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Small Height Inductor for DC-DC Converter

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Abstract- Micro-inductors with thickness close to 1mm used in DC-DC converter circuit were developed. The thin-film coil sandwiched between upper and lower ferrite layers was fabricated using photolithography process with introducing photo-resist-sheets and electroplating technology. The developed micro-inductors with a thickness of 1.26mm had inductance of 4.25 μ H and impedance of 77mΩ at 1kHz. It was confirmed that the inductors operated normally in a DC-DC converter circuit.

I. INTRODUCTION

Recent remarkable miniaturization of portable electronic devices such as handy phones and digital video cameras, etc. is continuing supported by the progress of miniaturization in electronic modules and individual electronic parts such as resistors, capacitors and inductors, etc. The miniaturization of power modules (DC-DC converter unit) is strongly required. In the conventional inductors for the DC-DC converter circuit, the leading wire is wounded around the ferrite drum core. This configuration disturbs drastic miniaturization of the inductors.

Therefore, we have started to develop the small height inductors to promote the miniaturization of the DC-DC converter circuit [1]. The purpose of this study was to fabricate the small height inductors with the size of 7mm in width, 8mm in length, about 1mm in thickness, allowable DC current over 1A, and inductance of 4.7 μ H.

II. FEM ANALYSIS

Prior to fabrication of the small height inductors, relationship among inductance, allowable DC current value and the structure of inductor was examined using magnetic field simulation based on a finite element method (FEM). The analysis was carried out for the two-dimensional axial symmetric inductor model.

Figure 1 illustrates the analyzed inductor model. A nine turns thin-film coil in which a center magnetic core was inserted was sandwiched with upper and lower magnetic layers. The analysis was done in the case the thickness of the upper magnetic layer was 0.3mm and 0.5mm, and the peripheral core was added and not added. Relative permeability and saturation magnetic flux density of the center and peripheral magnetic cores and the upper and lower magnetic layers were assumed to be 400 and 430mT, respectively.

Figure 2 shows DC current dependence of inductance. Allowable DC current value was defined as the DC load current value at which inductance decreased by 10% from the value at zero DC current. The thickness of the lower magnetic layer was fixed to 0.5mm. In this figure, solid lines are for the case without peripheral core.

In case of 0.5mm thick upper magnetic layer, inductance was 3.47 μ H and allowable DC current value was 1.5A as

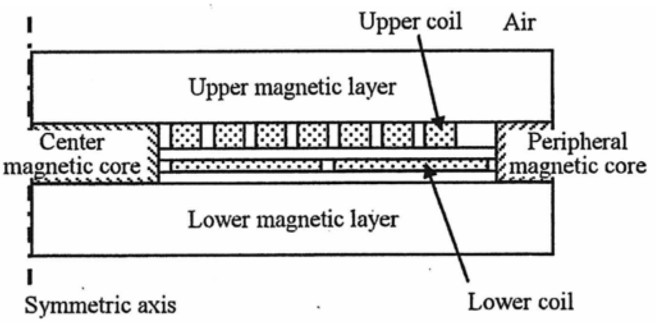

Fig.1 Cross-sectional view of inductor analyzed by FEM.

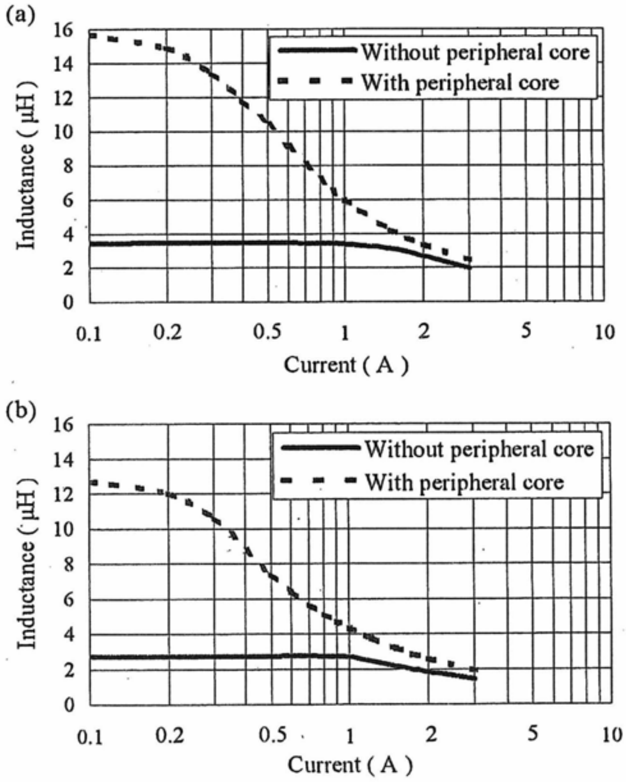

Fig.2 DC current dependence of inductance (analysis by FEM).
(a) Thickness of upper magnetic layer is 0.5mm.
(b) Thickness of upper magnetic layer is 0.3mm.

shown Fig.2(a). When the thickness of the upper magnetic layer was reduced to 0.3mm, inductance was decreased to 2.73 μH and allowable DC current value was decreased to 1.2A as shown Fig.2(b). It was found that the reduction of the thickness of the upper magnetic layer resulted in about 20% decrease in both inductance and allowable DC current value.

Broken lines in Fig.2 are for the case with peripheral magnetic core. When the thickness of the upper magnetic layer was 0.5mm, inductance was 15.7 μH and allowable DC current value was 0.25A. When the thickness of the upper magnetic layer was reduced to 0.3mm, inductance became 12.7 μH and allowable DC current value decreased to 0.23A. By adding the peripheral core, while the inductance increases by about four and a half times, allowable DC current value decreases to about one-sixth times as large as the inductance of the model without peripheral core.

The FEM analysis results described above show that both inductance and allowable DC current value gradually decrease with reducing thickness of upper magnetic layer. The results also show that by adding side core, inductance increases substantially, however allowable DC current value decreases drastically because of magnetic saturation in center core.

Based on the FEM analysis results, the configuration of the inductor was determined to satisfy the required specifications: allowable DC current over 1A and inductance of 4.7 μH. Finally, we decided that the thickness of the upper and lower magnetic layers was 0.5mm and peripheral core was not introduced.

III. STRUCTURE OF INDUCTOR

Figure 3 illustrates the structure of the small height inductors fabricated in this study. The size was 7mm in width, 8mm in length and about 1mm in thickness. Coil winding part of this inductor consisted of a lower electrode, an insulation layer and a thin-film coil. To decrease electric resistance, the width and thickness of thin-film upper coil were increased to 200 μm and 150 μm, respectively. Number of turns of the upper coil was seven and the coil spacing was 90 μm. To achieve the required inductance of 4.7 μH, it was necessary to increase the total number of coil winding to nine turns. Therefore the thin-film coil whose winding number was 1.5 turns was also formed in lower electrode.

To achieve low electric resistance increases, the coil in lower electrode was widened to 1000 μm. The coil spacing in the lower electrode was 100 μm. Figure 4 shows calculated electric resistance value of upper coil and lower electrode versus their thickness. It was not necessary to make the lower electrode thicker as compared with upper coil because the coil width in the lower electrode was five times as large as that in the upper coil. The thickness of coil in lower electrode was chosen to 40 μm to decrease resistance effectively.

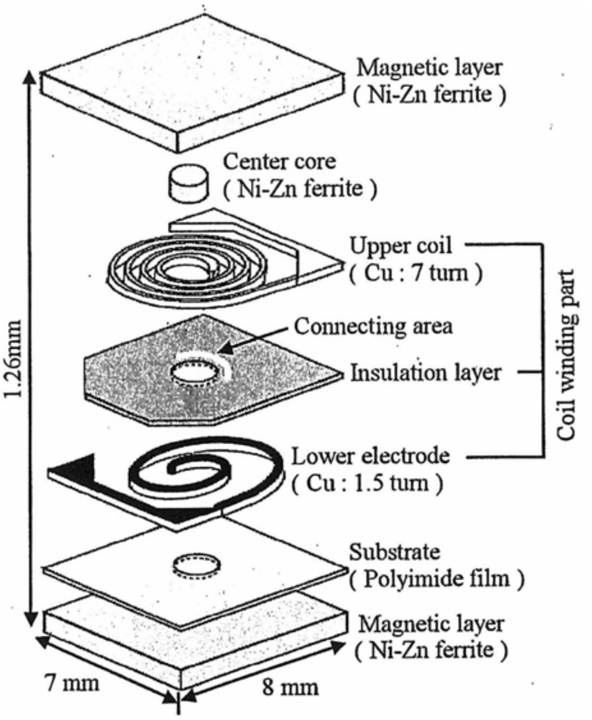

Fig.3 Schematic view of inductor.

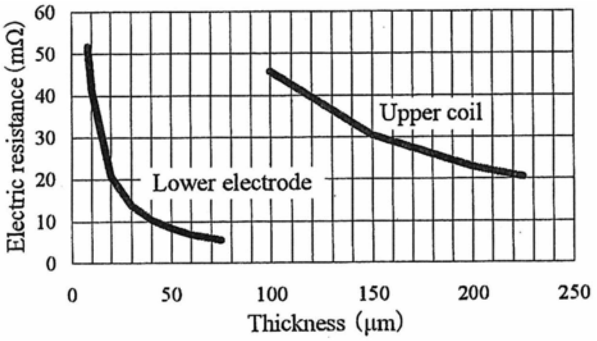

Fig.4 Upper coil and lower electrode thickness dependence of calculated electric resistance.

Ni-Zn ferrite core with a diameter of 2mm and height of 1.5mm was inserted in the center of the thin-film coil. The coil winding part was sandwiched with upper and lower Ni-Zn ferrite plates whose size were 7mm in width, 8mm in length and 0.5mm in thickness.

IV. FABRICATION PROCESS

Fabrication process of the thin-film coil is shown in Fig.5. As a substrate under the lower electrode, a 50 μm thick polyimide film with smooth surface, *UPILEX*, was used. The lower electrode was fabricated in the following process. At first, a 0.5 μm Cu thin-film was deposited using RF magnetron sputtering apparatus as the underlayer for pattern-electroplating (Fig.5(a)). Then, photo-resist-sheet whose thickness was 75 μm was laminated on *UPILEX* substrate utilizing a laminate machine, and was exposed using a mask-aligner with g-line irradiation and developed (Fig.5(b) and (c)). Succeedingly, pattern-electroplating using a copper sulfate solution was performed to make coil thick (Fig.5(d)). The current density of the cathode was optimized to 45mA/cm^2 and the electroplating time was 40 minutes to achieve 40 μm thick Cu film. After that, residual photo-resist-sheet was removed using acetone solution and then, coil was formed by etching the surplus parts of Cu underlayer (Fig.5(e) and (f)).

After that, an insulation sheet (epoxy resin with a thickness of 50 μm) was laminated on the lower electrode. Use of the insulation sheet enabled us to get a thick insulation layer with smooth surface. The insulation layer was formed on lower electrode using the same fabrication process as the lower electrode's. Then, the part of the connecting area between the lower electrode and the upper coil was made thick by pattern-electroplating. This was one of the key points to realize low electric resistance.

Finally, upper thin-film coil was formed on this using the almost same process as the lower electrode's described above with exception that not one but two photo-resist-sheets (thickness:150 μm) were laminated, and that the electroplating time was changed to 190 minutes. To complete the inductor, the thin-film coil part in which the center magnetic core was inserted was sandwiched with upper and lower magnetic layers.

V. RESULTS

Figure 6 shows the photograph of thin-film coil part of the fabricated small height inductor. The size of the inductor was 7mm in width, 8mm in length and 1.26mm in thickness. Figure 7 shows frequency dependence of inductance and impedance of the inductor. Inductance and impedance at 1kHz were 4.25 μH and 77mΩ, respectively, and allowable current value was 1.1A. This inductor was installed in an actual DC-DC converter circuit in which input voltage, output current and loading electric resistance were 4.5V, 700mA and 5Ω, respectively. It was confirmed that our fabricated inductor operated normally and cleared the environmental test in high and low temperature and humidity.

VI. SUMMARY

The novel process to fabricate the thick thin-film coil in the small height inductor was established. Thick coil conductor was successfully achieved by sticking the photo-resist sheet instead of spin coating of photo-resist. Reduction of impedance was also succeeded by making the lower electrode thick enough and enlarging the connecting area between the lower electrode and upper coil. The size of the fabricated small height inductor was 7mm in width, 8mm in length and 1.26mm in thickness. Inductance and impedance at 1kHz, allowable DC current value of the inductor were 4.25 μH, 77mΩ and 1.1A, respectively. The inductor was installed in a DC-DC converter and normal operation was confirmed.

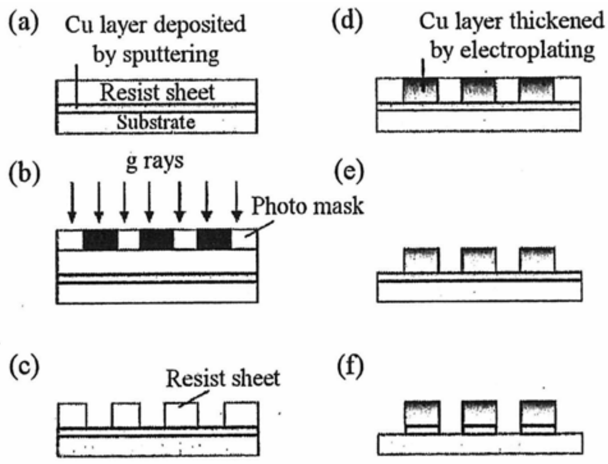

Fig.5 Fabrication process of thin-film coil.

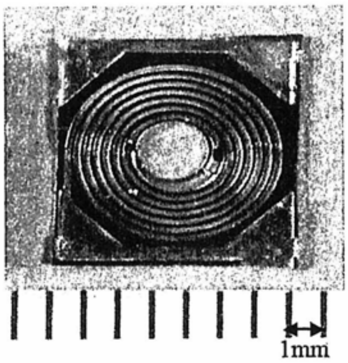

Fig.6 Photograph of fabricated inductor.
(Upper ferrite layer is removed.)

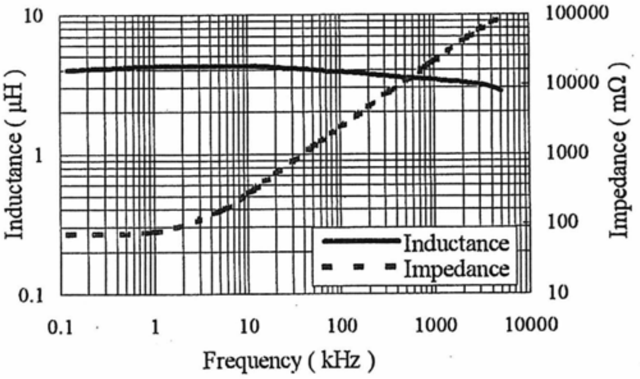

Fig.7 Frequency dependence of inductance and impedance of inductor.

The authors believe that the inductor whose height is less than 1mm will be possible to fabricate using coil forming technology developed in this study.

REFERENCE

[1] S. Yamamoto, Y. Ojima, K. Nishimura, H. Kurisu, M. Matsuura, K. Ishida, I. Okano, *Digest of 23rd Annual Conf. on Magnetics in Japan*, p.356 (1999).