

Magnetic core power inductor embedded in glass/epoxy interposer toward power supply integrated in LSI Package

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□ Outline

Power delivery to LSIs

- From board-level to package-level (chip-level) power grid
 - Need for integrated power supply technology
- Power magnetics on chip or embedded in package ?

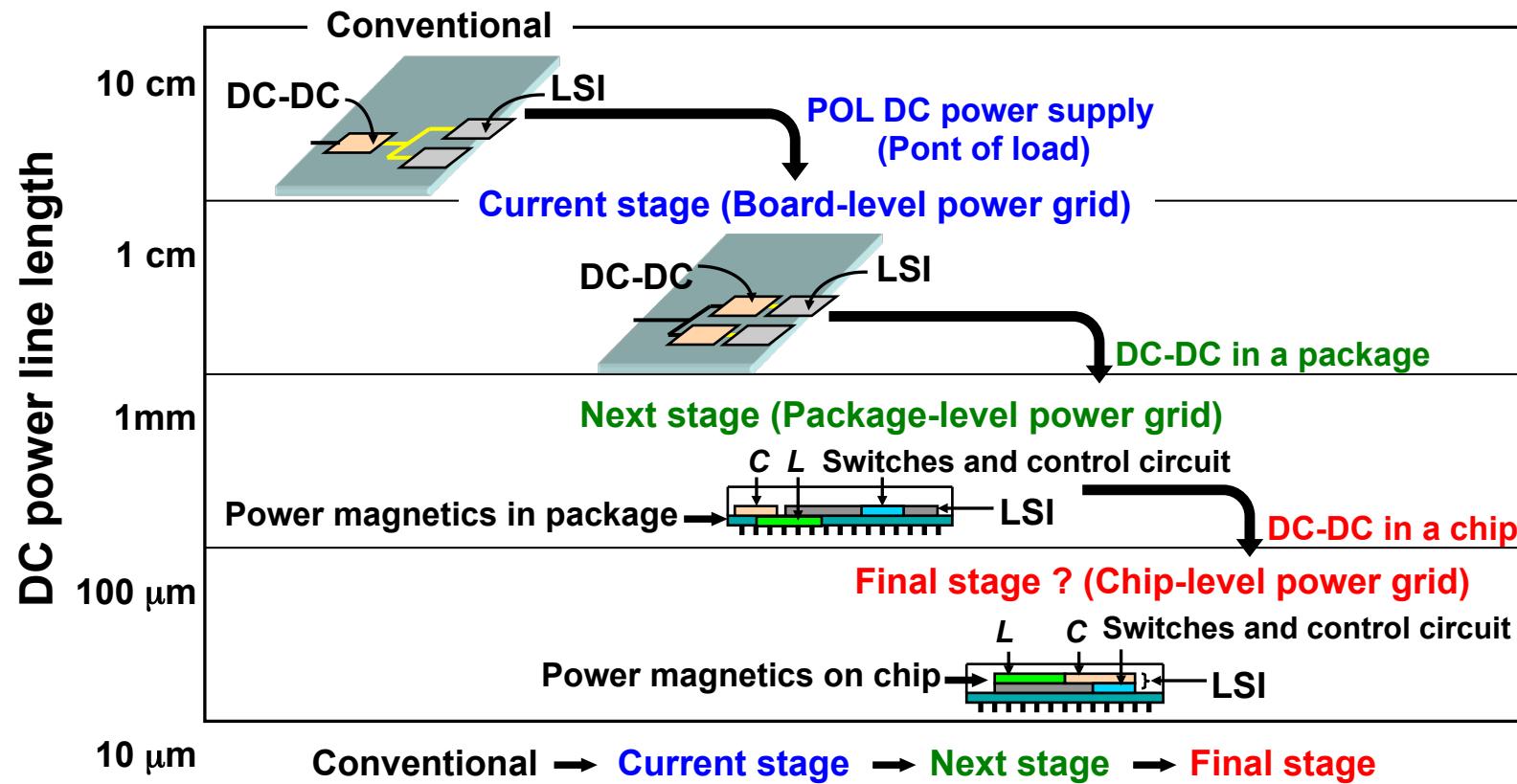
Objective of this work

- Final goal : Package-level DC power grid with integrated power supplies in LSI package

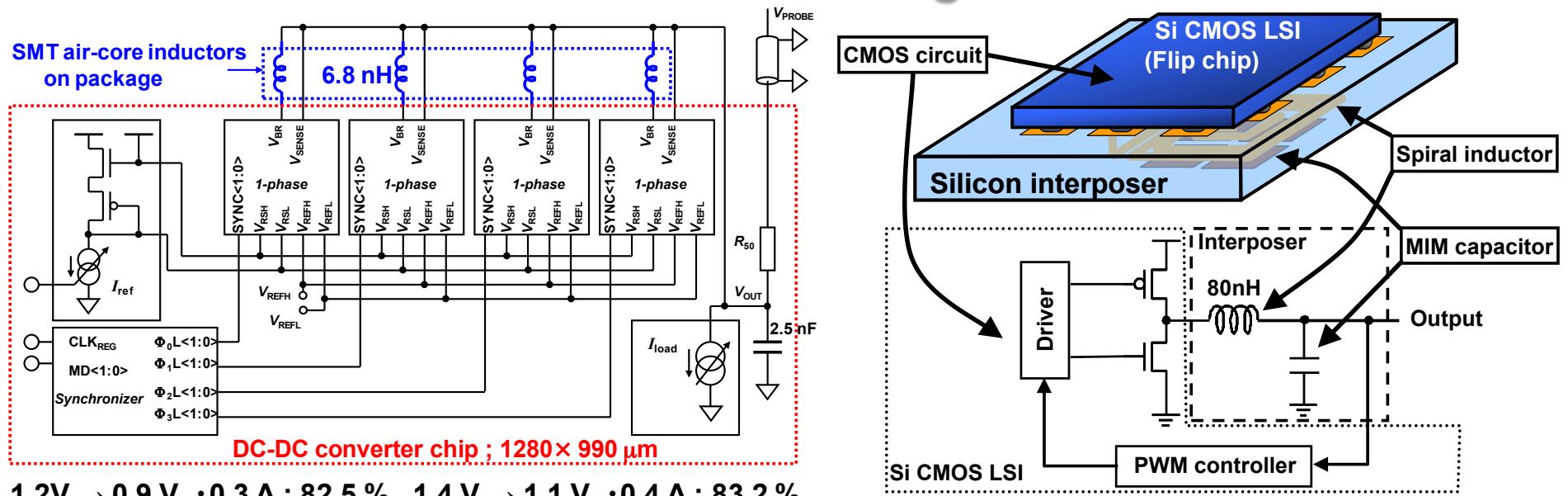
This study

- A possibility of embedded power inductor for power supply integrated in LSI package, performance ?, cost ?, ...
Fabrication and evaluation of embedded magnetic core power inductor

□ Technology trend of power delivery to LSIs



Examples of CMOS-switch DC-DC converter using air-core inductor

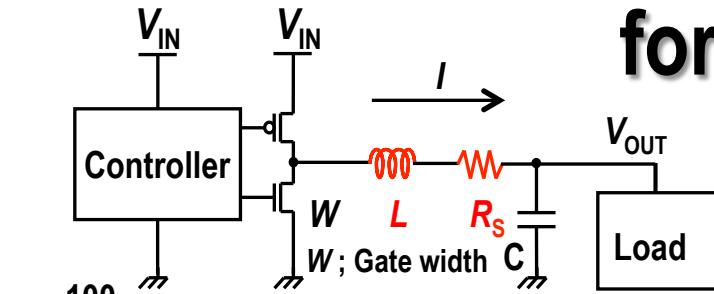


Air-core inductor ; Merit and demerit

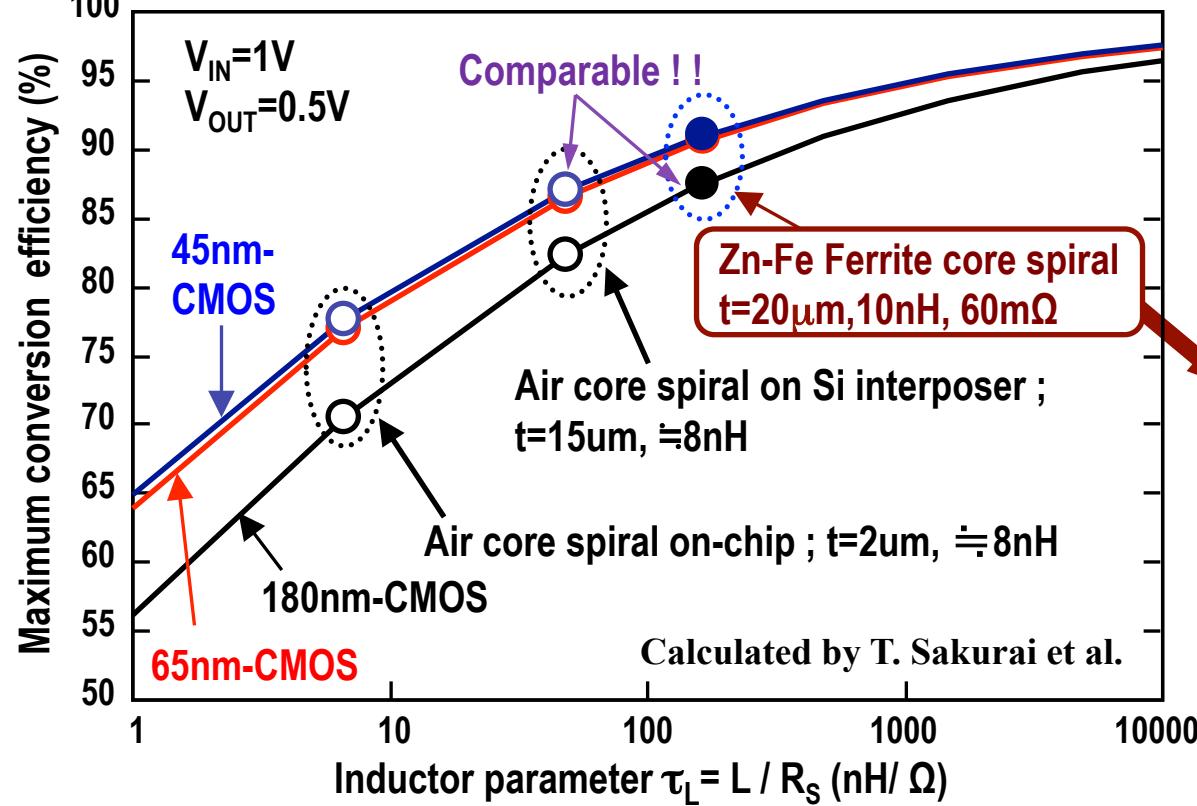
- Low cost (only winding)
- Low inductance, large foot-print
- Local EMI noise (leakage magnetic flux)



□ Possibility of magnetic core power inductor for CMOS-switch DC-DC converter

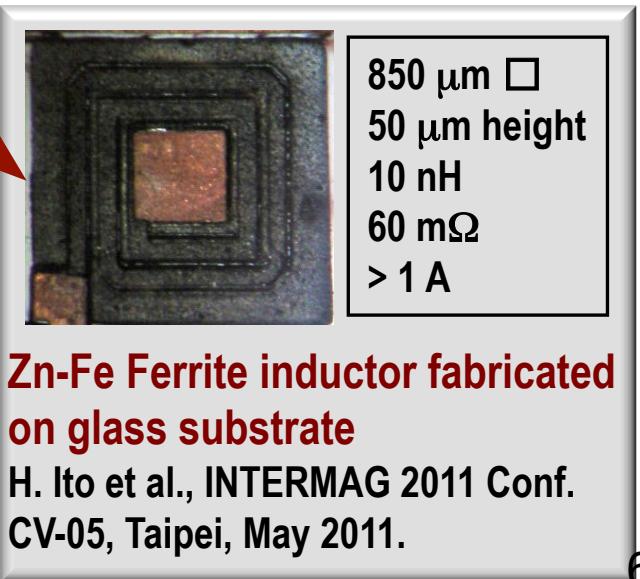


G.Schrom et al., IEEE ICICDT, pp.65-67, Feb. 2006



$$\eta = \frac{1}{1 + \sqrt[3]{\frac{24R_0C_0(1-D)}{D^2L/R_s}}}$$

D:duty, R_0C_0 : MOSFET const.

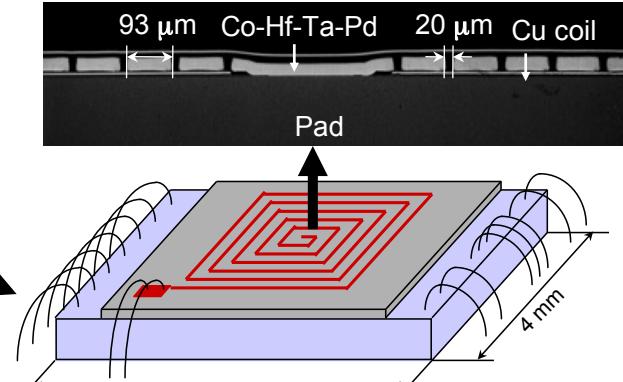
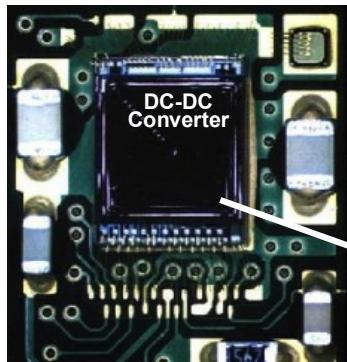


□ Power magnetics on chip or embedded in package?

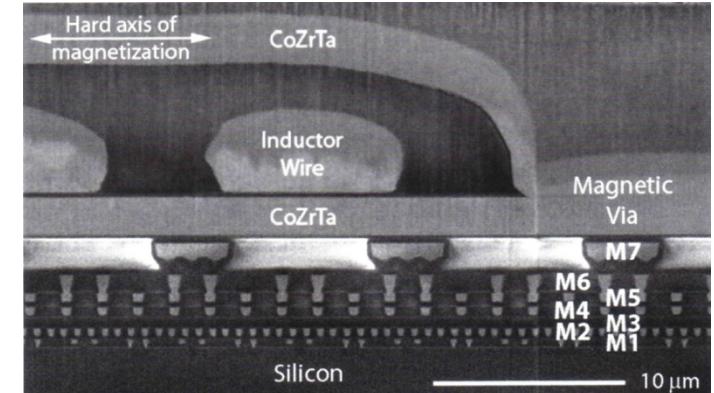
Which will be better solution for power delivery to LSIs?

On-chip inductors

In 2000, Fuji Electric Corp.



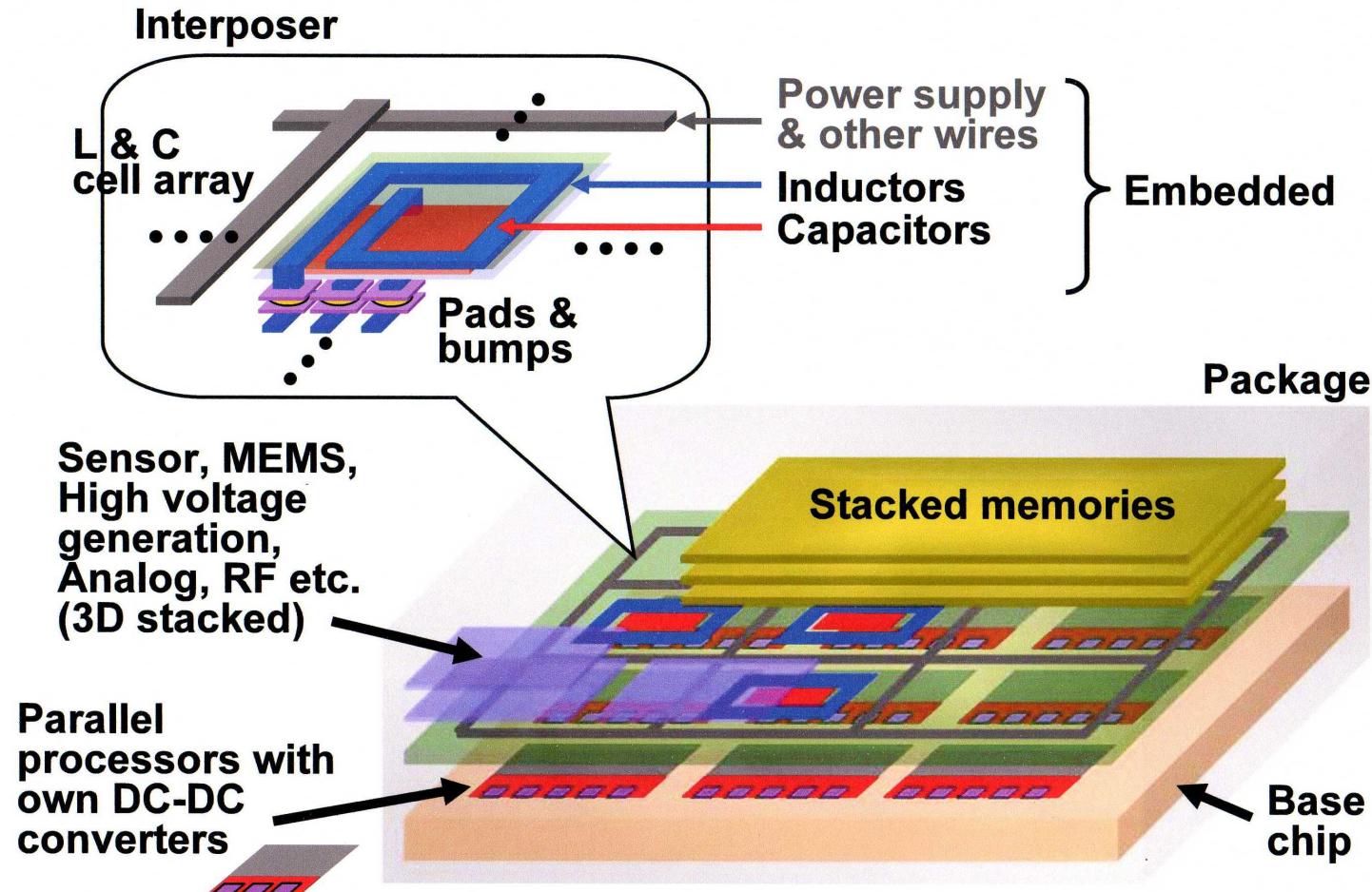
In 2009, INTEL Corp.



**Power magnetics on chip technology should be established
in the future chip-level power grid.**

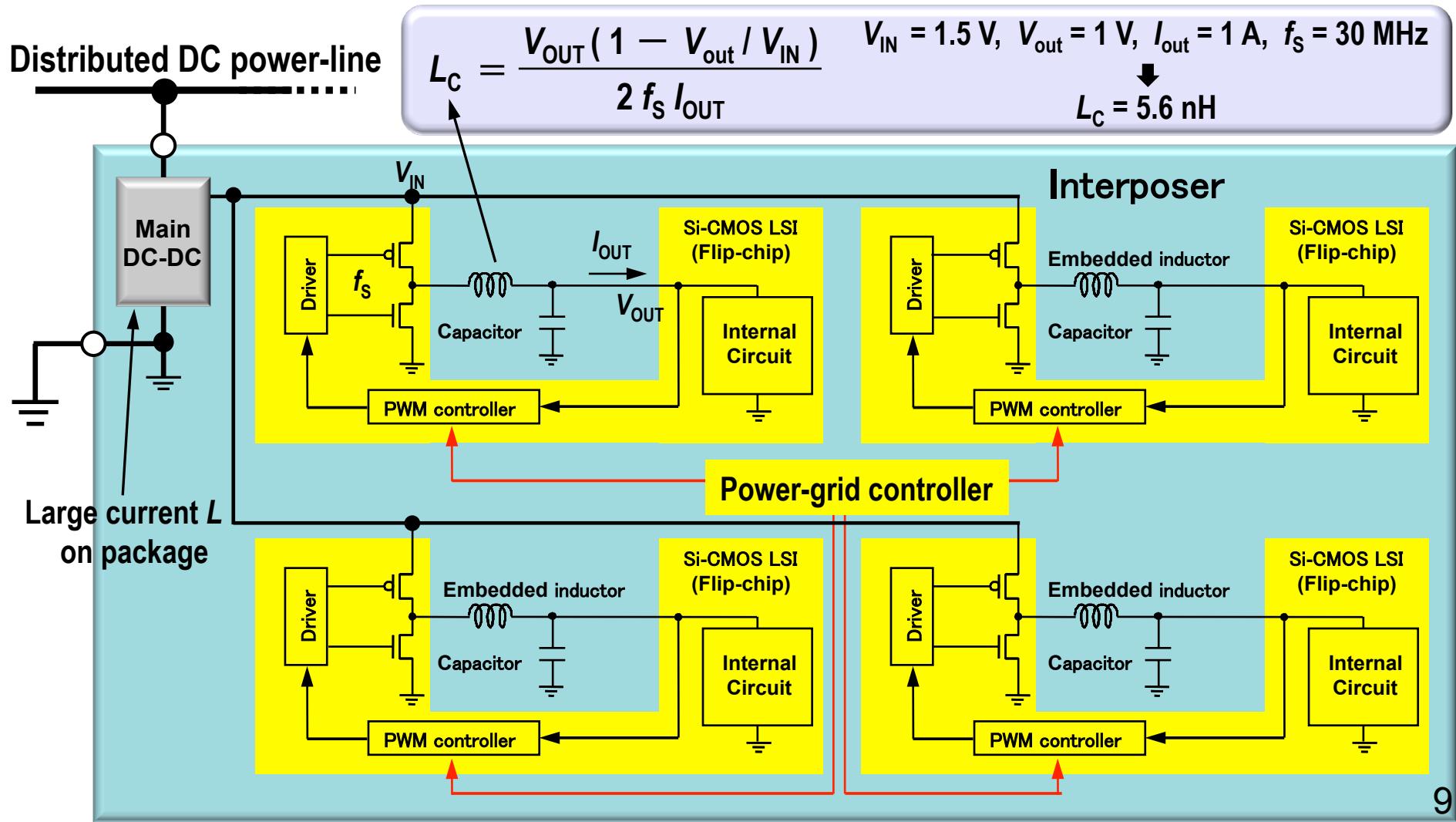


System in Package (SiP) with DC power grid



By Prof. Sakurai's Group, The University of Tokyo

□ Objective ; Package-level power grid (PLPG)

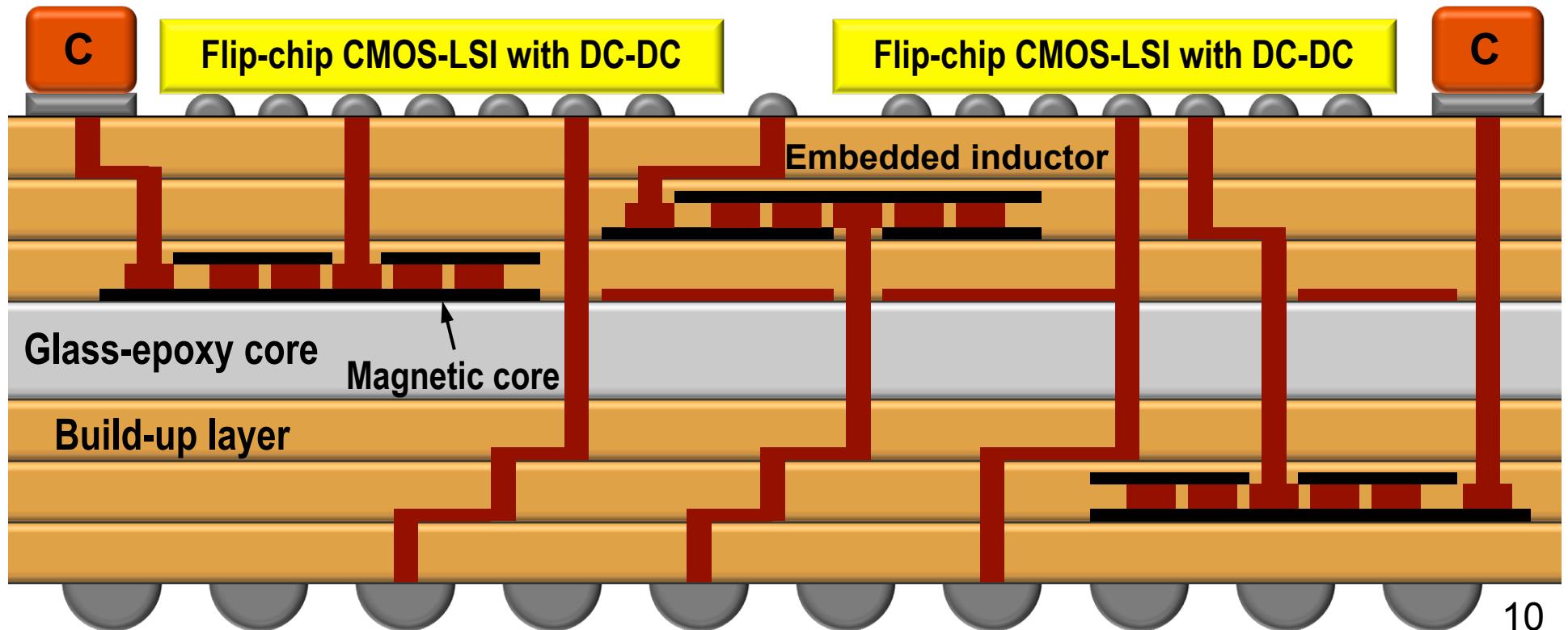


□ Objective ; Package-level power grid (PLPG)

Power magnetics embedded in package

Embedded power inductor in package

Low cost, Low profile ; tens micron height, Small near-EMI ; magnetic core



□ Magnetic core materials for planar power inductor

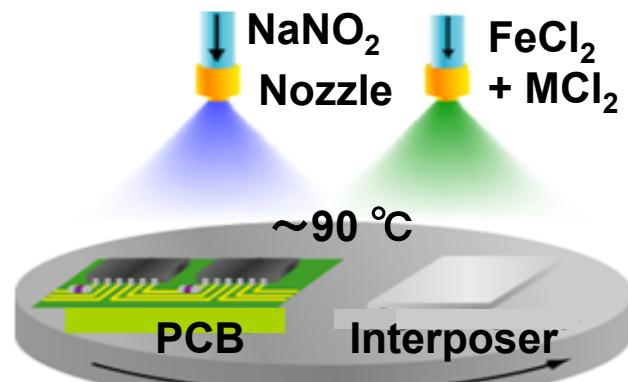
Magnetic core fabrication

Process-compatible with glass/epoxy interposer

Low temperature process below 200 °C

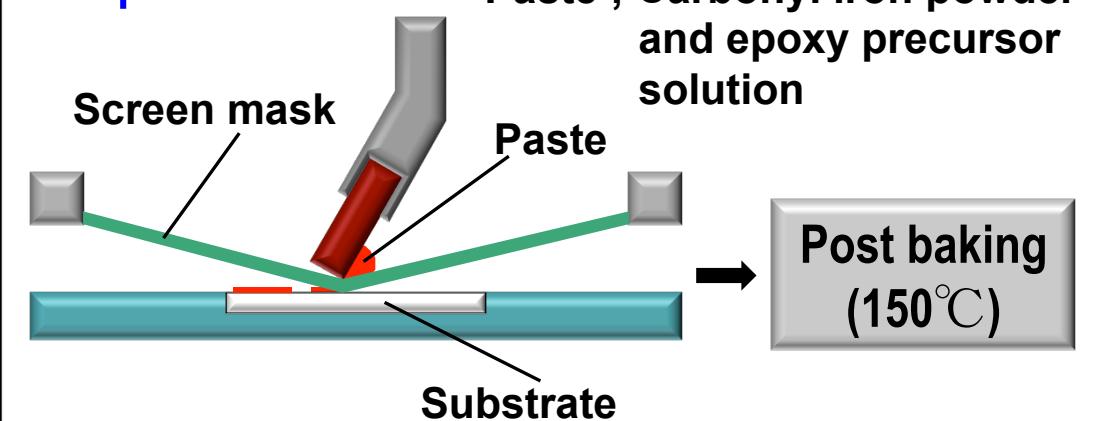
- ◊ Spin-spray method for spinel-ferrite deposition; ≈ 90 °C
- ◊ Screen-printing for Carbonyl Fe/epoxy composite; ≈ 150 °C

Spin-sprayed ferrite core



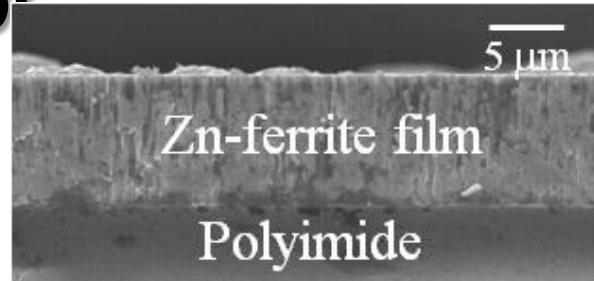
Spin-spray method (TIT, Japan)

Composite core

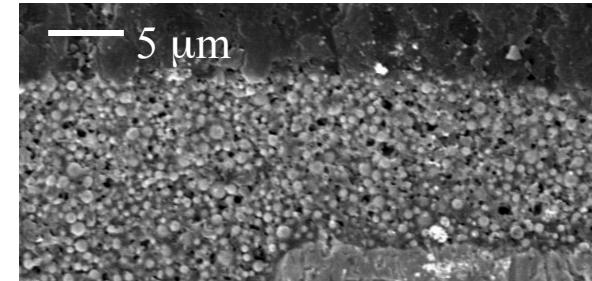
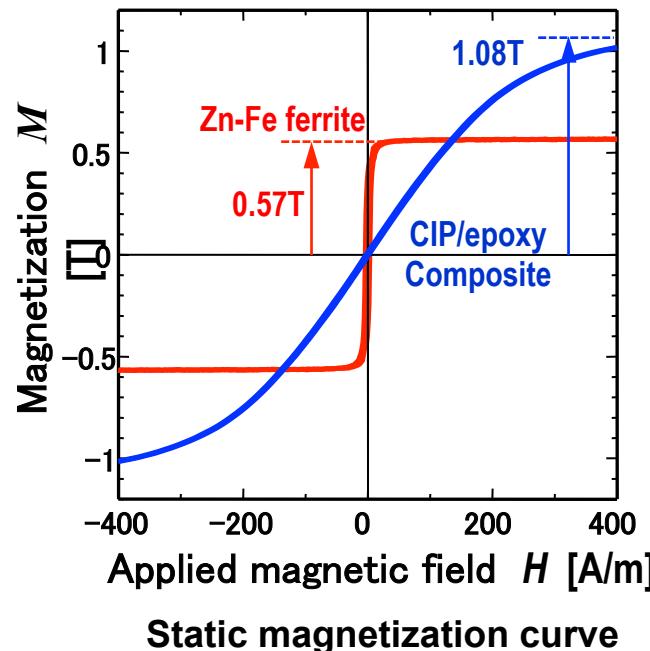


Screen-printing method (Shinshu Univ., Japan)

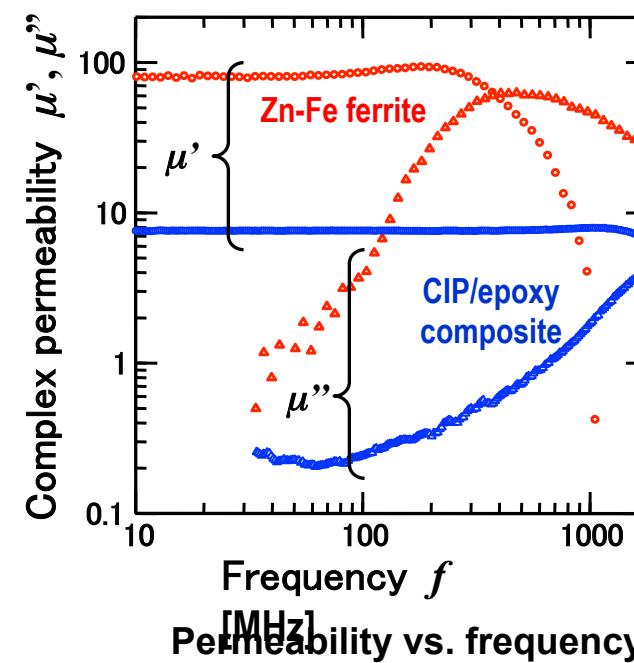
□ Magnetic core materials for planar power inductor



Zn-Fe ferrite ($Zn_{0.36}Fe_{2.64}O_4$) thick film with a columnar-grain structure



54 vol.% Carbonyl iron powder (CIP)/epoxy composite

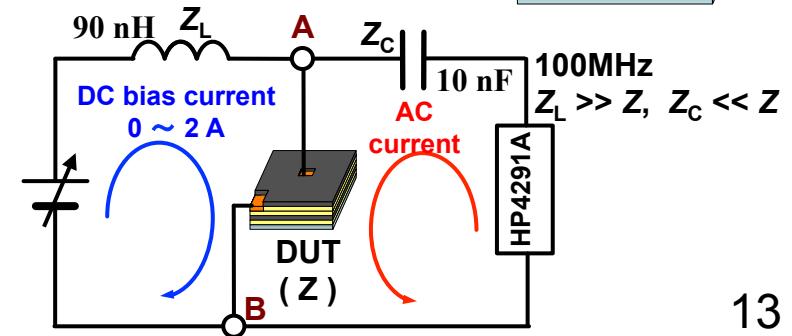
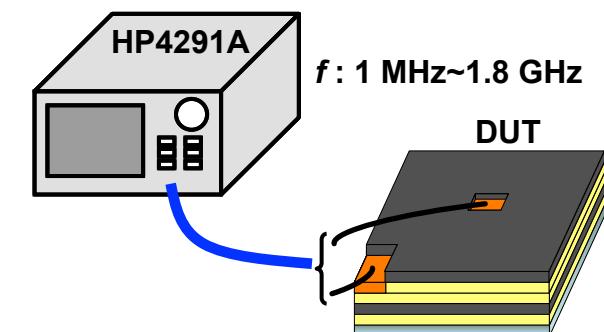
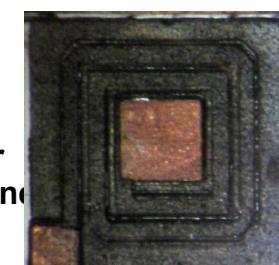
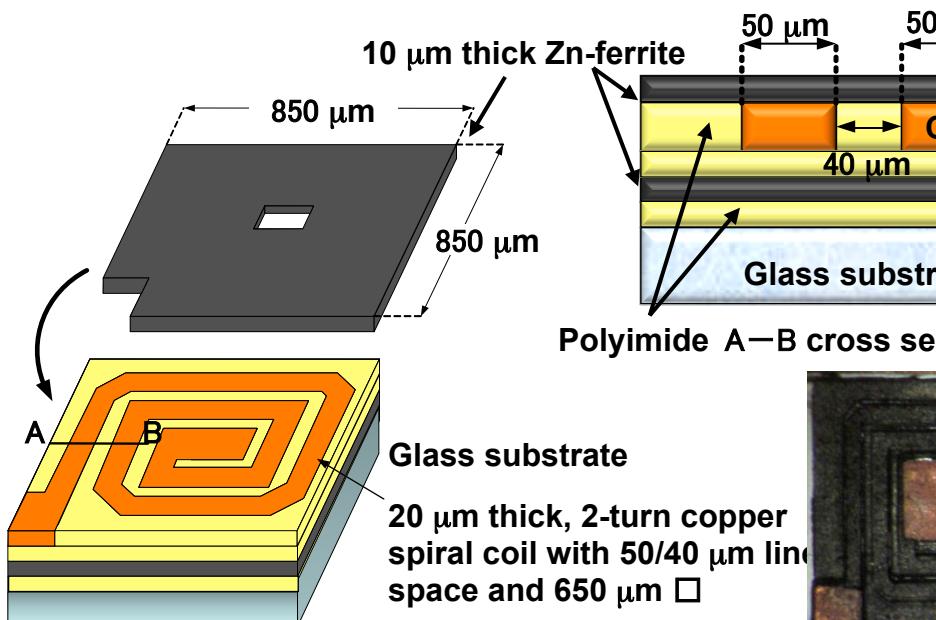


□ Zn-Fe ferrite planar power inductor on glass

In order to confirm an intrinsic potential of the planar inductor for embedded passives,

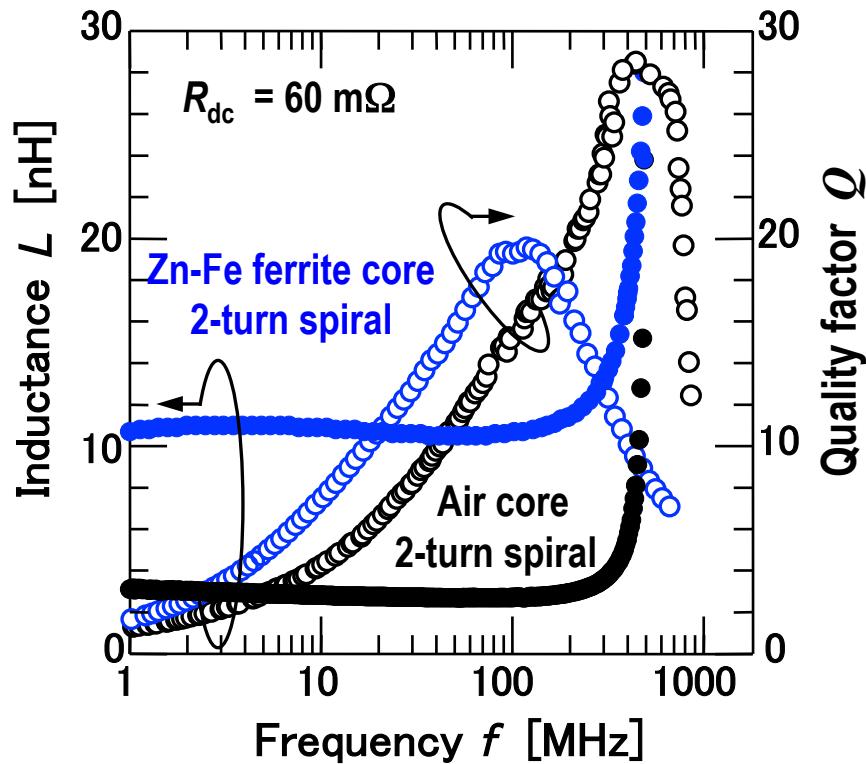


- Zn-Fe ferrite inductor has been fabricated on glass substrate.
- Electrical properties have been evaluated.

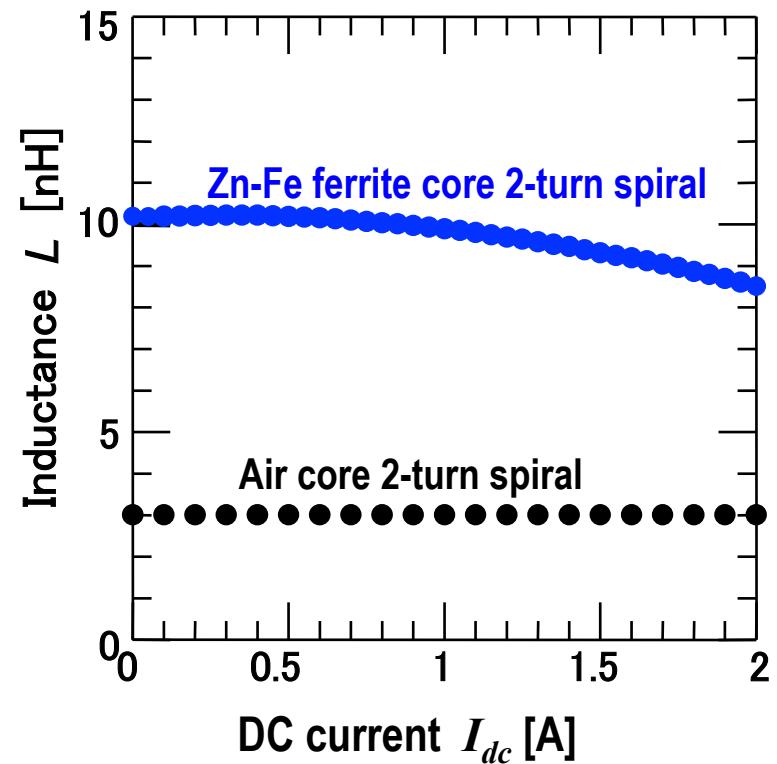


□ Zn-Fe ferrite planar power inductor on glass

Electrical properties



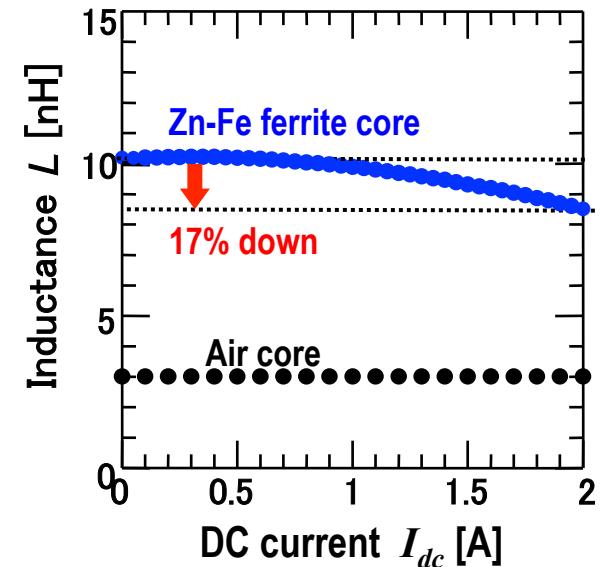
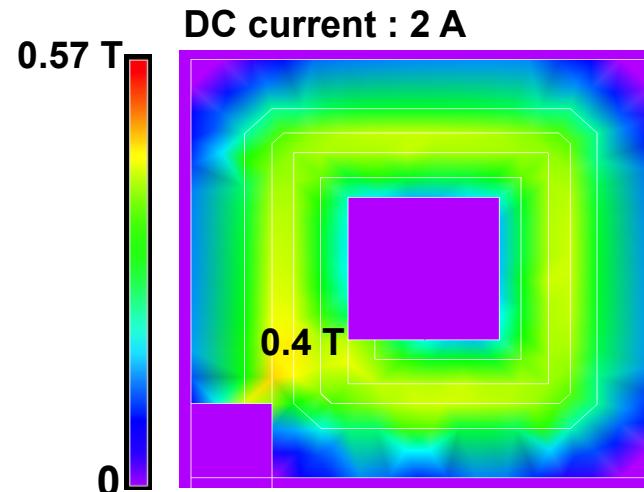
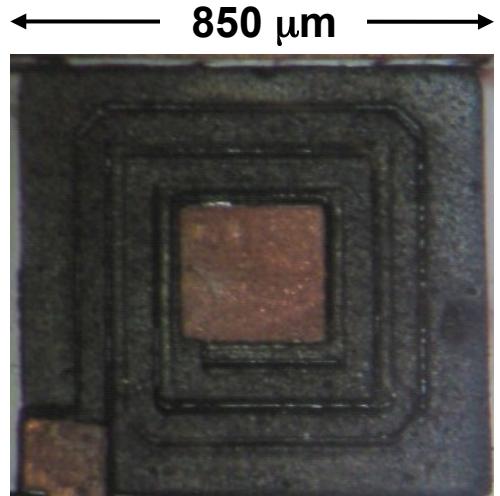
L and Q vs. frequency



Superimposed dc current charac.

□ Zn-Fe ferrite planar power inductor on glass

Flux density in Zn-Fe ferrite core @ superimposed dc current 2 A

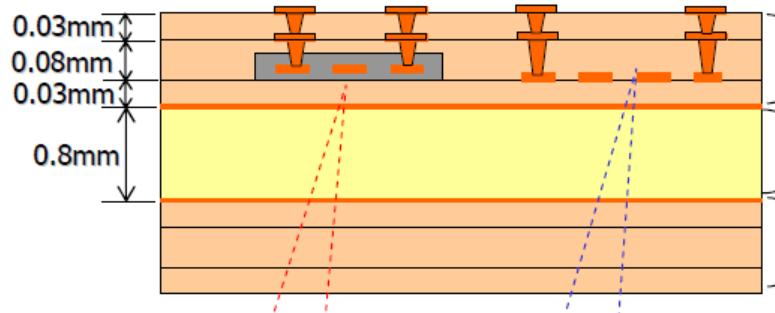


Rating dc current over 1 A

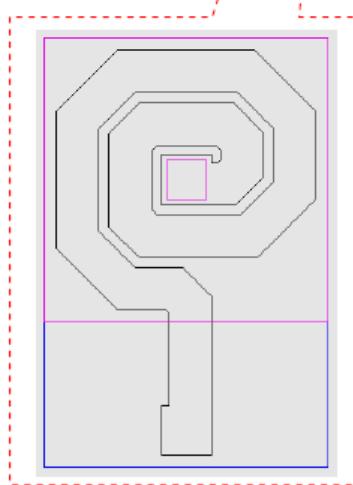
→ Possible application to low power POL converter for PLPG

□ First trial of embedded inductor

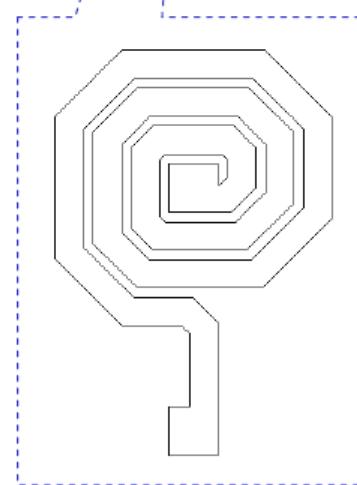
in glass/epoxy interposer



①Build up layer, ②Glass-epoxy core



Zn-Fe ferrite core
2-turn spiral



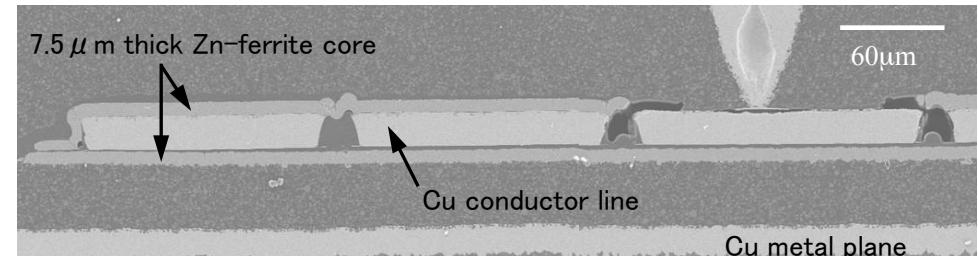
Air-core, 3-turn spiral

(Shinshu Univ., Tokyo Inst. Tech., SHINKO Elec. Ind. Co.)

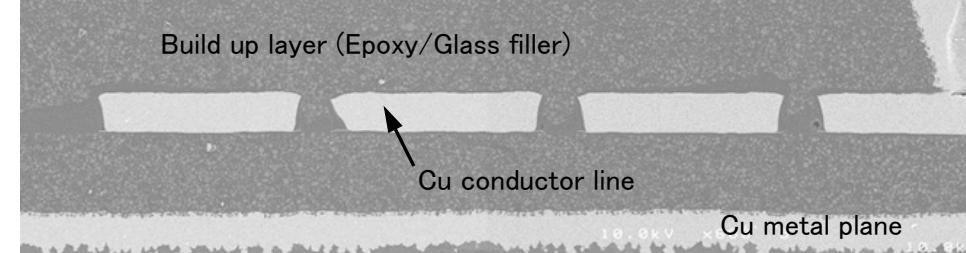
Process-compatible with interposer and inductor

Thermal stress, adhesion to under layer, Via-contact, ...

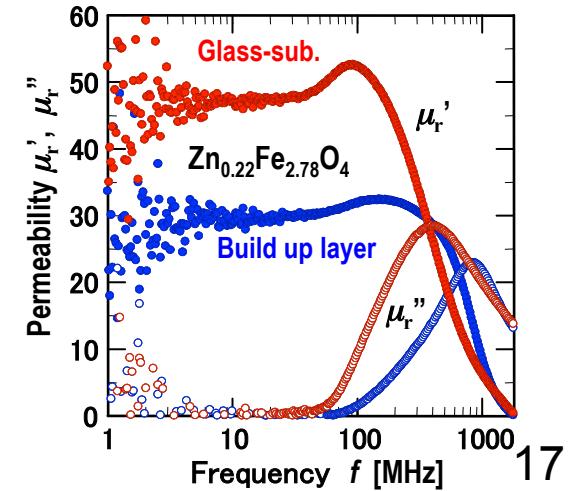
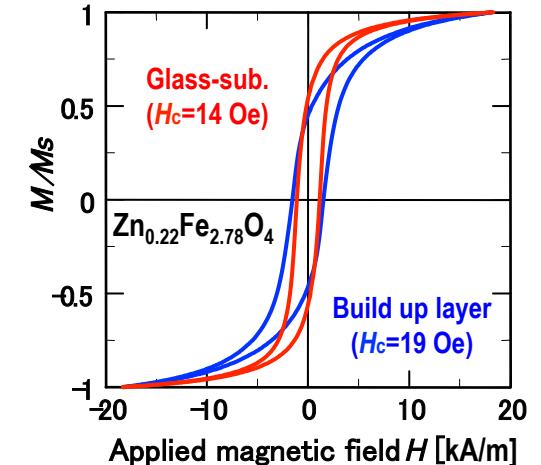
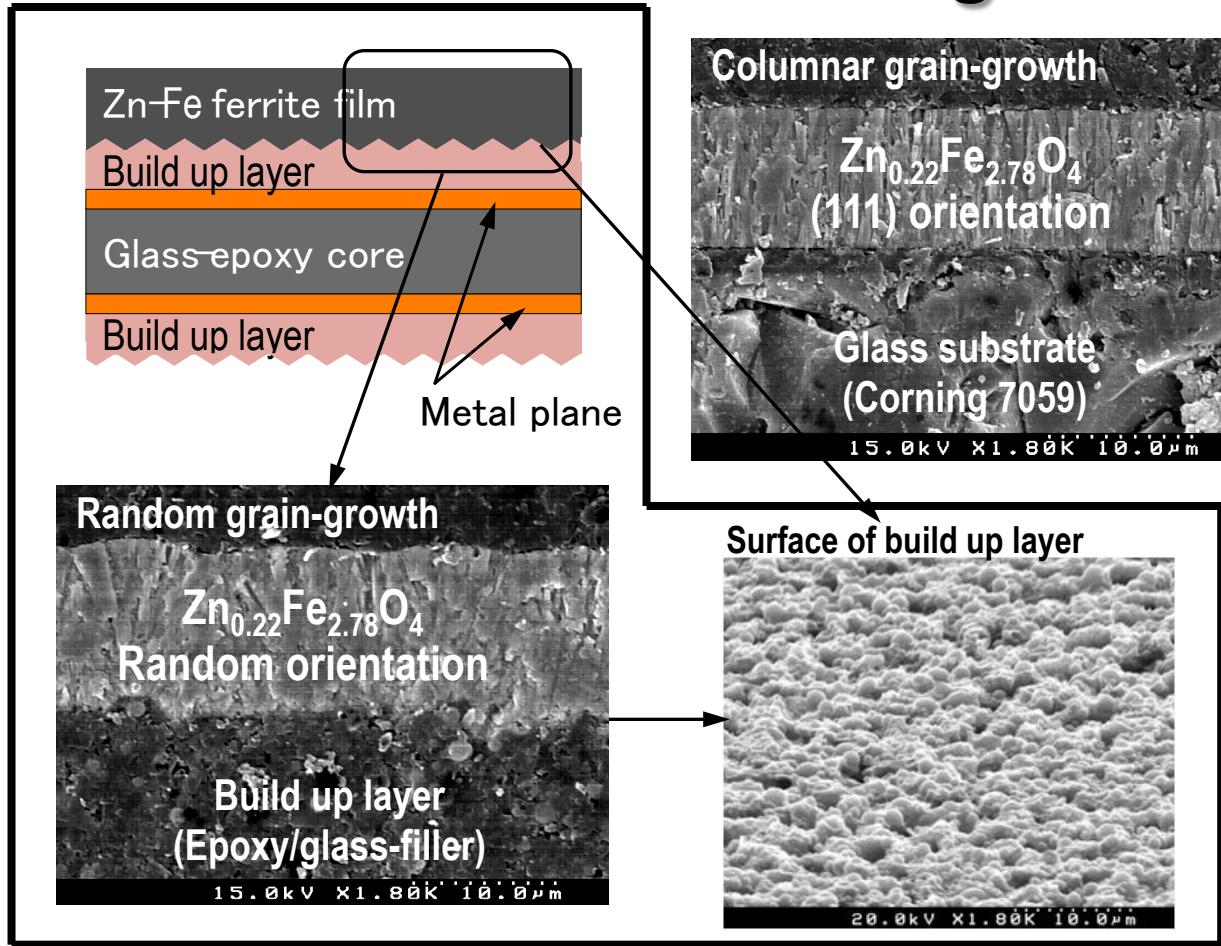
Zn-Fe ferrite core, 2-turn spiral



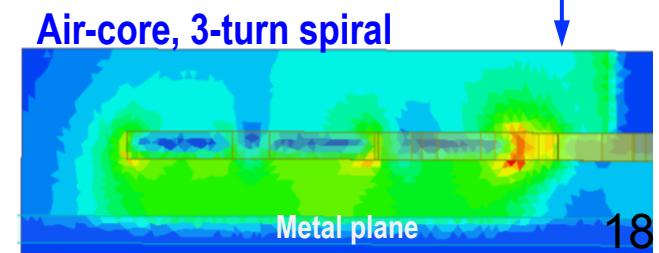
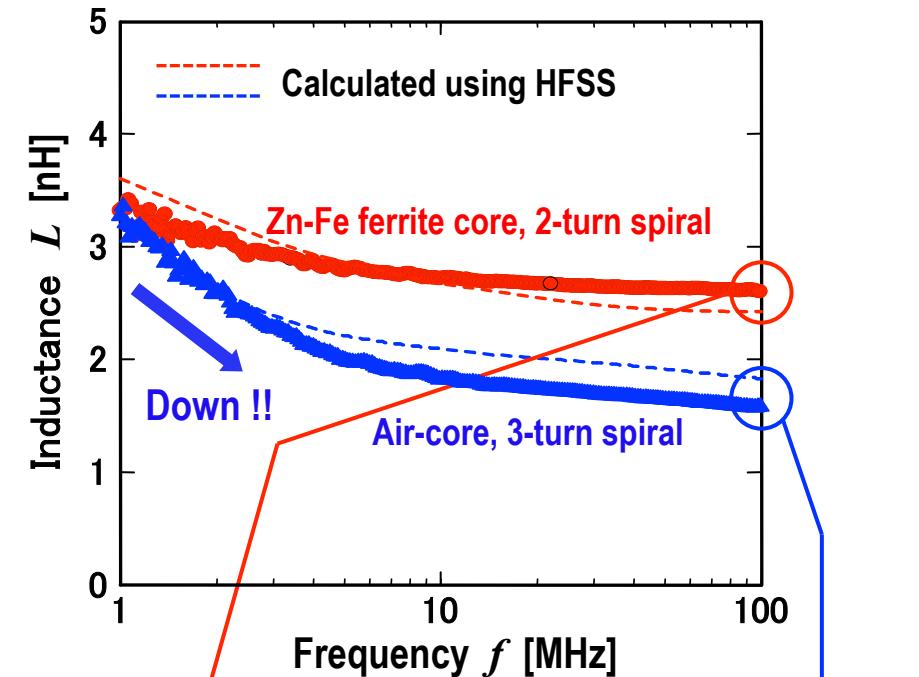
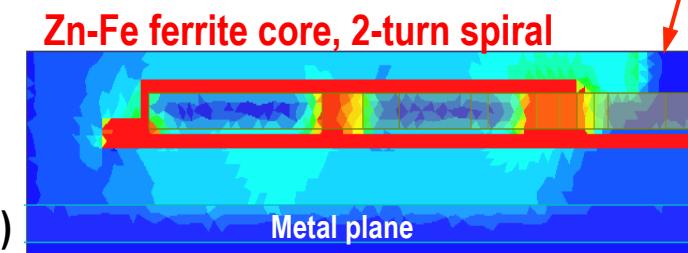
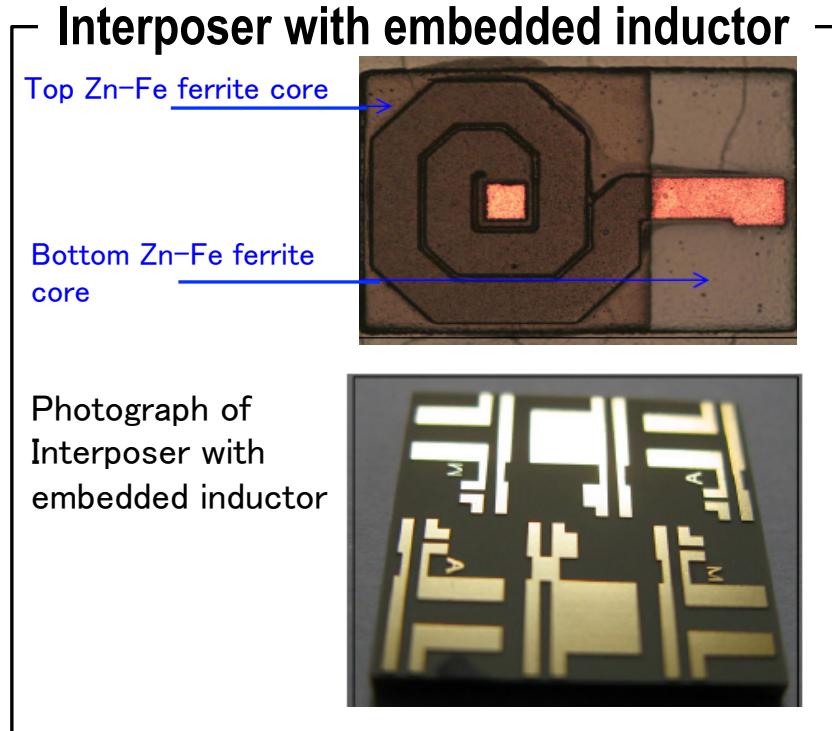
Air-core, 3-turn spiral



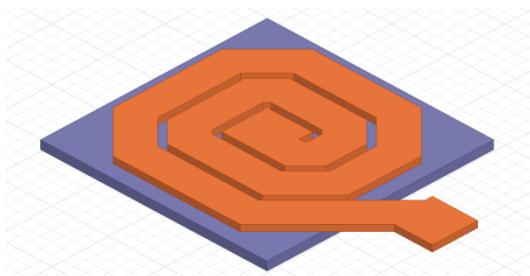
□ First trial of embedded inductor in glass/epoxy interposer



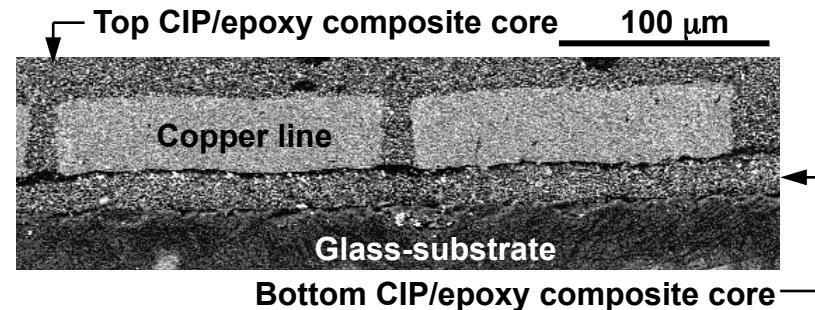
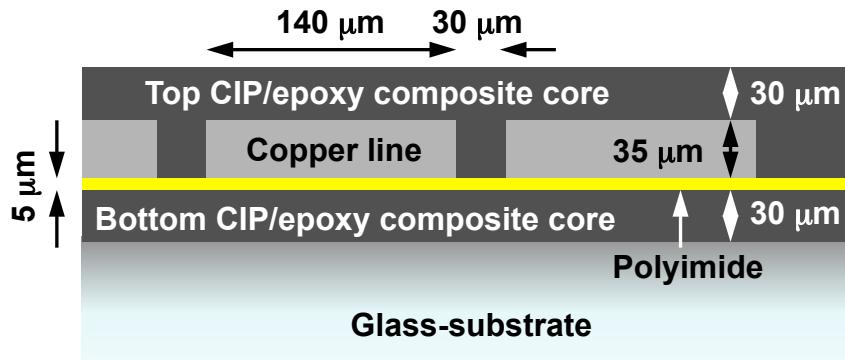
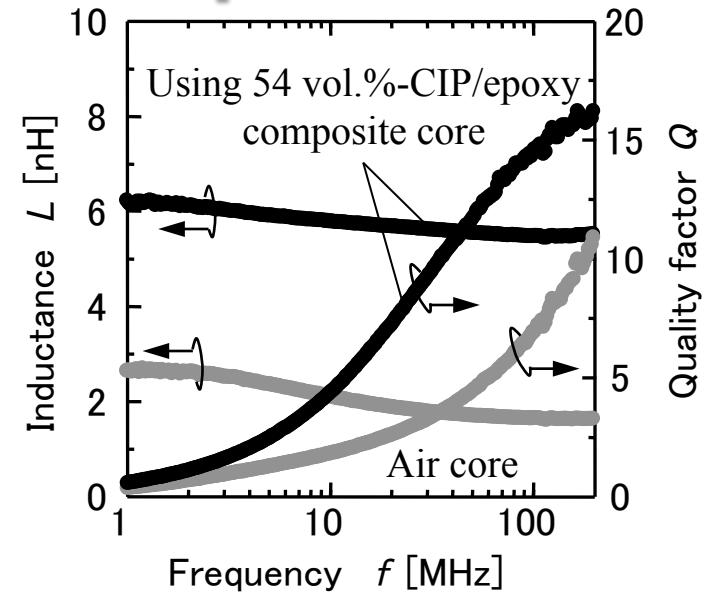
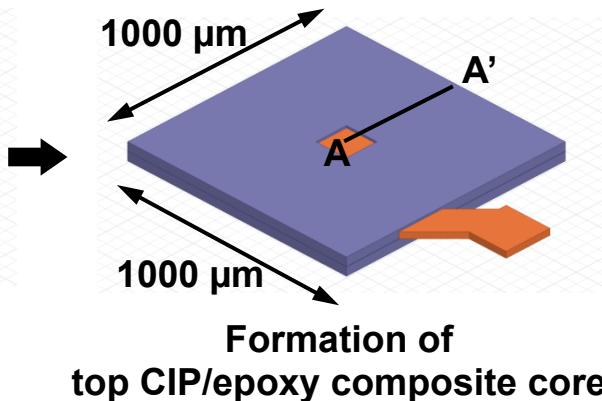
□ First trial of embedded inductor in glass/epoxy interposer



□ First trial of large current inductor using CIP/epoxy composite core



880 μm -square, 2-turn,
35 μm thick copper spiral
coil on bottom CIP/epoxy
composite core



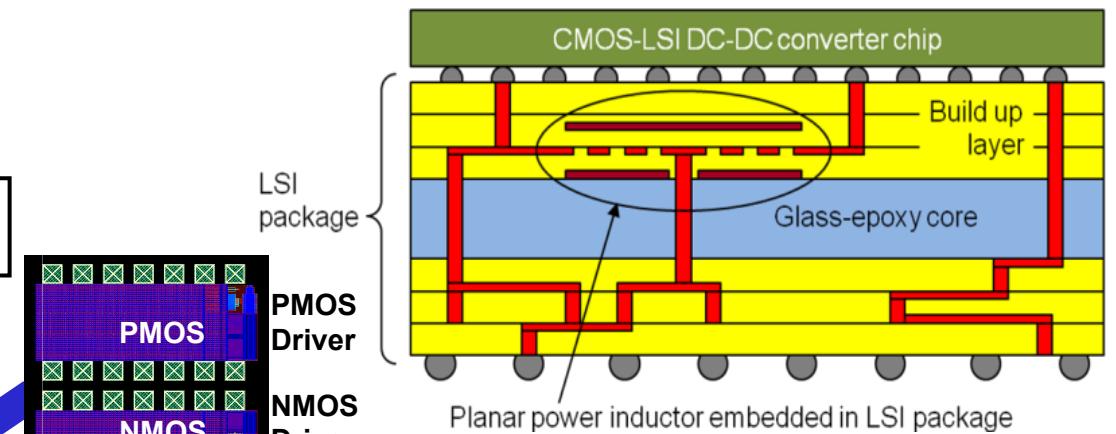
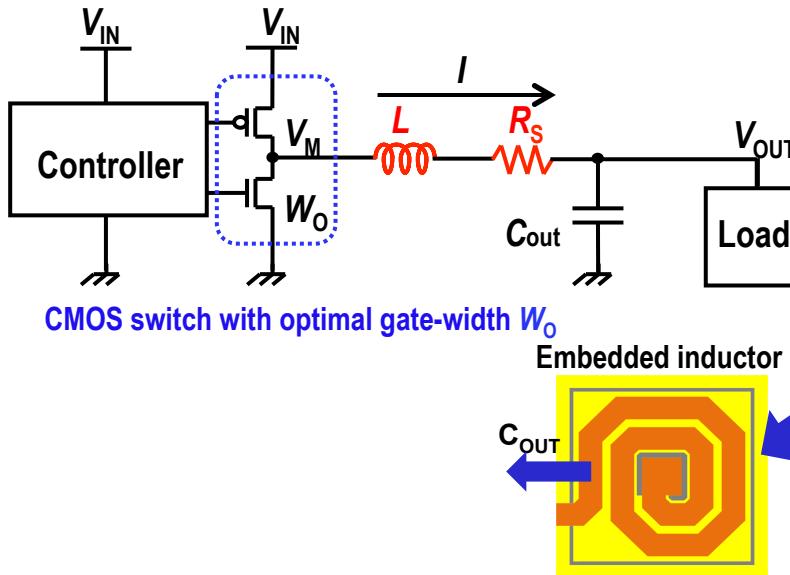
We are currently developing the CMOS-switch dc-dc converter integrated in LSI package !!

Collaborating with

N. Matsushita Lab., Materials and Structures Laboratory, Tokyo Institute of Technology, Yokohama, Japan

R & D Div., SHINKO ELECTRIC INDUSTRIES Co. Ltd., Nagano, Japan

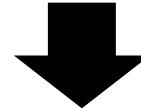
T. Sakurai Lab., Institute of Industrial Science, the University of Tokyo, Tokyo, Japan



□ Conclusion and future work

Magnetic core power inductor for package-level power grid

- Zn-ferrite inductor embedded in glass/epoxy interposer
- Carbonyl-iron/epoxy core for large current inductor on package



Future work

Package-level power grid will be demonstrated.

