Formation of High Aspect Ratio Microcoil Using Dipping Method*

Daiji NODA**, Shuhei YAMASHITA**, Yoshifumi MATSUMOTO**, Masaru SETOMOTO** and Tadashi HATTORI**
**Laboratory of Advanced Science and Technology for Industry, University of Hyogo,
3-1-2 Koto, Kamigori, Ako, Hyogo 678-1205, Japan
E-mail:noda@lasti.u-hyogo.ac.jp

Abstract
Coils are used in many electronic devices as inductors in mobile units such as mobile phone, digital cameras, etc. Inductance and quality factor of coils are very important value of the performance. Therefore, the requests for coils are small size, high inductance, low power consumption, etc. However, coils are unsuitable for miniaturization because of its structure. Therefore, we have proposed and developed the microcoils of high aspect ratio with the dipping method and an X-ray lithography technique. In dipping method, centrifugal force and highly viscous photoresist solution were key points to evenly apply resist in the form of thick film on metal bar. The film thickness of resist on bar was achieved about 50 µm after single coating. Using these techniques, we succeeded in creating threaded groove structure with 10 µm lines and spaces on 1 mm brass bar. In this case, the aspect ratio was achieved five. It is very expected the high performance microcoil with high aspect ratio lines could be manufactured in spite of the miniature size.

Key words: Spiral Coil, High Aspect Ratio, Dipping Method, X-Ray Lithography, Metallization, Microcoil

1. Introduction
Coils are mounted in electronic devices as inductors. When these coils are turned in mobile units such as mobile phones, digital cameras, personal digital assistants (PDA), further reduction in size must be attained. Therefore, the requests for coils are small size, high inductance, low power consumption, etc. In terms of its performances, inductance and quality factor (Q factor) should be increased to save power consumption.

The development and miniaturization of innovative coils is recognized as one of the most important. However, the processing technology for micrometer sized three-dimensional (3D) structure is very difficult. On the other hand, LIGA (German acronym for Lithographite Galvanosformung and Abformung) process1 can fabricate nano- and micro-parts for devices. Then, we have developed X-ray exposure stage carried out with a specially manufactured nine parts. Thus, this stage makes it feasible to fabricate 3D structure2-4.

In this research, we have proposed and developed a cylindrical microcoil with high aspect ratio. Using the X-ray lithography technique, coil lines were obtained narrow and high aspect ratio5-8. Figure 1 shows the calculation of Q factor and resistance for different aspect ratios of the microcoils. Here, we used coil parameters as coil turn of 20 and coil line width of 10 µm. Increasing the aspect ratios from 0.5 to 5 generates a higher Q factor. Therefore, the performance of microcoil was very improved9. In order to use X-ray
lithography, the coil line width and space were designed of our own accord. And, it is very expected that the high performance microcoils with high aspect ratio coil lines could be manufactured in micro actuators such as electromagnetic actuators.

2. Process flows for microcoil

Figure 2 shows process flows for coil lines using X-ray lithography technique. First, we applied positive type photoresist polymethylmethacrylate (PMMA) on a master bar
using dipping method. This PMMA thickness was thickness of coil lines. Thus, it is very important factor of microcoil. Next, threaded structure was formed on bar by X-ray lithography that uses synchrotron radiation. We used the beam line 11 of NewSUBARU synchrotron radiation facility at our university. This was operated at energy of 1.5 GeV. Next, coil lines were made by electroforming of Au. After coating of coil lines, the metal bar was removed by wet etching to make through hole inside coil. Finally, inner part of coil was coated by resin treatment. In this process, we would obtain the hollow type microcoil with high aspect ratio.

3. Dipping method

We used the dipping method in order to obtain a thick layer of photoresist. This thickness is key point of coil lines with high aspect ratio. The dipping method comprises four steps: dipping, recovery, air drying and baking. Then, we succeeded in reducing the difference in film thickness in the process of photoresist coating by applying centrifugal force in the dipping method. To make 3D structure of microcoil, a metal bar with thick photoresist has been exposed by X-ray lithography. Centrifugal force and highly viscous photoresist solution were the key points in this dipping method to evenly apply photoresist in the form of a thick film, and thus it could be produced high aspect ratio coil lines.

Figure 3 shows the dipping process to fabricate thick layer on cylindrical surface. An aluminum bar with 4 mm in diameter and brass bar with from 1 to 4 mm in diameter were used as master materials for coil. First, these bars were machined in order to adjust the surface roughness. To prepare photoresist solution, positive type PMMA sheet was crushed and dissolved in 2-ethoxyethyl acetate for over 15 hours at 51 °C. First, we used as dipping solution of 4% PMMA. When the rotation was high speed, PMMA thickness was
decreasing, and reduced the difference in thickness in the axial direction due to centrifugal force. Then, the rotation speed was kept constant at 160 rpm in these experiments. PMMA thickness was also dependent of round velocity, as shown in Fig. 4. Rotation speed was different in diameter of metal bar. Therefore, we have used the value of a round velocity. Here, the round velocity was defined as the rotation speed $\times$ radius. In this case, we used high concentration of PMMA solution that has high viscosity. Thus, when the round velocity was high, film thickness was increasing due to wind PMMA solution.

![Graphs showing PMMA thickness dependence of PMMA concentration.](image)

**Figure 5.** PMMA thickness dependence of PMMA concentration.

Figure 5 shows the relationship between thickness and PMMA concentration. Figs. 5(a) and 5(b) were used brass bar and aluminum bar of 4 mm diameter, respectively. The thickness was taken as the average of the values measured from three different points. When the PMMA concentration was high, film thickness was increasing. However, a viscosity of over 10% PMMA solution is so high that it is very difficult to create a homogeneous solution. In these results, PMMA film thickness of about 50 $\mu$m was obtained on brass and aluminum bar in single coating. Thus, an aspect ratio of coil lines was achieved over 5 as coil lines of 10 $\mu$m.

In order to obtain thicker PMMA layer, we repeat this dipping process. But, the second layer was sometimes contaminated with bubbles into photoresist. We have obtained the film thickness of about 50 $\mu$m by single coating. Therefore, we have used the single coating of
4. X-ray lithography and metallization

The threaded structure was produced by an X-ray lithography technique. In the X-ray lithography technique, double sided exposure method was performed on 1 mm bars. In this case of 4 mm bars, exposure process was divided into 60 steps in order to close to continuity exposure. Thus, the master bar was rotated through an angle of 6 degree while the X-ray mask was advanced by just 1/60 pitch for each X-ray exposure cycle as shown in Fig. 6. A screw thread PMMA structure was developed on surface bar after development. The structure of micro coil lines was observed using scanning electron microscope (SEM). Figure 7 shows the SEM image of threaded structure of coil lines with a pitch of 20 µm. These aspect ratios were realized about 5.

To make coil lines of current paths, we performed the metallization process including gold electroplating. Electroplating Au layer was grown up from the bottom metal bar of grooves having high aspect ratio, completely. The isotropic spiral Au lines of current path were formed. Now, we are trying these processes.

5. Conclusions

We have achieved development of the 3D deep X-ray lithography technique for solid microstructures such as the spiral microcoil. We have proposed and developed microcoils of
high aspect ratio with dipping method and X-ray lithography technique. In dipping method, the resist thickness was reached about 50 µm using centrifugal force control and highly viscous solution in single coating. And, we succeeded in producing a threaded structure with 10 µm in coil lines width and about 5 in the maximum aspect ratio using by X-ray lithography technique. Now, we have been proceeding to fabricate and measure the microcoil with high aspect ratio.

Using this technique, the microcoils with high aspect ratio have been expected to manufacture with high inductance and Q factor. It is very expected the high performance microcoil with high aspect ratio lines could be manufactured in spite of the miniature size.

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