Manufacturing Development of a New Electroplated Magnetic Alloy Enabling Commercialization of PwrSoC Products

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PowerSoC 2012

CONTENTS

- Definitions and business motivation
- Technology landscape and roadmap
- Need for Wafer Level Magnetics
- Path to PowerSoC
- FCA alloy introduction
- Device design considerations
- Transfer to production challenges and strategy
- Conclusions

POWER MANAGEMENT MARKET FORCES

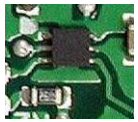
Energy Savings

Complexity

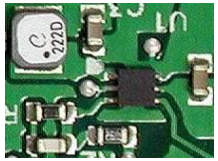
Higher Data Speeds

Industry wide demands are challenging power designs to deliver
Higher Efficiency, Smaller Size and **Lower Noise @ LOWEST Cost**

Traditional Solutions

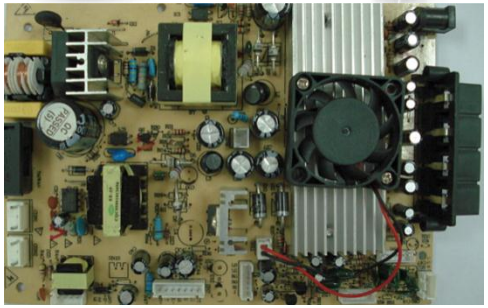


Linear Regulators



DCDC Switching Converters

Power Supply Solutions

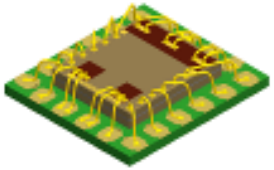


Emerging Technology

PSiP

&

PwrSoC



OVERVIEW

- Market forces are driving Power Electronics towards Power System in Package (PSiP) and even further towards Power System on Chip (PwrSoC)

- Enpirion's customers driving Power-System-on-Chip integration to enable smallest footprint, highest performance, higher reliability without compromising cost per watt
  - Enpirion shipped PSiP in 2005

- Enpirion is commercializing first PwrSoC based on Wafer Level Magnetics – FCA technology in 2012

WAFER LEVEL MAGNETICS INTEGRATION

(Enabled by Operating at High Frequency)

Discrete

High Part Count

Large Foot Print

Layout Issues

Noisy signals on PC Board

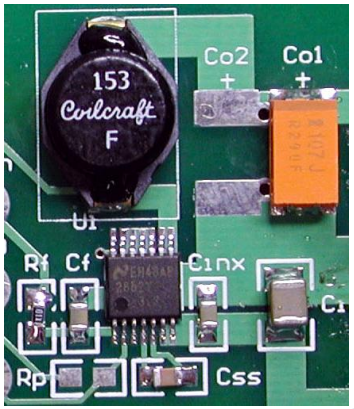
Power SoC

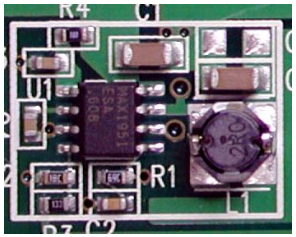
3 external capacitors

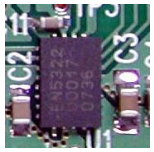
Very small foot print

Smaller value capacitors

Very quiet signals on PC board



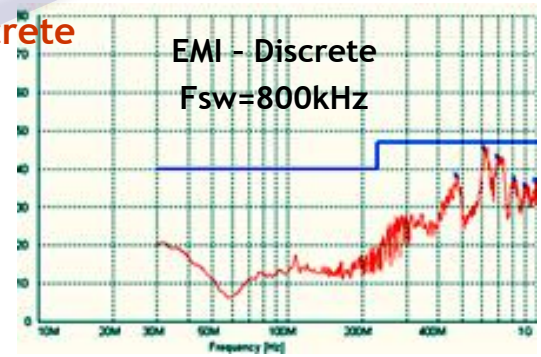


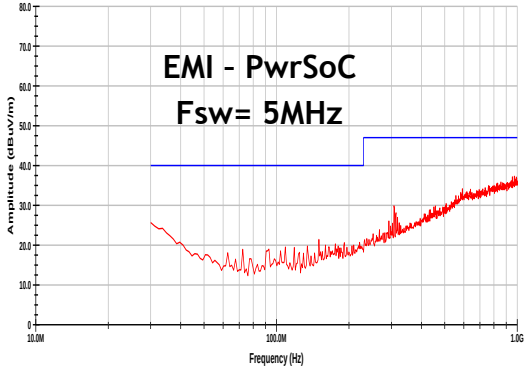


High Frequency
Power SoC

Medium Frequency
Discrete

Low Frequency
Discrete

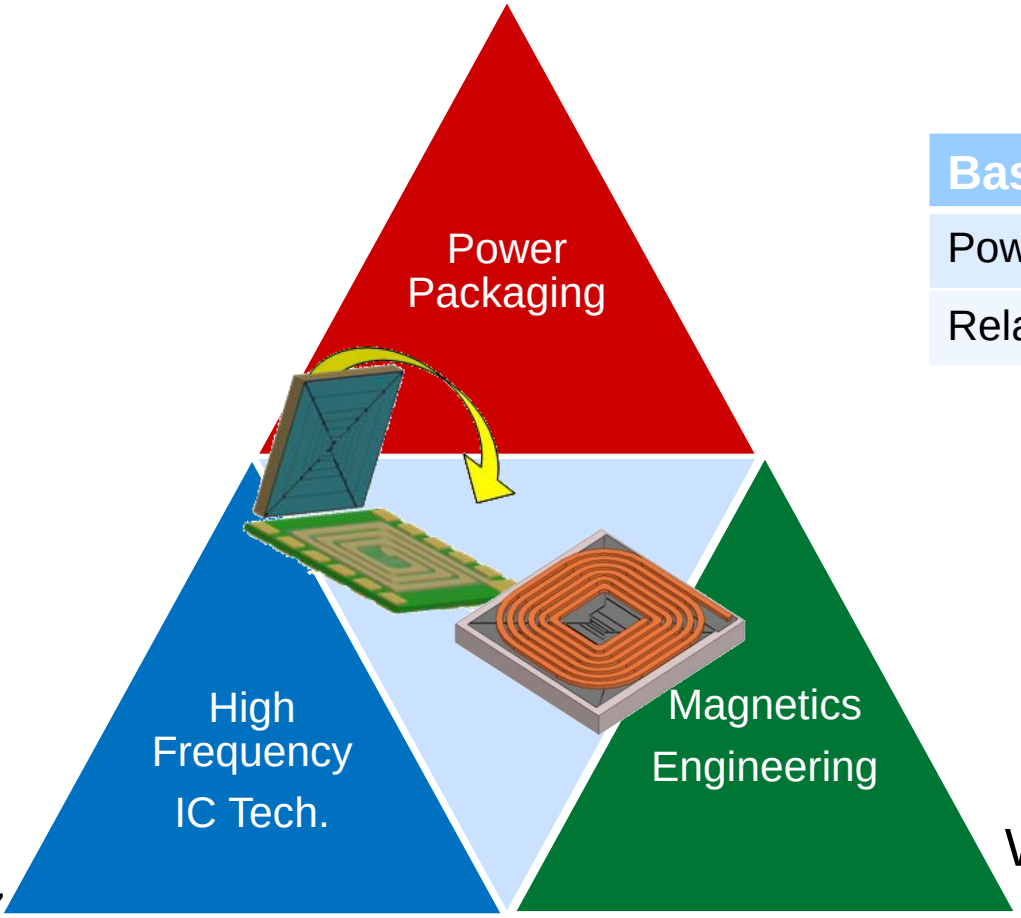




3-PRONG TECHNOLOGY DEVELOPMENT

(2012: Gen 4; PwrSoC Introduction)

Spiral Coils in Package

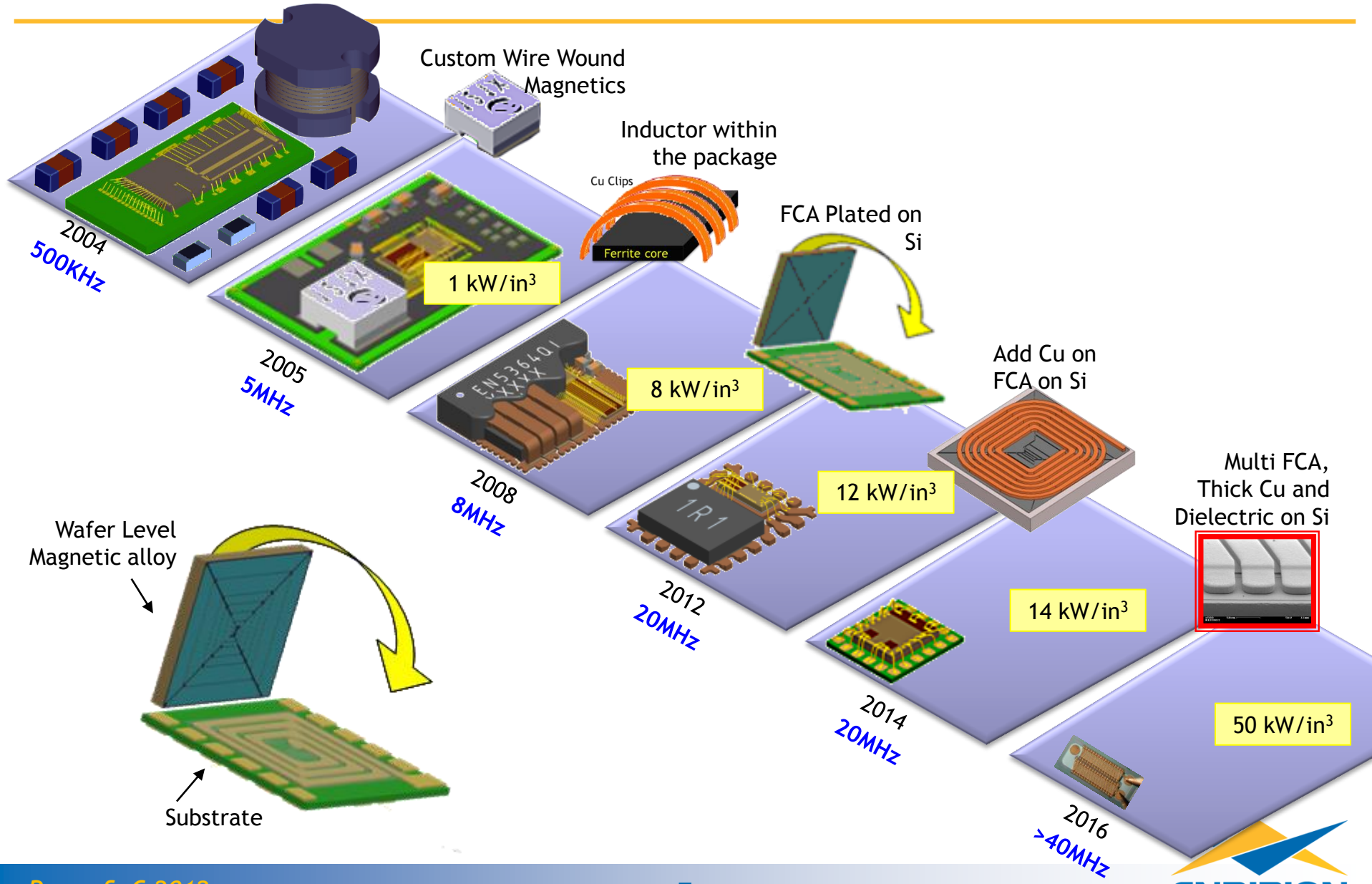


Basic Metrics	
Power Density	8 kW/in^3
Relative Cost	1/8 Baseline

20 MHz
LDMOS

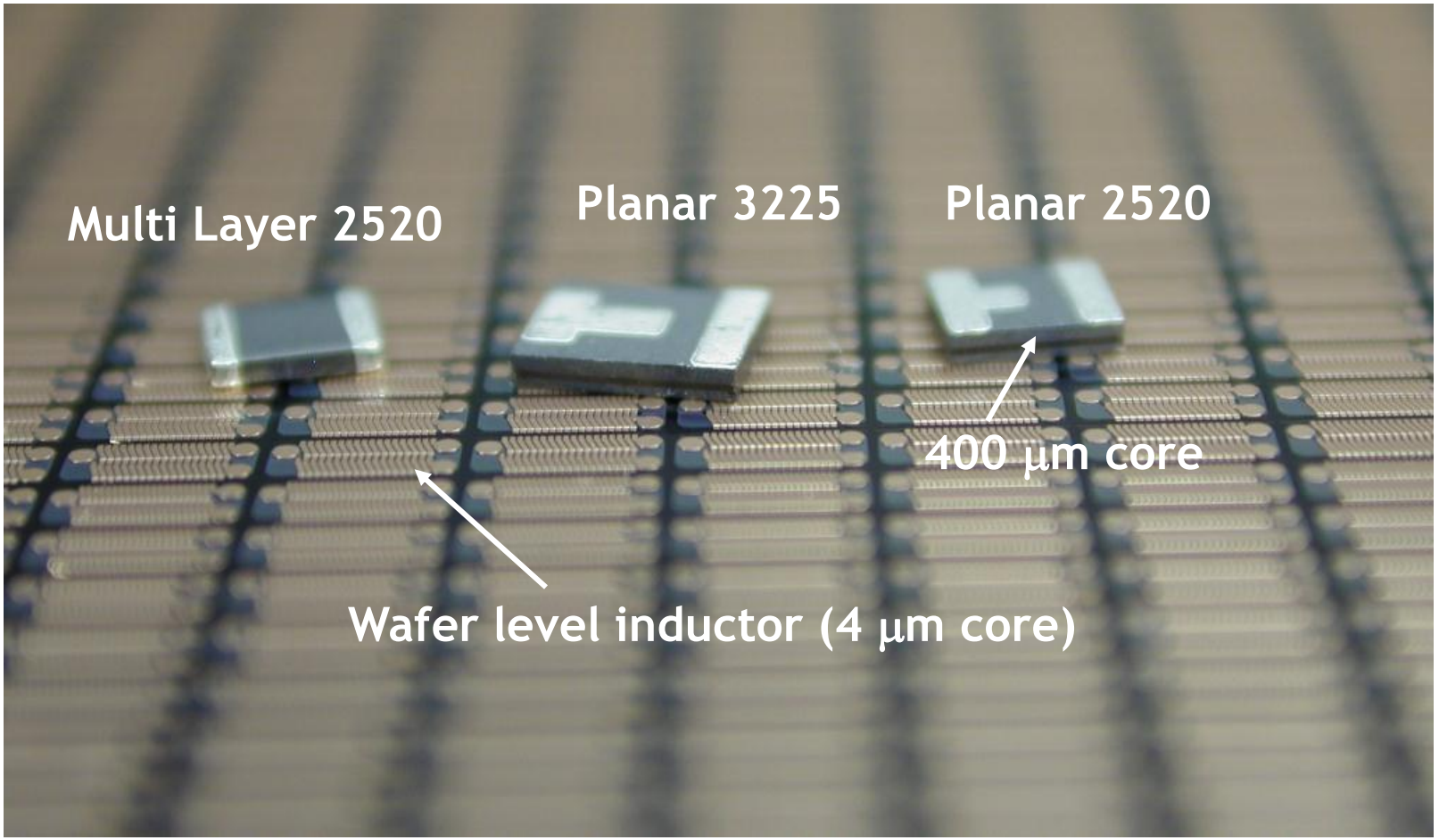
Wafer Level
Magnetics
Silicon Process

DC-DC POWER CONVERTER INTEGRATION



WAFER LEVEL MAGNETICS

(Going from 3D to 2D)

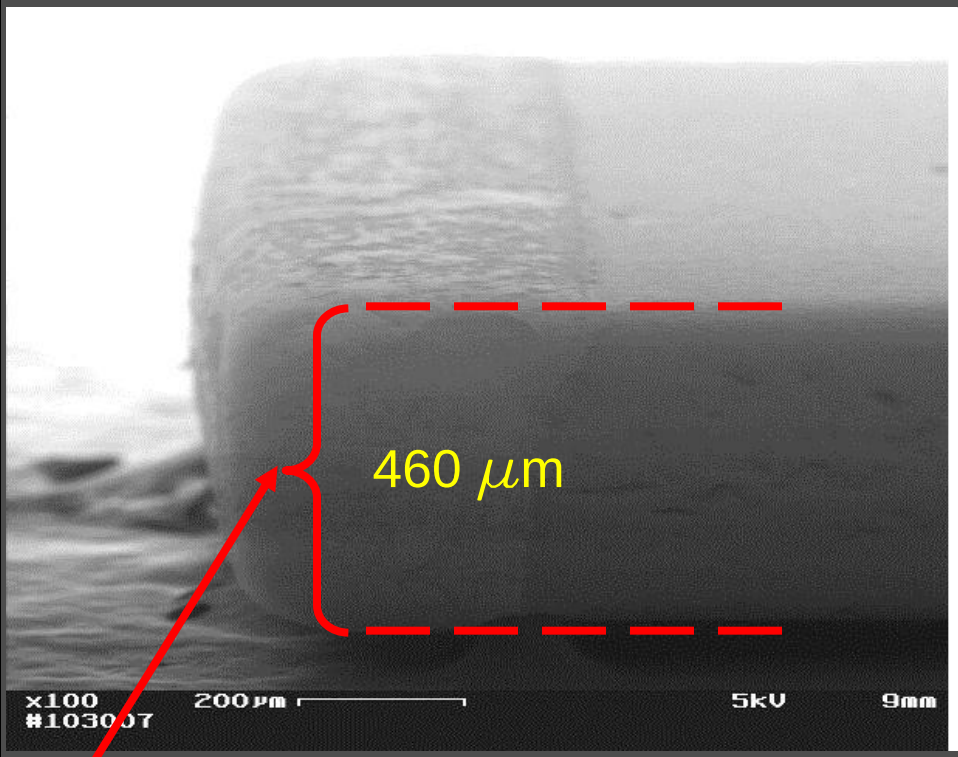


FCA film magnetic core is ~100 times thinner than discrete inductor core

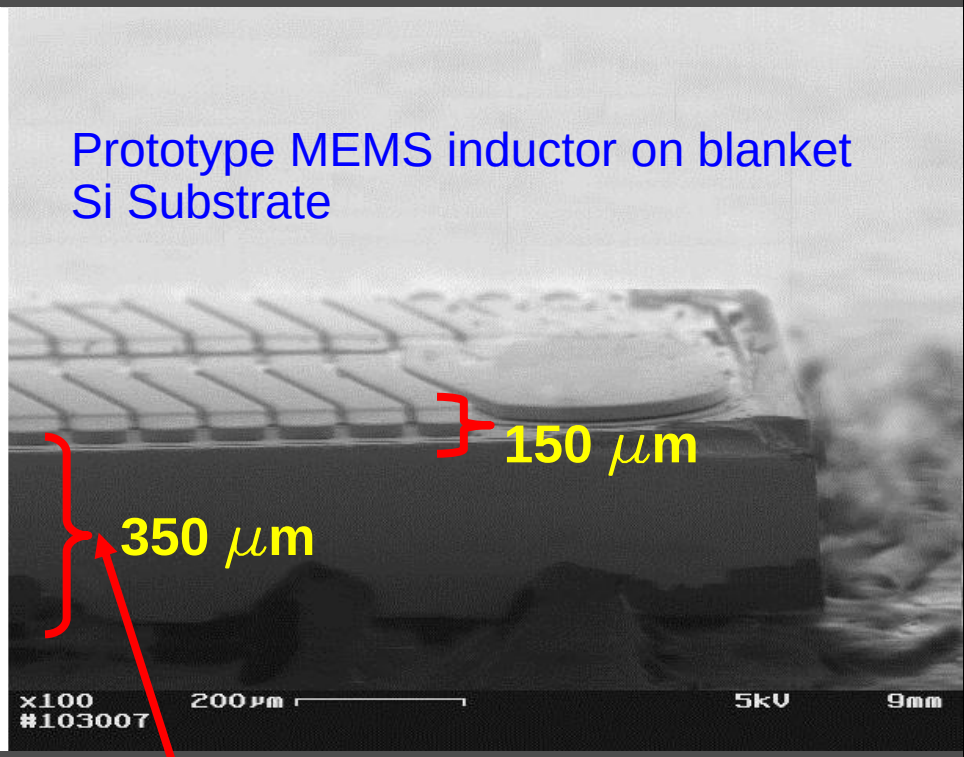
OUR VISION: COMPLETE DC-DC SOLUTION

(In less volume than a tiny discrete inductor)

- In scale size comparison -



Just a Discrete Inductor

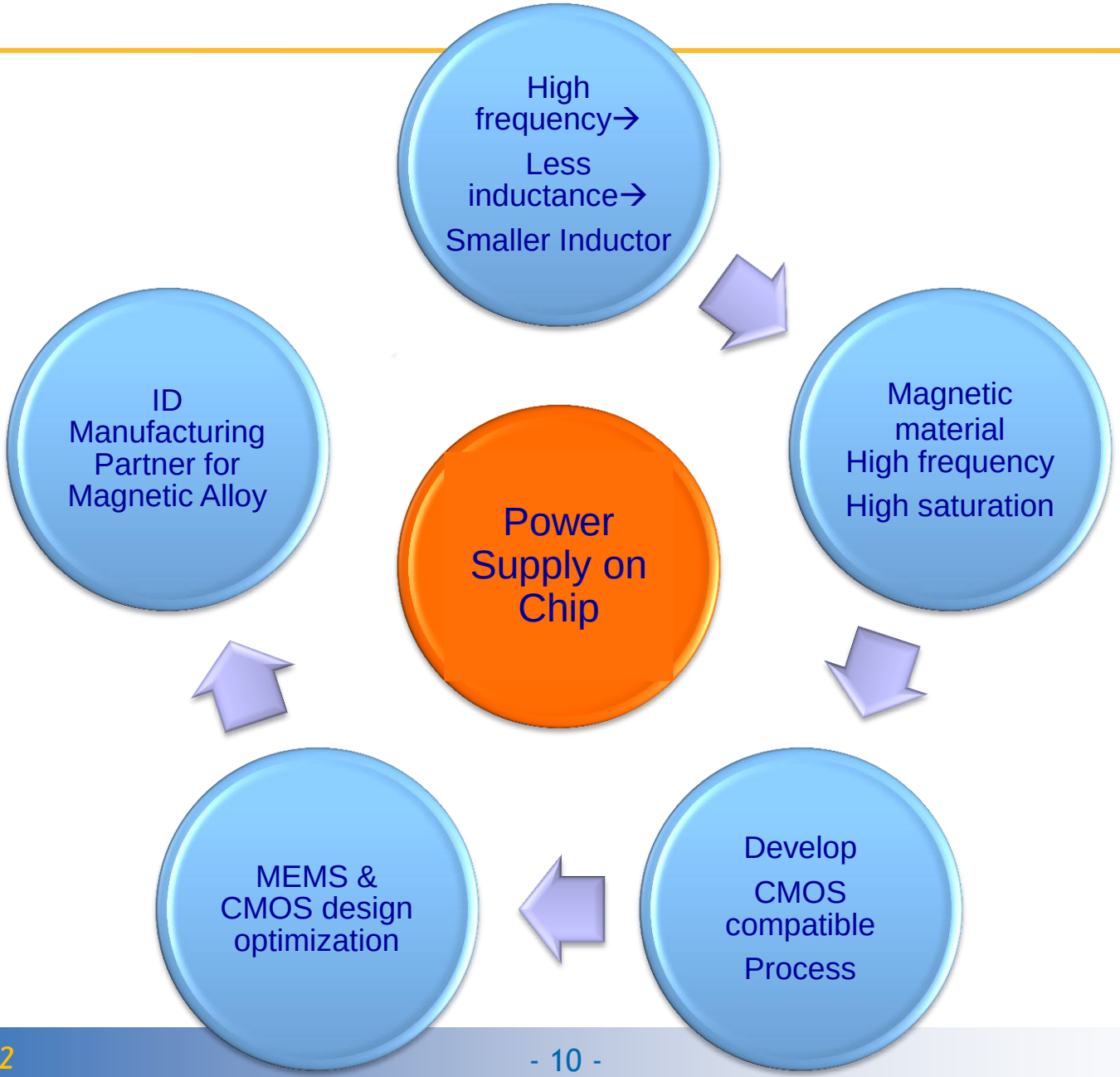


Monolithic Solution:

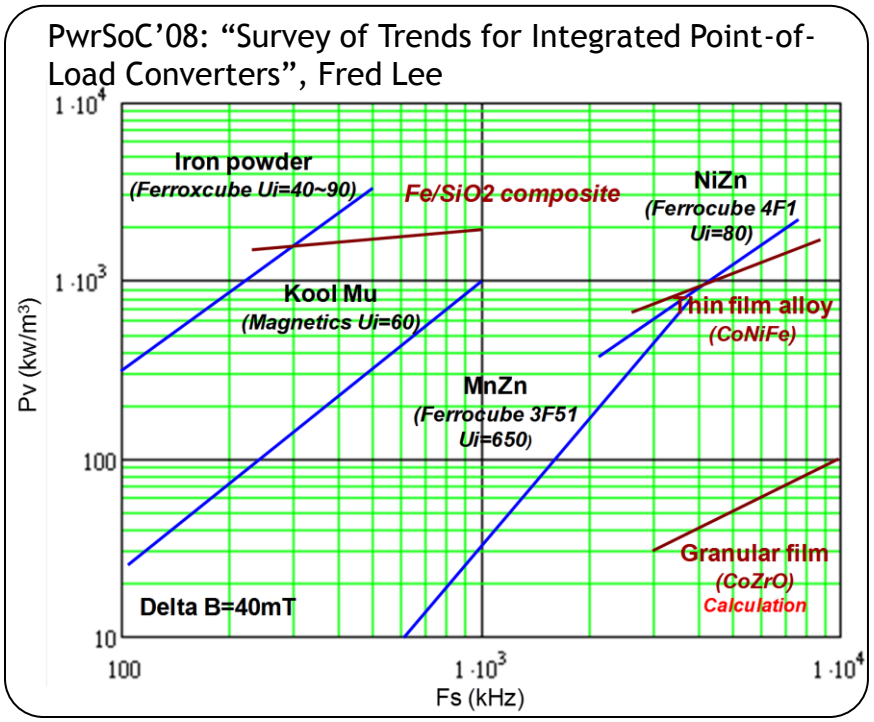
Active Inductor(~150 μm)

CMOS buck-boost circuitry

BUILDING INTEGRATED POWER CONVERTER



CHOOSING THE ALLOY;
(Power SoC Magnetic Materials Used)



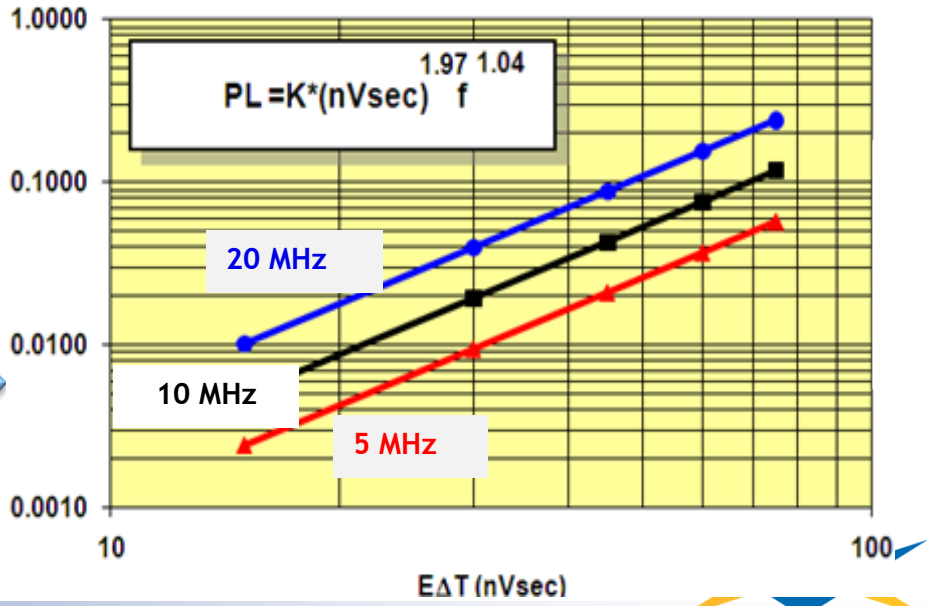
- **An Fe-Co Alloy (FCA) was developed:**
- Amorphous → high resistivity ρ>120μΩ cm
- Wafer compatible electroplating process
- Film thickness: **2-20μm**
- High magnetic saturation **Bs>1.5T**
- Maintain permeability at **freq > 25MHz**

From many materials

Thin-film Fe-Co Alloy is chosen (B_{sat} = 1.5 T)

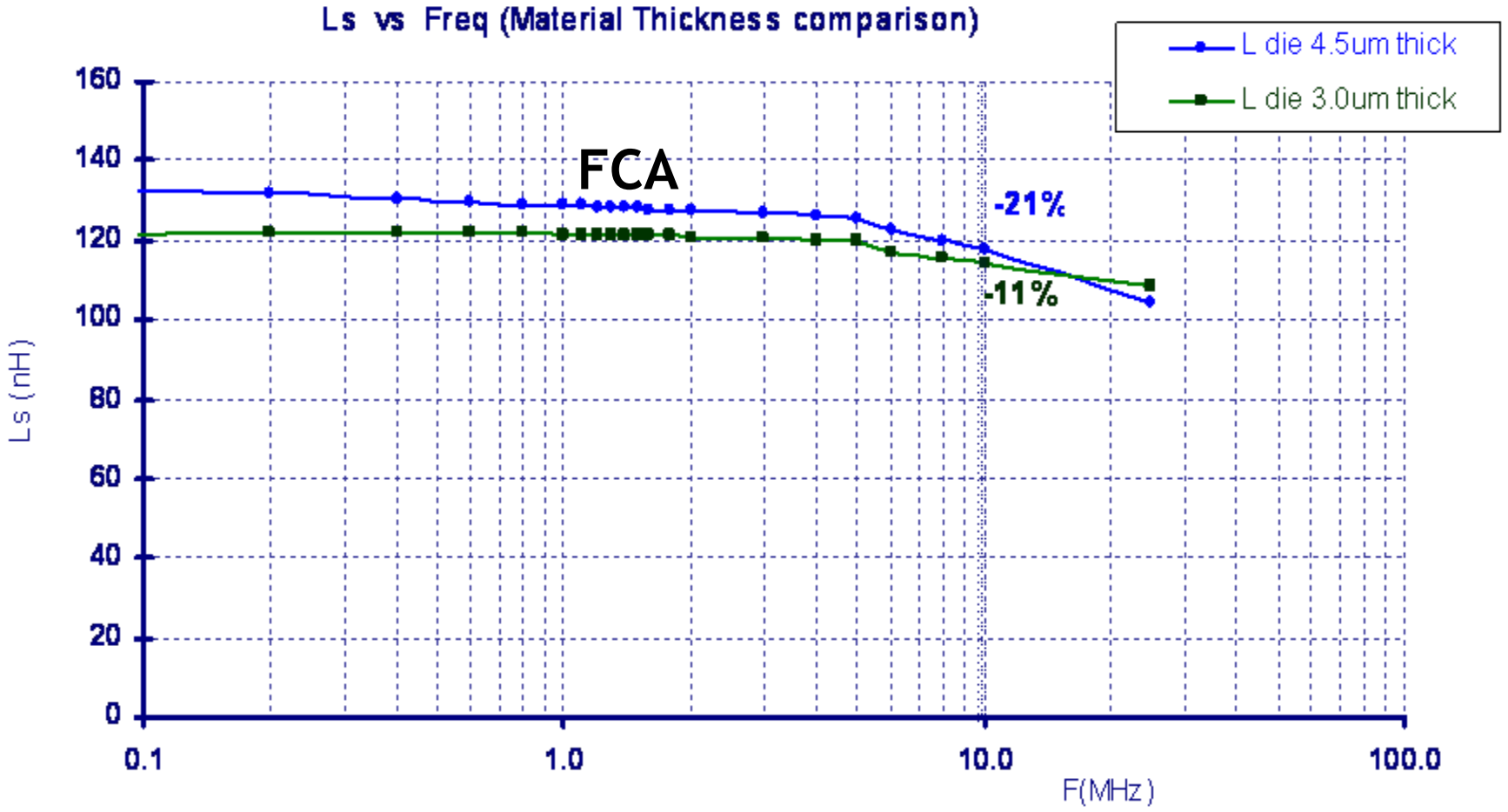
Truly post CMOS compatible process

Fe-Co Alloy inductor AC Loss, Watts



FCA MAGNETIC MATERIAL

(High Frequency Performance)

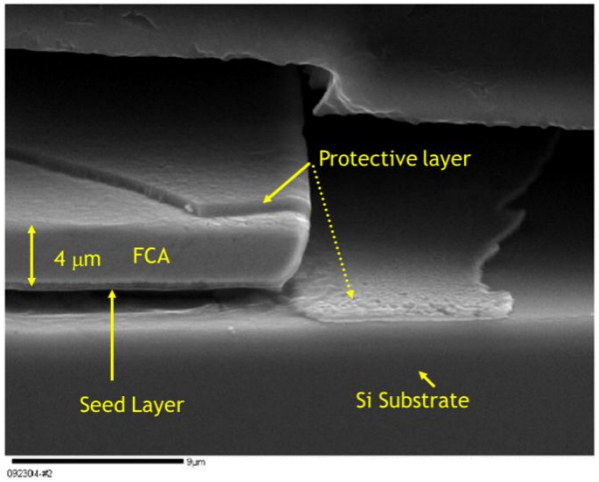


FCA MANUFACTURING
(Process Challenges)

- Stress
  - Impact on front end assembly processes – back grind, dicing
  - Impact on electrical characteristics

- Magnetic Alloy Consistency
  - Composition
  - Thickness

- Optical Inspection Standards
  - Impact on electrical performance
  - Impact on reliability



- Electrical Performance Validation
  - Magnetic Coupling (magnetic material)
  - Galvanic Connection (inductor on wafer)

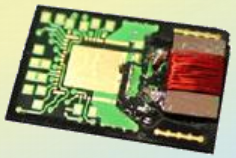
PROCESS CONTROL

(Development and Pilot Phase Tests)

Plating development

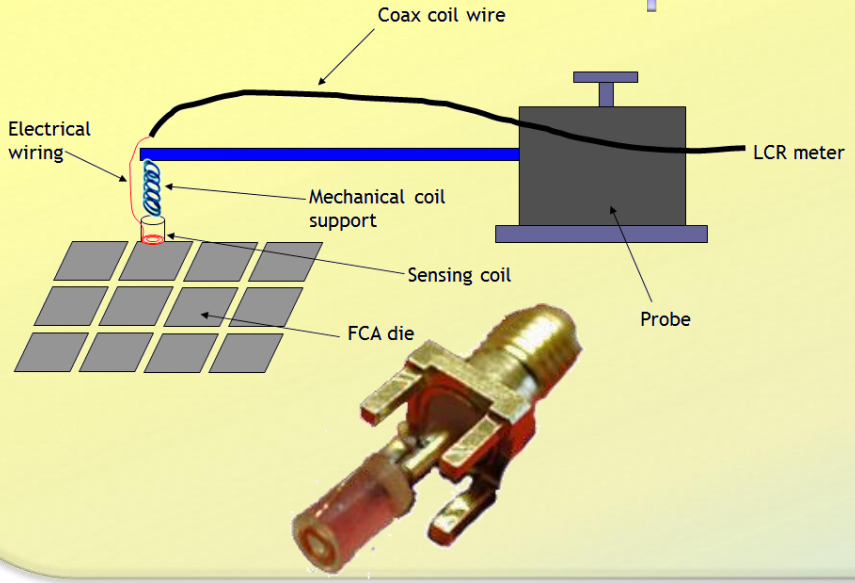
Electroplate FCA on substrates and dice to create FCA cores for tests

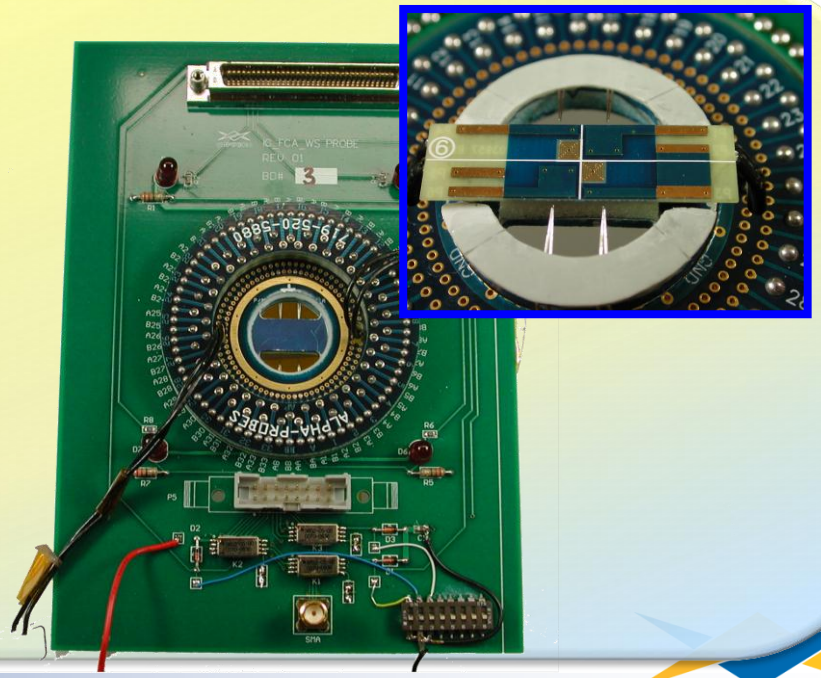
Wire-wound the cores and measure FCA performance



Mount on test substrate and characterize inductor

Product development





PROCESS CONTROL IN PRODUCTION

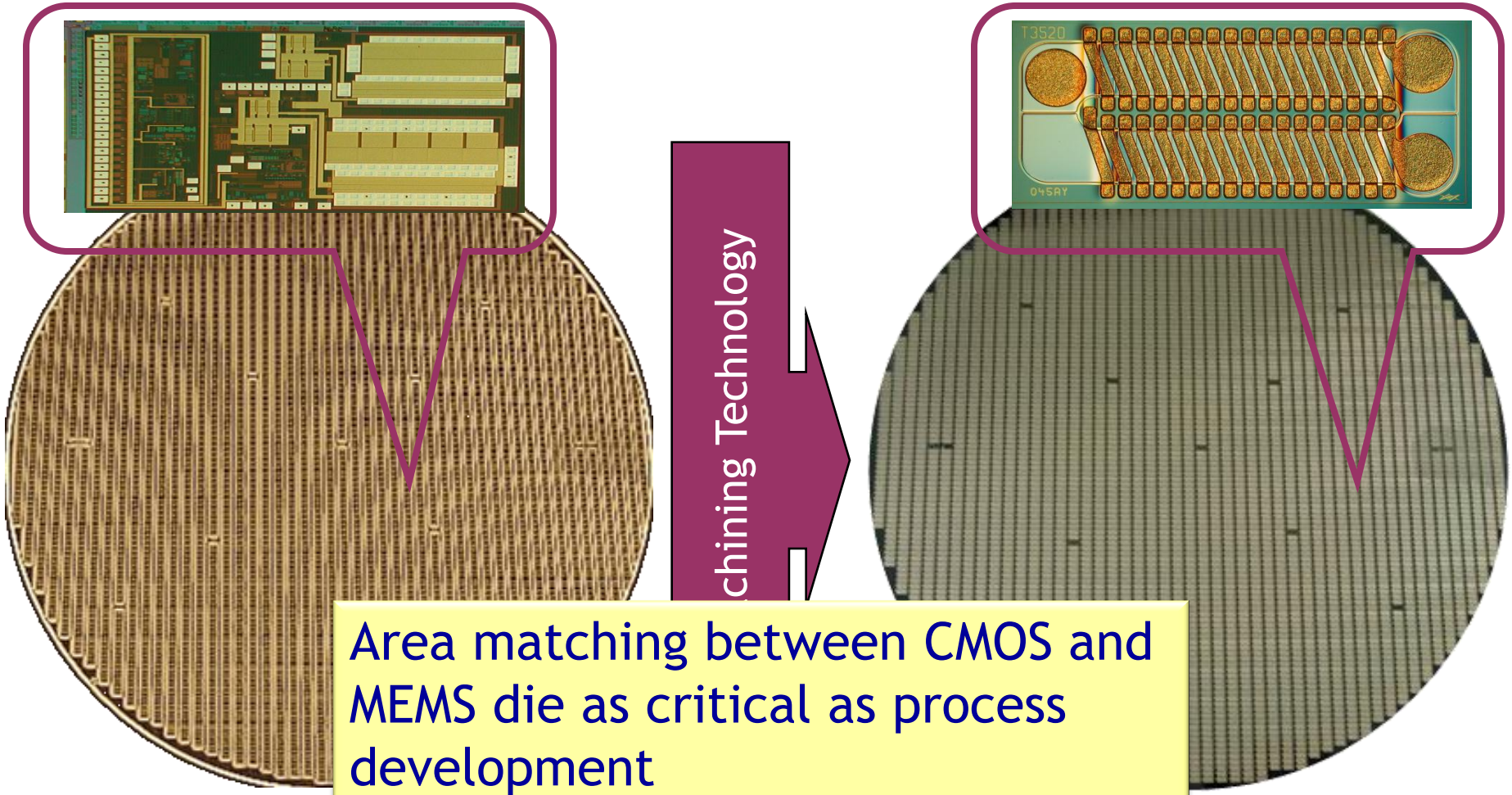
(Tests and Measurements)

- Establish correlation of plating process and procedures with deposited alloy characterization
- Control the plating parameters
  - Current efficiency
  - Current density
  - pH
- Monitor the bath chemistry
- Run material composition validation tests after certain number of plated lots

FCA IS POST–CMOS COMPATIBLE

CMOS wafer

Micromachined wafer

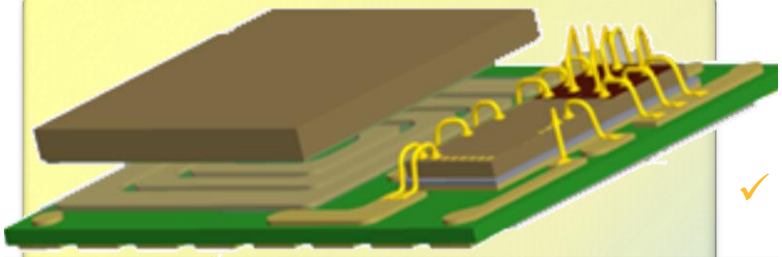


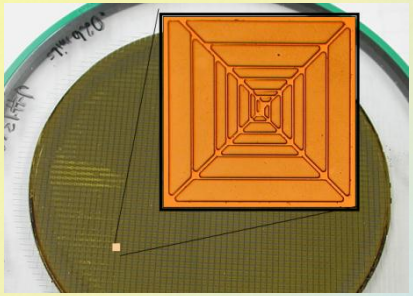
Area matching between CMOS and MEMS die as critical as process development

DESIGN ITERATIONS and DEVELOPMENT

(Quest For Optimum Micro-Inductor Application)

Product

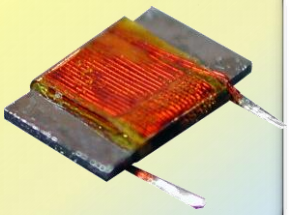




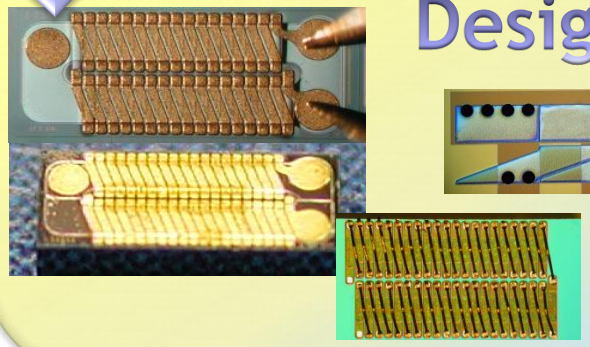
Process

- ✓ Continuous interaction with marketing needs
- ✓ Adaptable process development
- ✓ Device development with production constraints in mind

FCA



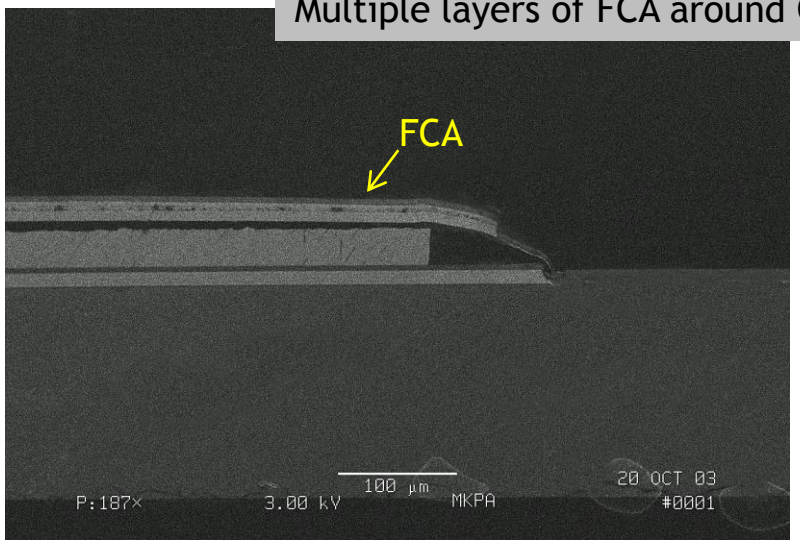
Design

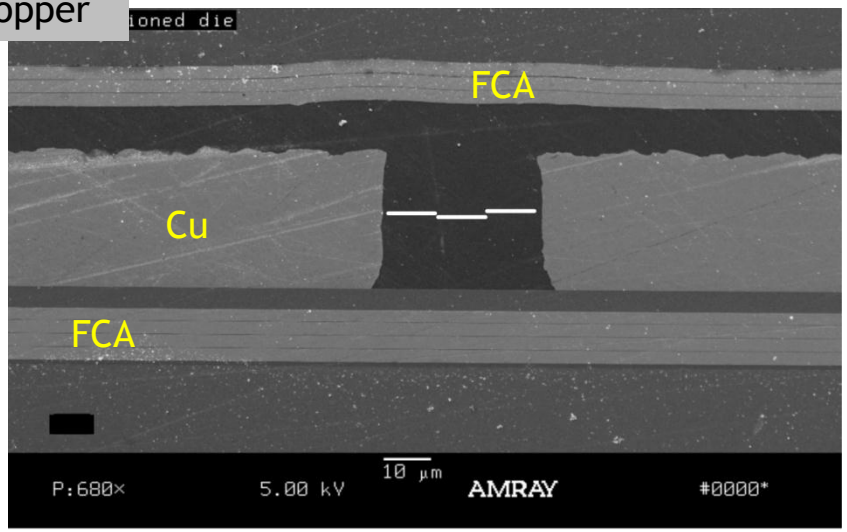


FCA APPLICATIONS

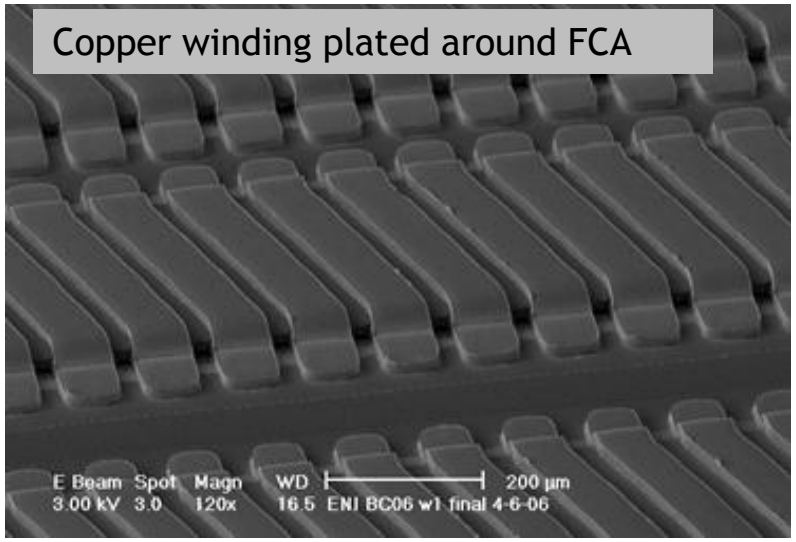
(Multi – layers deposition is possible)

Multiple layers of FCA around Copper

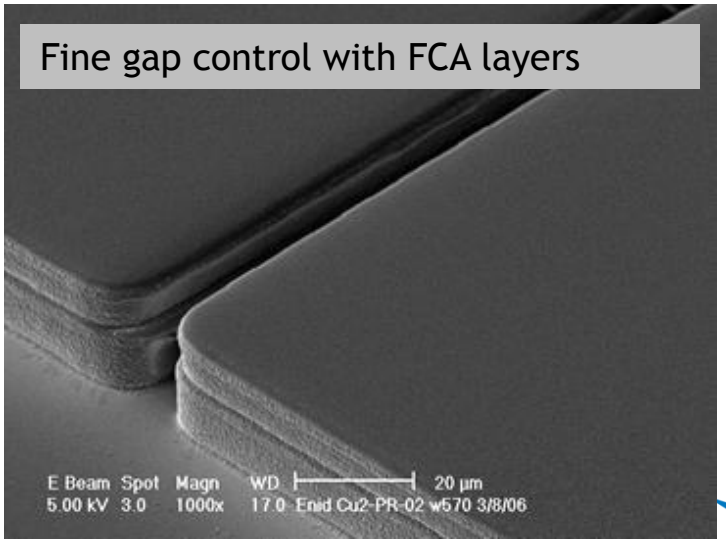




Copper winding plated around FCA



Fine gap control with FCA layers

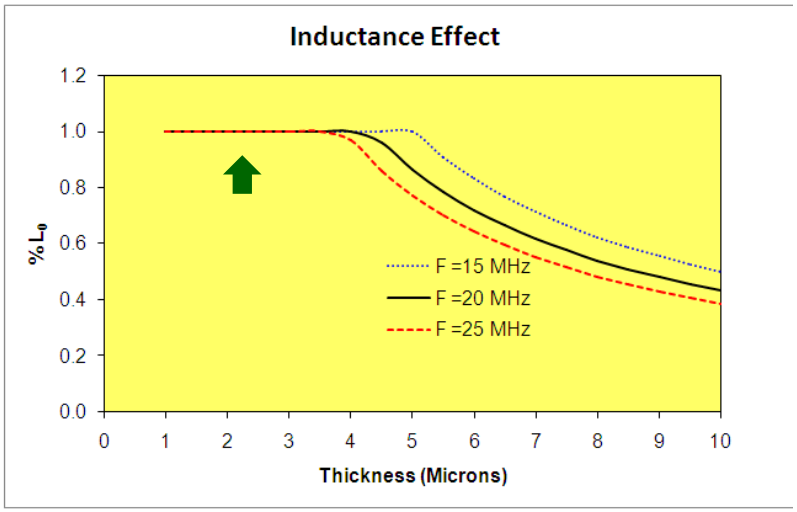


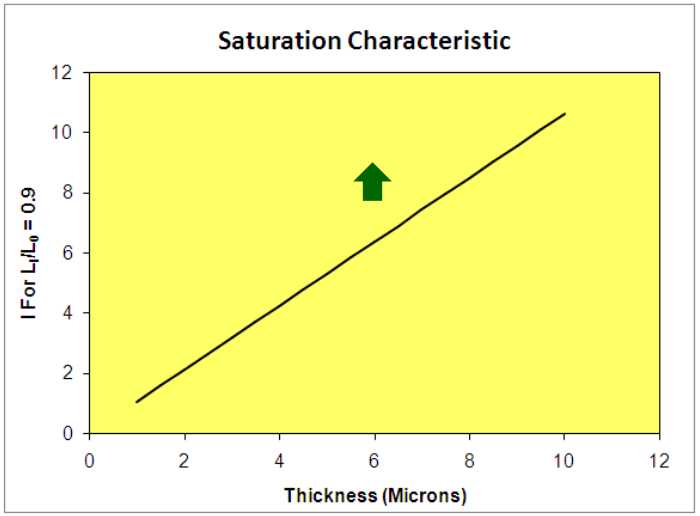
ENPIRION

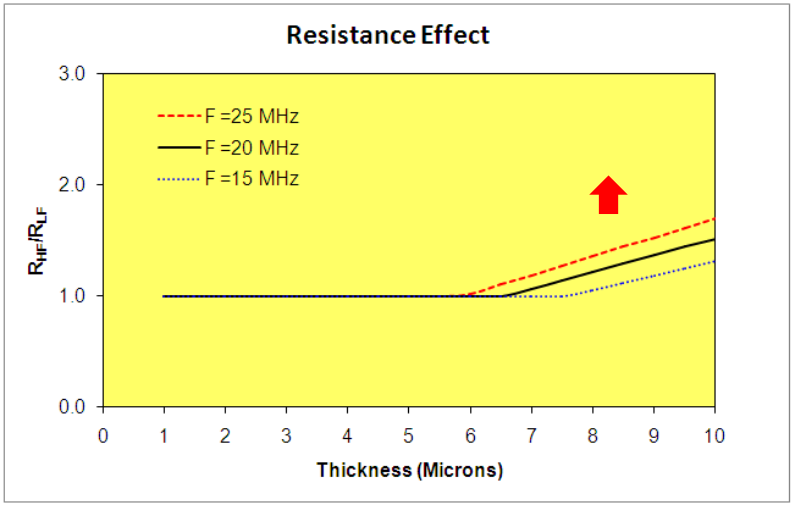
FCA DESIGN CONSIDERATIONS & TRADE OFFS

(Effects of Magnetic Alloy Thickness Variation)

- L_0 Distribution
  - Thick ⬆
  - Thin ⬇
- L Vs I
  - Thick ⬆
  - Thin ⬇
- R_S Vs F
  - Thick ⬆
  - Thin ⬇



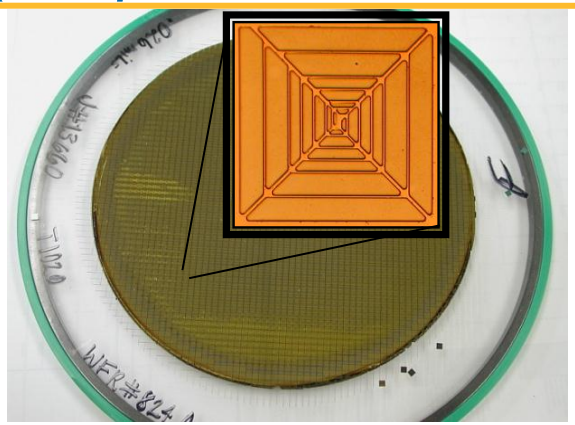




Must balance the benefits of thicker film with the Power Loss penalty

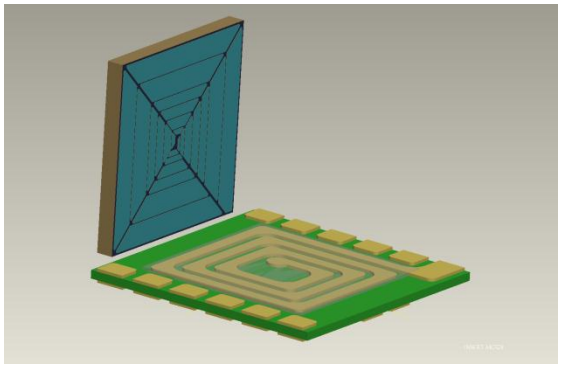
Introduction of Wafer Level Magnetic

(Simple but effective inductor design at mature process cost)



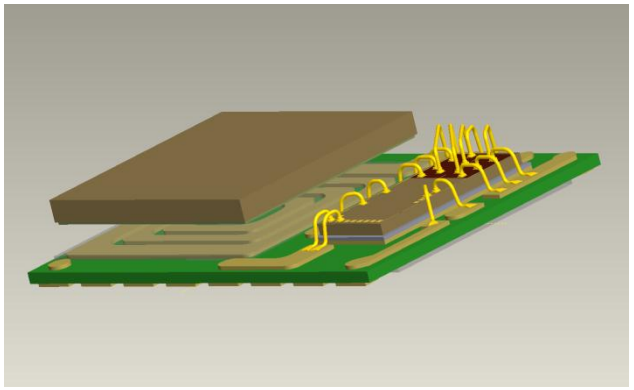
Step 1.

Electroplate FCA on wafer



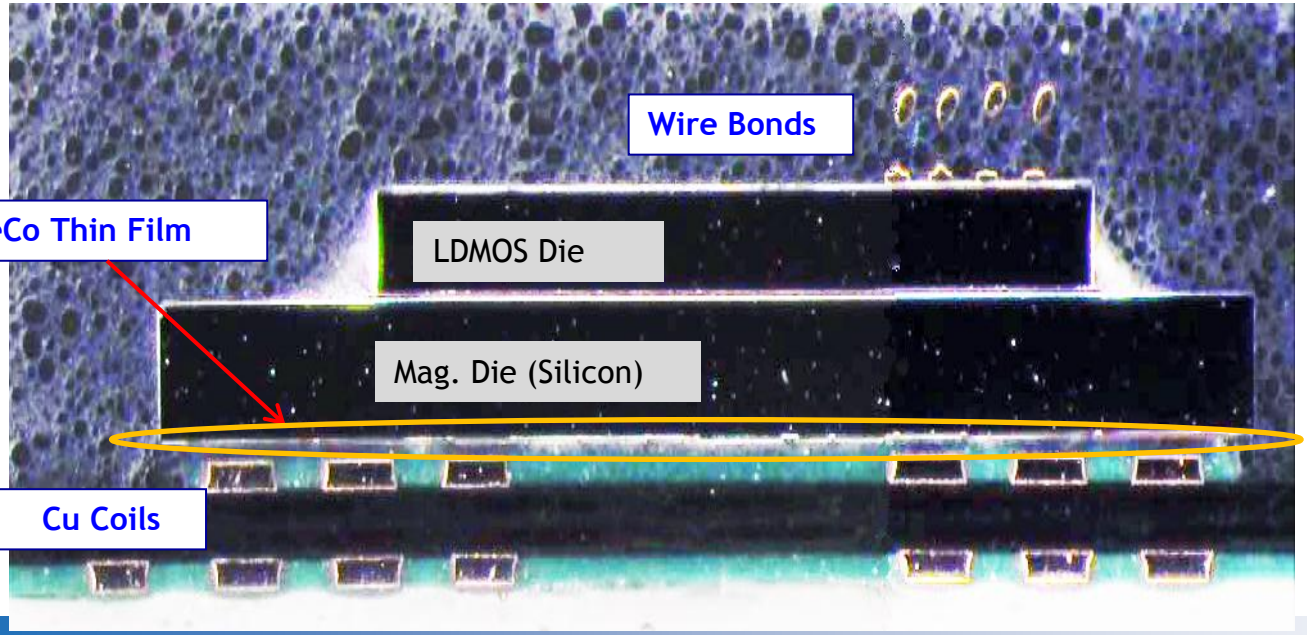
Step 2.

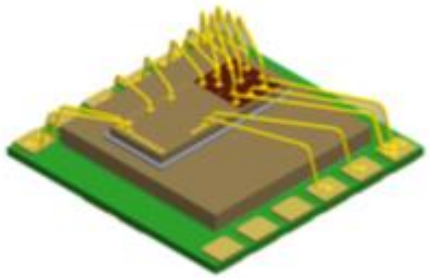
Flip FCA over a Cu spiral coil



Step 3.

Package PowerSoC





TRANSFER MAGNETIC PLATING IN WAFER FABS

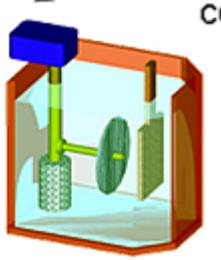
- Traditional wafer fabs are not compatible with magnetic plating process
- Back end wafer processing fabs are more suitable for magnetic plating
  - Wafer bumping fabs
  - Cu redistribution layer fabs
- Packaging facilities with post-CMOS processing are found to be ideal
- Lower the COST & TIME barrier of process development
  - Simplify manufacturing process (simple but effective design)
  - Process transfer rather process development
  - Prepare turn key process module ready for transfer with minimum or no capital investment
- Address materials and consumables requirements, restrictions and availability in the production facility
  - Import / export restrictions
  - Shipping costs and taxes
  - Lead times and quality standards

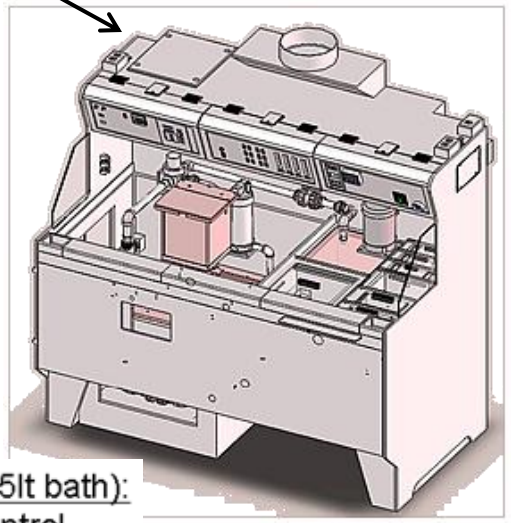
ENPIRION's PATH TO PRODUCTION

- Proof of concept
  - Small scale prototype (Bench top)
- Design and build production equipme
- Setup an FCA pilot facility
  - Process validation
  - Generate engineering samples
- Enable turn-key plating process module
  - Includes: Chemistry, process and equipment
- ID partner foundry for early stage process support and volume production'
- Transfer process / equipment in production line
- Qualify production process

Beaker experiments:
FCA Proof of concept

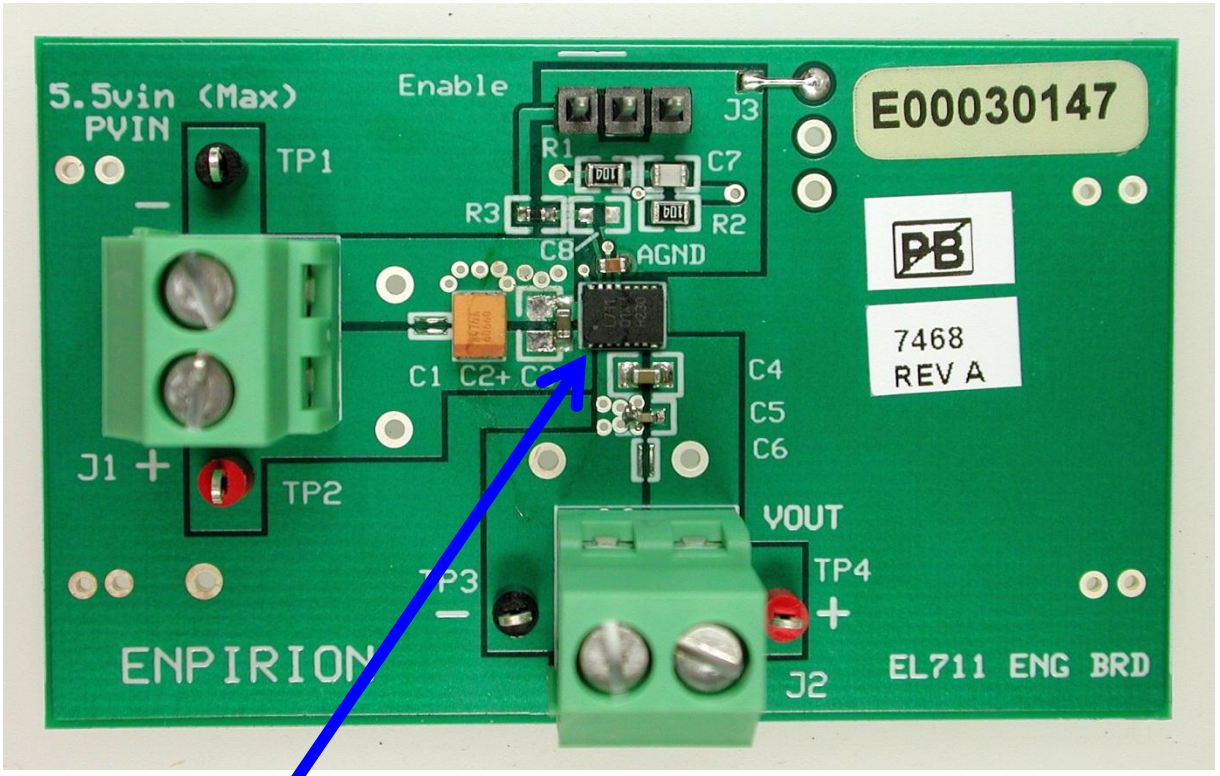
6" wafer plating cell (10lt bath):
chemistry control and cell design





6" or 8" wafer plating tool (55lt bath):
•Large volume chemistry control
•Wafer throughput improvements (some automation)
•Mixing and rinsing procedures

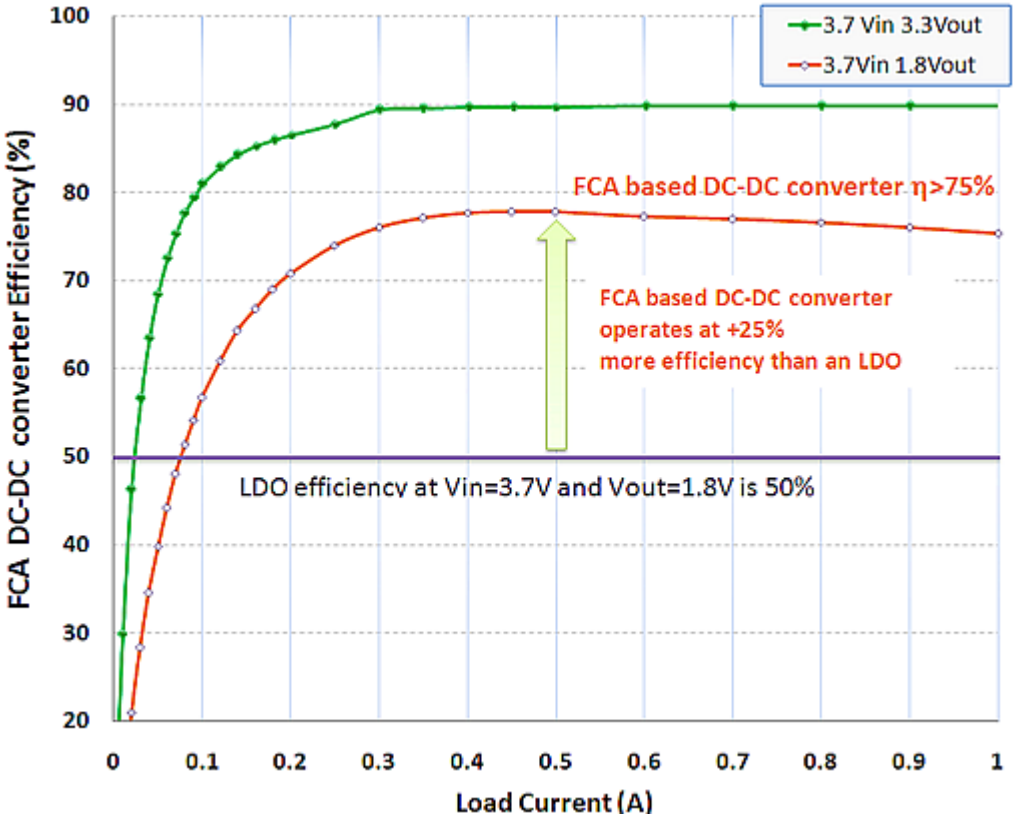
IN PRODUCTION FIRST PowerSoC

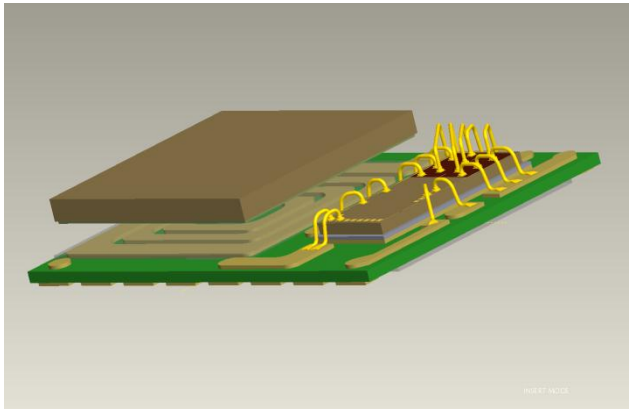


EL711 – First PowerSoC DC-DC (1Amp) converter

FCA in Enpirion's first PwrSoC product

- Enpirion implement FCA in its first PwrSoC product
- FCA offered +25% improvement in efficiency over existing solutions





WAFER LEVEL MAGNETICS
(Other possible FCA Applications)

Magnetic Passives: Inductors, Transformers, Isolators

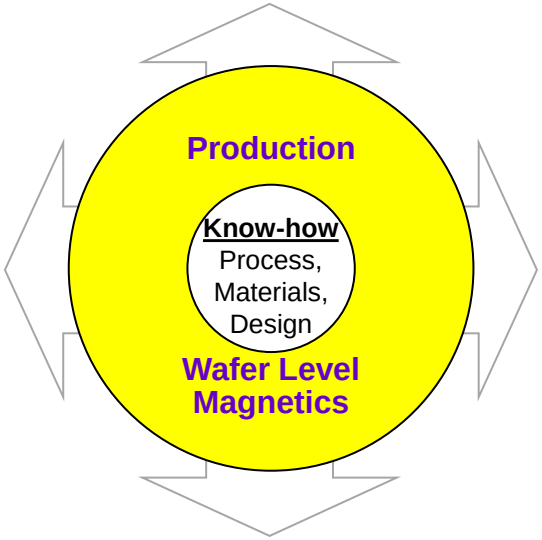
Target Markets:

Telecomm Industry, Mobile phones

Magnetic Actuators: Sensors & electromagnets

Target Markets:

Industrial, Biomedical



Micro magnets: Relays, switches

Target Markets:

Solar energy conversion

Green Energy Harvesting

Magnetic Sensors: Fluxgate…

Target Markets:

Petrochemical drilling, Guidance Systems, Aerospace

CONCLUSIONS

- Power management market drives the need for solutions:
  - Smaller
  - Efficient
  - Cost effective
- Wafer Level Magnetics integration is enabled by operating at high frequencies
- FCA was created to meet the high magnetic performance requirements for Wafer Level Magnetic based power devices
- Develop competitive technology in a cost effective way
  - Continuous interaction with marketing needs
  - Focus on target – product support
- Strategy: Setup a pilot facility to create a transferable FCA plating module
- Identify the right manufacturing partner
- FCA wafer level magnetic core enables industry's first PwrSoC

THANK YOU FOR YOUR ATTENTION