Magnetics Integration - from Thin Film Heads to On-Chip Inductors

Naigang Wang, IBM T. J. Watson Research Center

nwang@us.ibm.com

PowerSoC2012

Team

- IBM T. J. Watson Research Center

  Eugene O'Sullivan; **Lubomyr Romankiw**; Bucknell Webb; William Gallagher

- IBM Almaden Research Center

  Philipp Herget; **Robert Fontana**;

- Columbia University

  Noah Sturcken; Kenneth Shepard

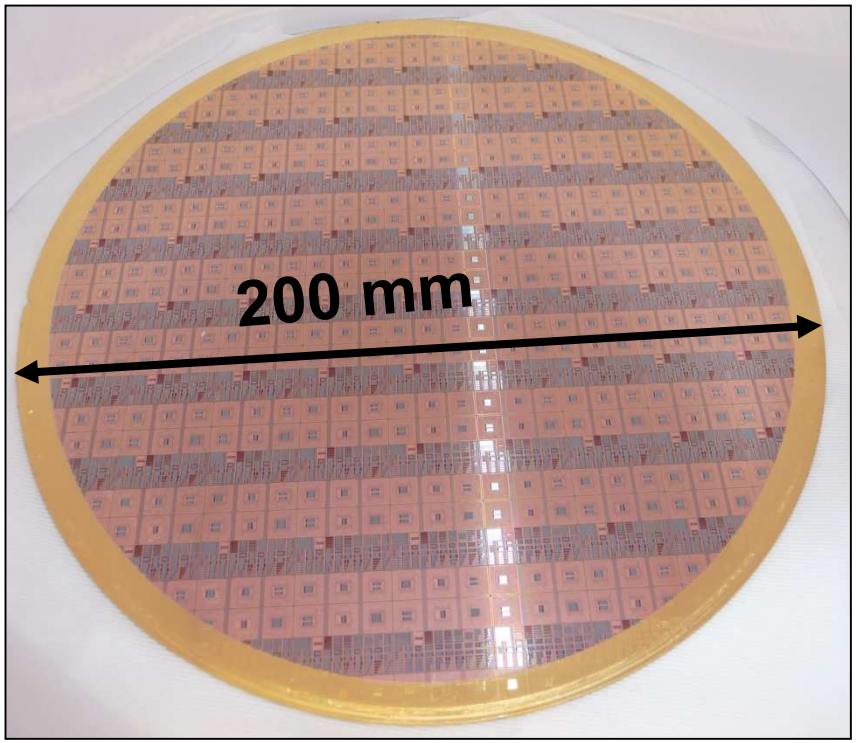
Acknowledgement

- DOE support under contract DE-EE0002892

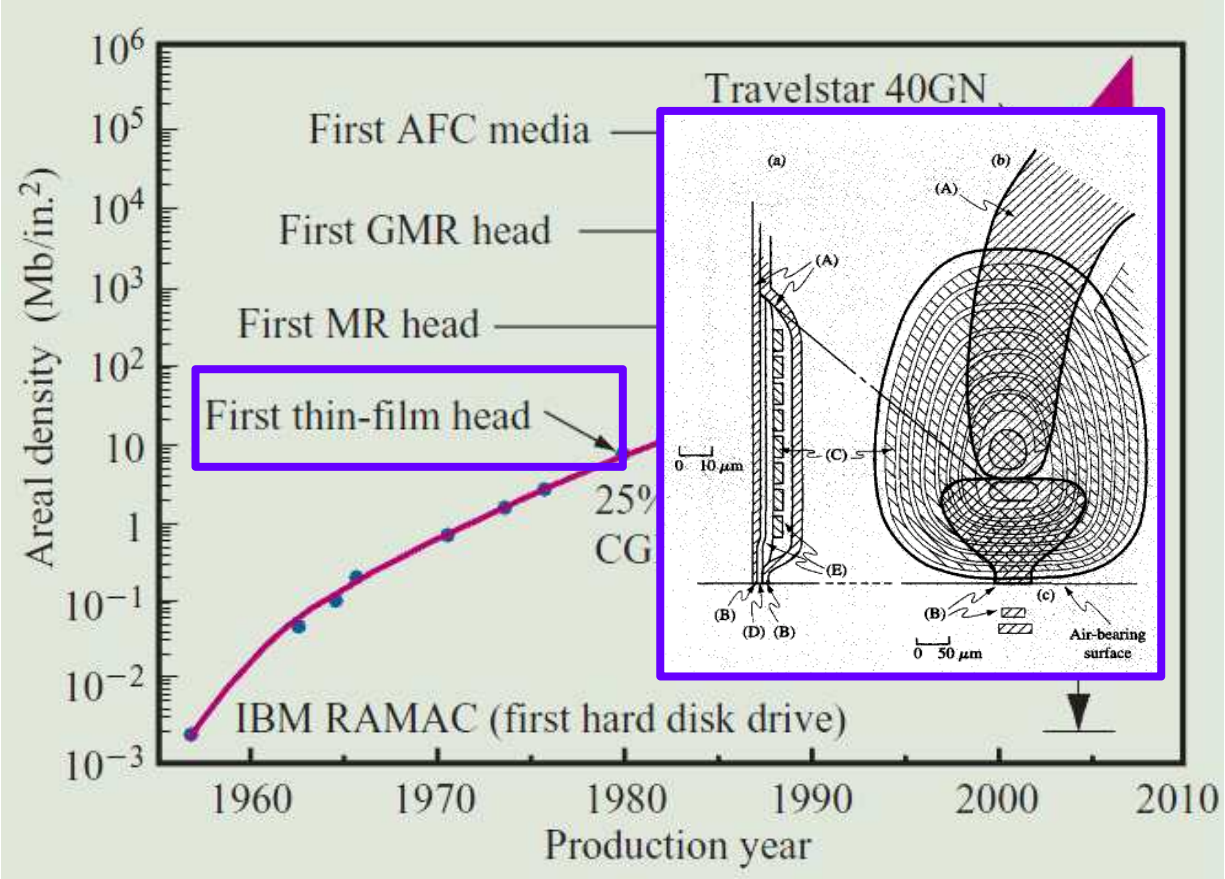
- Microelectronics Research Laboratory at IBM T. J. Watson Research Center

Outline

- Review of the integration of thin film recording head
- Fabrication of on-chip inductors using “old” technologies.
- Magnetic materials properties
- Inductor performance
- Summary

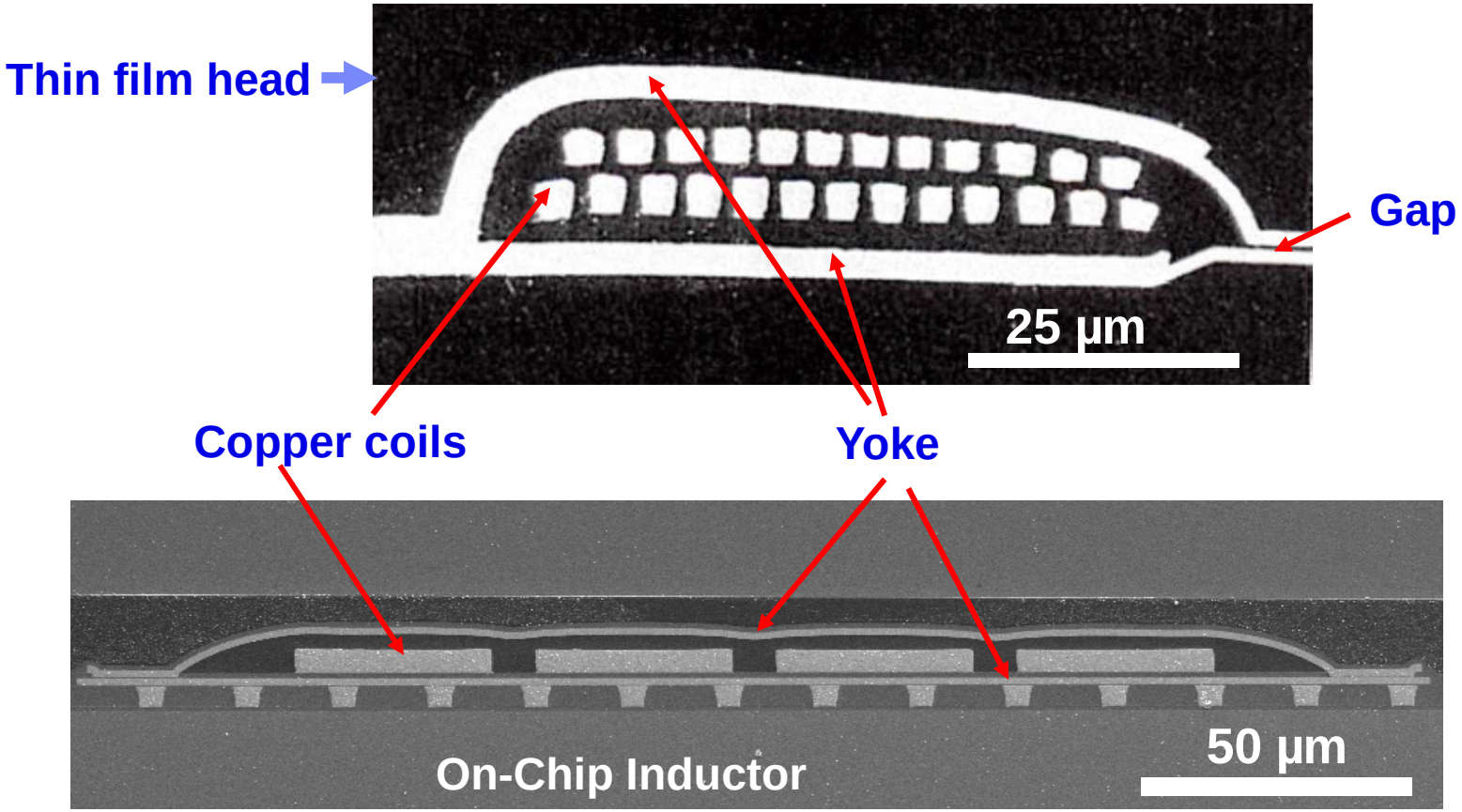


Individual manual made → mass manufacture

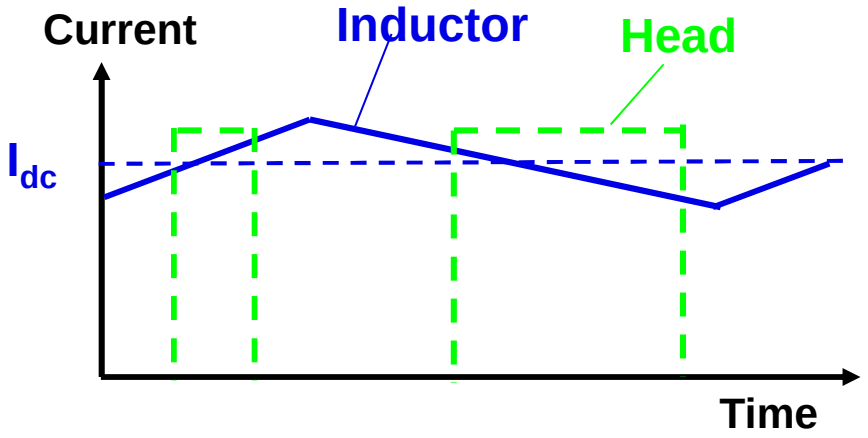


- In 1979, IBM introduced batch fabricated heads which was the first major paradigm shift in the commercial fabrication of inductive heads and resulted in an order of magnitude increase of bit density, faster data access, and smaller, less expensive systems.

Similar Structure and Dimension!



Compare the requirements



Head

- High moment
- Low inductance

Inductor

- Relatively high inductance
  - 1-100 nH (>50 MHz)
- Low DC loss: << 1 Ω
- Low AC loss
- High Q: 8-30

Magnetics

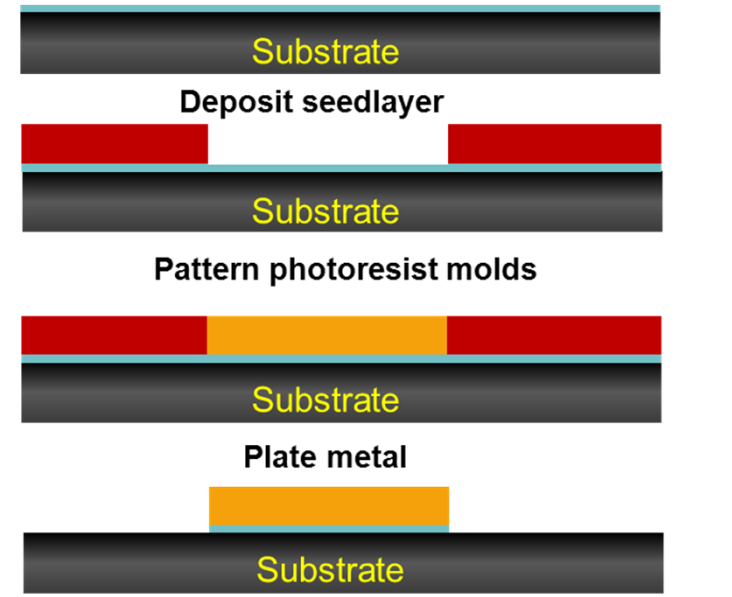
- Thickness: 0.5-5 um
- High μ:>500
- High moment
- High ρ
- Low H_c

Mass Manufacturability

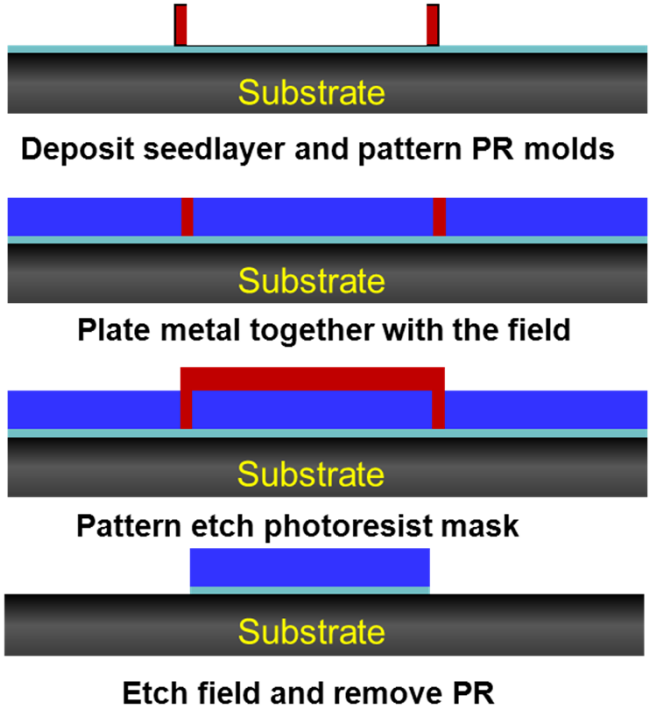
- Compatibility: temp., corrosion…
- Stress, adhesion and wafer bowing
- Alignment/overlay and patterning
- **Low cost**

Major integration technologies for thin film heads

Plating through masks



Frame plating magnetic yokes



Electroplating

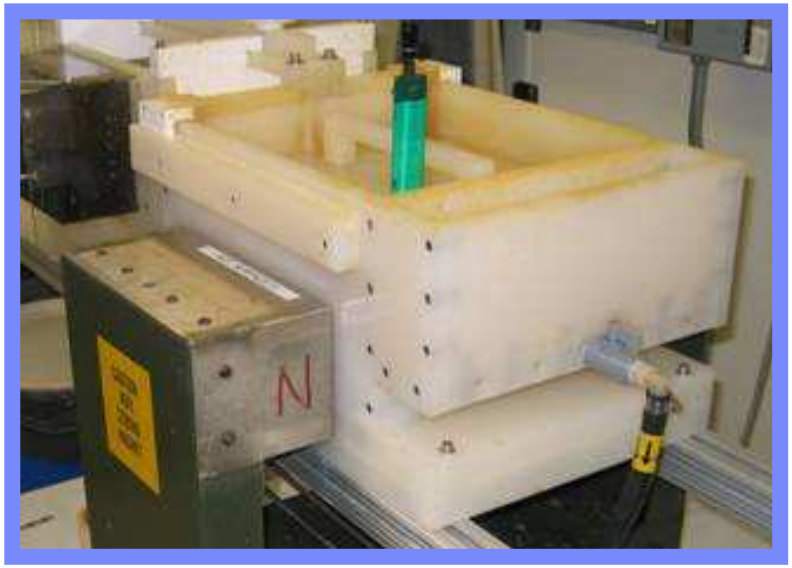
- Low cost
- High deposition rate
- Conformal coverage
- Patterning yokes with smooth edges

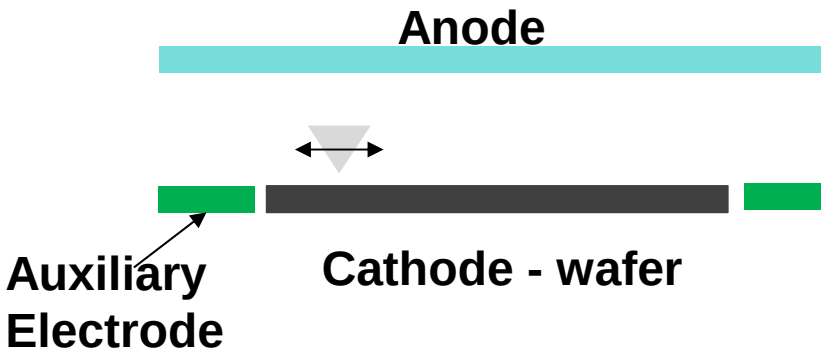
Frame plating

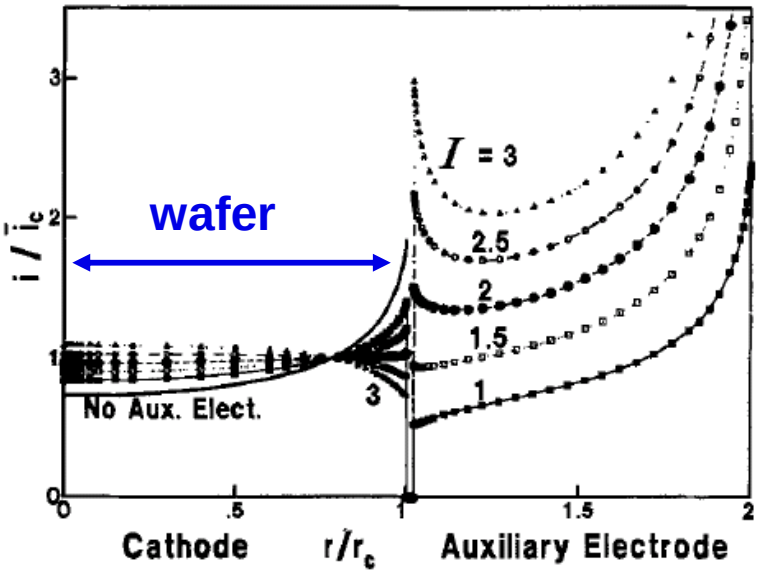
- Precise control of thickness and composition
- Easy application of an in-plane magnetic field across the narrow pole tip

Electroplating tools for large scale wafers

Paddle cell



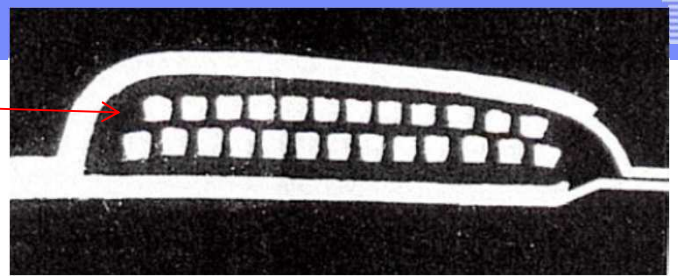




- Efficient agitation
- Particularly important for Fe containing alloys
- Auxiliary electrode ensure the thickness and composition uniformity across the whole wafer

S. Mehdizadeh, J. Electrochem. Soc., vol. 137,1990

Hard baked photoresist



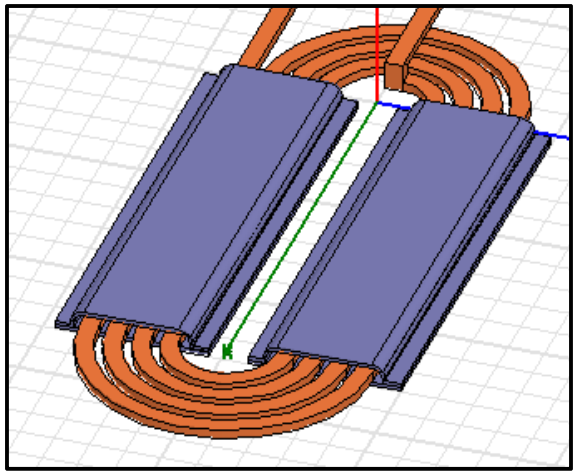
- Novolac resin based photoresist
- Reflow at around 120 C and hard baked at 200-250 C
- Chemically inert and mechanically strong
- Provide partially planarization for top yoke deposition
- Provide smooth surface and edge

Huge knowledge base!

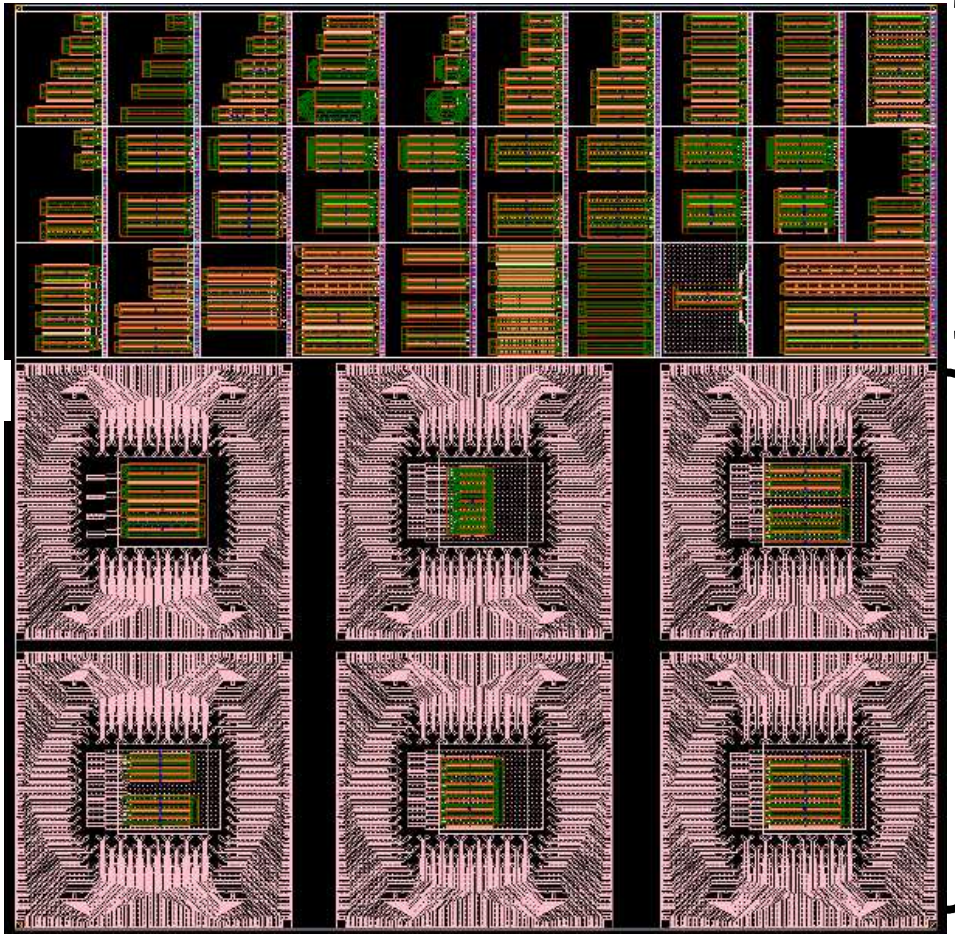
- Magnetic materials
- Magnetic domain control
- High frequency magnetic switching dynamics
- Magnetic and eddy current loss
- …

On-chip inductor fabrication

- Fabrication processes on 200 mm silicon wafers
- Structure: Elongated sandwiched spiral
- Yoke materials: $Ni_{45}Fe_{55}$
- Fabrication: Inductive thin film head processing



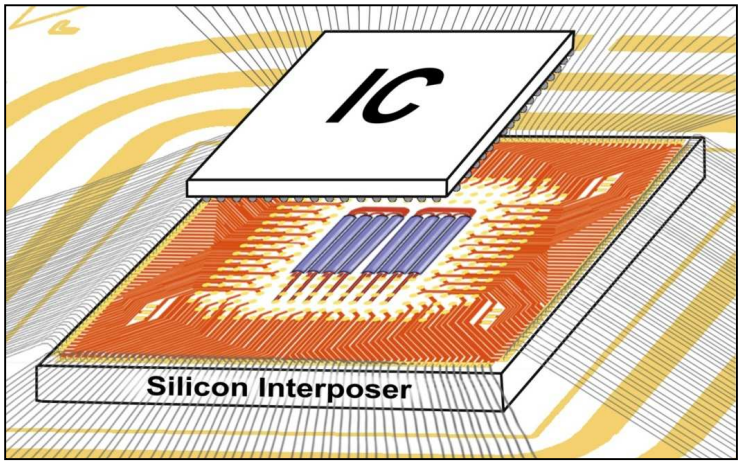
Testsite: Process integration development



2 cm

Inductor experiments

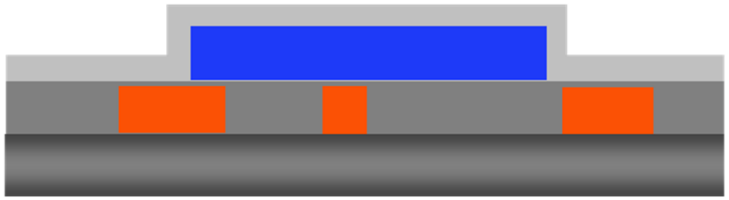
Multiphase coupled inductors with interposer wiring



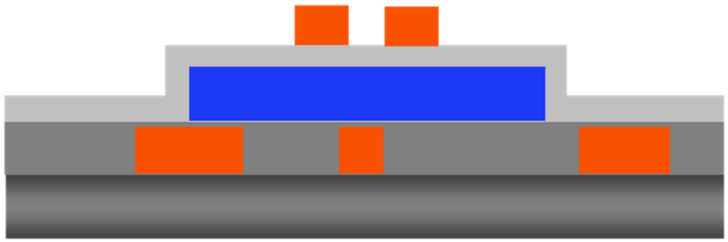
Fabrication process

Damascene Cu interconnector

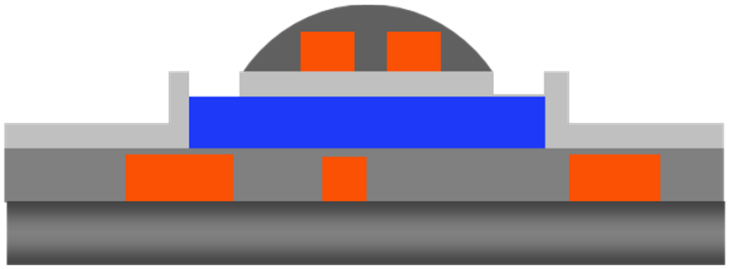
Frame plating bottom yoke



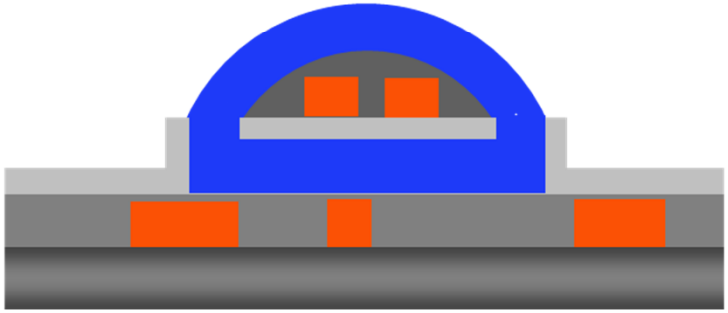
Remove field & dielectric encapsulation



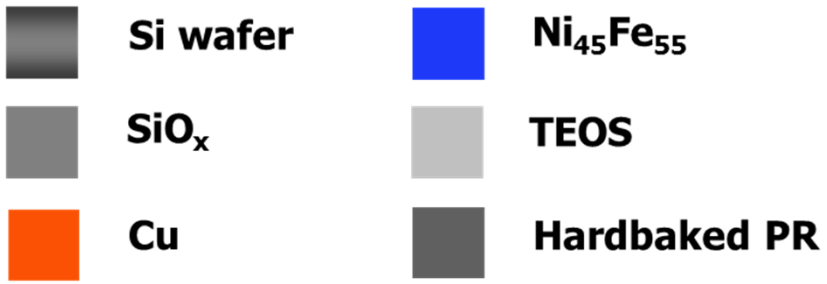
Electroplating Cu coils through masks

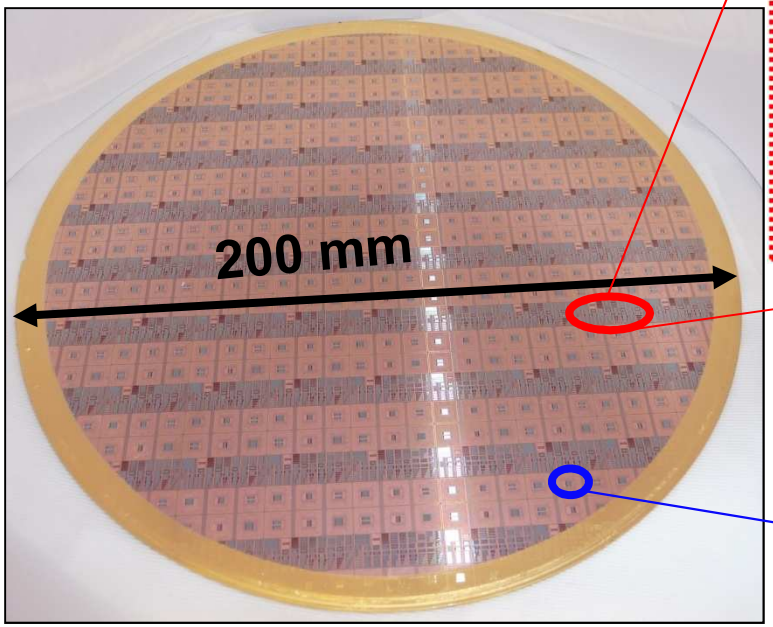


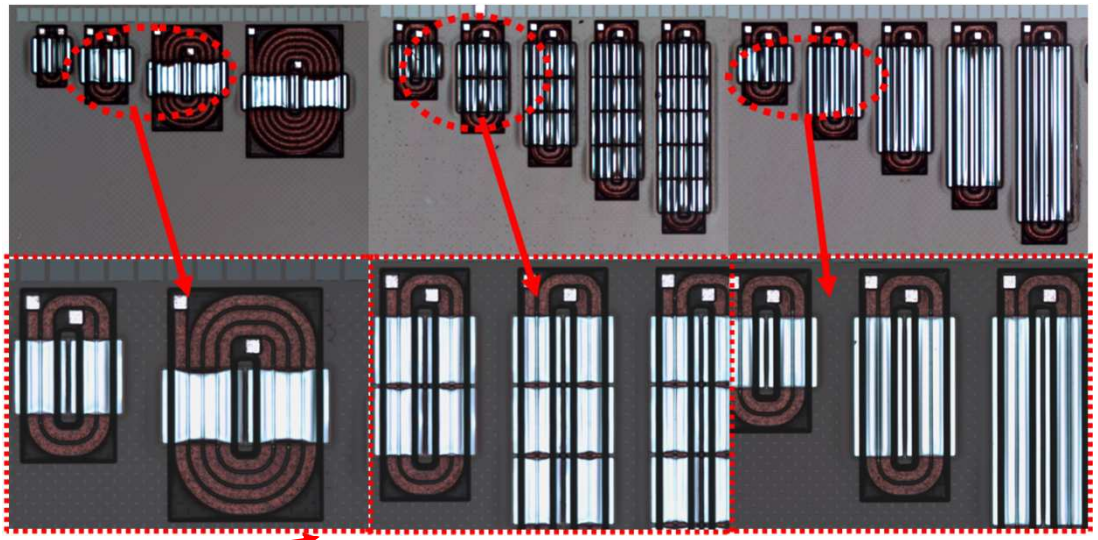
PR encap, reflowed & hardbaked

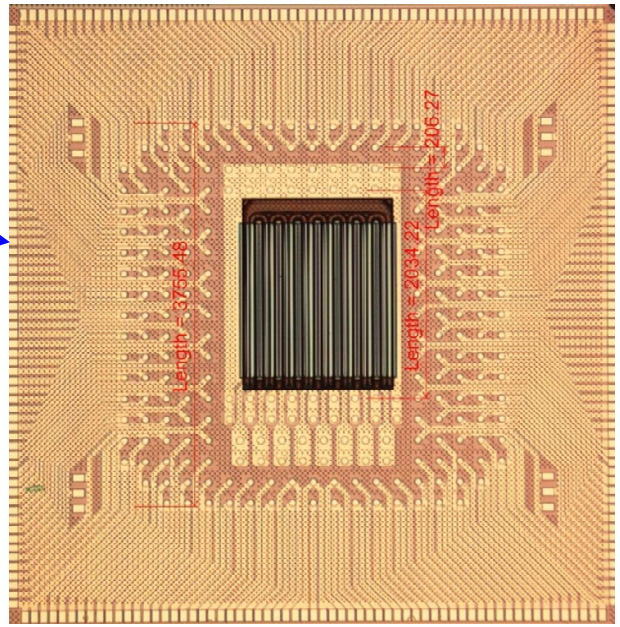


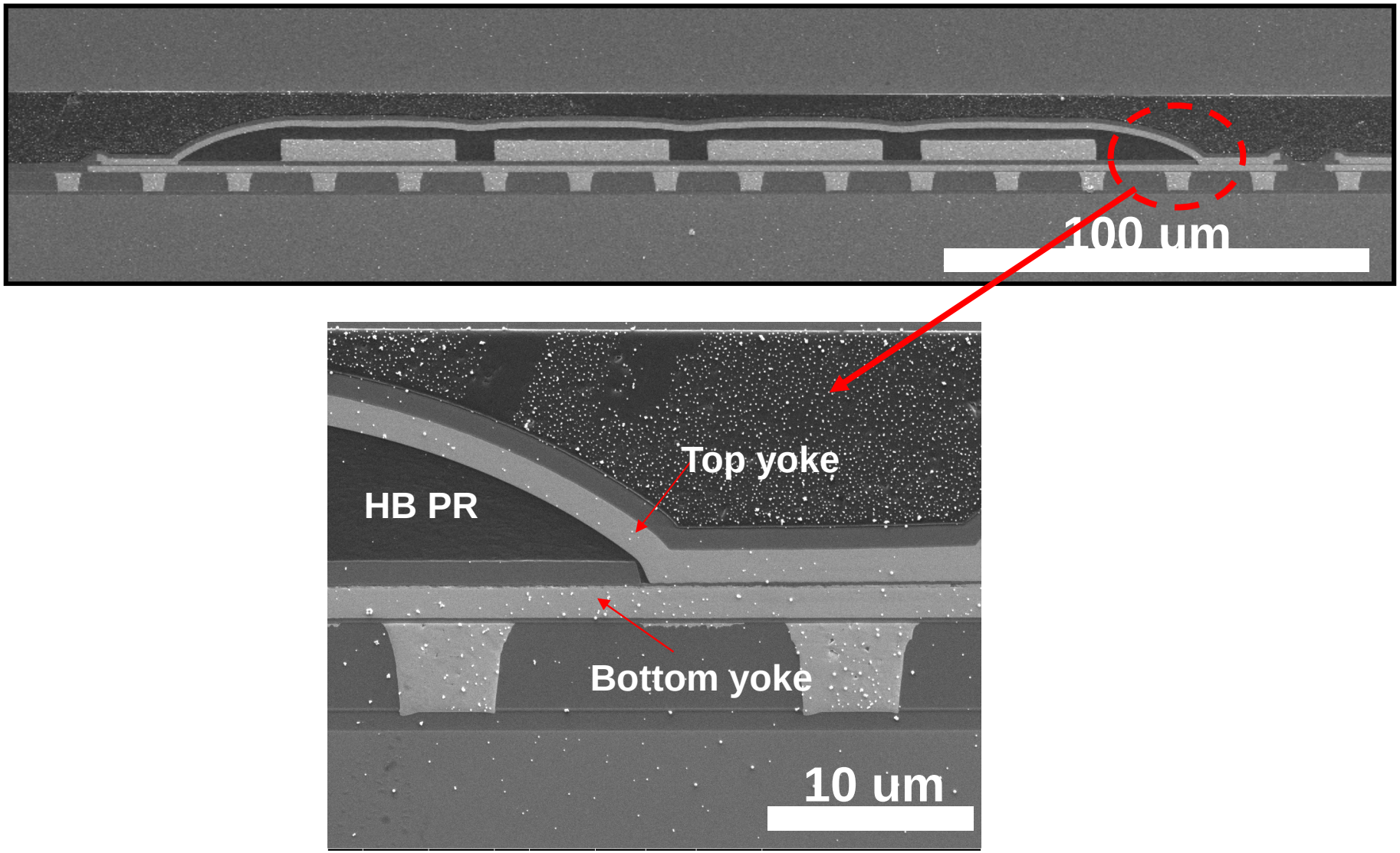
Frame plating top yoke




200 mm

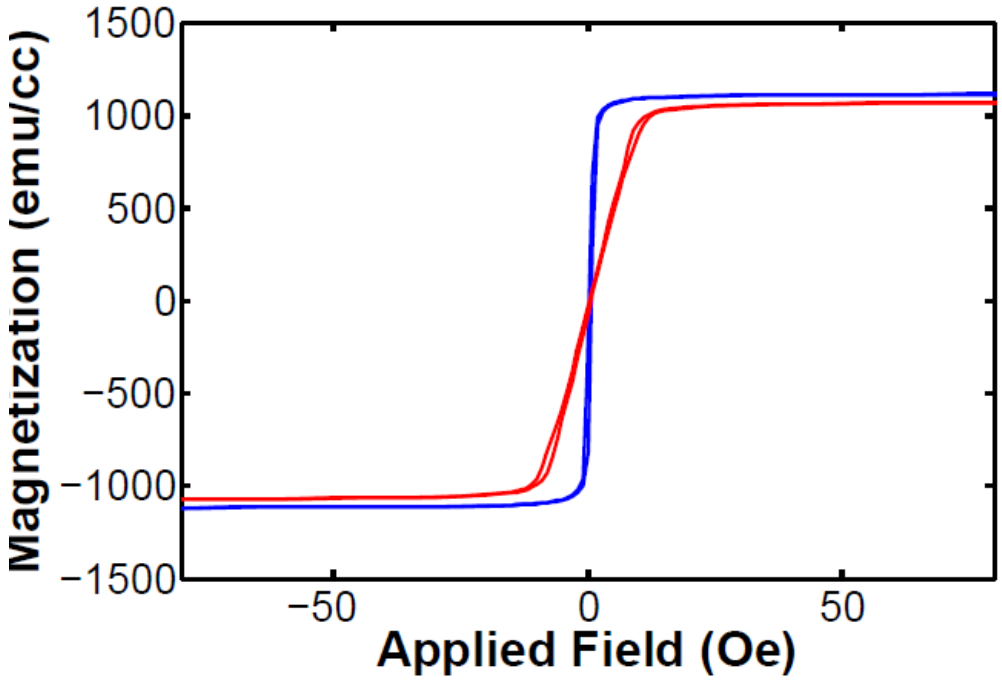



Length = 3755.48
Length = 2034.22
Length = 206.27



Plating has much better conformal coverage!

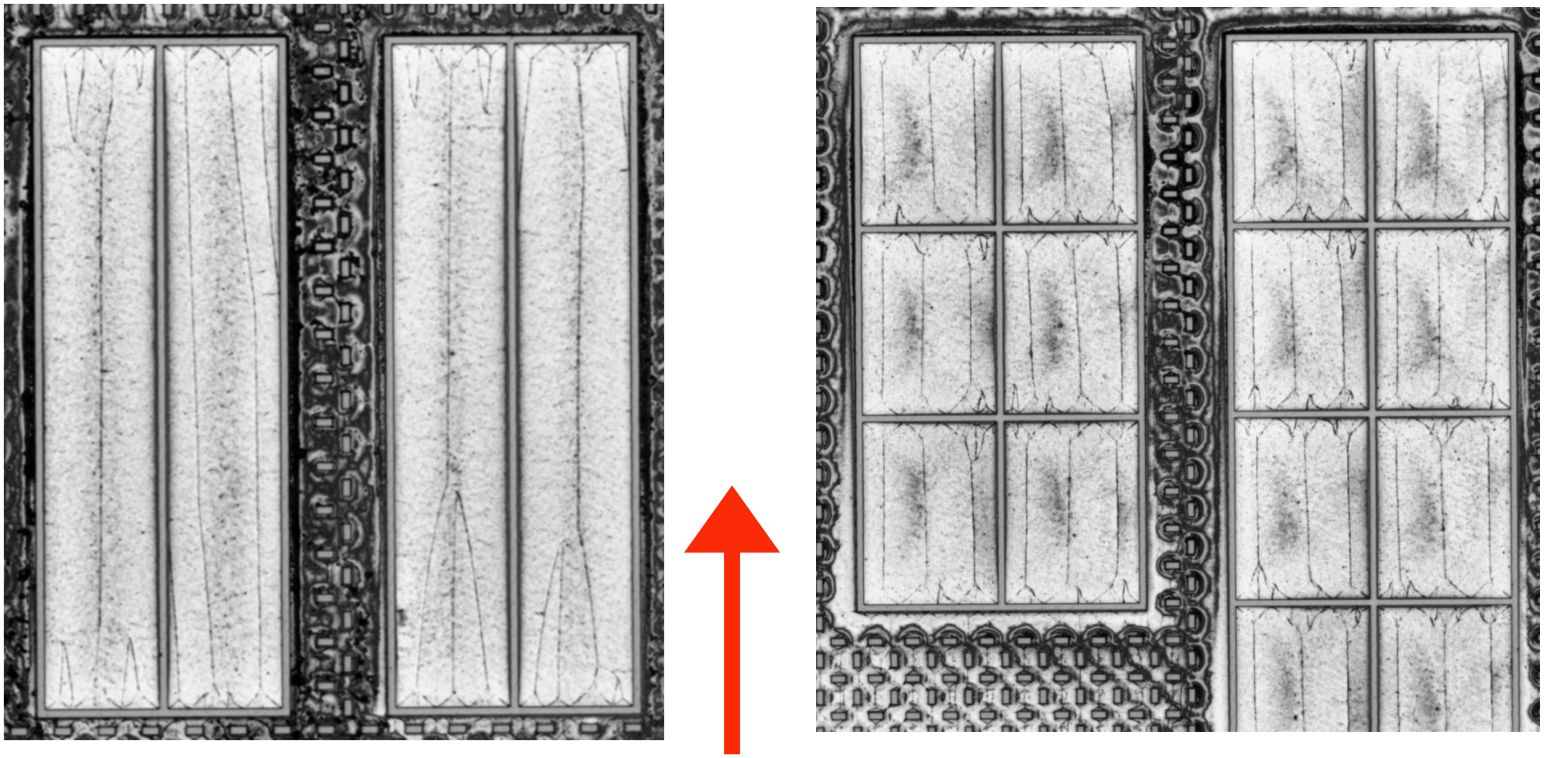
Materials properties



- Sample dimension: 1 cm × 1cm × 1 µm

Property	45/55
B_s (T)	1.5 T
H_k (Oe)	13
H_c (Oe)	0.2 (Easy) 0.2 (Hard)
μ_r	~1000
Resistivity (µΩ·cm)	45
Density (kg/m3)	~8.3×10^3
Stress as plated (MPa)	130 (1 um) 110 (2.5 um) 100 (3 um)

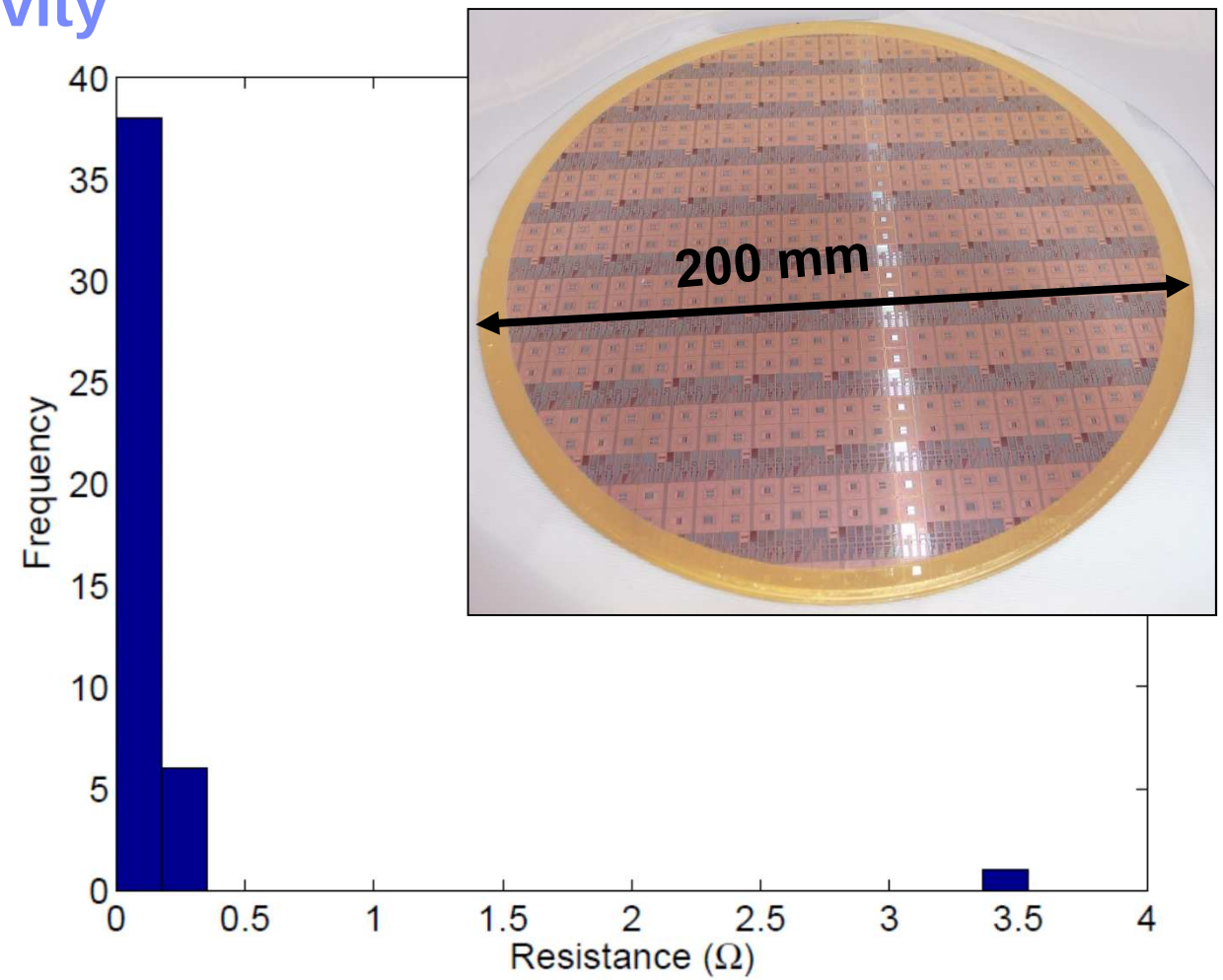
Magnetic domain pattern



Easy axis

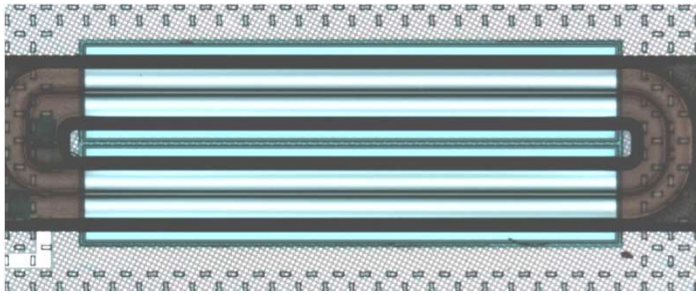
- Domain structures were obtained by Bitter Pattern Technique
- Ferrofluid was provided by Ferro Tech (EMG508)

DC Resistivity

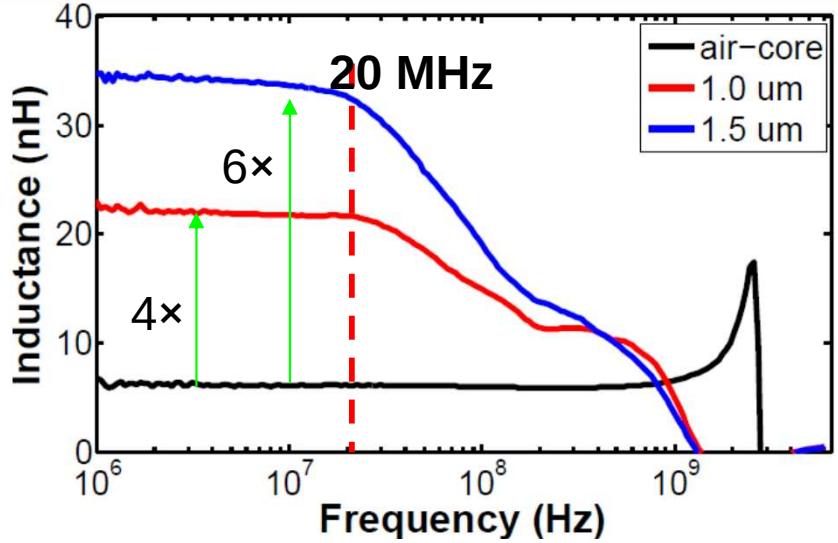


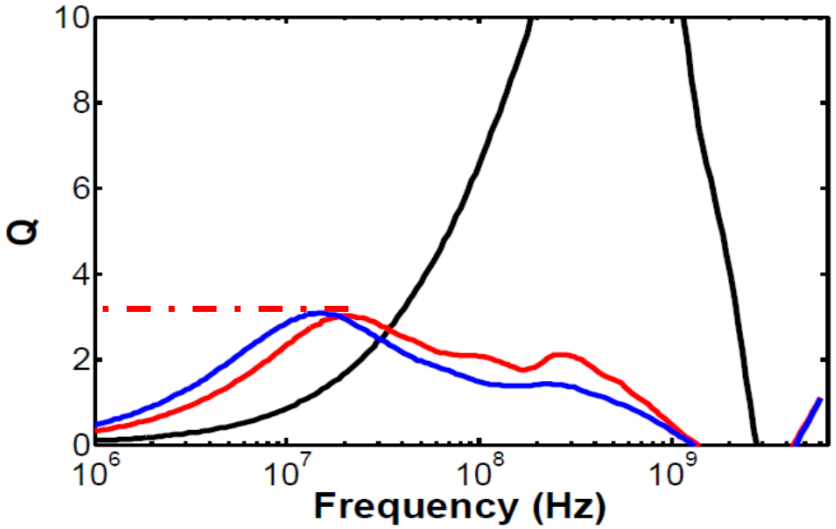
- A 1mm-long, 2-turn inductor from all chips on a 200 mm wafer
- DC resistance is 0.16 ± 0.06 Ω

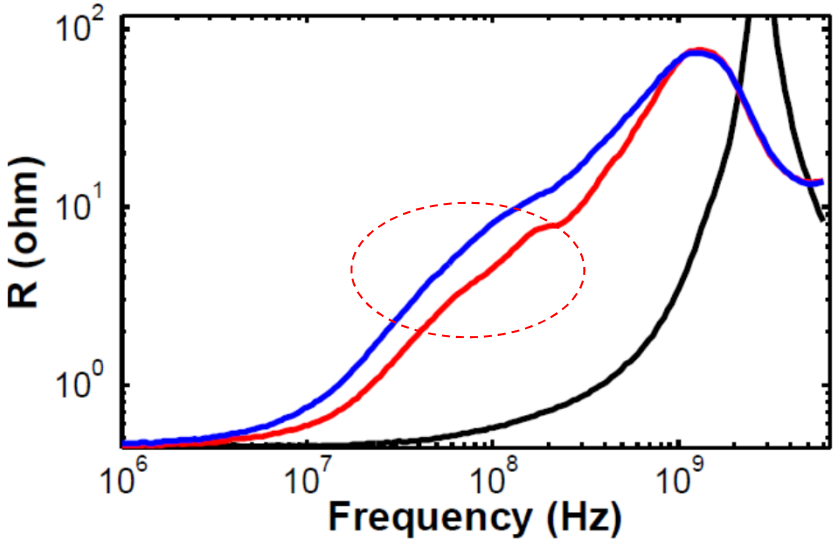
Inductor performance – Yoke thickness



2-turn coil, 1.25 mm-long yoke

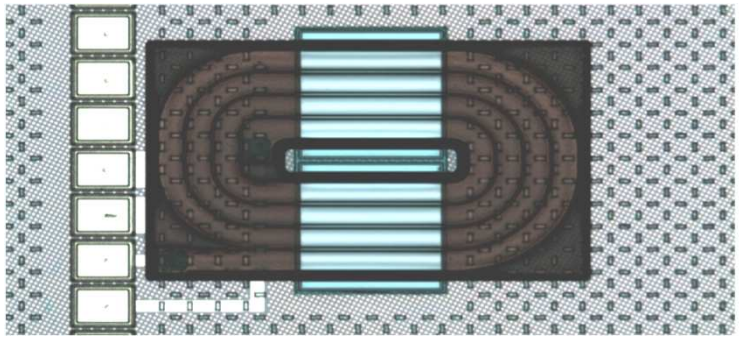




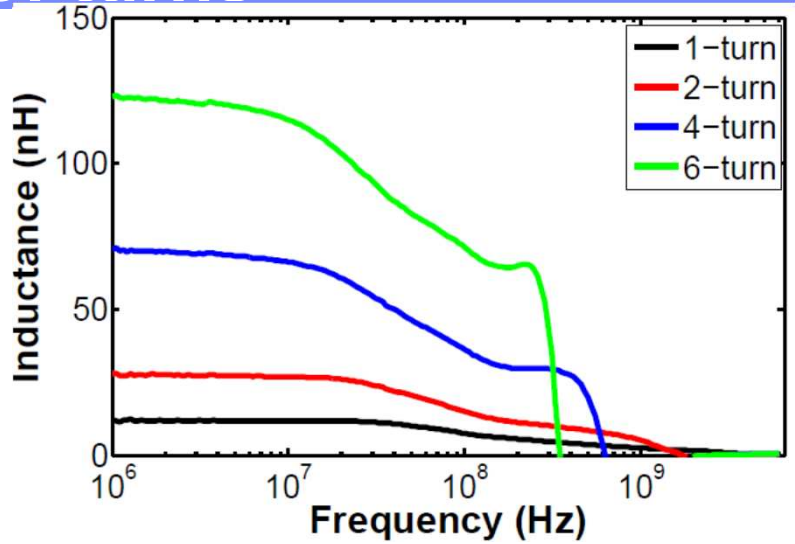


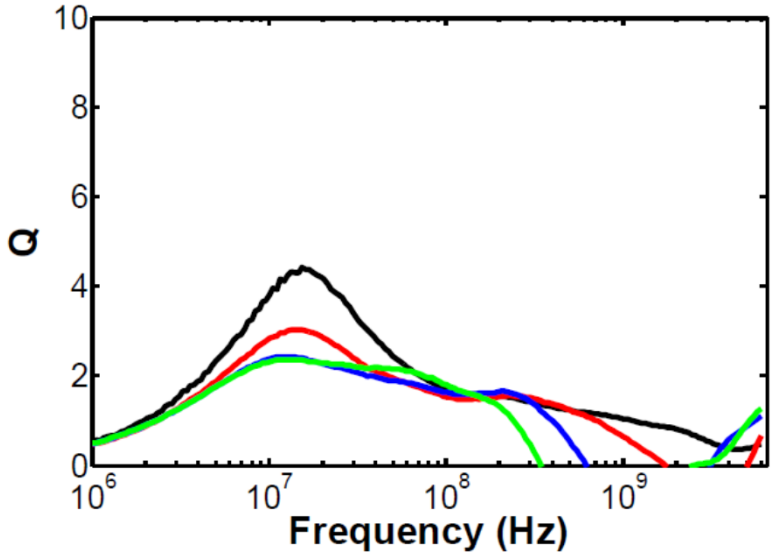
- **Inductance enhanced by 4× and 6×**
- **Inductance proportional to the yoke thickness**

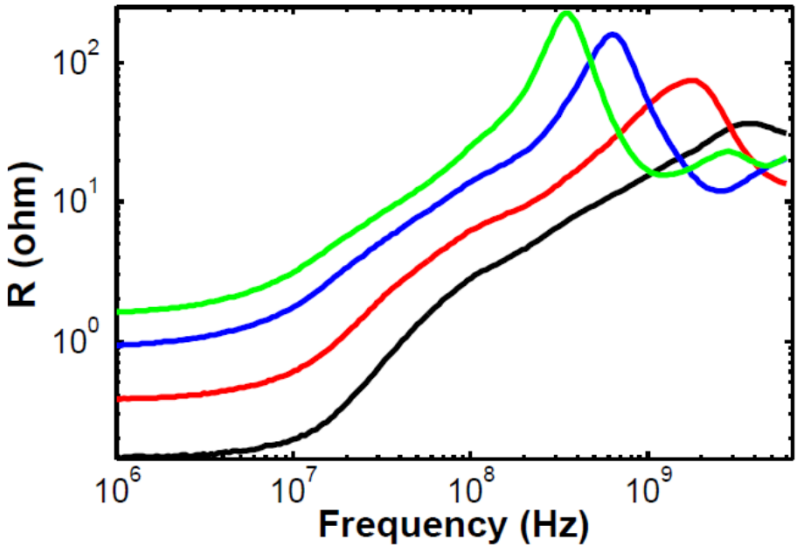
Inductor performance – # of turns



1.5 um thick, 1 mm-long yoke

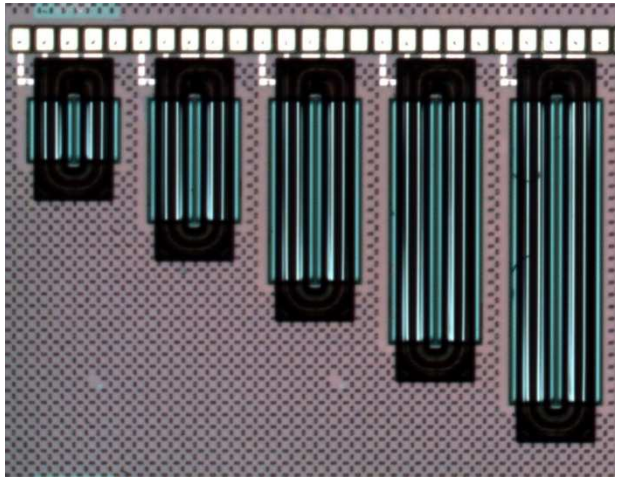


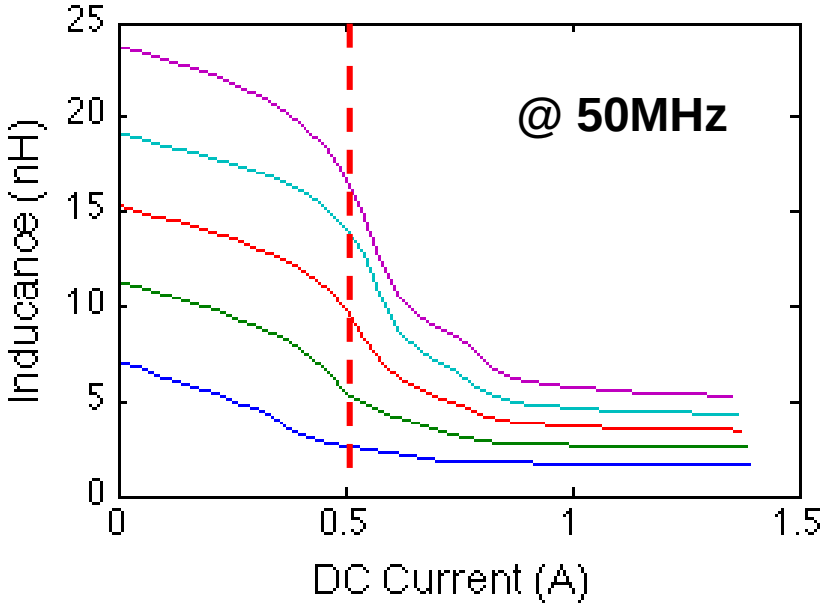


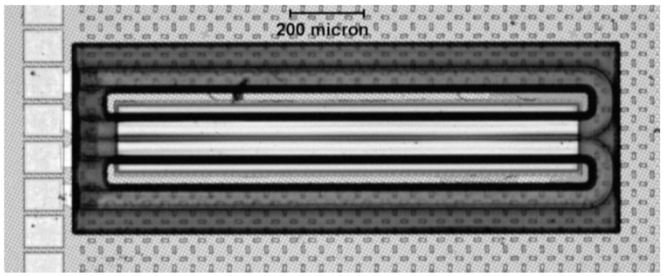


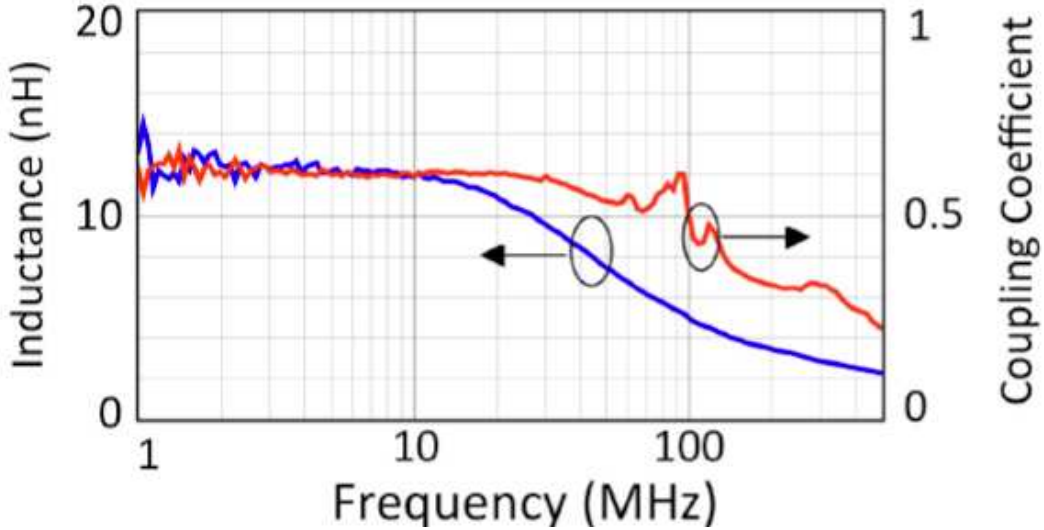
- Inductance reaches up to 125 nH.
- Self-resonant frequency decreases due to the increased capacitance.

Saturation and coupling

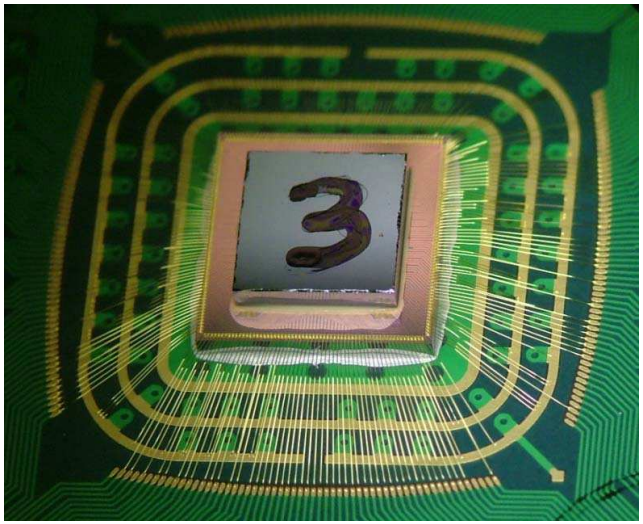


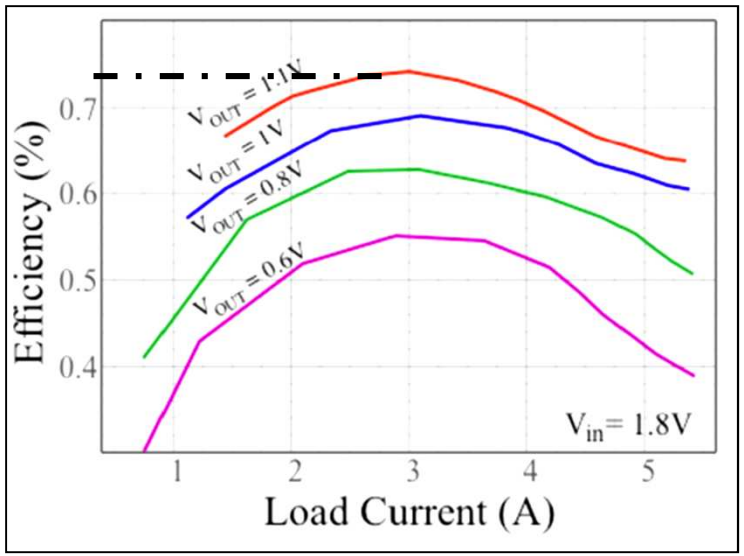




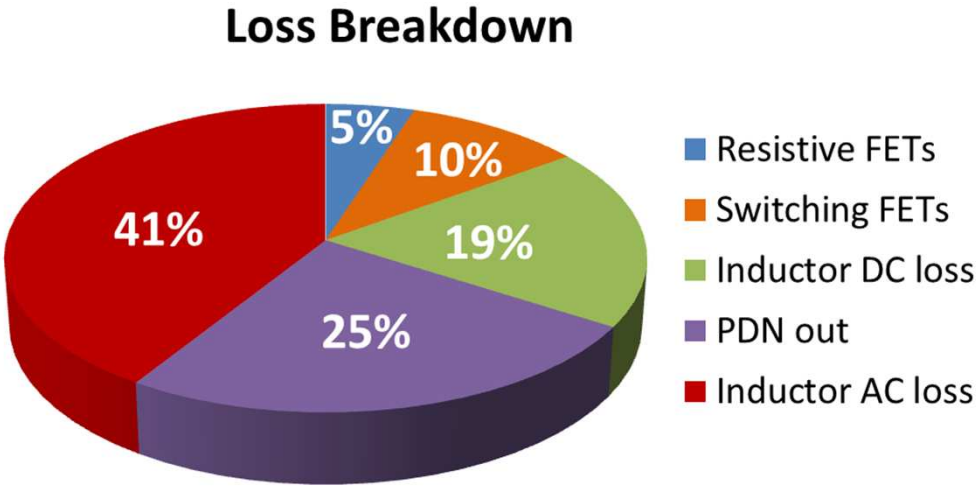


Chip stack – initial results





- Peak efficiency of ~74% at 75MHz.
- Inductors are the primary source of loss.
- High resistive material and/or lamination.



Dr. Shepard's presentation on Saturday

Summary

- We have developed processes for batch fabrication of magnetic inductors using thin film head integration technologies.
- The inductors show enhanced inductance, but low Q due to eddy current loss.
- High frequency losses can be reduced by using laminated yokes and/or new magnetic materials.