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A 33% Improvement in Efficiency of Wireless Inter-Chip Power Delivery by Thin Film Magnetic Material

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1. Introduction

Recently, exploiting the benefit of device scaling has become more and more difficult. Three-dimensional (3D) system integration has started to get attention.

In 3D system integration, chips are stacked and connected with vertical inter-chip links. Performance of the inter-chip link deeply affects the total system perfomance of 3D system integration. Inductive-coupling link was reported as one of the high-performance inter-chip links [1].

In previous work [1], data and clock were transmitted with inductive-coupling link. In addition to the clock and data communication, wireless inter-chip power delivery using on-chip inductors with high frequency was reported [2,3]. However, the highest power efficiency ever reported until now is only 10% since it uses an on-chip inductor whose Q factor is very low due to lossy silicon substrate and an on-chip rectifier whose efficiency is very low at high frequencies.

In this work, a thin film magnetic material is applied for the first time to an inductive-coupling inter-chip power delivery for improvement in efficiency. Test chips were fabricated in 0.18 μm CMOS and the improvement in efficiency was verified.

2. Power Delivery with Thin-film Magnetic Material

Figure 1 shows the concept of 3D system integration with thin film magnetic material. By attaching thin film magnetic material on top the of inductors for power delivery after the chip fabrication, high efficiency can be achieved. This method can be cost effective since it does not require modifications in LSI process unlike the previous work reported in [4].

Figure 2 illustrates the mechanism of improving efficiency in power delivery by thin film magnetic material. The existence of magnetic material with horizontal hard magnetization enhances the magnetic flux density. With this change, mutual inductance of on-chip inductors increases and the efficiency can be improved.

3. Test chip Design, Measurement Setup and Results

The stacked chip microphotograph and schematic of power delivery for this study is shown in Fig. 3. The design of the circuits is described in the previous work [2]. The test chips were designed and fabricated in 0.18 μm CMOS technology. The transmitter chip is stacked on the receiver chip and both chips are face-up. The transmitter chip is polished to have a thickness of 10 μm. The communication distance is 15 μm including a glue layer. The diameters of transmitter and receiver inductors are 700 μm.

Figure 4 shows measurement setup and properties of a thin film magnetic material utilized in this study. Thin film magnetic material was diced from the wafer and put on the stacked chips. Ferromagnetic resonance frequency of the magnetic material is more than 500 MHz, and it is enough to apply the power delivery since required operational frequency is less than 200 MHz. Saturated magnetic flux density is much larger than that in inductive-coupling power delivery. Curie temperature is high enough to utilize even the automobile application.

Figure 5 shows the measurement results. The curve shown in figure depicts the power efficiency depends on an operational frequency. The transferred power was improved from 36 mW to 48 mW where operational frequency is 140 MHz. Figure 6 shows the improvement in efficiency with respect to operational frequency. The curve decreases rapidly as it approaches the ferromagnetic resonance frequency of the magnetic material.

4. Conclusions

In this work, an improvement of efficiency in power delivery using thin film magnetic material was proposed and investigated. To verify the proposed technique, we designed and fabricated test chip in 0.18 μm CMOS and measured effect of thin film magnetic material. Measurement results show that a 33% improvement in efficiency was achieved at 140 MHz and achieved efficiency is highest reported so far.

Acknowledgement

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References

[1] N. Miura, et al., "A 1 Tb/s 3 W Inductive-Coupling Transceiver for Inter-Chip Clock and Data Link," IEEE ISSCC, Dig. of Tech. Papers, pp. 424-425, Feb., 2006.
[2] Y. Yuxiang, et al., "Non-Contact 10% Efficient 36mW Power Delivery Using On-Chip Inductor in 0.18-μm CMOS," IEEE A-SSCC, Proceedings, pp. 115-118, Nov., 2007.
[3] K. Onizuka, et al., "Chip-to-Chip Inductive Wireless Power Transmission System for SiP Applications," IEEE CICC, Proceedings, pp. 575-578, Sep., 2006.
[4] D. S. Gardner, et al., "Integrated On-Chip Inductors With Magnetic Films," IEEE Trans. Mag. Vol. 43, No. 6, pp. 2615-2617, Jun., 2007.

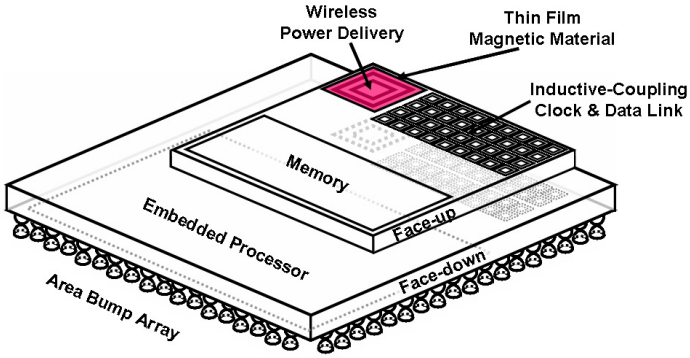


Fig. 1. Concept of the 3D system integration with wireless power delivery using thin film magnetic material.

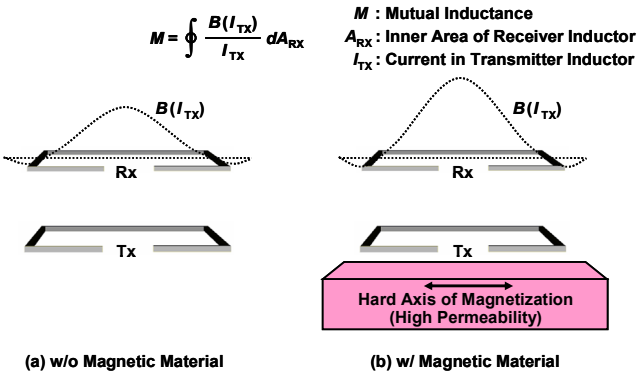


Fig. 2. Improvement of efficiency by thin film magnetic material.

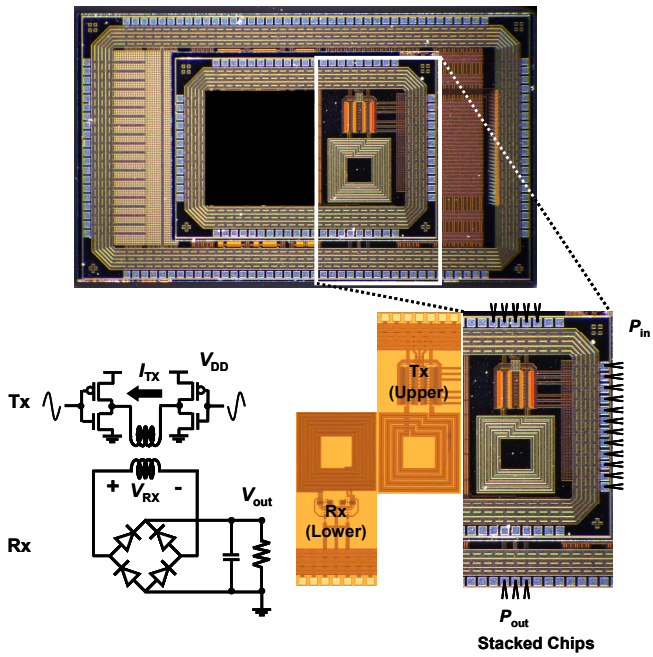
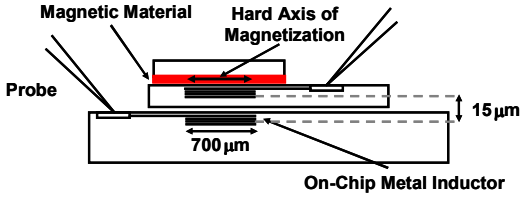


Fig. 3. Stacked chip microphotograph and schemetic of wireless inter-chip power delivery.



Composition	Cobaltiferous
Film-Forming Method	Spattering
Thickness	1 μm
Permeability (Hard Axis)	470 (at 1 MHz)
Ferromagnetic Resonance Frequency	500 MHz
Saturated Magnetic Flux Density	1.44 T
Curie Temperature	More Than 800 ℃

Fig. 4. Measurement setup and properties of a thin film magnetic material.

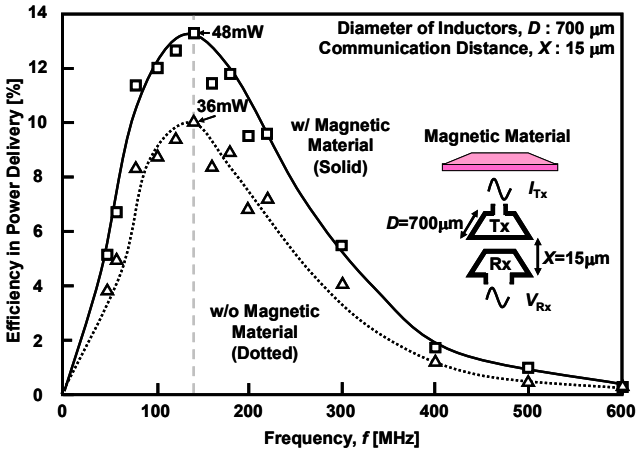


Fig. 5. Mesured efficiency dependence on operational frequency.

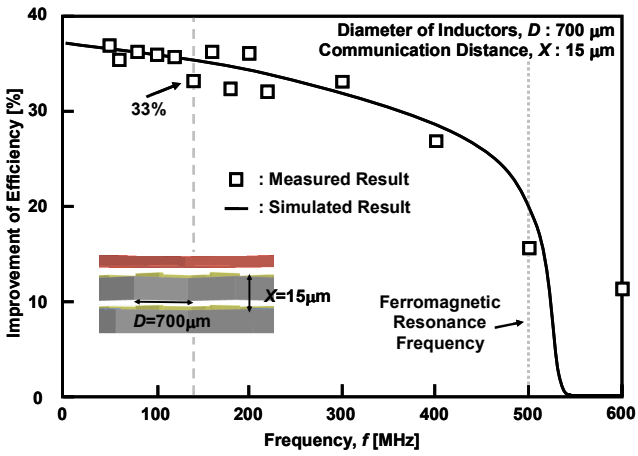


Fig. 6. Measured improvement of efficiency dependence on operational frequency.