Biophotonics & **M**icrosystems **L**ab

Inductors In Silicon Based on SU-8 Enhanced Silicon Molding Technique for Portable Electronics

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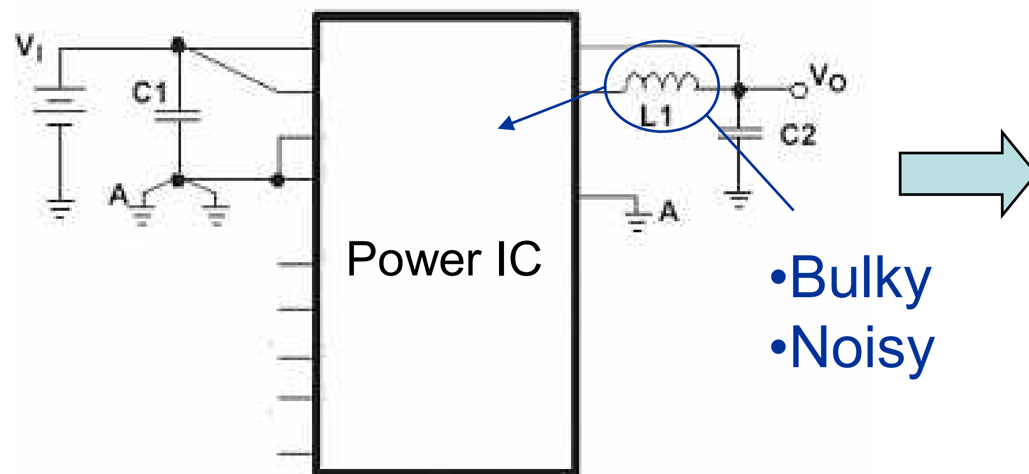
Outline

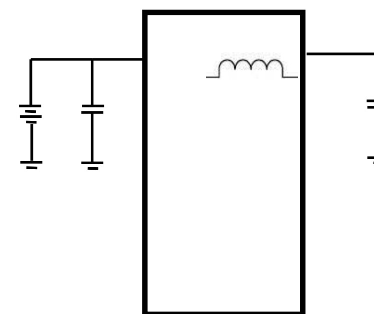
- Introduction
- Concept of MEMS Inductors Based on Silicon Molding Technique
- Direct Silicon Molding Technique
- SU-8 Enhanced Silicon Molding Technique
- Testing and Results
- Summary

Introduction

- Typical specifications of DC-DC converters in portable electronics
  - •Input voltage: 2.5~5.5V,
  - •Output Current: 0.5~2 A, output voltage: 1.2~1.8



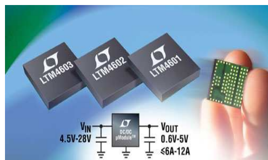
•Bulky
•Noisy

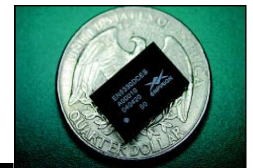


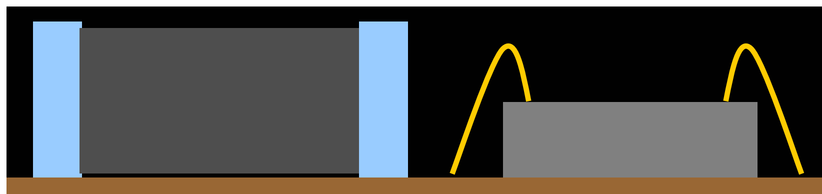
Monolithic integration of miniaturized inductor and power ICs

Products with Embedded Inductors

	f (MHz)	L (uH)	Vin (V)	Vout (V)	Iout (A)	Footprint (mm^3)
LTM4608	1.5	-	2.375~5.5	0.6~5	8	15×9×2.8
EN5396Q	5	0.09	2.375~5.5	0.75~ 5	9	10×12×1.8
EN5368QI	5	0.5	2.4~5.5	0.6~ 5	0.6	3×3×1.1
LM3218	2	2.6	2.7~5.5	0.8~3.6	0.65	3×2.5×1.2
MIC3385	8	0.47	2.7~5.5	0.6~5	0.6	3×3.5×0.9
FB6831J	2.5	-	2.7~5.5	0.8~4.8	0.5	2.9×2.4×1







Lead frame

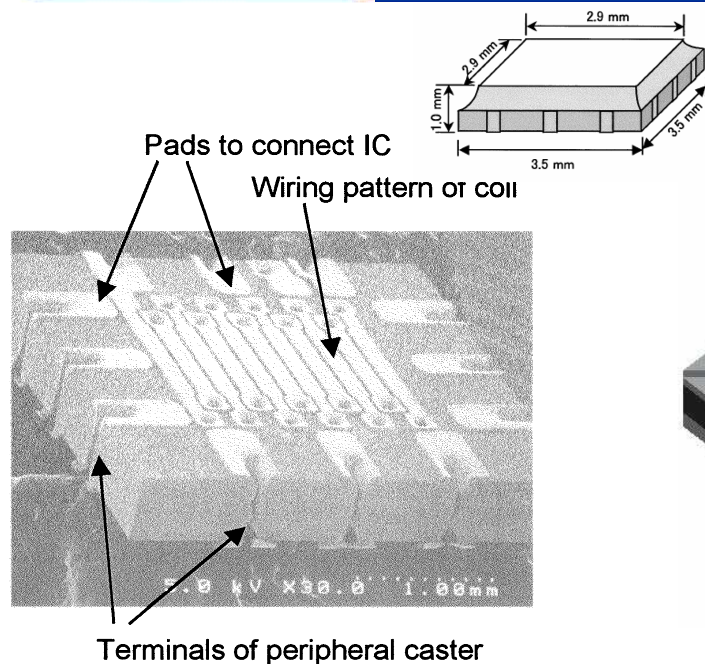
Mounted side by side on lead frame

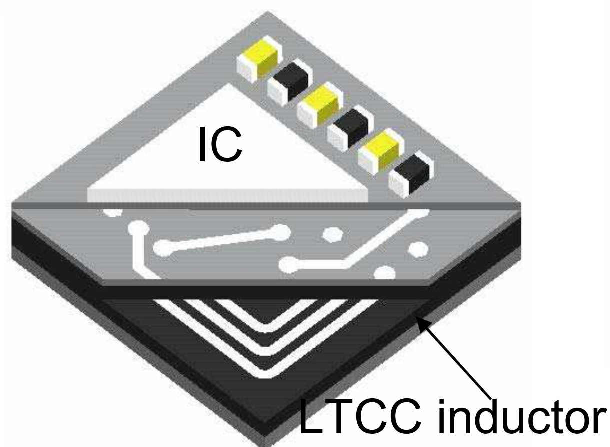
Stacking together

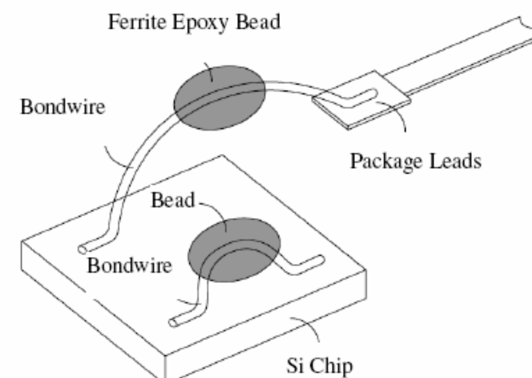
Power IC

SMT inductors

Inductors by Packaging Technologies







- *Inductor on Magnetic substrate*
- Inductance: 1.65 μH
- DC resistance: 0.18 Ω
- Output current: 500 mA
- Size: 3.5*3.5*0.6mm^3

Hayashi, Fuji Cop.,2003

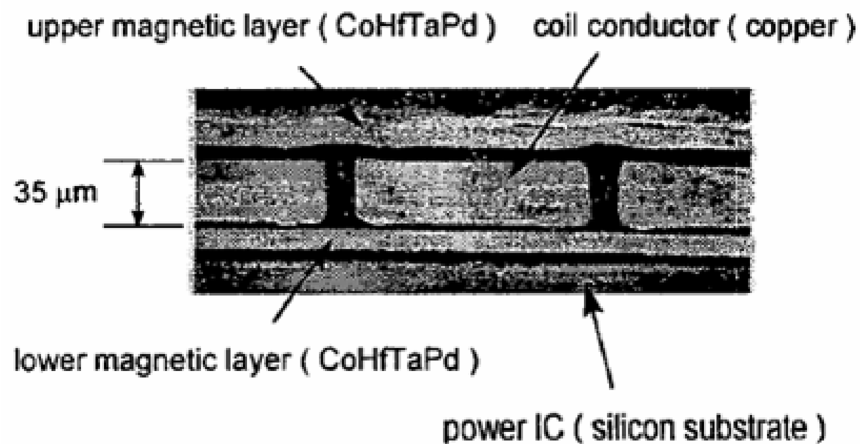
- *LTCC inductor as substrate*
- Inductance: 1.5 μH
- DC resistance: 0.46 Ω
- Output current: 700 mA
- Size: 5*5*0.6mm^3

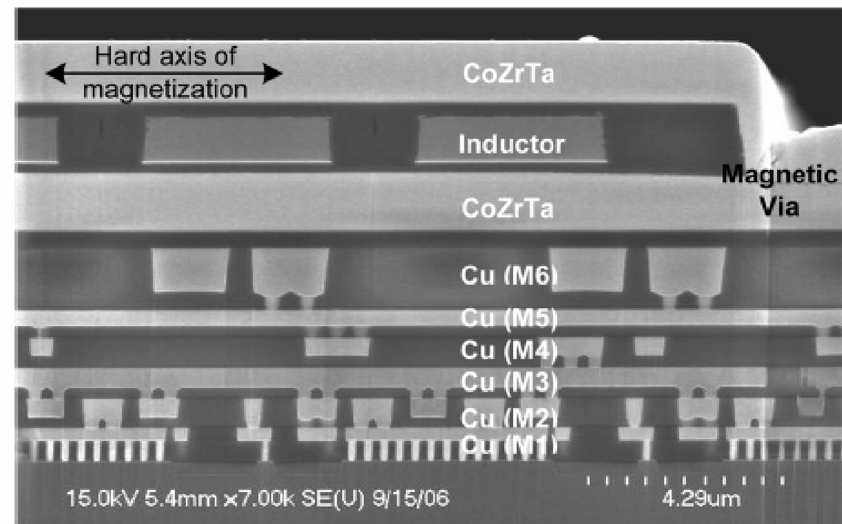
Mikura, Kyocera Inc.,2006

- *Magnetic coated bond wires*
- Inductance: 38 nH
- DC resistance: 7.1 mΩ

Shen, UCF,2007

Inductors on Silicon





- 35µm Cu, 9µm CoHfTaPd (Magnetic)
- Inductance: 0.96 µH
- DC resistance: 0.9 Ω
- Output current: 300 mA

Katayama, Fuji, 2000

- 1.5~2µm CoZrTa (Magnetic)
- Inductance: **9**× air core spiral inductor
- Output current: < 400mA

Gardner, Intel, 2007

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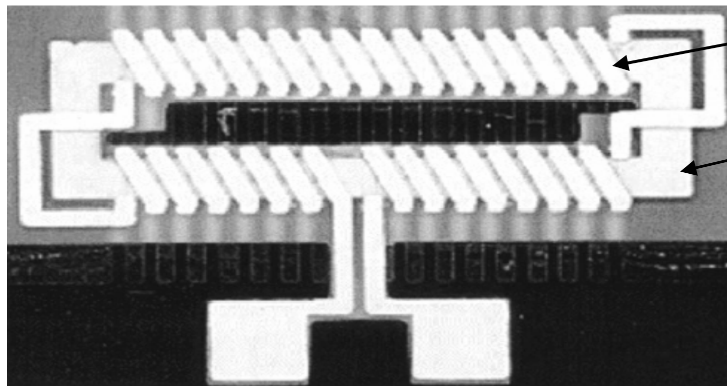
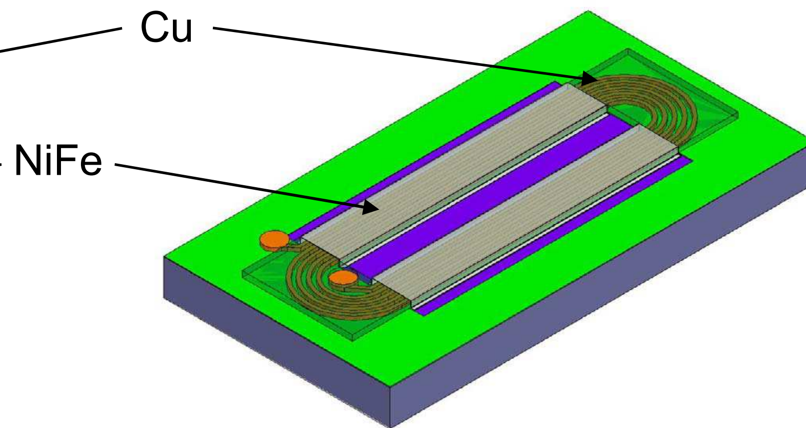
Inductors on Silicon





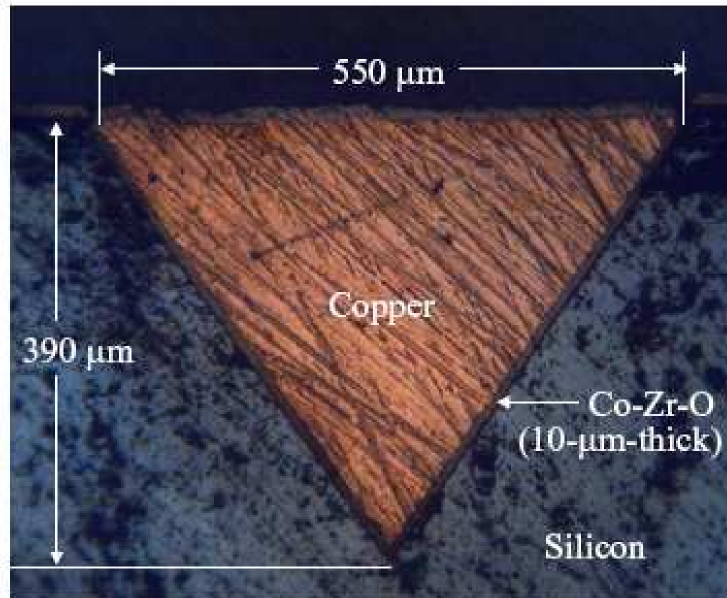
- 30μm Cu, 72 layers of 1μm NiFe
- Inductance: 2.3 μH
- DC resistance: 0.15 Ω
- Area: 4×3 mm^2
- Output current: 200 mA

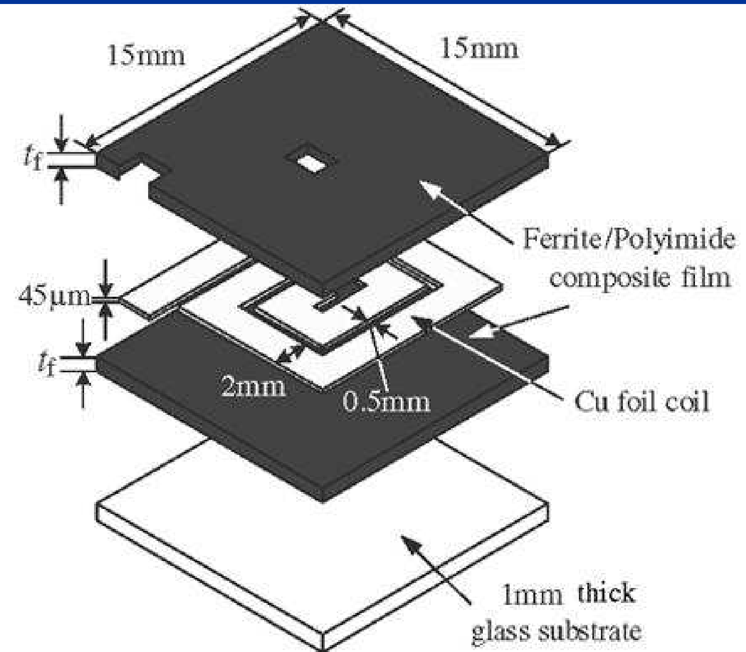
Park, GaTech, 2003

- 50μm Cu, 10μm NiFe
- Inductance: 100 nH
- DC resistance: 0.13 Ω
- Area: 6.4 mm^2
- Output current: 500 mA

Donnell, Tyndall, 2008

Inductors on Silicon





- Inductance: 11 nH
- DC resistance: 3 mΩ
- Size: 11mm straight line
- Output current: 5A

Prabhakaran, Dartmouth, 2005

- 45µm Cu, 200µm NiFe ferrite powder
- Inductance: 50 nH
- DC resistance: 15 mΩ
- Size: 15×15 mm^2
- Output current: 10 A

Kowase, Shinshu U., 2008

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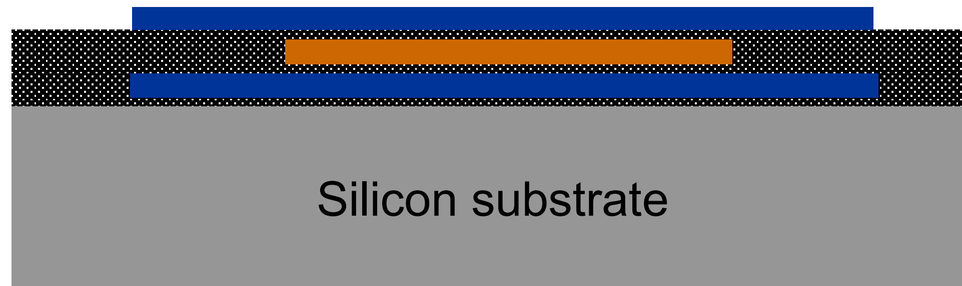
In Package VS On Silicon

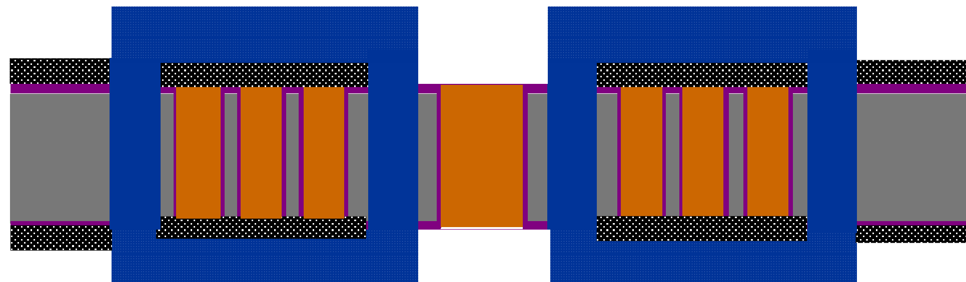
	Inductor in package	Inductor on silicon
Inductance	**High**	**Low**
DC resistance	**Low**	**High**
Saturation Current	**High**	**Low**
Magnetic material	**More options**	**Limited**
Size	**Large**	**Small**
Cost	**High**	**Low***

*Two reasons: 1. wafer level process
2. “in house” fabrication for semiconductor companies, not components from magnetic manufactures

On Silicon VS In Silicon

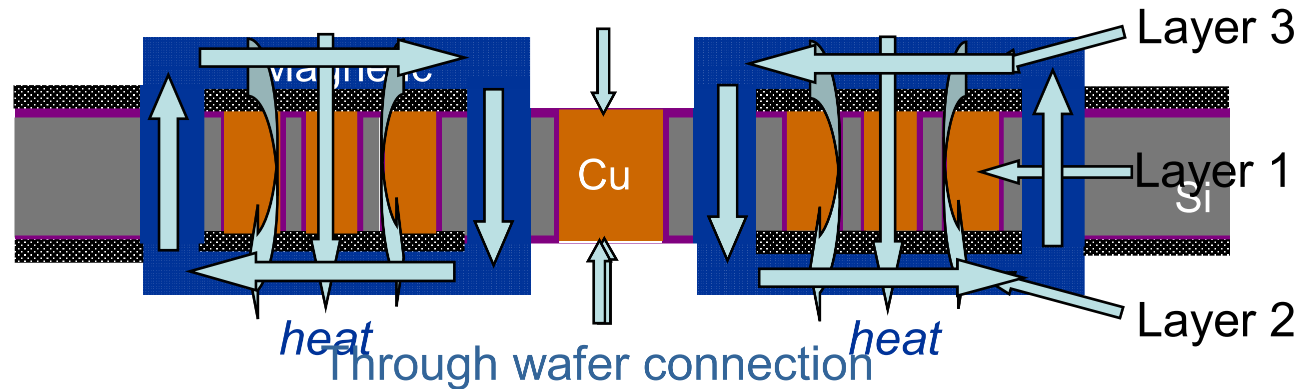


State of Art Technologies: *Stacked* **on** *the top of silicon substrate*



Our Approach: *Fabricated* ***INTO*** *(through wafer) silicon substrate*

Features



❖ Copper as thick as silicon substrate (200 μm~500 μm)

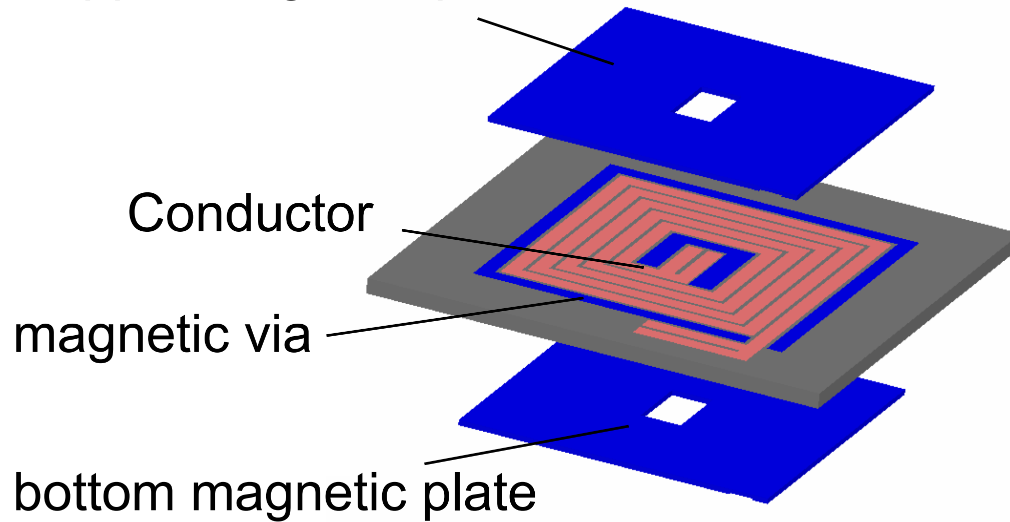
❖ Three metal layers distribute at frontside, backside and inside of substrate

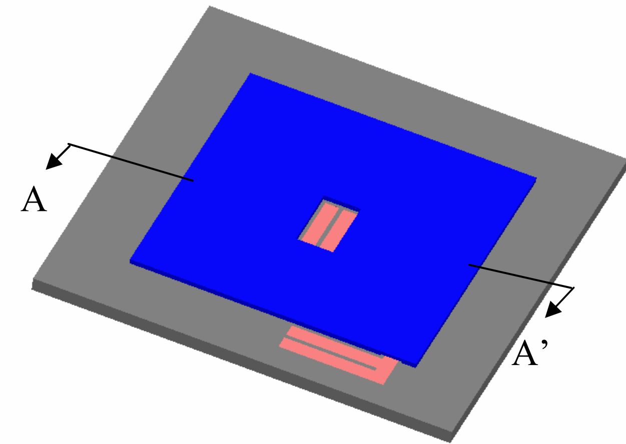
❖ Closed Magnetic path

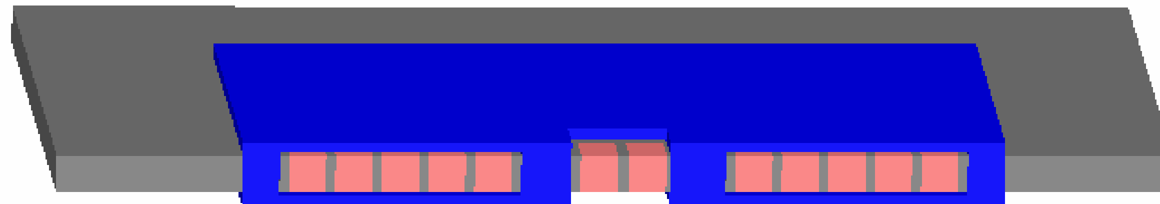
❖ Excellent thermal dissipation

❖ Through-wafer metal can be used as interconnections for three-dimension packaging, and also ready for packaging

Inductors In Silicon

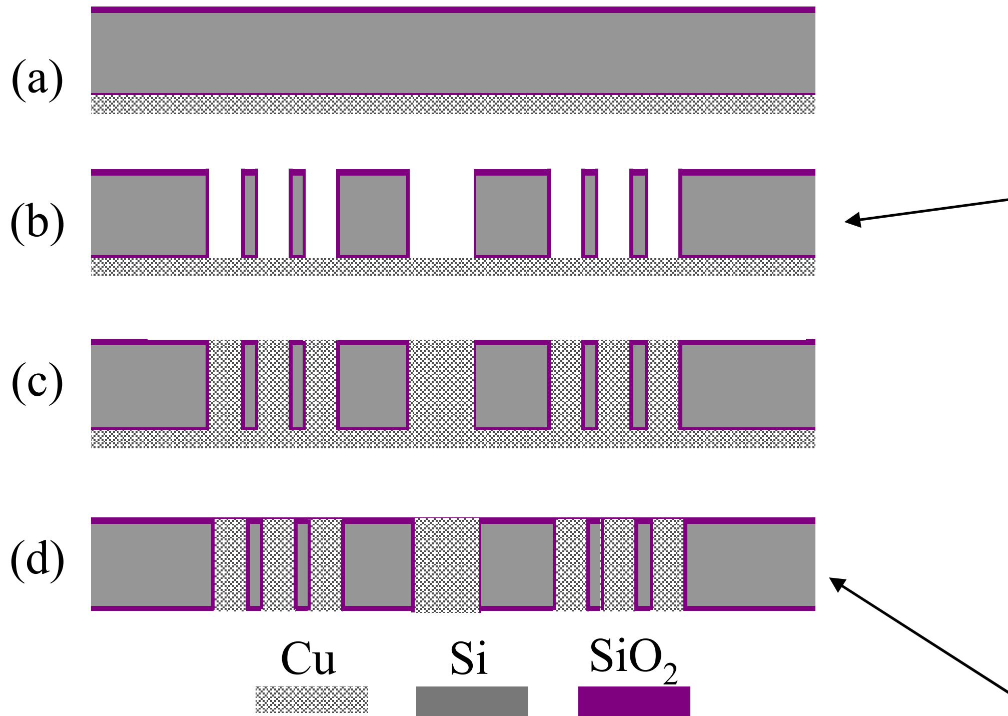


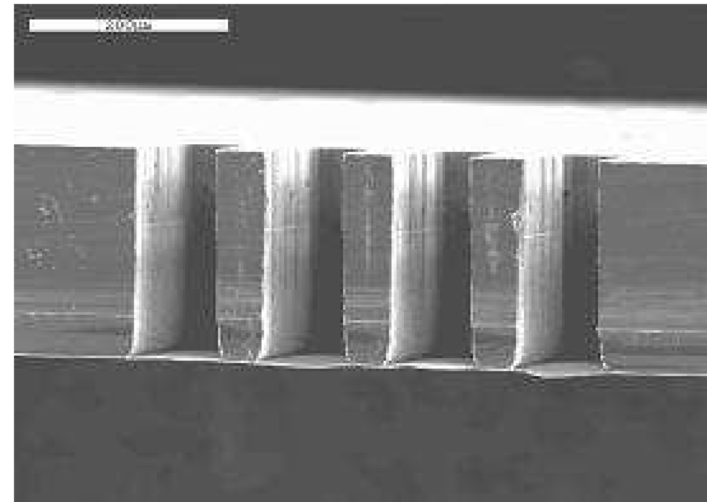




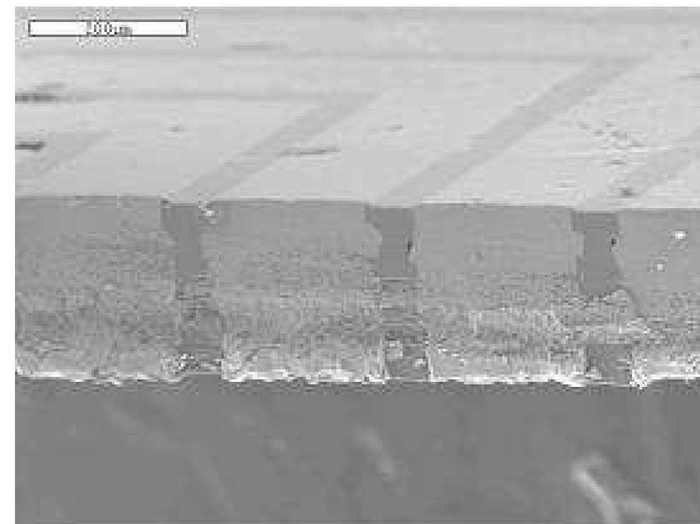
Cross-section view along A-A'

Direct Silicon Molding Techniques





SEM of (b)



SEM of (c)

(a) 10 µm Cu deposition on the backside
(b) Through-wafer Si trenches by DRIE
(c) Metal electroplating and surface polishing
(d) removal of the 10 µm-thick Cu on the backside.

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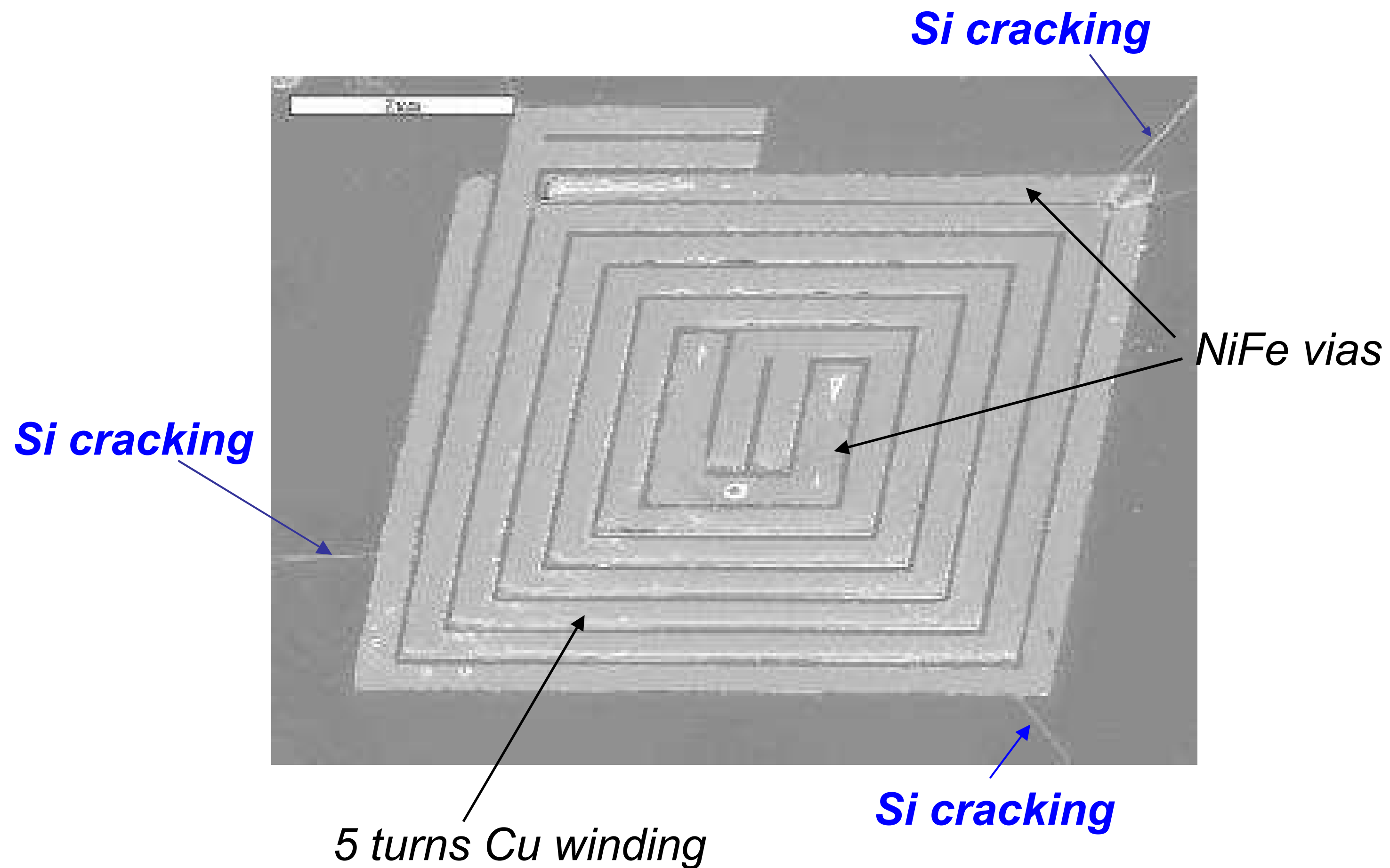
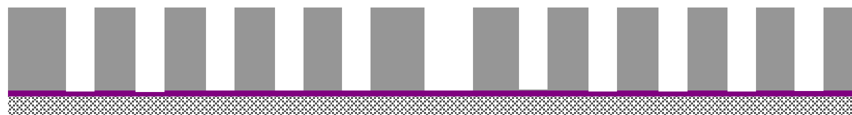
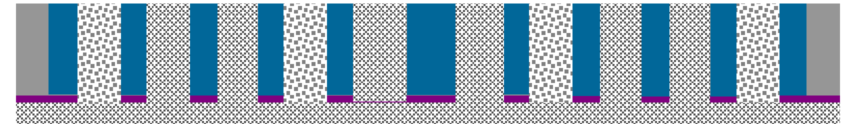
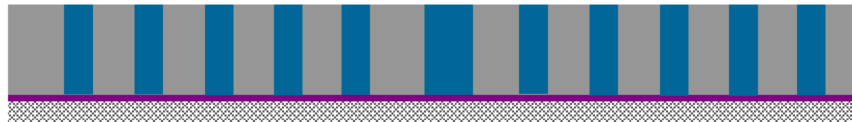
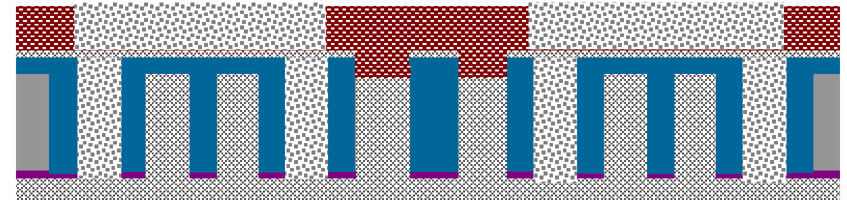
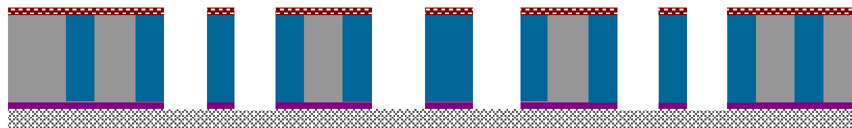
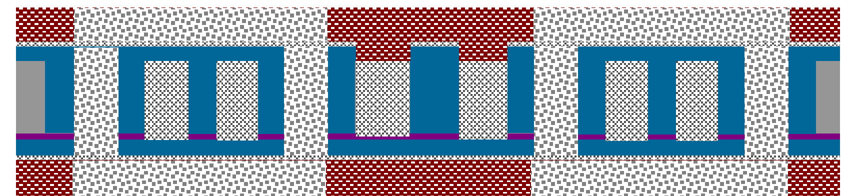
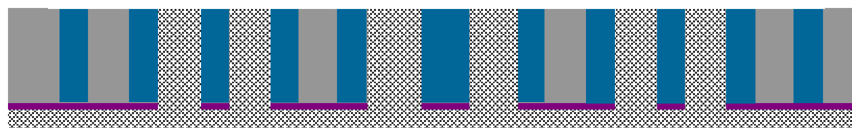
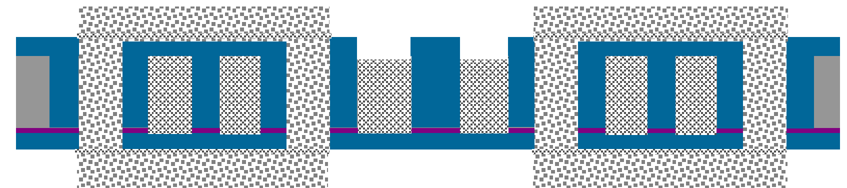
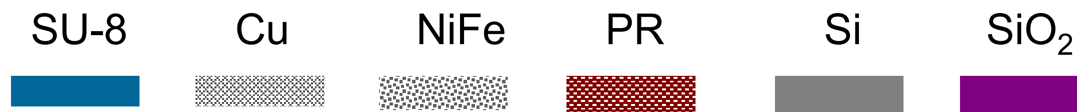
Reported Problem



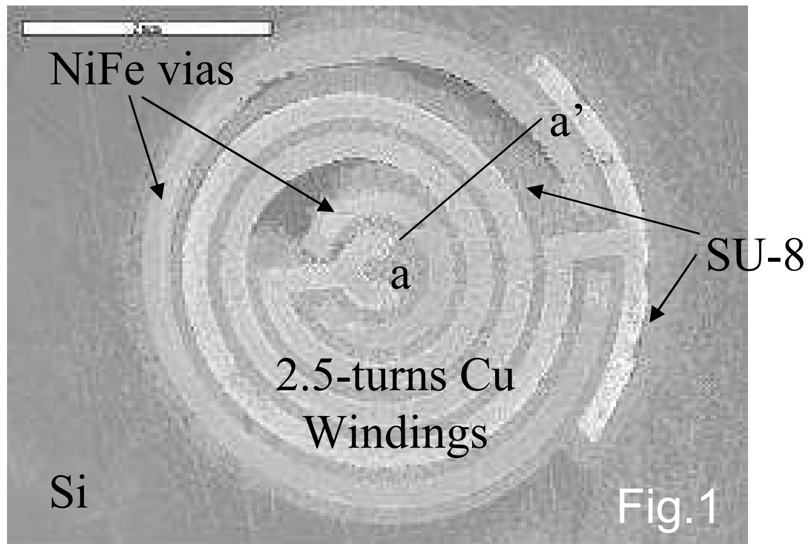
Thermal stress due to the difference of thermal expansion coefficient

Mingliang Wang, Khai D. T. Ngo and Huikai Xie. PESC07, 2007

SU-8 Enhanced Process

Fabricated Device



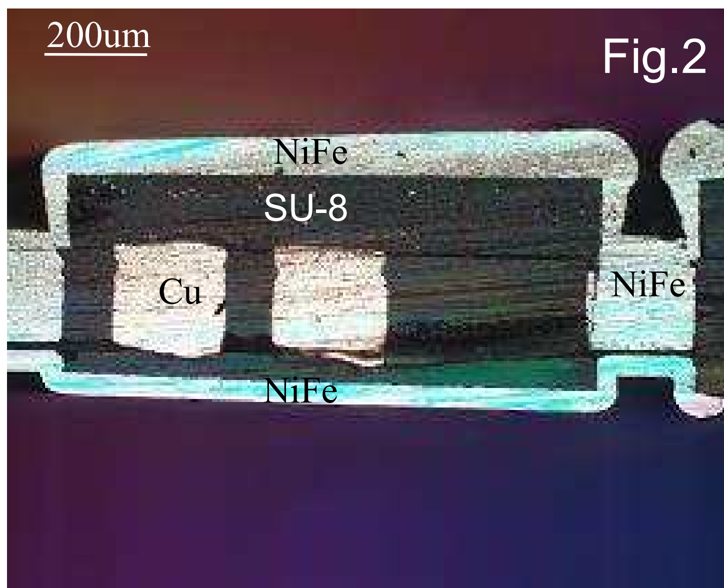
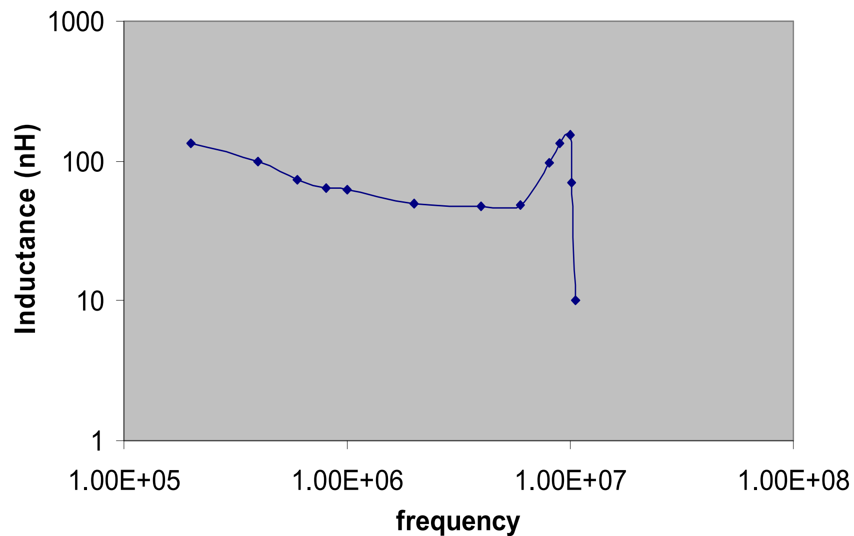


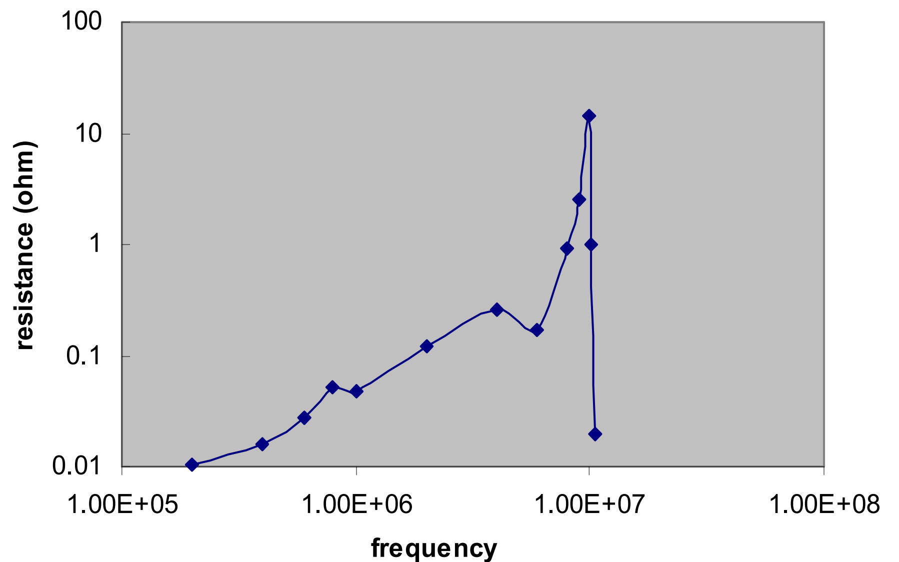
Fig.1 Metals inside the silicon wafer
Fig.2 Cross-section view along A-A'
Fig.3 Top view of fabricated device

Testing and Results

(1) DC resistance: ***10.1 mΩ***



(2) Inductance versus frequency



(3) AC resistance versus frequency

Summary

- State-of-art technologies were reviewed
- Concept of Silicon Molding Technique was demonstrated
- SU-8 Enhanced Process was developed to solve the thermal crack problems
- An inductor with 134 nH and 10 mΩDCR was fabricated
- Magnetic material should be replaced by high frequency material to reduce the loss

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Questions?