Co-based amorphous alloy on the silicon substrate, therefore the key technology is to produce solenoid coils around the thick Co-based amorphous alloy, particularly the preparation of a micro-vias column.

2. Design of Micro-fluxgate sensor

Because of the high permeability of the Ni-Fe permalloy, early fluxgate core commonly used it as the magnetic core. While iron-nickel can also get a high saturation magnetic flux density, and its resistance is low [5]. When the Co-based amorphous alloy soft magnetic material appears, because of its high permeability, low coercivity, low hysteresis loss, excellent wear resistance and corrosion resistance, good temperature and aging stability, it become the ideal substitute of permalloy and widely used in production of the fluxgate sensor. For those reasons, cobalt-based amorphous alloy, brand name VITVAC 6025Z, was used as the magnetic core. The relative permeability, magnetic loss, magnetostriction, electrical resistivity, squareness ratio of VITVAC 6025Z is better than Ni-Fe permalloy, and its magnetic parameters as shown below.

| material                     | Relative permeability $\mu_r$ (1kHz) ($\times 10^3$) | Magnetic loss $P_{cv}$ (kW/m3) | Squareness ratio $Br / Bs$ (%) | Magnetostriction coefficient $\lambda_s$($\times 10^{-6}$) | Resistivity $\rho$ ($\mu\Omega \cdot \text{cm}$) |
|------------------------------|------------------------------------------------------|--------------------------------|--------------------------------|-------------------------------------------------|----------------------------------|
| 80% nickel permalloy         | 50.0                                                 | 1000                           | 55                             | 0                                               | 65                               |
| Co-based amorphous alloy     | 115.0                                                | 280                            | 85                             | 0                                               | 142                              |

Making use of the runway-shaped magnetic core, with small Demagnetizing field and low vertical field induction, can improve the sensitivity of micro-fluxgate sensor. Conductor lines composed with bottom conductor, top conductor and vias [5]. The runway structure was designed as shown in figure 1.
The Cross section diagram was shown below. Sputtering 25 μm thick copper on the silicon/silicon dioxide substrate, and etching it into vias column with mixed solution of hydrochloric acid and iron chloride (HCl+FeCl3). Fabricating the bottom conductor lines with lift-off method. The magnetic core was pasted on the substrate using photoresist, and it was accurately positioned between the vias column. The top conductor lines were fabricated using lift-off method again. The top conductor lines and the bottom conductor lines were connected with vias column.

**Figure 1.** Structure of the Magnetic core and 3-D conductor solenoid.

**Figure 2.** The fabrication processing of the Micro-fluxgate was shown in the pictures. A 25 μm thick copper was etched to vias column in the mixed solution with HCL and FeCl3. The conductor lines made by copper was fabricatad by lift-off method. The magnetic core was pasted on the substrate using photoresist, and it was accurately positioned between the vias column.
3. Experiments & discussion

Co-based amorphous alloy was cut to runway-shaped with Laser as shown in figure 3. Magnetic hysteresis loop was tested with the VSM as shown in figure 4.

![Figure 3. The runway-shaped magnetic core.](image1)

Vias of the fluxgate conductor, 25μm thick Cu, Was deposited on the silicon substrate using RF magnetron sputtering and etched to be Column as shown in figure 5. The vias column was etched by a mixed solution of hydrochloric acid and ferric chloride.

![Figure 5. The vias column was etched by a mixed solution of hydrochloric acid and ferric chloride.](image2)

Bottom conductor of the fluxgate coil was prepared by the Lift-off method. Using thick photoresist (KMPE3260) and UV-lithography, the molds in the photoresist were prepared, to deposit the Ta(10nm)/Cu(1um) bottom conductors lines. Coated with KMPE3260 photoresist, exposed by ultraviolet light, the image would form a large depth to width ratio and a T-type structure as shown in figure 6. This will make it easy to complete the Lift-off.
The seed layer with the metal on was then removed and a thicker photoresist layer was spun to the wafer to mask the vias. Sputtering a layer of silicon dioxide for insulation. The magnetic core and the bottom conductor were sticked together by photoresist. Also, sputtering silicon dioxide on the core and prepared top conductor, Ta20nm/Cu2μm, using lift-off. Like the previous step. Then the micro-fluxgate devices was prepared as shown in figure 6. In the variable magnetic field generated by Helmholtz coils, the performance of the micro-fluxgate can be tested.

![Figure 6. The T-type structure of the KMPE3260 photoresist.](image)

4. Conclusion

Co-based Amorphous Alloy was chosen as the magnetic core first time. It was Etched by lazer into runway-shaped instead of electroplating. Compared with the permalloy, this material has a high relative permeability, Small magnetic loss, and a perfect squareness ratio. Using UV lithography and Lift-off method to realize the miniaturization and planarization of the fluxgate. The key technology is the Preparation of three-dimensional coil using thick...
photoresist. The magnetic core was pasted and accurately positioned between the vias column. The experiment results show that this fabrication method was available for micro-fluxgate. The size of micro-fluxgate device was 5.7mm×7.1mm ×60μm, which can be integrated in small devices, and it had a stable structure. Because the magnetic field measurement needed a specialized designed circuit, the performance of this device will be discussed in detail in a future article.

References

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