

Efficiency Increase in On-Chip Buck Converter by Introduction of High Permeability Material to Inductor on Interposer

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Abstract

In this paper, an inductor on interposer with a ferrite film is investigated for power supply circuits in order to improve the efficiency of the power supply circuits by introducing a high permeability material to the inductor. A DC-DC buck converter is used as a power supply circuit in this work. The dependence of the inductance on the location of ferrite film is discussed with field electromagnetic simulations. Simulation results indicate that the ferrite film should be located on both upper and lower sides of the inductor and between metals. By using the inductor with the 10 μ m-thick ferrite film, the efficiency of buck converter is improved by 13% when the efficiency of buck converter with the air core inductor is 60%.

Key Words: Buck Converter, Ferrite, Interposer

I. INTRODUCTION

Since mobile devices have been currently smaller and thinner, miniaturization of inductors used for power supply circuits is required. Although it is one of promising solutions that inductors are implemented in IC package or interposer, the inductance and Q factor of such inductors are smaller, which results in worsening the efficiency of power supply circuits. Therefore, introduction of high permeability material to the inductor is expected to improve the efficiency. In this paper, the efficiency using inductor on interposer with a ferrite film is investigated as shown in Fig. 1. A DC-DC buck converter is used as a power supply circuit in this work. In order to improve the efficiency of buck converter, the location of ferrite film is also discussed with electromagnetic field simulations.

II. SIMULATION SETUP

Fig. 2 shows a circuit schematic of buck converter evaluated in this paper. A controller circuit, buffers, and drivers of buck converter are implemented in the IC, while an inductor is fabricated in the interposer using metal interconnects of the interposer. V_{IN} and V_{OUT} are input and output voltages of buck converter, respectively.

According to [1], the efficiency η of optimally-designed buck converter is expressed as

$$\eta = \frac{P_{out}}{P_{out} + P_{loss}} = \frac{1}{1 + \frac{P_{loss}}{P_{out}}} = \frac{1}{1 + \frac{1}{D} \sqrt[3]{24 \frac{R_0 C_0}{\tau_L} D(1-D)}} \quad (1)$$

As defined in [1], P_{out} and P_{loss} represent the output power of buck converter and its power loss, respectively, $R_0 C_0$ is the technology-dependent parameter of the IC, and D is a duty ratio, which is given by V_{OUT}/V_{IN} .

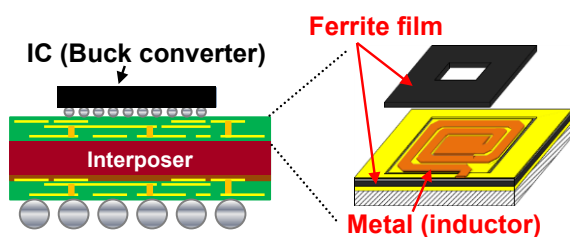


Fig. 1 Inductor on interposer with ferrite film.

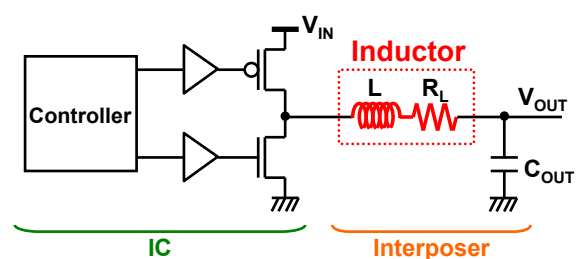


Fig. 2 Circuit schematic of buck converter.

τ_L in (1) is defined as

$$\tau_L = L/R_L \tag{2}$$

where L and R_L are the inductance and the DC resistance of the inductor, respectively. Equations (1) and (2) indicate that large τ_L improves η of buck converter and hence τ_L is evaluated in addition to L in this paper.

Fig. 3 shows the layout of the inductor used for simulations described in Section III. Table I summarize the simulation setup. The inductor is simulated by a 3D electromagnetic simulator (Agilent EMPro). In this paper, the dependence of relative permeability on frequency is not considered. The superimposed DC current characteristics are negligible at the output current of 1A, and hence the characteristics are not considered in this paper.

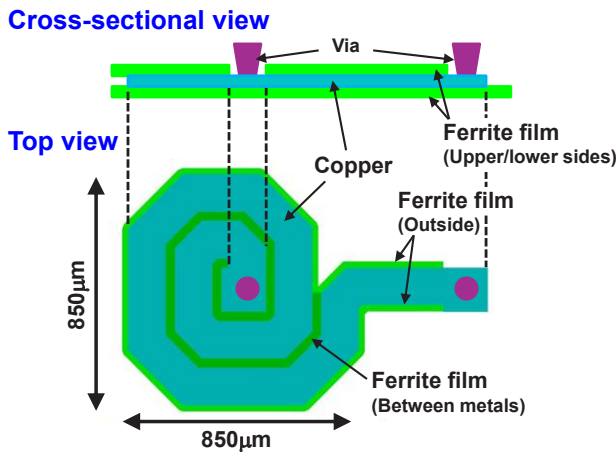


Fig. 3 Layout of inductor used for simulations.

Table I Summary of simulation setup.

Inductor	
Metal	Copper
Thickness/width of metal	20µm / 130µm
Diameter	850µm
Number of turns	2
Ferrite film	
Relative permeability	80
Thickness	1µm – 100µm
Buck converter	
Input/output voltage	1.8V / 1.0V
Output current	1.0A
Switching frequency	10, 100MHz

III. SIMULATION RESULTS

A. Dependence of Inductance on Location of Ferrite Film

In order to investigate the dependence of inductance on the location of the ferrite film, the following two conditions are evaluated; 1) the ferrite film is located on both upper and lower sides of the inductor or only lower side of inductor, and 2) the ferrite film is located between metals or not.

Fig.4 shows the inductance when the ferrite film is located on both upper and lower sides of the inductor and only lower side of the inductor. The inductance with the ferrite film located on both upper and lower sides of the inductor is much higher than that with the ferrite film located on only lower side of inductor. Fig. 5 illustrates the inductances with and

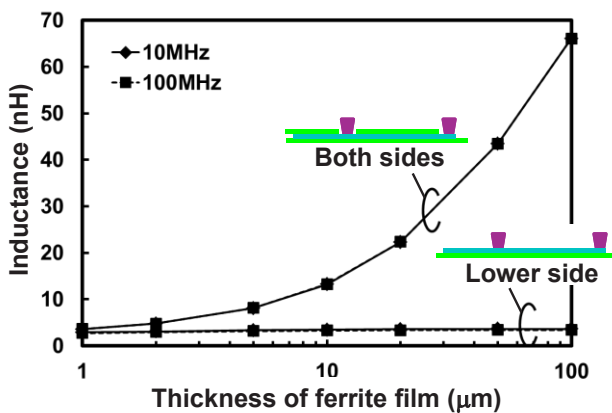


Fig. 4 Inductance when ferrite film is located on both upper and lower sides of inductor and only lower side of inductor.

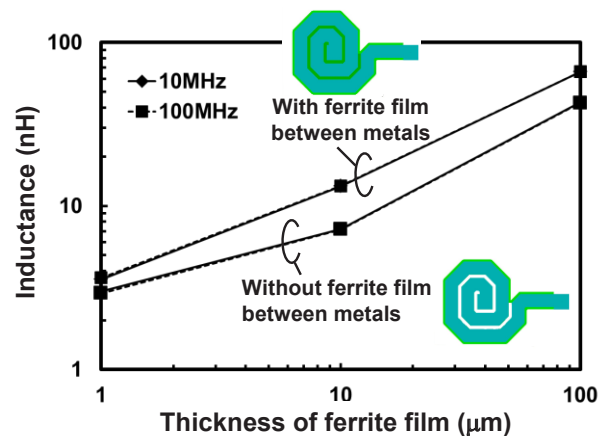


Fig. 5 Inductance with and without ferrite film between metals.

without the ferrite film between metals (the ferrite film between metals is indicated in Fig. 3). In both cases, the ferrite film is located on the upper and lower sides of the inductor (the thickness of the ferrite film is $10\mu\text{m}$) and the outside of the inductor (the width of ferrite film is $10\mu\text{m}$). The ferrite film between metals improves inductance by 20-60%.

The increase in τ_L improves the efficiency of buck converter as indicated in (1). In order to increase τ_L , Figs. 4 and 5 indicate that the ferrite film should be located on both upper and lower sides of the inductor as well as between metals, because τ_L depends on L as shown in (2).

B. Efficiency Improvement of Buck Converter by Using Inductor with Ferrite Film

In order to investigate the efficiency of buck converter improved by using the inductor with the ferrite film, τ_L , which is derived in (2), is evaluated. Fig. 6 shows the dependence of τ_L on the thickness of the ferrite film. $\tau_{L(\text{ferrite})}$ and $\tau_{L(\text{air})}$ are τ_L of the inductor with the ferrite film and the air core inductor, respectively. When the thickness of the ferrite film is $10\mu\text{m}$, $\tau_{L(\text{ferrite})}$ increases by 5.7 times compared with $\tau_{L(\text{air})}$, as indicated in Fig. 6.

Fig. 7 shows the efficiency improvement of buck converter by using the inductor with the ferrite film compared with the efficiency with the air core inductor when the switching frequency is 100MHz. By using the inductor with the $10\mu\text{m}$ -thick ferrite film, the efficiency of buck converter is improved by 13% and 8% when the efficiencies of buck converter with the air core inductor are 60 and 80%, respectively.

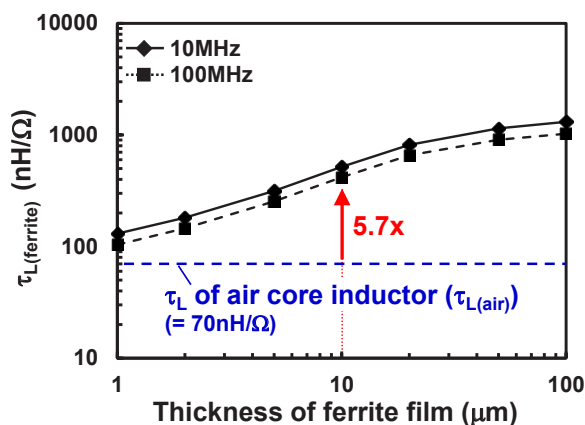


Fig. 6 Dependence of τ_L of inductor with ferrite film and air core inductor.

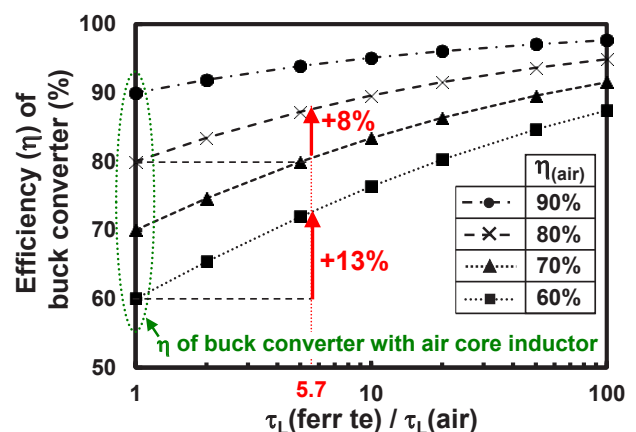


Fig. 7 Efficiency(η) improvement of buck converter by using inductor with ferrite film. $\eta_{(\text{air})}$ is η of buck converter with air core inductor.

IV. CONCLUSION

In this paper, an inductor on interposer with a ferrite film was investigated for power supply circuits. A DC-DC buck converter was used as a power supply circuit in this work. The inductance and τ_L improved by the ferrite film was evaluated with field electromagnetic simulations. First, the dependence of the inductance on the location of the ferrite film was discussed. Simulation results indicate that inductance with the ferrite film located on both upper and lower sides of the inductor is much higher than that with the ferrite film located on only lower side of inductor. Furthermore, the ferrite film between metals improves inductance by 20-60%. These results indicate that the ferrite film should be located on both upper and lower sides of the inductor as well as between metals. Then, the efficiency improvement of buck converter by using the inductor with the ferrite film was evaluated. By using the inductor with the $10\mu\text{m}$ -thick ferrite film, the efficiency of buck converter is improved by 13% when the efficiency of buck converter with the air core inductor is 60%. An investigation considering the dependence of relative permeability on frequency is future work.

REFERENCES

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