Development of Small Height Inductors for DC-DC Converter

Setsuo YAMAMOTO
Faculty of Engineering, Yamaguchi University
2-16-1 Tokiwadai, Ube, Yamaguchi 755-8611, Japan

Abstract - Two types of inductors available in DC-DC converter circuit were developed. A height of the inductors was 1.1 – 1.6 mm. One consists of the thin-film coil sandwiched between upper and lower ferrite layers. The thin-film coil was fabricated using simple photolithography process with introducing photo-resist-sheets and electroplating technology. The other is a coil-embedded-type inductor which was fabricated using a Spark Plasma Sintering method.

I. INTRODUCTION

Small inductors are widely used in portable electronic devices such as handy phones and digital video cameras, etc. for which miniaturization is strongly required. The conventional inductors used in a DC-DC converter circuit equipped in the portable devices consists of a ferrite drum core and a leading wire wounded around it. This configuration disturbs drastic miniaturization of the inductors.

The purpose of this study is to develop the inductors whose height is 1.1-1.6 mm and inductance was 1.9-23 μH. From practical viewpoints, we have attached importance to a simple and easy fabrication process of the inductor. As a result, two types of inductors were successfully developed: One was thin-film coil type and the other was coil-embedded type. In this paper, the configuration, the fabrication process, and the electric characteristics of the inductors are described.

II. INDUCTORS WITH THIN-FILM COIL

A. Basic Configuration

Prior to actual fabrication of the inductors, basic structure of the inductor was designed using magnetic field simulation based on a finite element method (FEM). The analysis was carried out for the two-dimensional axial symmetric inductor model taking account of nonlinear characteristics of a ferrite.

Figure 1 illustrates the structures of a thin-film coil type inductor. A coil winding unit of this inductor consists of a lower electrode, an insulation layer, and an upper thin-film coil. A Ni-Zn ferrite core with a diameter of 2 mm is inserted at the center of the thin-film coil. The thin-film coil unit was sandwiched by upper and lower Ni-Zn ferrite plates. Based on this configuration, two inductors with a different inductance of 4 μH and 23 μH were fabricated.

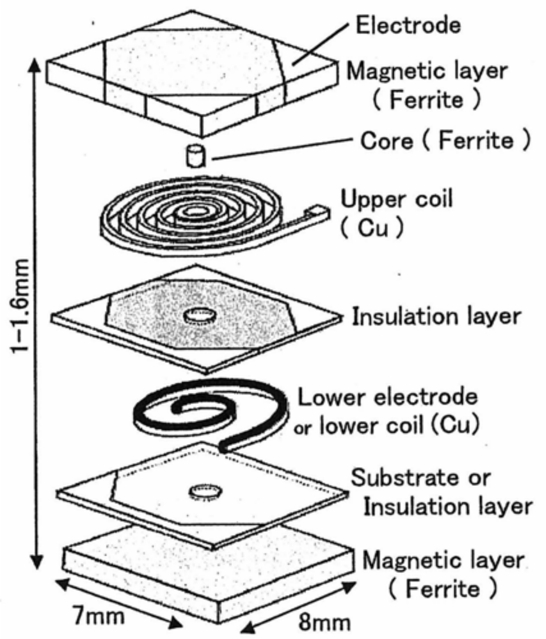

Fig.1 Inductor with thin-film coils.

B. 4 μ H inductor [1]

In a 4 μH inductor, the thin-film coil unit was fabricated using photolithography. The manufacturing process of the coil unit was as follows: At first, 0.5 μm thick Cu underlayer was sputter-deposited on a polyimide film substrate. A 75 μm thick photo-resist sheet was pasted on the substrate, and was exposed using a mask-aligner and developed. Pattern-electro-plating was introduced to make lower electrode thick. The lower electrode was formed by etching the surplus parts of the underlayer using a ferric chloride solution. After that, an insulation sheet (epoxy resin, thickness: 50 μm) was laminated on this. The upper thin-film coil was formed on the insulation sheet using the same fabrication process as lower electrode. Two 75 μm thick photo-resist sheet was used to make the upper coil thicker.

Winding number of the lower coil was 1.5 turns, and its width, height and spacing were 1000 μm, 40 μm and 100 μm, respectively. Winding number of the upper coil was 7 turns, and its coil width, height and spacing were 200 μm, 150 μm and 90 μm, respectively.

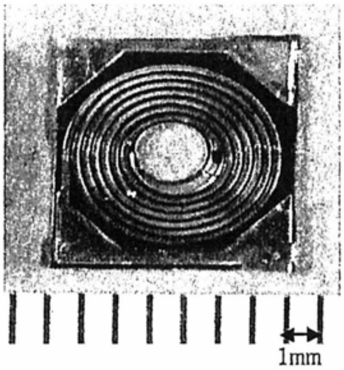

Fig.2 Photograph of thin–film coil for 4.7 μH inductor.

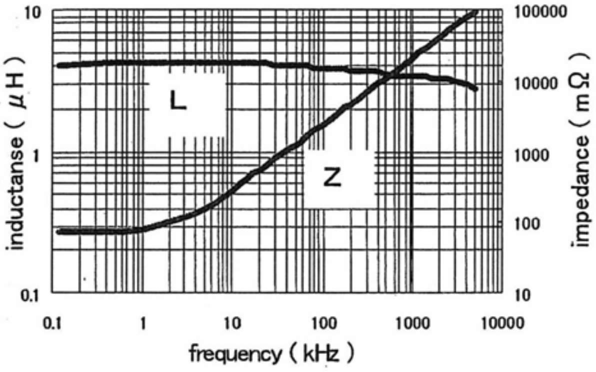

Fig.3 Frequency dependence of inductance and impedance for 4 μH inductor.

Figure 2 shows a photograph of the fabricated thin-film coil. The coil unit was sandwiched by the 500 μ m thick ferrite plates. The size of the manufactured inductor was 7mm in width, 8mm in length, 1.26mm in thickness.

Inductance and impedance at 1kHz was 4.25 μ H and 77m Ω, respectively, as shown in Fig.3. An allowable current value which was defined as the loading DC current showing 10 % decrease in inductance 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 5 Ω, respectively. It was confirmed that our fabricated inductor operated normally and passed the high and low temperature and humidity environmental test.

C. 23 μ H inductor

In a 23 μ H inductor, a 75 μ m thick Ni-Zn ferrite plate was used as a substrate, and thin-film coils were formed onto this ferrite substrate sequentially. The Ni-Zn ferrite substrate processed by normal sintering method, i.e. without pressurizing, was used because their price is low. To achieve sufficient smoothness for photolithography, ferrite substrate was polished, and then an insulation sheet with a thickness of 50 μ m was pasted on this ferrite substrate. By this process, the averaged surface roughness, R_a, could be decreased from 873 nm (original ferrite surface) to 377 nm (insulation sheet).

The 9 turns lower coil were formed by the almost same method as the 4 μ H inductor. The line width, height and spacing of the lower coil were 125 μ m, 110 μ m and 75 μ m, respectively. Prior to the fabrication of upper coil, planarization of the surface was carried out by spin-coating a liquid insulation material. After that, a 9 turns upper coil was successfully formed by the same process as the lower coil. The line width, height, spacing of the upper coil were 125 μ m, 150 μ m and 75 μ m, respectively. Figure 4 shows the photograph of the manufactured thin-film coil unit.

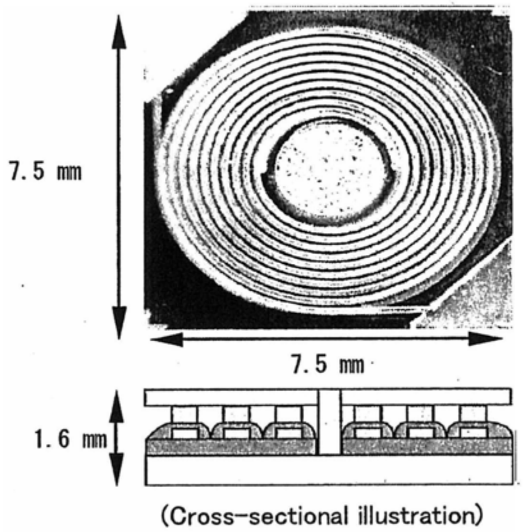

Fig.4 Top: Photograph of thin- film coil unit for 23 μ H inductor. Bottom: Cross-sectional illustration of inductor.

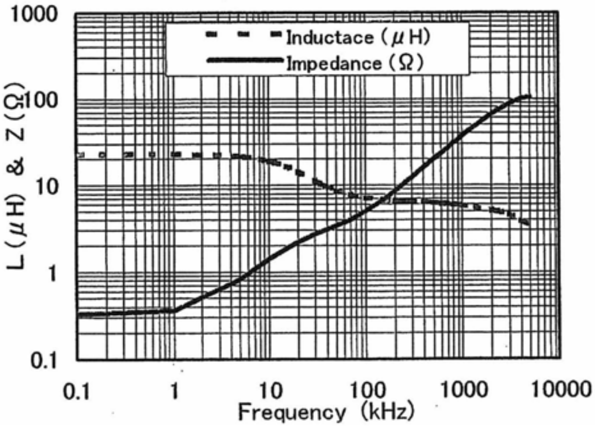

Fig.5 Frequency dependence of inductance and impedance for 4μH inductor.

The size of this inductor was 7.5mm wide, 7.5mm long, 1.6mm in thickness. Figure 5 shows the frequency dependence of inductance and impedance of the inductor. Inductance and impedance at 1kHz was 23 μH and 367mΩ, respectively. For this inductor, allowable current was 400mA.

III. COIL-EMBEDDED-TYPE INDUCTOR [2]

The configuration of an inductor in which a coil was directly embedded into a ferrite core was shown in Fig. 6. The inductor was fabricated using Spark Plasma Sintering (SPS) apparatus, (SPS-1050) made by IZUMI TECH. CORP. In SPS method, powder starting materials suffer pressure in uniaxial direction and are heated up by Joule heat and the effect of spark plasma. The SPS has specific features of lower sintering temperature and shorter processing time than conventional sintering method. In this study, Mn-Zn ferrite powder (Fe_2O_3 : MnO : ZnO=53.5 : 32.2 : 14.3 (mol%)) made by TODA KOGYO CORP. was used for ferrite core.

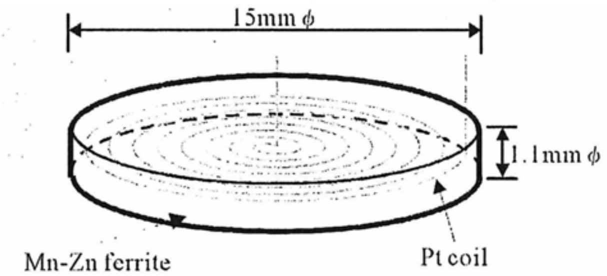

Fig.6 Configuration of coil-embedded-type inductor.

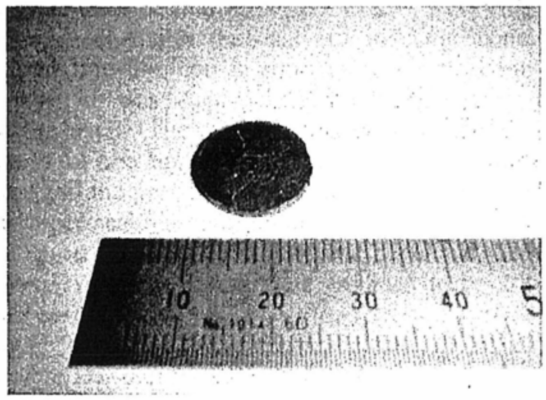

Fig.7 Photograph of coil-embedded-type inductor.

Fabrication of this inductor was as follows: at first, carbon film as a parting agent was pasted inside a graphite die and punches. A half of Mn-Zn ferrite powder was put in a graphite die, and was pressed from upside and downside by graphite punches. An eight turns Pt coil was put in ferrite powder, and Remained half ferrite powder was supplied in the graphite die. SPS was carried out at a sintering temperature of 900℃, a welding pressure of 29.4MPa and a holding time of 5 minutes.

The size of the fabricated inductor was 15mm$^{\phi}$ × 1.1mm^{t}, and inductance was 1.9 μH. This inductor has advantages of very simple fabrication process, rapid fabrication and low cost production as compared with thin-film coil type inductor.

IV. SUMMARY

Two types of small height inductors were proposed and fabricated: One is composed of thin-film coils formed photolithography and a ferrite core, and the other is coil-embedded-type inductor fabricated by Spark Plasma Sintering method. The former has an advantage of high inductance and possibility for further miniaturization. The advantage of the latter is low cost and short time processing.

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