Fabrication of the three-dimensional solenoid type micro magnetic sensor

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Abstract. There has been a large demand for the realization of on-chip fluxgate magnetic sensors, with exciting and sensing control IC circuits. Based on UV lithography and other MEMS technology, a new three dimensional solenoid type micro magnetic sensor has been designed and fabricated to measure the components of magnetic induction vector in outer space. The fabricated micro sensor was integrated in IC circuits of MEMS satellite.

1. Introduction
Compared with traditional fluxgate magnetic sensors, micro fluxgate magnetometer has many advances, such as less mass, smaller size, less power consumption, better performance and mass production. Magnetic field sensing and measuring has always been an essential function for numerous applications for many years. DC or slow varying magnetic field measurements are more challenging than the relative straightforward AC magnetic field measurements. Different techniques and sensors have been developed to measure magnetic fields from $10^{-10}$ to $10^{-3}$ T [1-3].

The device designed and fabricated by us has three-dimensional symmetrical structure, comparing with two dimensional micro fluxgate magnetometers, the enclosed path for magnetic fluxes increased the effective area of across section, making it easier to saturate and increasing the effective permeability.

2. Sensor Structure
The fluxgate sensor is based on the fluxgate principle which was expatiated on by Primdahl. When the ferromagnetic core is driven periodically into saturation by the exciting coil around, the inductive electromotive force is generated in the pick-up coil located on the same core. Due to the nonlinear behavior of magnetic material, harmonic components of the exciting frequency appear in the faradic signal [4].

According to this effect, a new type of two-axis micro-fluxgate magnetic sensor was designed. A enclosed ferromagnetic core, with squared ring forming filleted corners, is enwrapped with SU-8 2025...
resist as its insulating and supporting layer. The twelve coils (3 coils for each side) are wrapped through the isolated core, having the function of exciting and compensation (See figure 1).

The coils each with 38 turns have symmetries to the centre and the two axes respectively. The length of each side of core is 5000 µm, the cross section is 400 µm long and 20 µm thick. The gap between the core and the coils is 20 µm wide and 10 µm thick.

![Figure 1. The sketch of the micro magnetic solenoid](image)

Because of the novel design, different connecting of coil pairs, different forms of sensor with different features can be formed. For example, with the different coil pair number ratio (exciting coil pair: pick-up coil pair: compensation coil pair), a two-axis magnetic sensor without feedback loops of compensation or a one-axis fluxgate sensor can both be formed through different connections[5].

3. Fabrication process

A technique combining with positive and negative resists is exploited for special functionality, the multilayer resist coating and lithography technique is also developed. The fabrication process is demonstrated in figure 2.

![Figure 2. The fabrication process](image)

(a) Sputtering the seed layer for electroplating the bottom Cu layer;
(b) Electroplating the bottom Cu layer;
(c) Electroplating the NiFe permalloy core;
(d) Electroplating the middle Cu layer;
(e) Electroplating the top Cu layer;
(f) Encapsulation.

Step.1 Preparing for electroplating the bottom Cu layer: Firstly the Ti/Cu/Ti layer was sputtered on the surface of an oxidized Si wafer, then a thin positive resist was coated on it. The bottom SiO$_2$ microstructure was fabricated by UV lithography and ion beam etching process.
Step 2 Electroplating the bottom Cu layer: The structure mold insert about 25 µm was formed for electroplating the bottom Cu layer. The solution for electroplating Cu is composed of H₂SO₄ (60 g/L), CuSO₄·5H₂O (160 g/L) and glucose (32 g/L). The bath was stirred at a speed of 300rpm. The bottom Cu layer was formed with 560µm length, 15µm width and about 20µm thickness.

Step 3 Electroplating the NiFe core: The design was to electroplate the NiFe permalloy before the Cu pillars. Permalloy is usually used as a core material for fluxgate sensors due to its high permeability and fast frequency response. The higher the permeability of the core, the easier saturation can be reached with low excitation current. The SU-8 2025 resist was used as the insulator support between the bottom layer and the NiFe core. The condition for electroplating NiFe core was listed in Table 1 and Table 2 below. The core was plated about 20µm thickness (See figure 3).

Table 1. The NiFe-plating bath

| Component                      | Concentration |
|--------------------------------|---------------|
| NiSO₄·6H₂O                     | 0.2mol/L      |
| FeSO₄·7H₂O                     | 0.014mol/L    |
| CoSO₄·7H₂O                     | 0.063mol/L    |
| NH₄Cl                          | 0.28mol/L     |
| H₃BO₃                          | 0.4mol/L      |
| NaLS(SDS, C₁₂H₂₅NaO₄S)         | 0.15g/L       |
| Sacc(C₁₂H₆O₃NS)                | 0.2g/L        |

Table 2. The parameter for electroplating the NiFe core

| pH   | Temperature | Current density | Electroplating rate |
|------|-------------|-----------------|--------------------|
| 3.5  | 63°C        | 7mA/cm²         | 0.25µm/min         |

Figure 3. The NiFe core upon the SU-8 2025 resist insulator.
Step 4 Electroplating the Cu pillars: Coating AZ9260 resist with a low spin speed for three times to obtain the desired resist thickness of 60µm. After UV lithography and electroplating process, the Cu pillar was formed with the length of 50µm, the width of 15µm and the thickness about 60µm (See figure 4). The AZ9260 resist mold was removed and the SU-8 2025 resist was coated again as the insulator support between each Cu pillar.

![Figure 4. Top view of the plated Cu pillars](image)

Step 5 Electroplating the top Cu layer: After sputtering the Au seed layer on the wafer, the AZ9260 resist was spun to the surface. The resist mold was shaped by UV lithography for electroplating the top Cu layer. The top Cu layer was plated about 20µm thickness.

Step 6 Encapsulation: Removing the AZ9260 resist mold and the Au seed layer, SU-8 2025 resist was coated on the surface and the encapsulated sensor was fabricated by UV lithography (See figure 5).

![Figure 5. Top view of the micro sensor](image)

4. Summary
A micro-fluxgate magnetic sensor has been designed and fabricated. MEMS techniques were used to fabricate the micro fluxgate sensor, which is composed of a magnetic core and the three-dimensional solenoid coils formed with twelve groups. The novel structure distinctly increases the effective area of across section and gets a proportional sensitivity. It is also easy to achieve saturation and increases the effective permeability. Sensors with multiple functions using different connecting of coil pairs can be fabricated. The high sensitive, on-chip fluxgate sensors can be widely applied in the applications for space researches and other uses.
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