Low Temperature Co-fired Heterogeneous Ferrite Planar Inductor for High Density Power Applications

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Outline

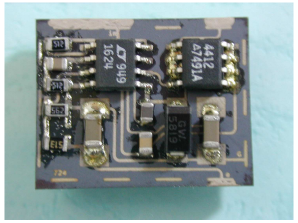
- Introduction
- 2D/3D magnetic simulation of heterogeneous multilayer power inductors
- Process, components and modules
- Summary

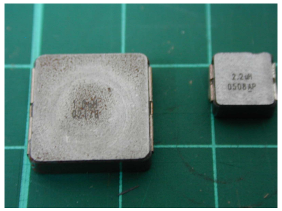
Magnetic laboratory in ITRI

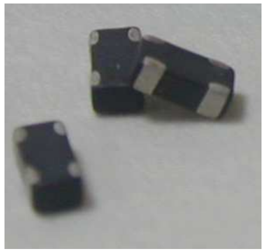
Since 1984

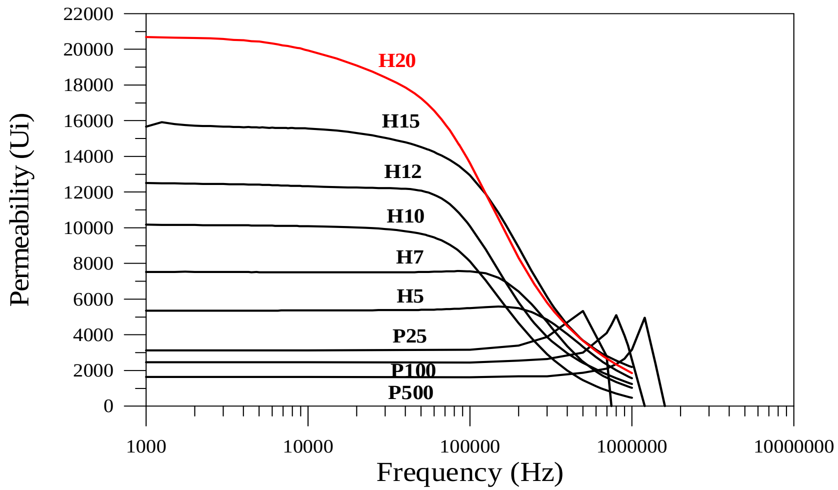
Focus on soft/hard magnetic materials and components for power and EMI applications

More than 60 case of technology transferred to Taiwan local industries for mass production

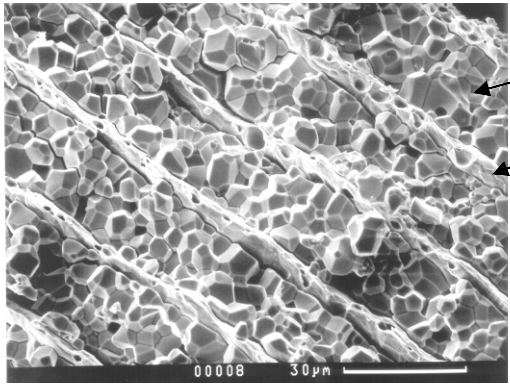








ITRI's Co-fire ceramics

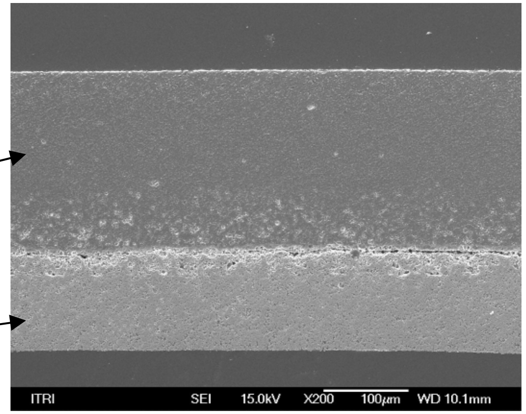


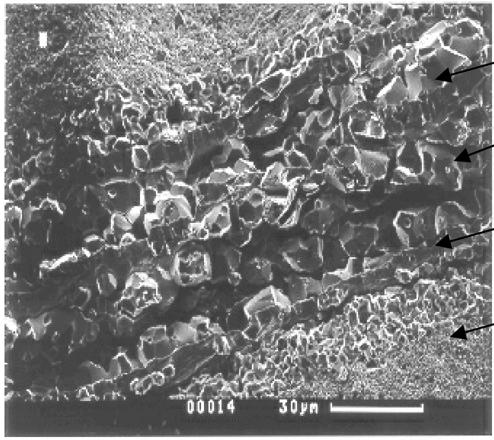
$BaTiO_3$

Ag electrode

LTCC

Ferrite





Relaxer dielectric material

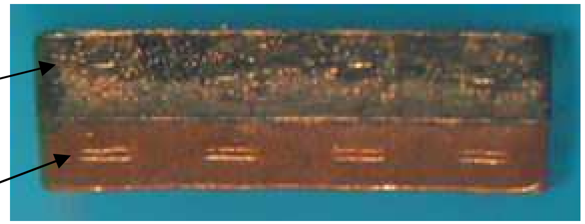
Ag electrode

Relaxer dielectric material

Ferrite

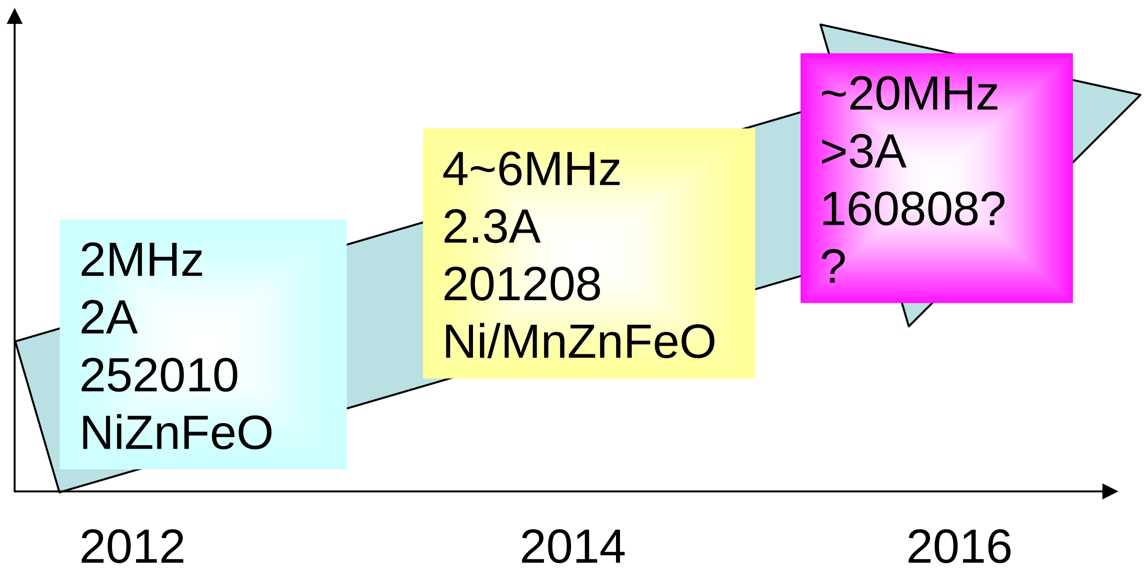
MgFeO dielectric

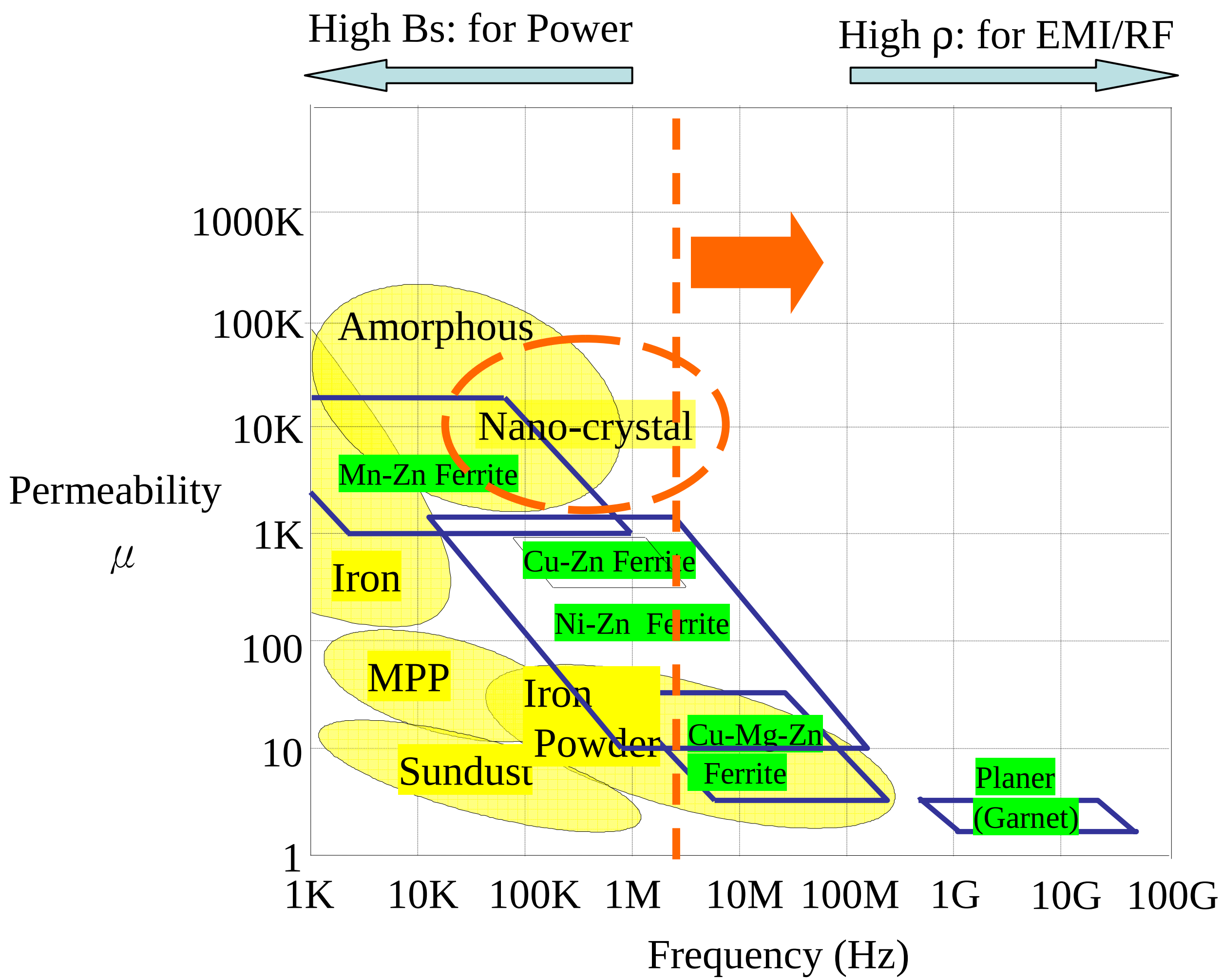
Ferrite



Trend of power inductor for mobile devices

- The development of power inductors toward high frequency and high current density. While approaching the limitation of material properties
- Integration of materials, winding, active/passive components and circuit will improve both the working frequency and power density.
- Low temperature co-fire ferrite may provide a reasonable solution mobile devices



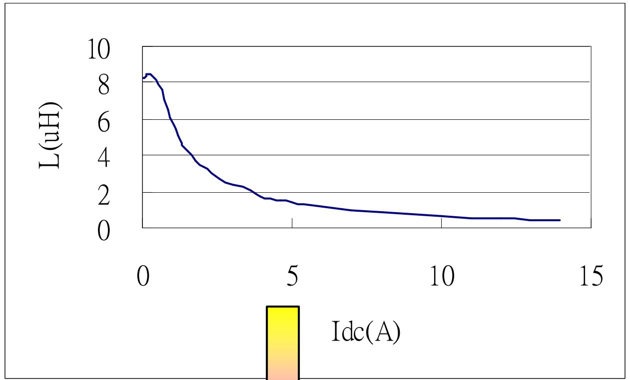

High Bs: for Power
High ρ: for EMI/RF
1000K
100K
10K
1K
100
10
1
Permeability
μ
Amorphous
Nano-crystal
Mn-Zn Ferrite
Iron
Cu-Zn Ferrite
Ni-Zn Ferrite
MPP
Iron Powder
Sundust
Cu-Mg-Zn Ferrite
Planer (Garnet)
1K
10K
100K
1M
10M
100M
1G
10G
100G
Frequency (Hz)

2D/3D simulation of ML power inductors

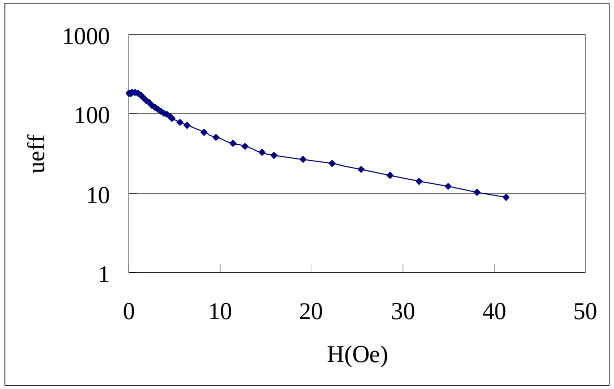
Database of non-linear BH curve of ferrites

Model of multilayer power inductors for magnetic circuit analysis

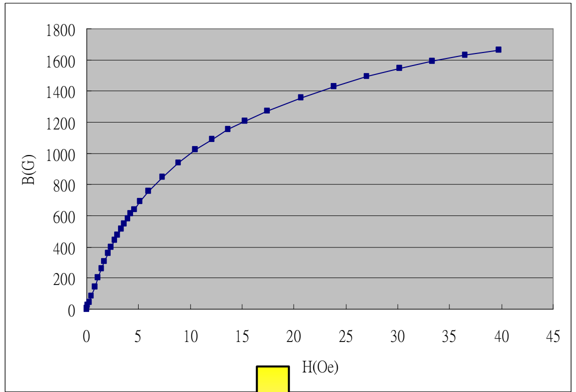
Measurement of L-Idc

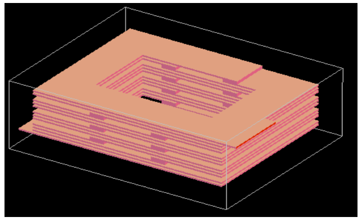


μ-f/μ-H/ μ-T…



Non-linear B-H response

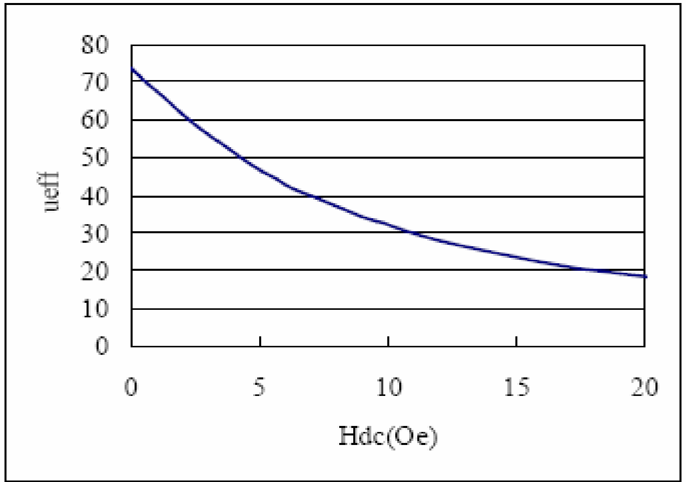


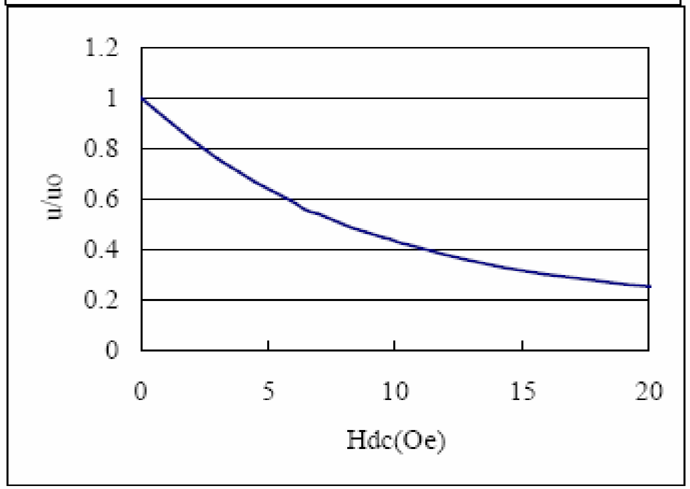


Use the material properties for the simulation will improve the accuracy of results

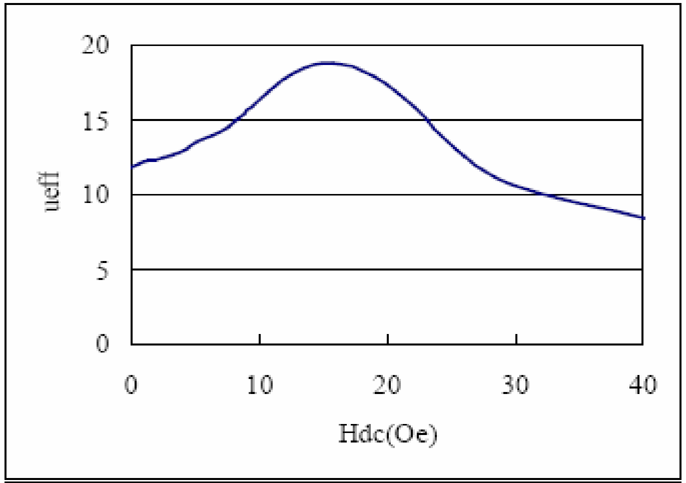
μ-H properties:

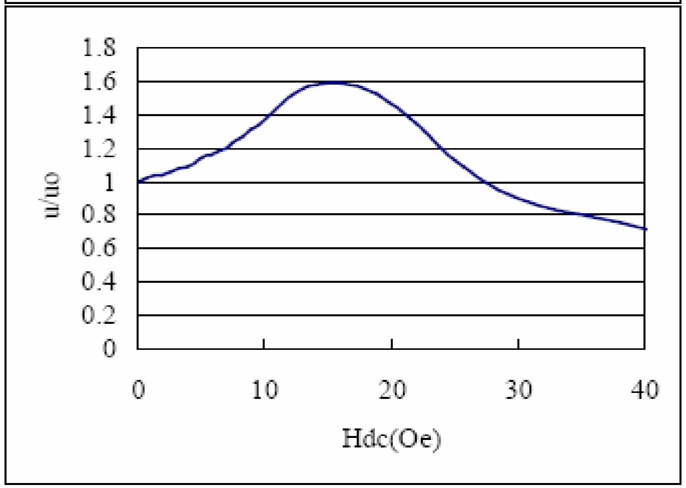
TR12





TR021



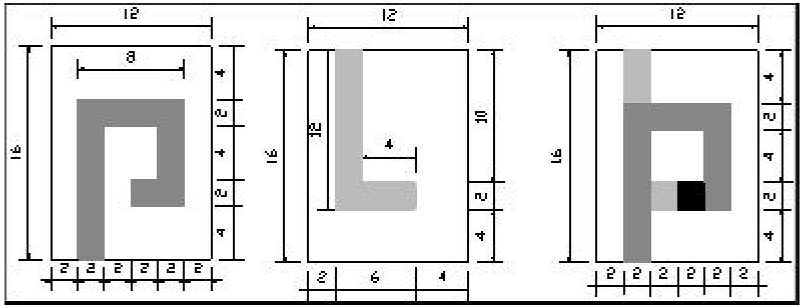


ui~120, Bs≧3700 Gauss

ui~20, Bs值≧2000 Gauss

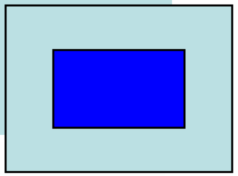
2D simulation

Chip size: 2.3x1.85x0.8mm
Coil pattern:1.2x0.75mm
N=2~9 - ¾ turn/layer
Line width:0.4mm
Line thickness:30um
Ferrite Thickness:20um

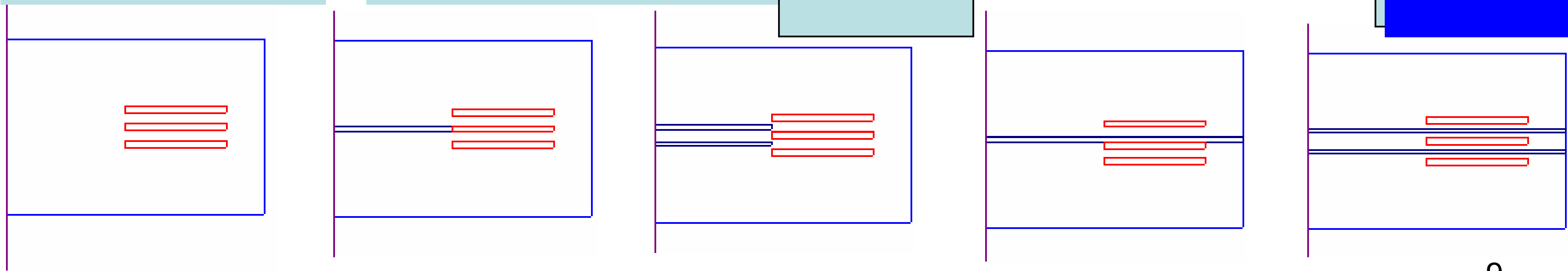


Without insertion layer
- pure TR12
- pure TR021

TR12 + TR021 insert layer
Insert in center area
- Single layer
- Two layer

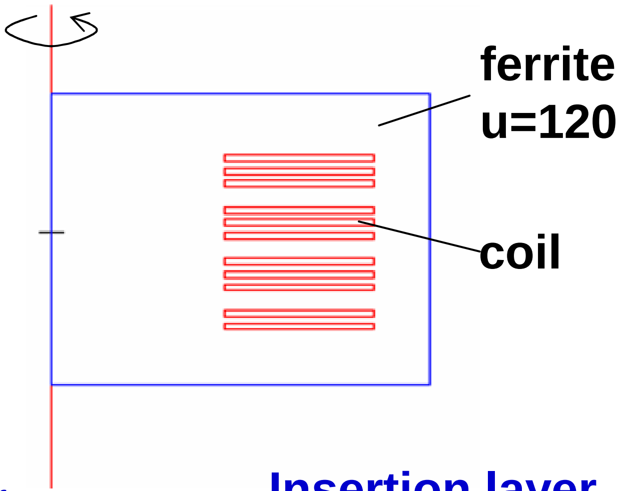


TR12 + TR021 insert layer
Insert a full layer
- Single layer
- Two layer

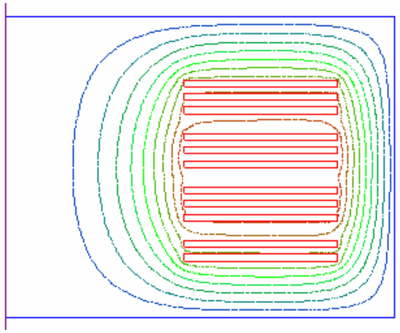


2D model

$$U = \frac{1}{2}LI^2 = \frac{1}{2}\int H \bullet B \, d\Omega$$

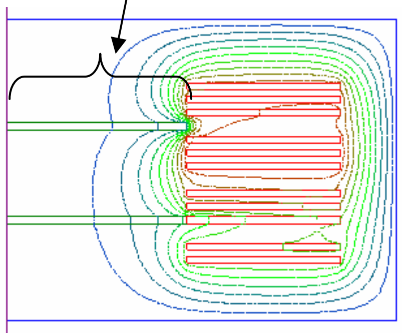


Pure TR12



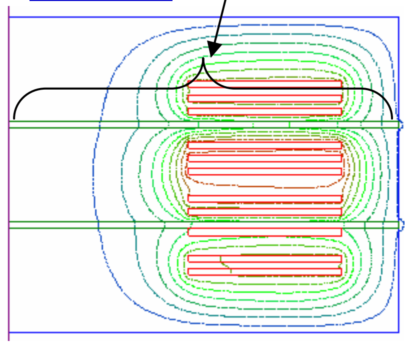
• L=10.7uH

Insertion layer (u=20)



•L=4.9uH

Insertion layer (u=20)

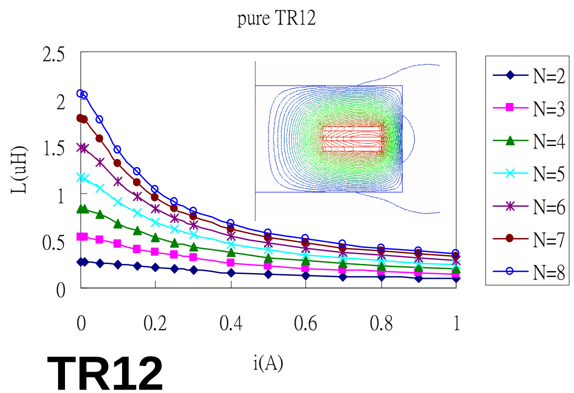


•L=3.05uH

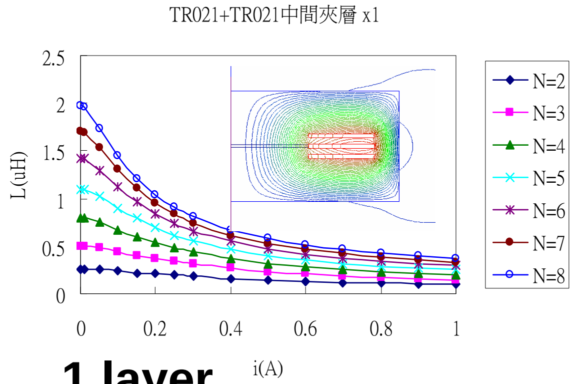
2D results – L vs I

Without insertion layer

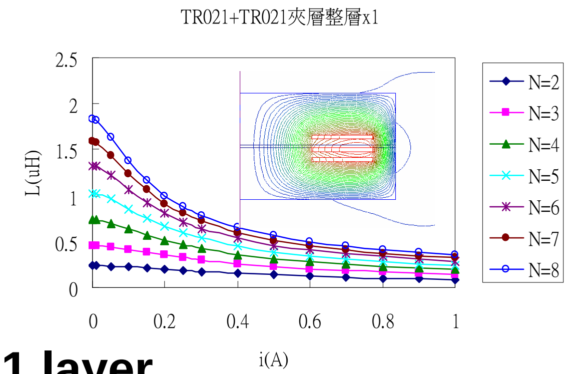
TR12 + TR021 insertion layer



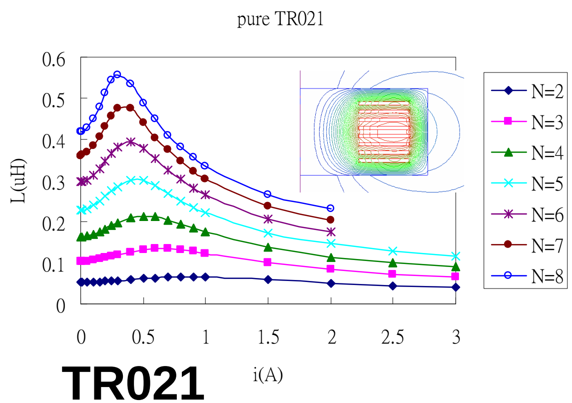
TR12



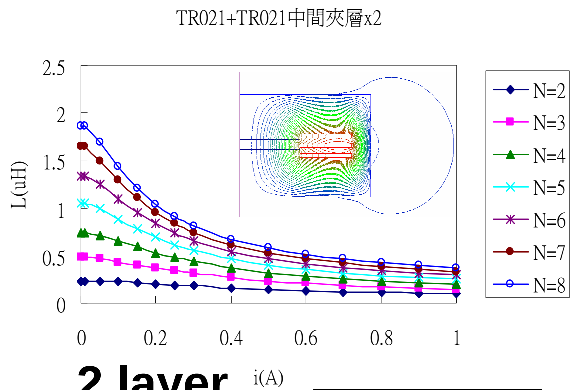
1 layer



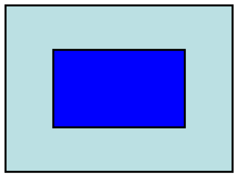
1 layer

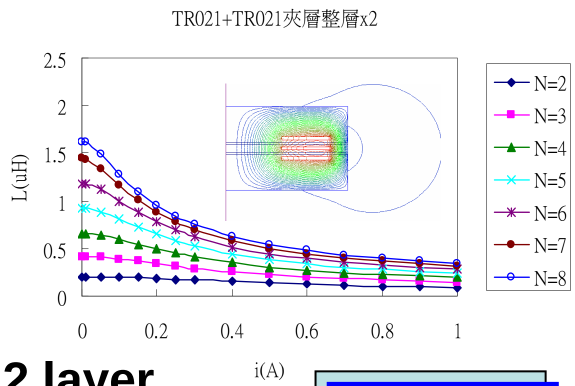


TR021



2 layer



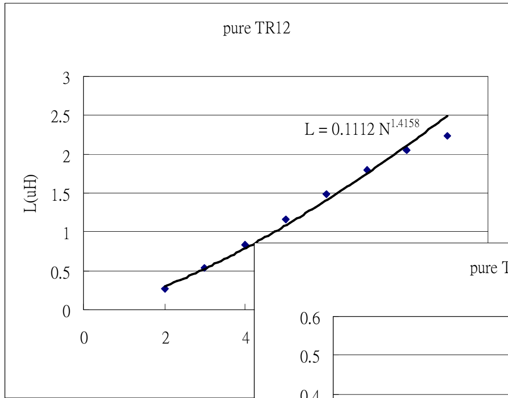


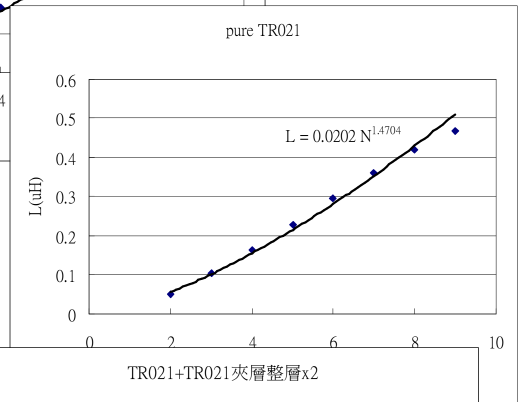
2 layer

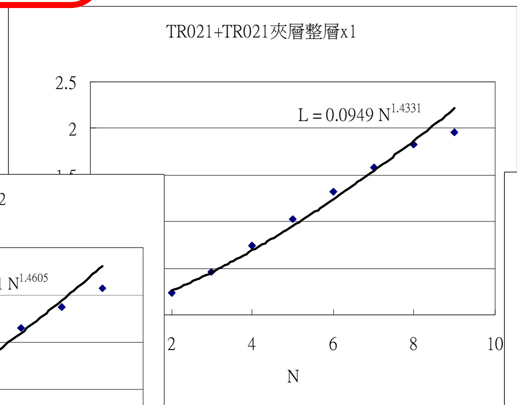
■Equation of inductance $L=L_0N^x$

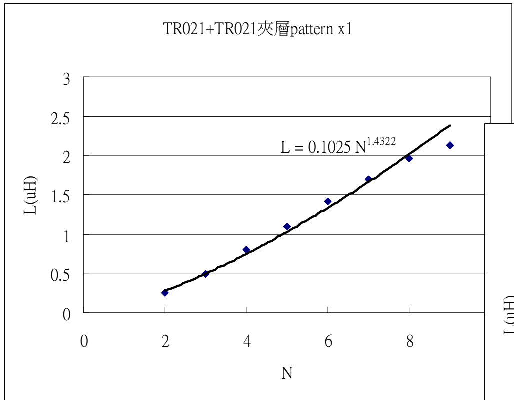
- x=2 for Idea case
- x=1.41~1.47 for multilayer inductor

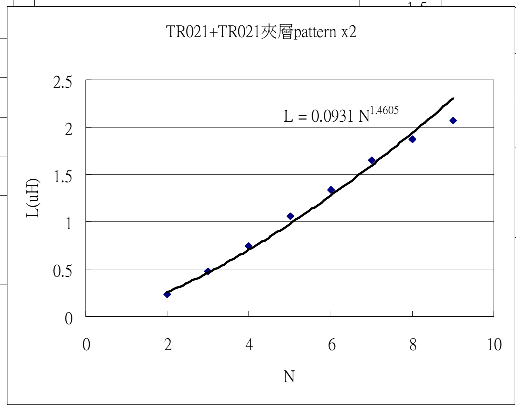
	L_O(uH)	x
pure TR12	0.1112	1.4158
pure TR021	0.0202	1.4704
TR12 + TR021 IL_p x1	0.1025	1.4322
TR12 + TR021 IL_p x2	0.0931	1.4605
TR12 + TR021 IL_f x1	0.0949	1.4331
TR12 + TR021 IL_f x2	0.0823	1.4523

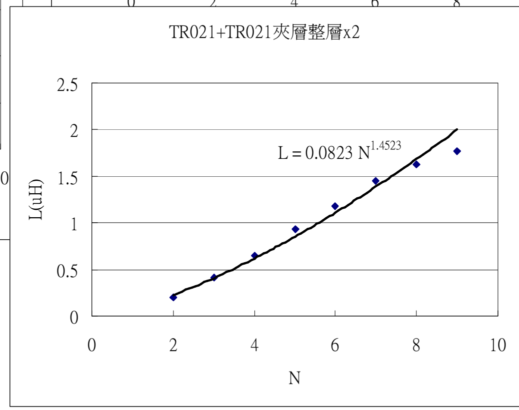








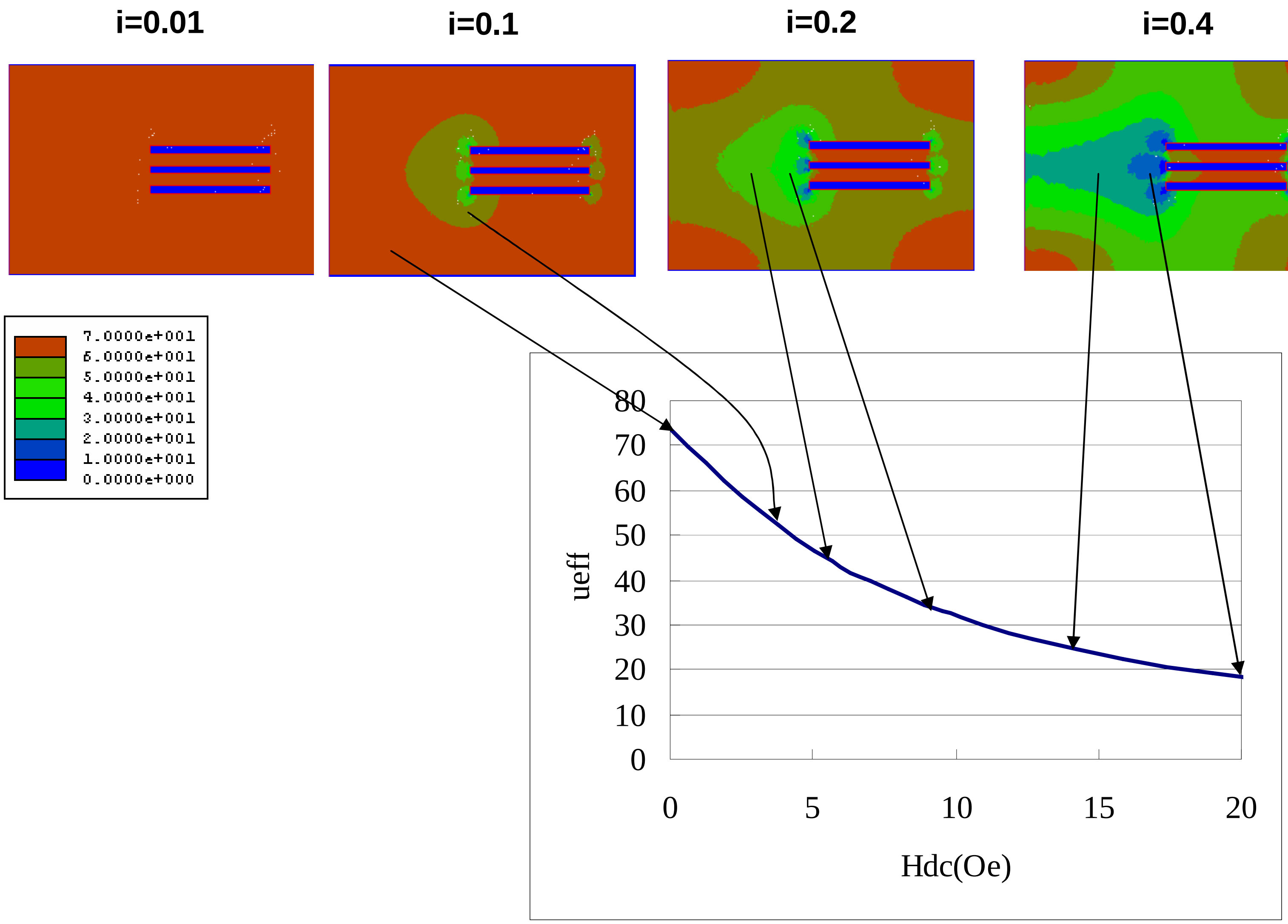




ITRI Industrial Technology Research Institute

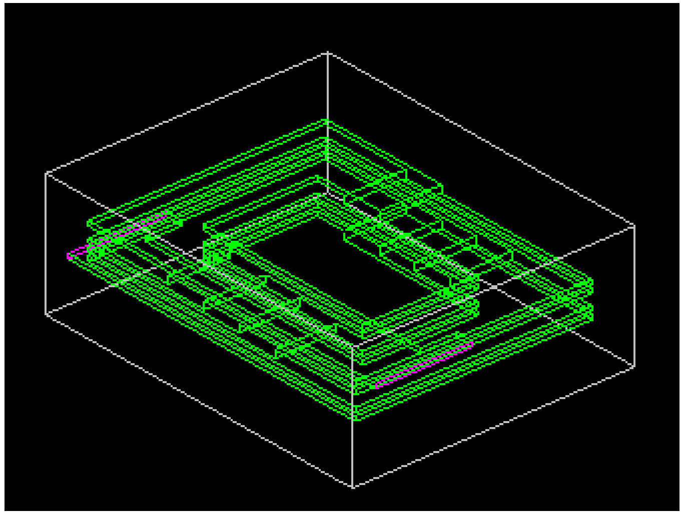
2D simulation (pure TR12)

Analysis of saturation and μ



3D simulation

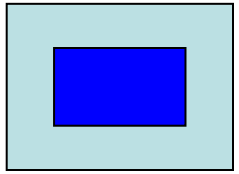
Chip size:2.3x1.85x0.8mm
coil pattern1.2x0.75mm
3.5 and 4.5 turns
Line width:0.4mm
Line thickness:30um
Ferrite thickness:20um
Use 3D axis symmetry model



Layers: same as 2D

Without insertion layer
- **pure TR12**
- **pure TR021**

TR12 + TR021 insert layer
Insert in center area
- **Single layer**
- **Two layer**



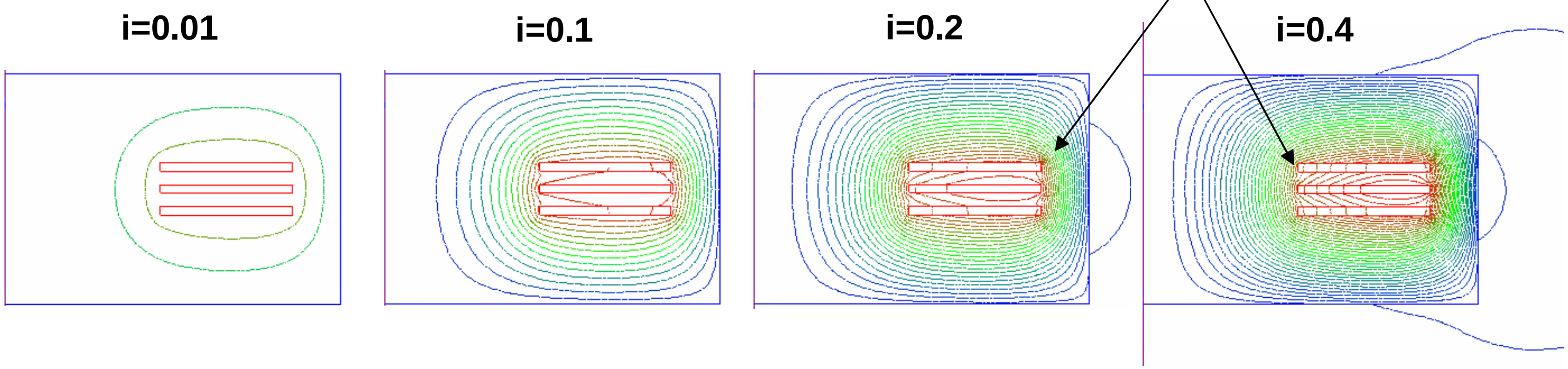
TR12 + TR021 insert layer
Insert a full layer
- **Single layer**
- **Two layer**

Flux distribution - 2D/3D simulation (pure TR12)

2D simulation

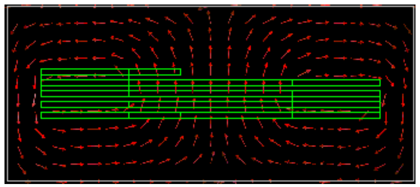
(N=3)

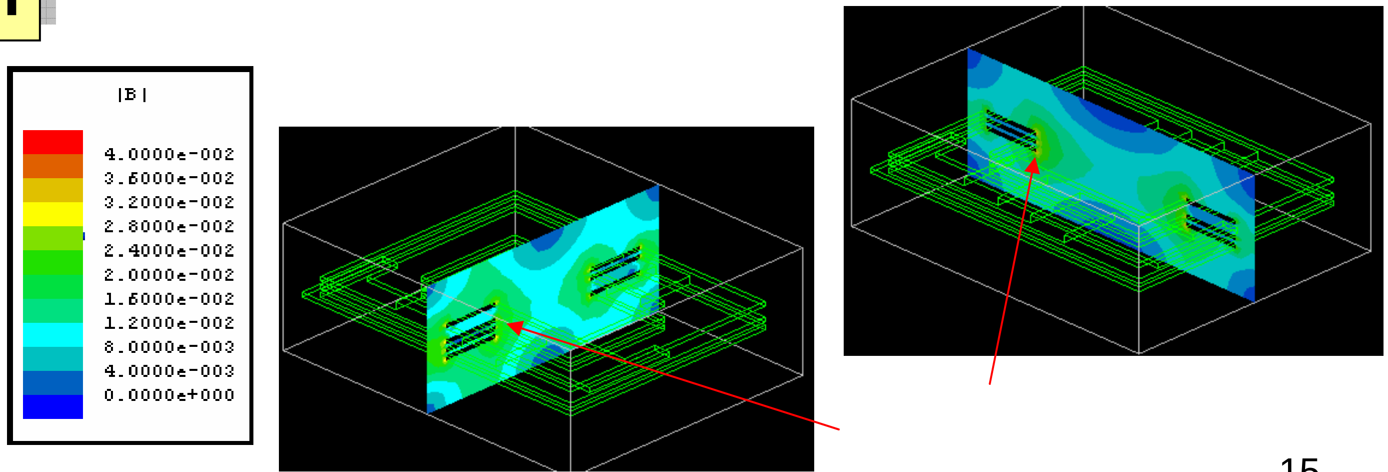
High flux density



3D simulation

(N=3, i=0.1)





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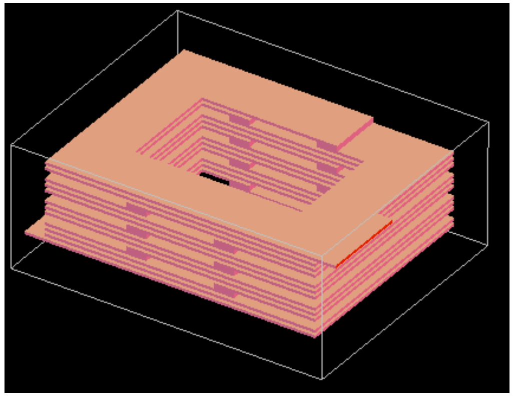
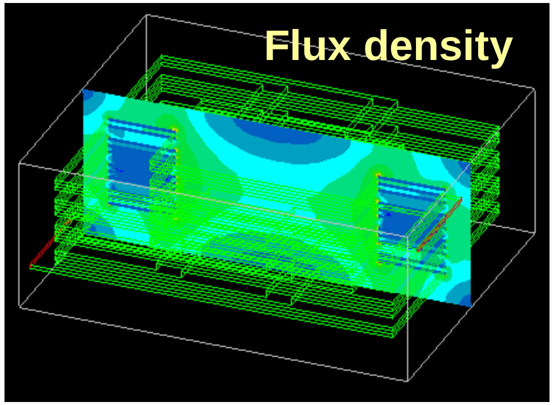
Summary of Simulation

3D model

- Real size 3D magnetic model
- Good inductance results from integration of flux and magnetic energy



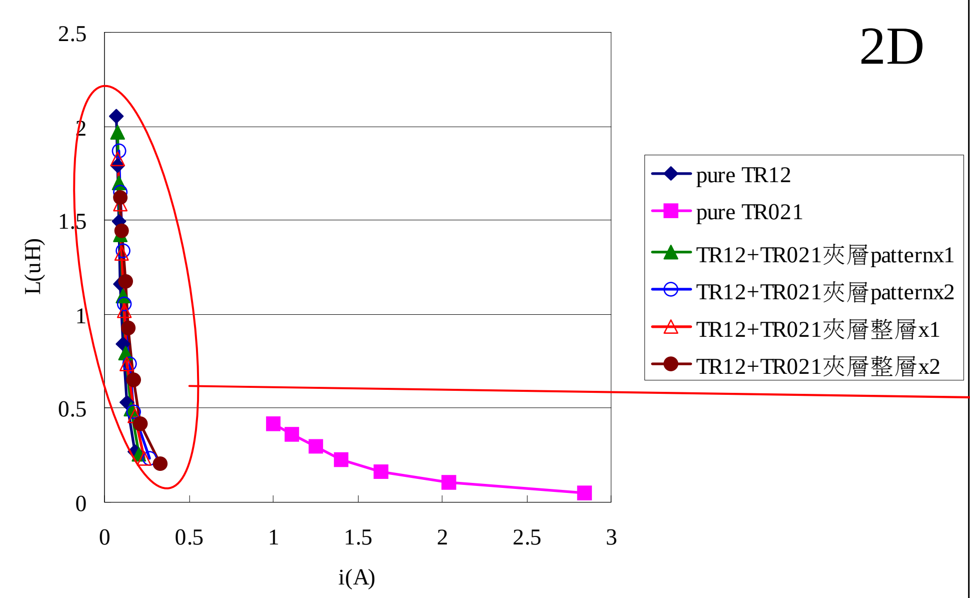
Simulation results

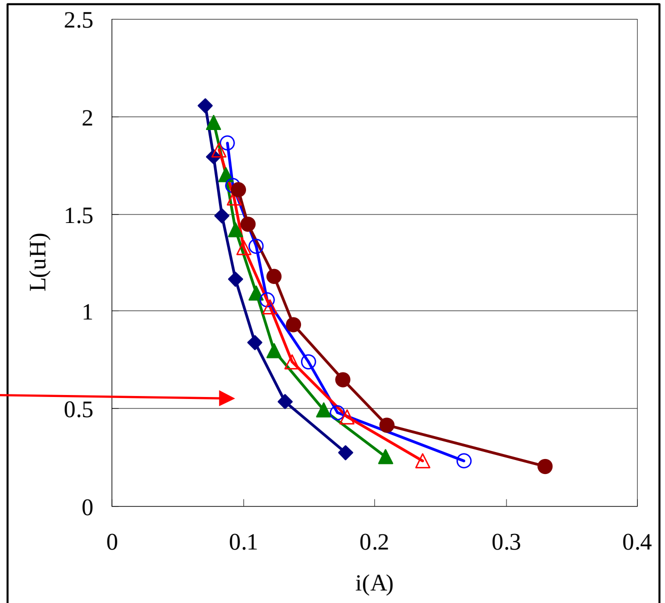


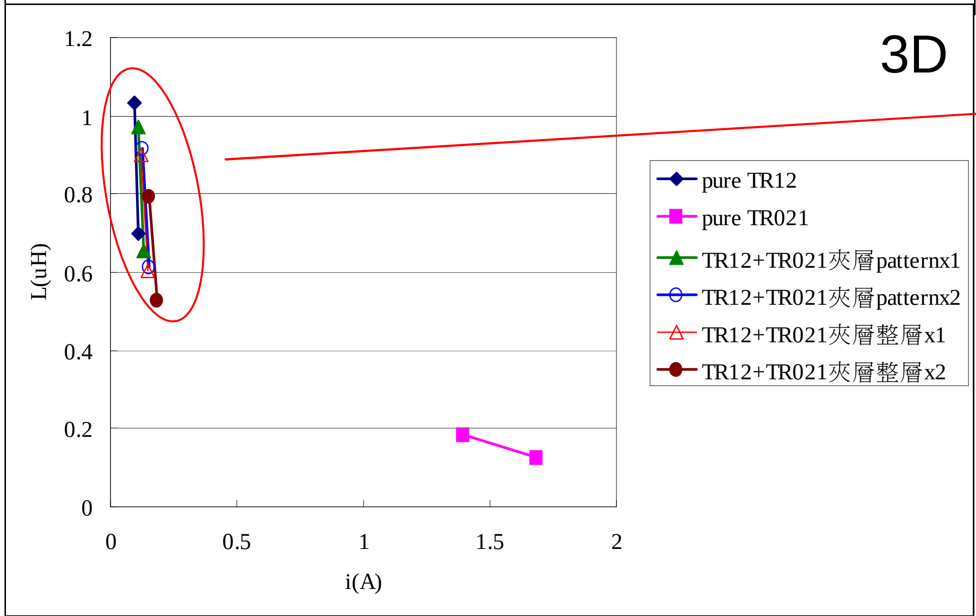
Multilayer model	2D	3D
Pure	10.7uH	11.3uH
2-layer insertion layer-full	3.05uH	3.1uH
2-layer insertion layer-partially	4.9uH	4.8uH

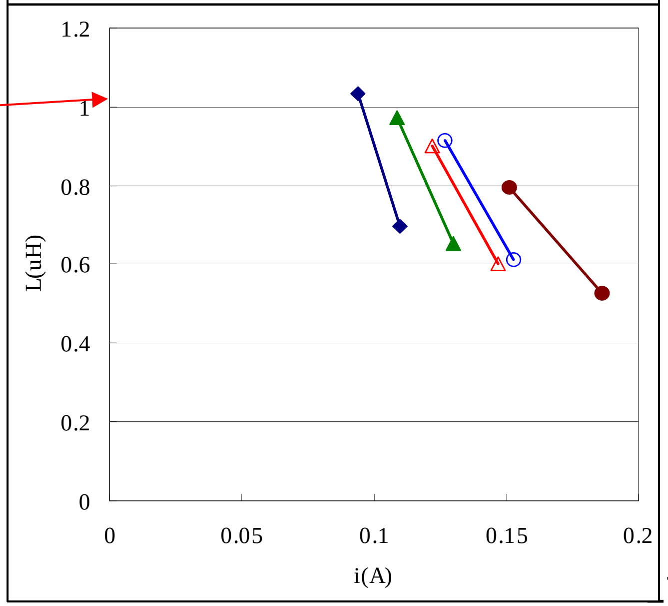
Measurement - L=4.3uH, deviation ~ 10%

Inductance vs. current from 2D/3D

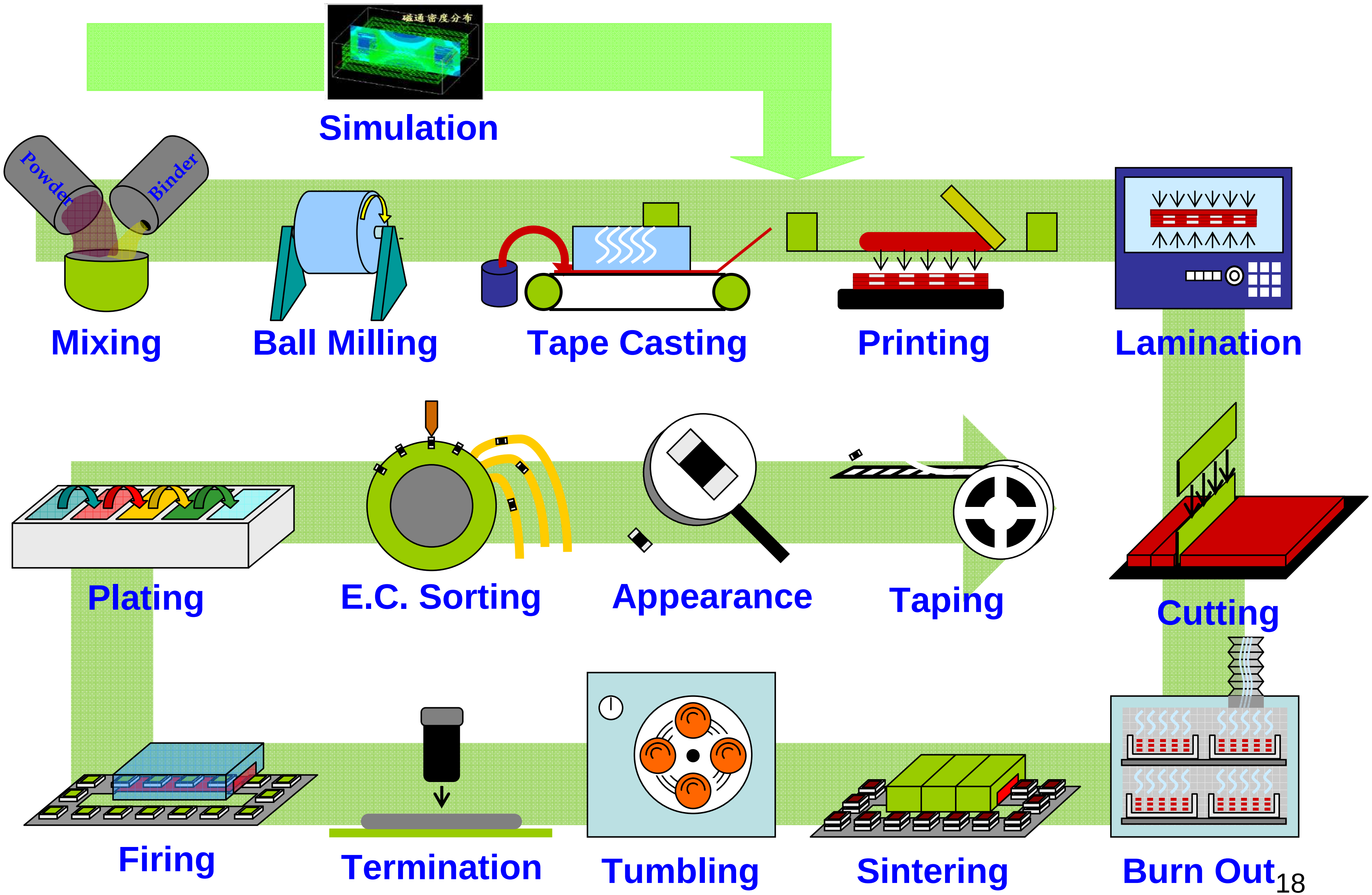








Process of Multilayer inductor

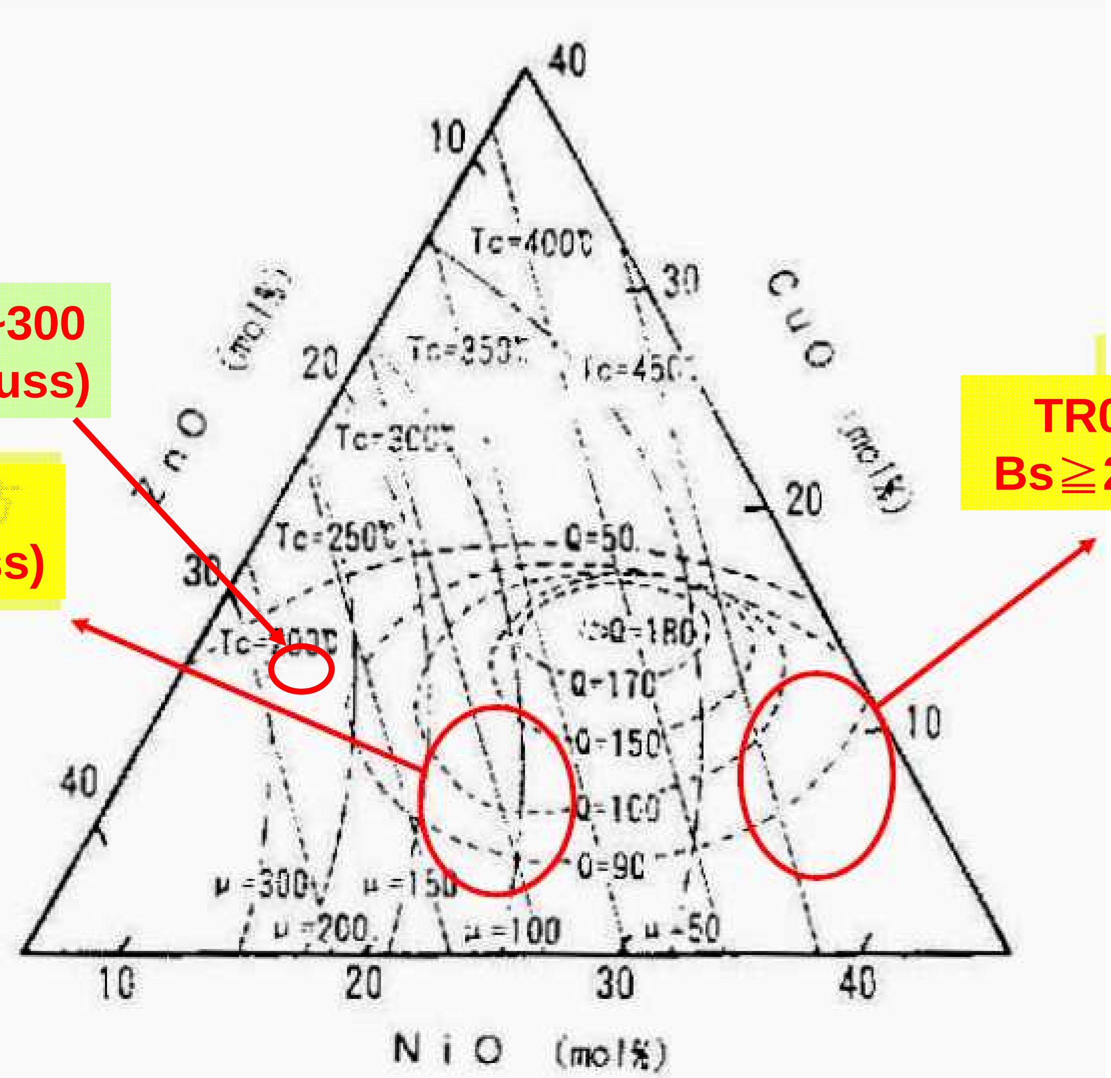


$(Fe_2O_3=48mole\%)$

New TR30(ui~300
Bs≧4200 Gauss)

TR12 (ui~120
Bs≧3700 Gauss)

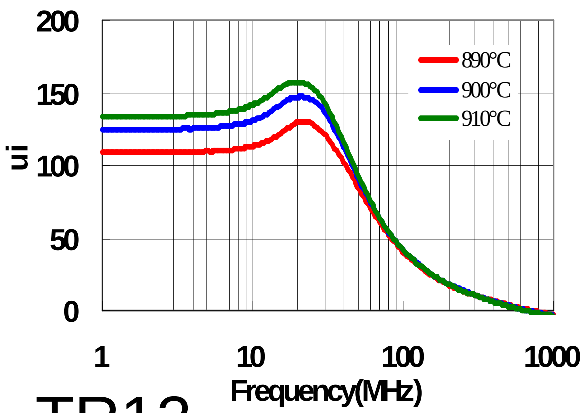
TR021 (ui~20
Bs≧2000 Gauss)

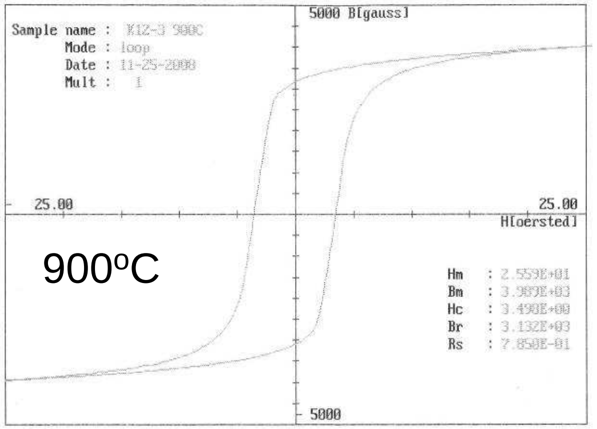


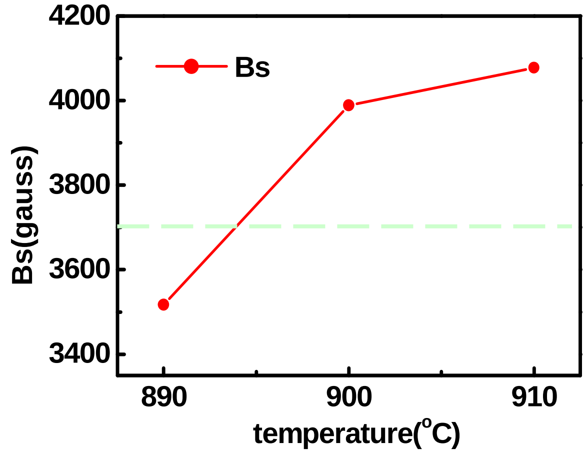
Permeability (ui)

B-H Curve

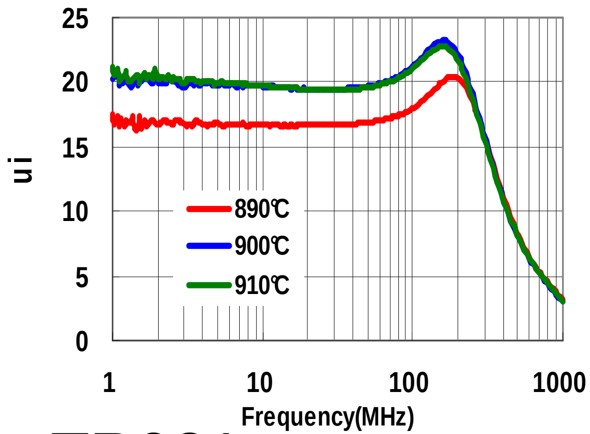
Flux density(Bs)

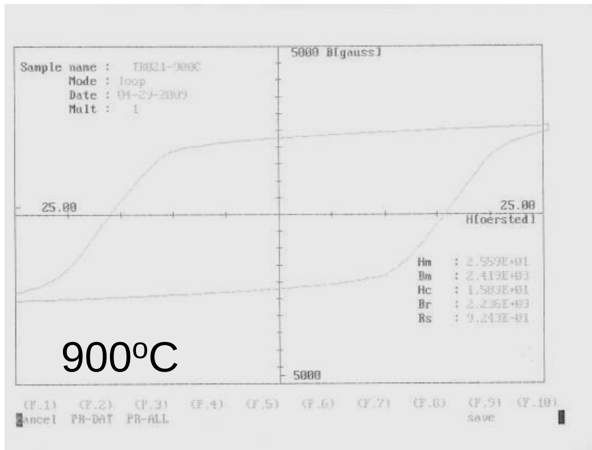


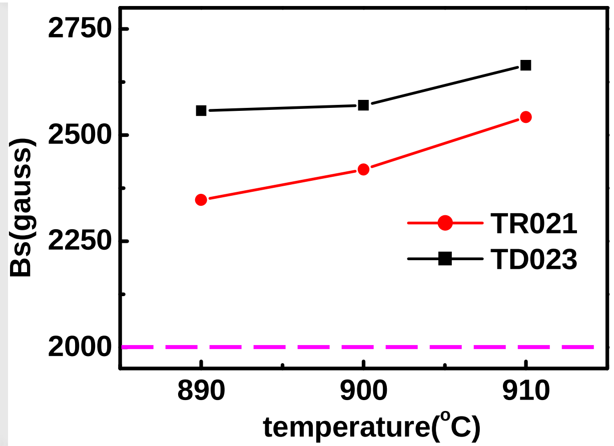




TR12



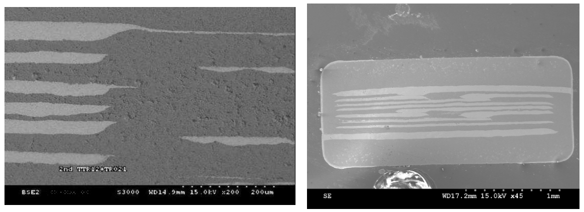


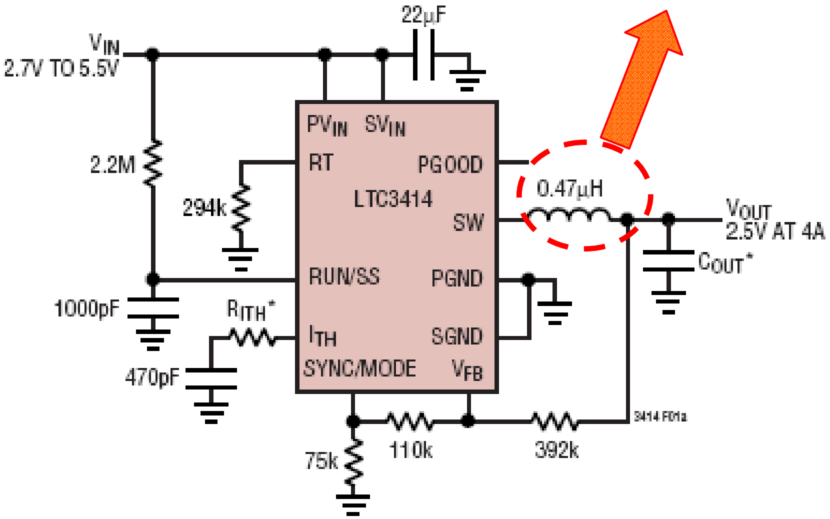


TR021

Results of multilayer power inductor and DC to DC converter

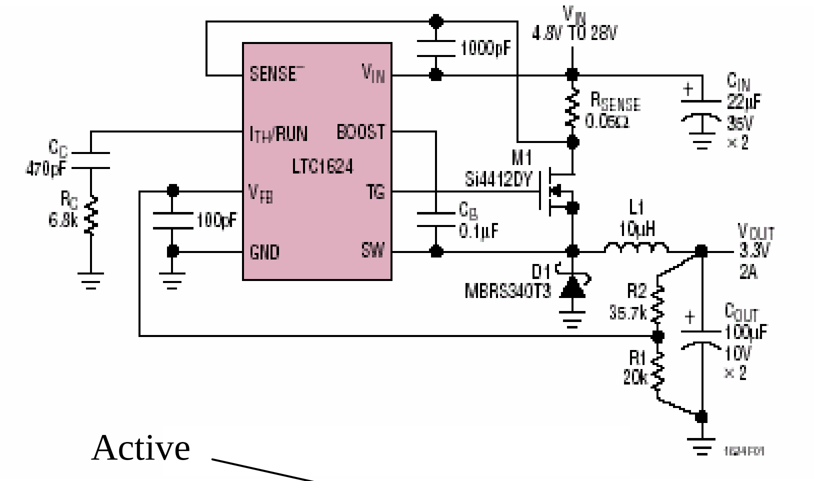
Type	L(μH)	Rated current (A)	f max(MHz)	DCR (mΩ)	L x W xT (mm)
Multilayer	0.47	1.8~2.4	6	59.2	2.5 x 2.0 x 0.9

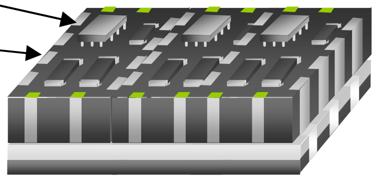


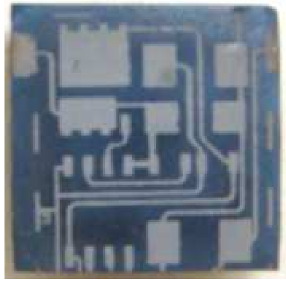


- Vin:2.7~5.5V
- Vout:2.5V
- Iout:≧1.8A
- Eff.≧85%
- fs=~4MHz

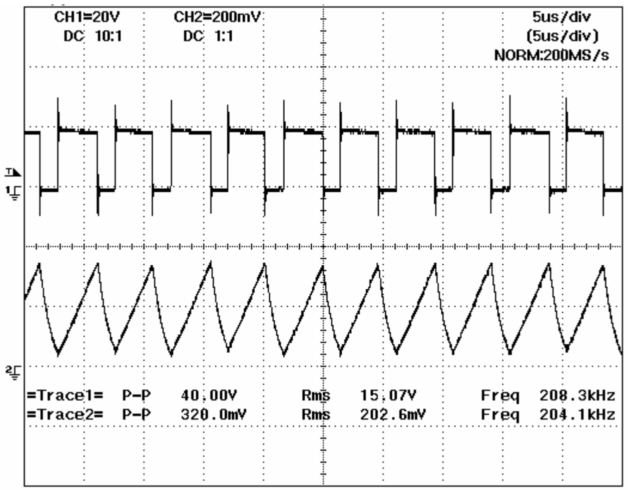
Integrated Multilayer Power Converter

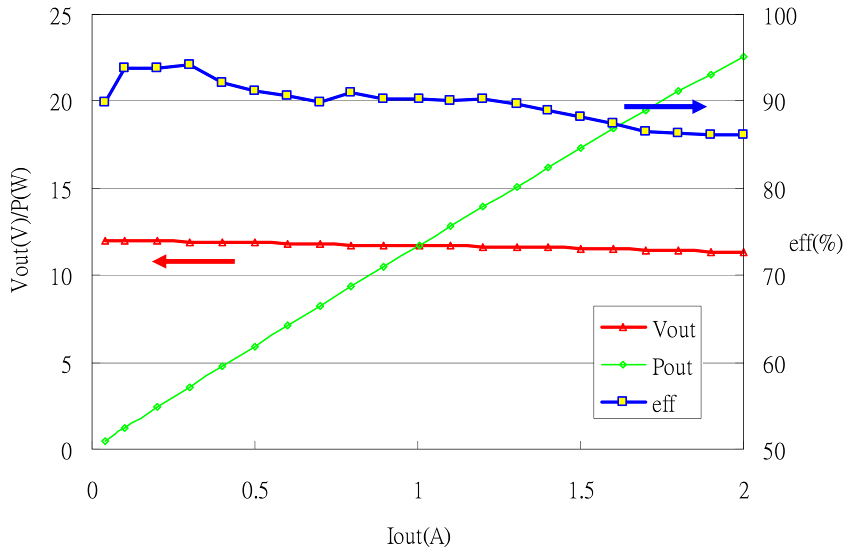






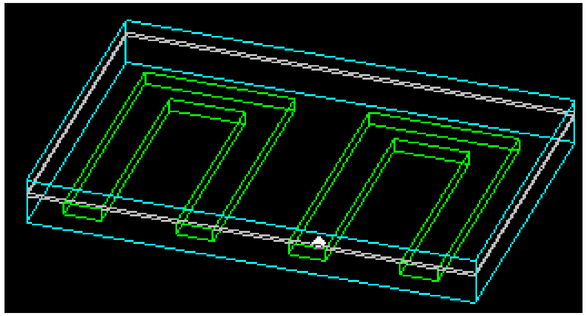
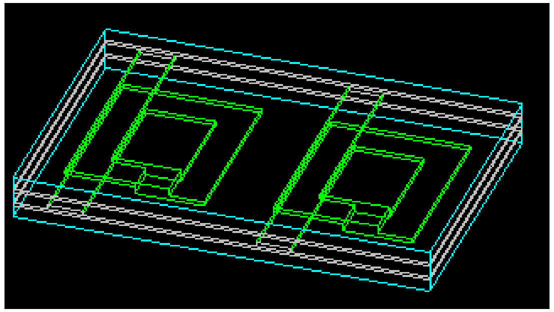
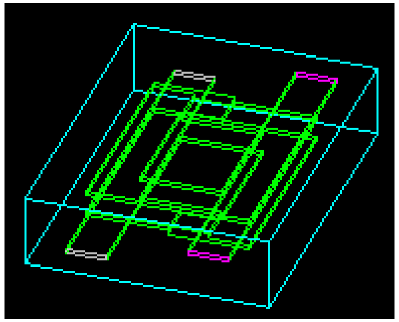
Pout (W)	~20
Efficiency (%)	>80
Power density (W/in3)	>200
Frequency (MHz)	0.2
Vin (V)	24
Vout (V)	12
Iout (A)	2
Size (mm)	15*15*6

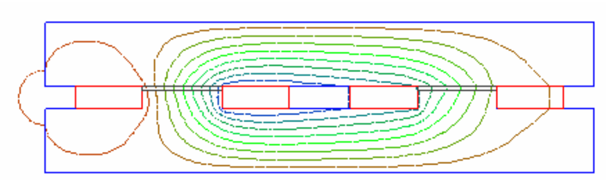
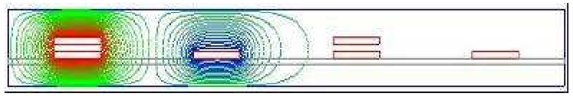
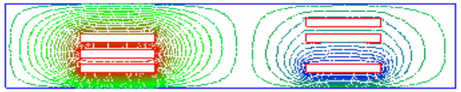




2D/3D model of multilayer Coupled Inductor

conventional wire-wound type	multilayer type lateral coupling	multilayer type vertical coupling

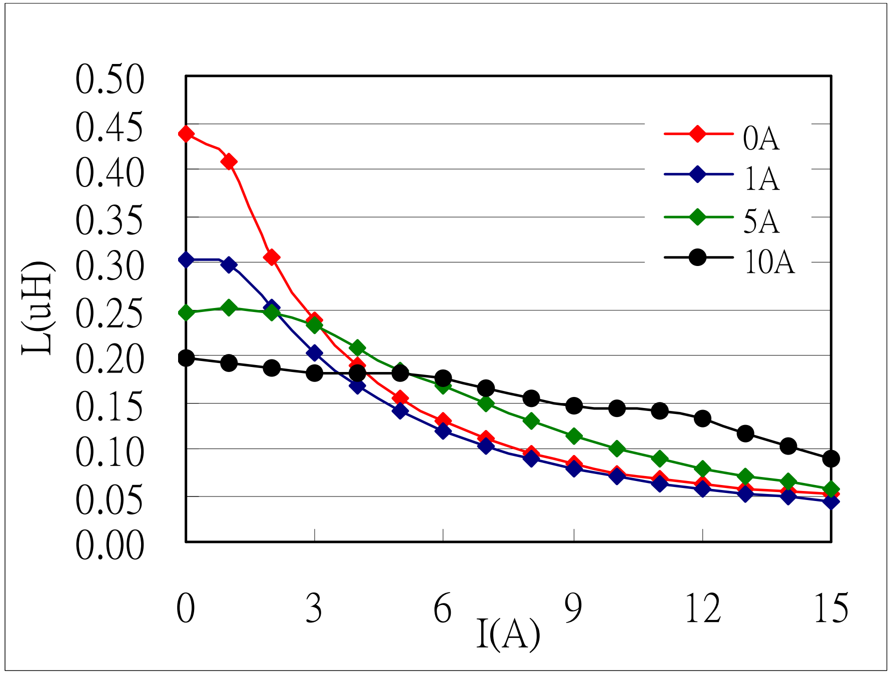




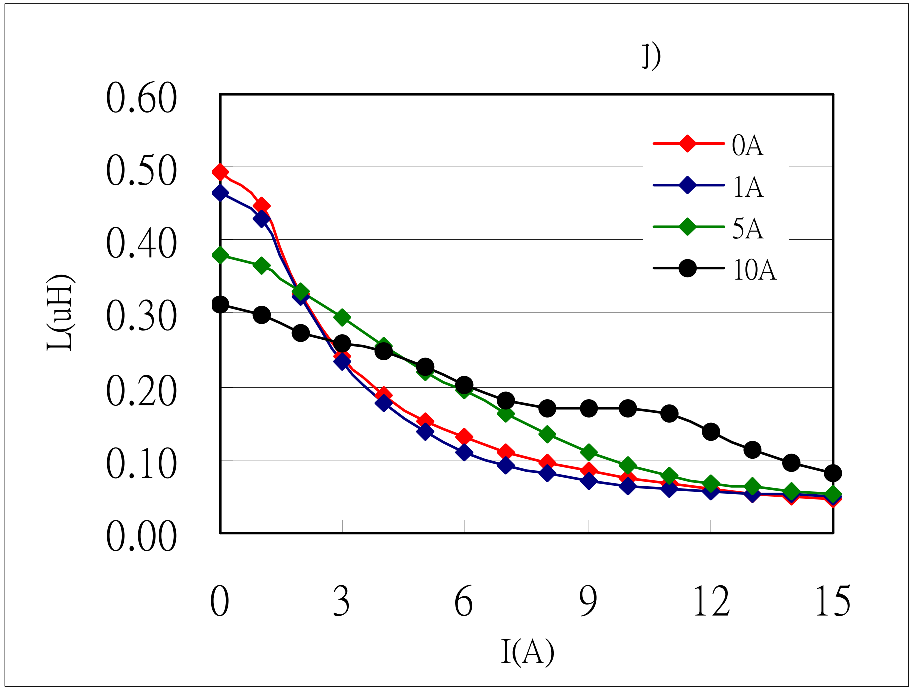
larger size	weak coupling	better coupling coupling can be adjusted

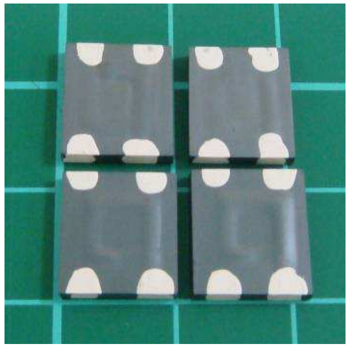
DC current loading testing

2 coil wired - measurement



2 coil wired –simulation





Size:12*10*1.9(mm)

ITRI Industrial Technology Research Institute

PWR SOC '12

Summary

1. High Bs (0.42 Tesla) and high permeability (~300) low temperature co-fired Ni-Cu-Zn ferrite has been developed in order to further enhance the rated current of multilayer planner inductor.
2. The results of 2D and 3D simulation display a good consistency at inductance and rated current properties. Also the results shown the inductance are proportional to N^1.4 instead of N^2. Low permeability layer will be enhance the current handling of the inductor.
3. The heterogeneous multilayer process provide very flexible way for planar inductor and the 252010 size Inductor has been demonstrated which the inductance L=0.47μH, Isat>1.8A @6MHz (up to 2.4A). The rated current can up to 15A for coupled inductor.
4. The integrated multilayer power module approach the power density up to 200W/inch^3 with efficiency in the range of 80%~90%.