Development of Film Transformer

S. Hayano, Y. Midorikawa, and Y. Saito
College of Engineering, Hosei University, Kajino, Koganei, Tokyo 184, JAPAN

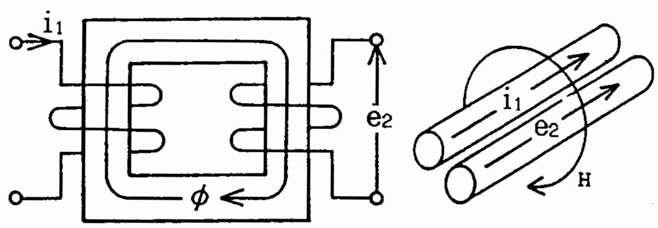
Abstract — In order to realize the light and small power supplies, we propose a film shape transformer. This new transformer is con structed by chemical etching process. Experi mental works show that this film transformer has about 98% coupling factor over 500kHz and operates over 95% efficiency at 1.5MHz. As an initial test, we applied our film transformer to a push-pull type DC to DC converter and succeeded in obtaining 11W output power.

I. INTRODUCTION

For the development of modern electronic devices such as the book size computer and word processor, it is required to reduce their size and weight for portability. This means that the magnetic parts, e.g. reactor and transformer, in their electric power supplies must be reduced because their size and weight greatly depend on the magnetic devices which are relatively larger in size and heavier than those of the other electronic parts. One way to reduce the size and weight of the magnetic parts is to employ high frequency excitation [1,2]. However, this high frequency operation creates a problem in which the performance of the device is dominated by the frequency characteristics of the core magnetic materials.

To overcome this difficulty, new magnetic materials, typically amorphous magnetic materials, have been used [3,4]. Nevertheless, it is difficult to avoid an essential increase of iron loss in accordance with the rise of operating frequency. Another solution of this problem is to exploit a coreless transformer. Recently, we have succeeded in realizing the coreless transformer with high efficiency and demonstrated its usefulness for the DC to DC converters [5,6].

In this paper, a thin and light weight high frequency transformer which we call a film transformer is proposed. This new transformer is composed of the lamination of thin film conductors. Each film is constructed by the chemical etching processes. The operating principle is based on the skin effect similar to that of our coreless transformer[5]. Depending on the load conditions, efficiency of the film transformer reaches over 95%. As an initial test, we applied our film transformer to a push-pull type DC to DC converter and succeeded in obtaining 11W output power. Thus, we experimentally verify that our film transformer is applicable to practical power supplies.



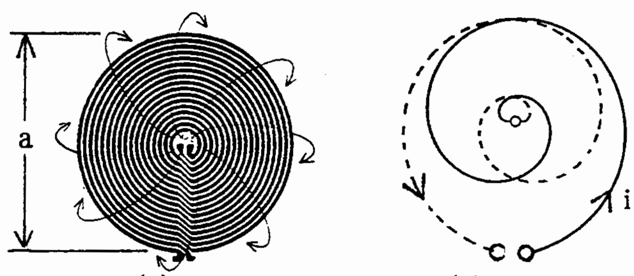
(a) (b)

Fig. 1. Principle of transformer operation. (a) Conventional core type transformer, and (b) film transformer.

II. THE FILM TRANSFORMERS

A. Principle Figure 1(a) shows a typical core type conventional transformer which utilizes the magnetic flux linking the conductors wound around the magnetic core. On the other side, our film transformer utilizes the magnetic flux enclosing the current carrying conductors as shown in Fig.1(b). This basic operating principle is the same as that of the twisted coils transformer [5]. However, in order to couple the primary and secondary circuits in a flat surface, we arrange both the primary and secondary coils in a circular, rectangular or L shape with proper separations.

Figure 2(a) shows a film transformer whose primary and secondary coils are arranged in a coaxially circular shape. When alternating current is flowing through the primary coil, at some instance, the magnetic flux starts from the center to outer on the top surface and returns from outer to center on the under surface of coaxially circular arranged coils



(a) (b)

Fig. 2. An example of the film transformer. (a) Coaxially circular arranged coils and supposed magnetic flux path, and (b) a way of coil connection in 2 layer. Solid and dotted lines are front and back side coils, respectively.

0018-9464/94$4.00 © 1994 IEEE

or viceversa. These magnetic fluxes essentially induce a voltage in a secondary coil because the secondary coil is arranged in a coaxially circular shape on a film base common to primary and secondary coils.

B. Practical considerations In order to realize film transformers for practical use, at least, three points should be taken into account to design of the film transformer. The first is concerning the terminal arrangement of the primary and secondary coils. It is desirable to install the terminals at the outside of film. With the coil arrangement shown in Fig. 2(a), one of the primary terminals is located at the outside and the other is located at the center of the film base. This means that connection to the electric source must cross over the transformer coils. This condition is the same for the secondary connection. To remove this fault, the coaxial circular arranged coils having symmetry is laminated in order to coincide with the direction of magnetic flux flow, and connected at the center as shown in Fig 2(b). Thus, it is possible to install the terminals of the primary and secondary coils at the outside. The second is concerning the ratio of transformation. As described in the reference [1], the ratio of transformation of this type transformer depends on the length of coils, i.e. a ratio of transformation corresponds to a ratio of the primary and secondary coils length. If a primary coil is longer than those of secondary, then lower voltage can be obtained to the secondary circuit but leakage flux of the primary coil is increased. Even though a large number of laminations is required, this fault can be removed by changing the circuit connection. For example, let us consider a pair of film transformer. If two primary coils are connected in series and two secondary coils are connected in parallel, then it possible to get half the primary impressed voltage at the secondary terminals. The third is concerning the improvement of coupling factor. Because of a proximity effect difference at the film edge, the magnetic flux does not flow ideally as shown in Fig. 2(a) but it may take closed paths penetrating the base films. Namely, the magnetic flux flow normal to the film surface is caused by the proximity effect difference at the film edge. Obviously, this bypassing magnetic flux makes the coupling factor low. One of the solutions of this problem is to increase the number of laminations. Figure 3 shows the computed magnetic field distributions by the integral equation method [7]. From the results in Fig. 3, it is obvious that increasing the number of laminations reduces the proximity effect difference at the film edge.

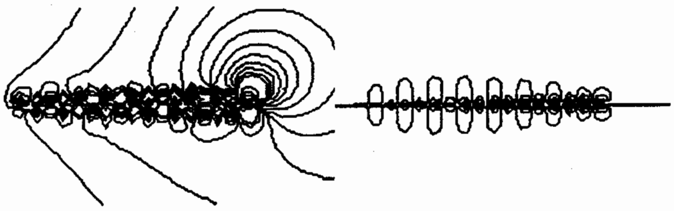


Fig. 3. Computed magnetic field distributions of film transformers. (a) Two layer film transformer with shorted secondary circuit at 100kHz, and (b) four layer film transformer with shorted secondary circuit at 100kHz. Computations were carried out for a circular shape film transformer by the integral equation method [7].

C. Experimental We worked out the three types of trial film transformers from copper coated polyimide film by the chemical etching processes. One is the coaxially circular coil pattern shown in Fig. 2(a) and the others are shown in Fig.4. Specification of the trial transformers is listed in table 1.

Figure 5 shows the frequency characteristic of the ratio of transformation, which corresponds to the coupling factor at high frequency. This figure shows the ratio of transformation of a film transformer composed of

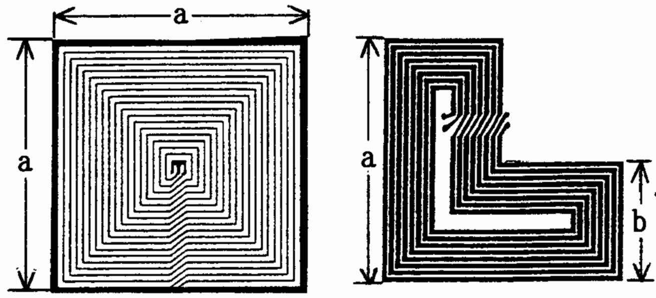


Fig. 4. The trial film transformer patterns. (a) Coaxially square arranged coils, and (b) coaxially L shape arranged coils.

TABLE 1
SPECIFICATION OF TRIAL FILM TRANSFORMERS

Shape	Size cm	Thickness	Width of Conductor	Turns
Circular	a=9	85 μm	1.7 mm	9
Square	a=10	(copper:35	(space:	9
L	a=10, b=5	base:50)	0.7)	4

series connected two and four layer films. The difference between them suggests that the frequency characteristic of the coupling factor can be improved by increasing the number of film laminations.

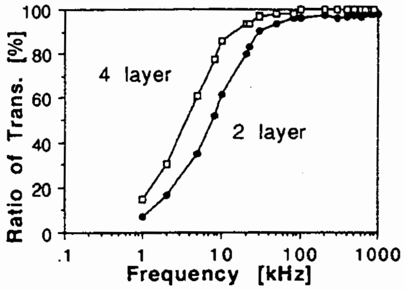
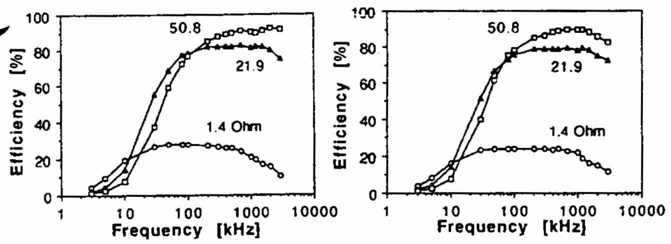


Fig. 5. The frequency characteristic of ratio of transformation, which corresponds to the coupling factor at high frequency.



(a) (b)

Fig. 6. The frequency characteristics of efficiency. (a) Four layer series connected circular shape film transformer, (b) four layer series connected rectangular shape film transformer. 1.4, 21.9 and 50.8 denote the load resistance value in Ohms.

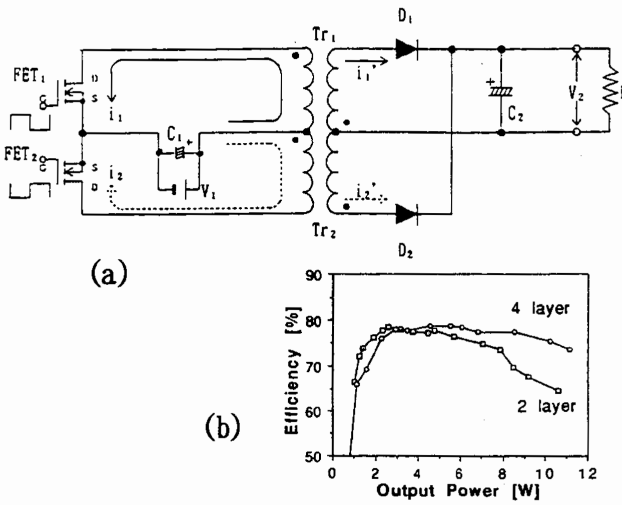


Fig. 7. Application to a DC to DC converter. (a) Circuit diagram of a push-pull type DC to DC converter, and (b) load characteristics. Coaxially square film transformer shown in Fig. 4(a) was used. Operating frequency of the converter, input and output DC voltages are 140kHz, 12V and 20V, respectively.

Figure 6 shows the frequency characteristics of efficiency. The results in Fig.6 suggest that it is possible to realize highly efficient film transformers even though the load and operating frequency conditions are limited. Also, Fig. 6 shows that the optimum operating frequency depends on the load resistance value, and it moves to a higher frequency in accordance with the larger load resistance value. This tendency is similar to the results in the Ref. [5].

D. Application to a DC to DC converter

Finally we applied our film transformer to a push-pull type DC to DC converter. Figure 7(a) shows a circuit diagram of the converter, also Fig. 7(b) shows the load characteristics of this converter operating at 140kHz. From the results shown in Fig. 7(b), it is revealed that available maximum output power is 11.1W with 74[%] efficiency.

III. CONCLUSION

In the present paper, the thin and light weight high frequency transformer has been proposed. Depending on the load conditions, efficiency of the film transformer reaches over 95%. As an initial test, we applied our transformer to a DC to DC converter and succeeded in obtaining 11.1W with 74[%] efficiency. Thus, as a first step, we have experimentally verified that our film transformer is applicable to the practical power supplies. Next step, we have to solve a packaging problem in order to reduce the radiation of magnetic fields. We are going to coat the magnetic materials on the surface of film. This may make it possible to reduce the radiating magnetic fields and to control the magnetic exciting current .

IV. REFERENCES

[1] K. Harada et al., *Proc. IEEE*, vol.76, pp.353-361, April 1988.
[2] F.C. Lee, *Proc. IEEE*, vol.76, pp.377-390, April 1988.
[3] K. Arai et al., *IEEE Trans. Magn.*, vol. MAG-20, No.5, pp.1463-1465, Sep. 1984.
[4] R.V. Major et al., *IEEE Trans. Magn.*, vol. MAG-20, No.5, pp.1415-1416, Sep. 1984.
[5] S. Hayano et al, *IEEE Trans., Magn.*, vol. 27, No.6, pp.5205-5207, Nov. 1991.
[6] T. Ogawa et al., *Journal of Electrical Engineering*, ELEKTROTECHNIKA., CAS., 44, No.7, pp.239-241, 1993.
[7] I. Marinova et al., *IEEE Trans. Magn.*, in submitted.