Commercialization Activities for Wafer Level Magnetics

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ENERGY SAVINGS

SIZE REDUCTION

PERFORMANCE ENHANCEMENT

MANUFACTURING SAVINGS

MISSING LINK

Brief Intro

- Trifon Liakopoulos, PhD - CEO and Founder Enachip
  - Prior to Enachip: Altera, Enpirion (co-founder), Bell Labs
  - Integrated Magnetics, MEMS, Materials
- Matt Wilkowski, MS – VP Magnetics Engineering Enachip
  - Prior to Enachip: Intel, Altera, Enpirion, Tyco, Bell Labs
  - Magnetics Technology, Design & Comercialization
- Prof. Mark Allen, UPENN, Founder & Sci. Advisory Board Chair Enachip
  - Scientific Director, Singh Center for Nanotechnology,
    Alfred Fitler Moore Professor
    Electrical and Systems Engineering, Mechanical Engineering and Applied Mechanics
- Jun Beom Pyo
  - PhD Candidate, UPenn

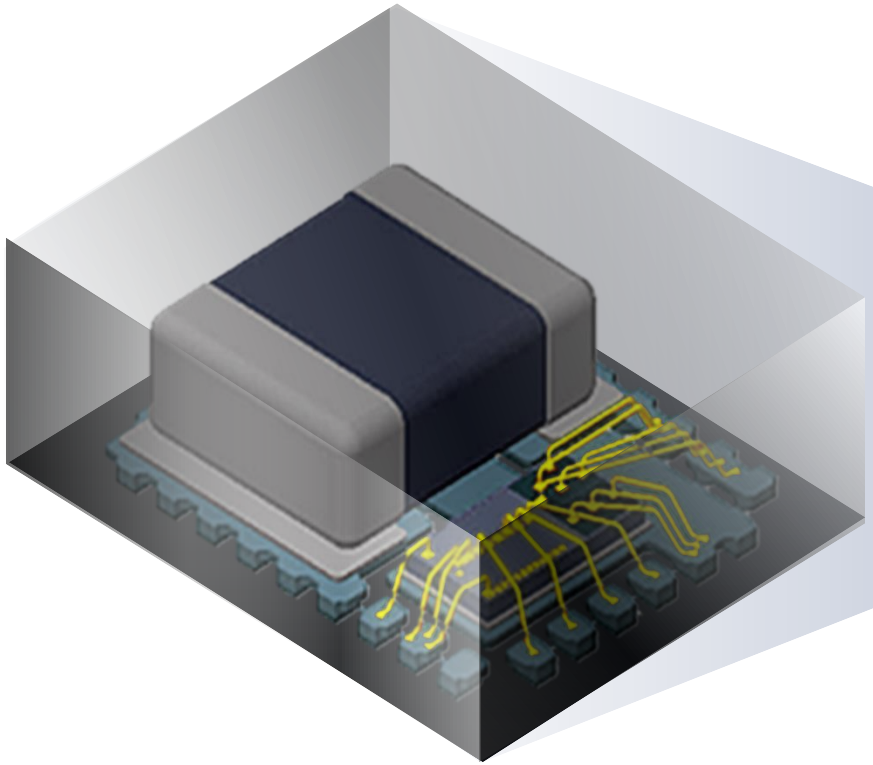
EnaChip Inc. – Intro

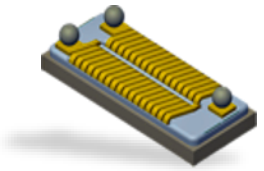
- Enachip *("One"-Chip) started operations in 2018 (early stage, VC funded startup)*
- *Mission: Re-invent Power Management by Commercializing Wafer Level Magnetics*

HQ Located between NYC and Philadelphia (30min south of Newark Airport)

EnaChip – Breakthrough Innovation in Integration

COMMERCIALLY VIABLE TECHNOLOGY THAT INTEGRATES POWER MAGNETICS WITH SILICON IC





20-50% Energy Savings
30x Smaller Size
3x Lower Cost

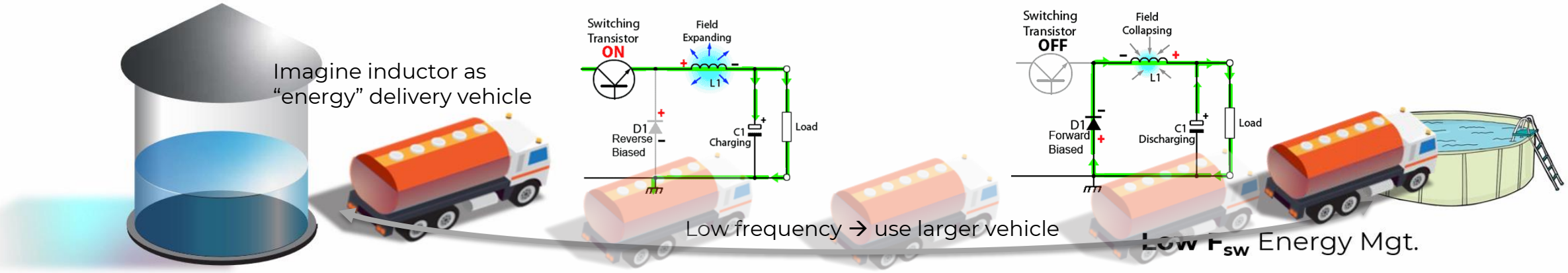
Power System in Package
State of the Art

Power System on Chip
EnaChip Enabled Solution

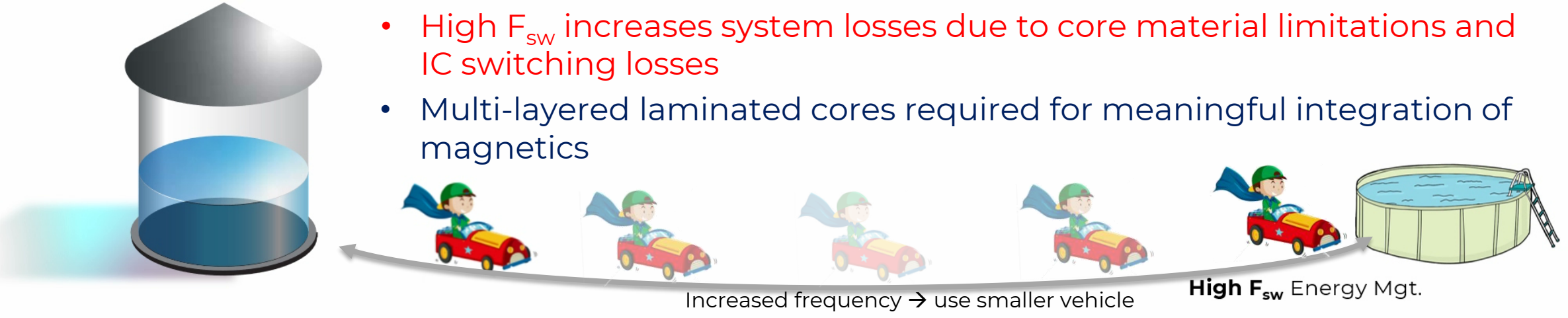
Wafer Level Magnetics

(Si & GaN trends to higher Fsw shift the PwrSoC's bottleneck to magnetics)

The inductor is acting as an energy storage element on a switching converter

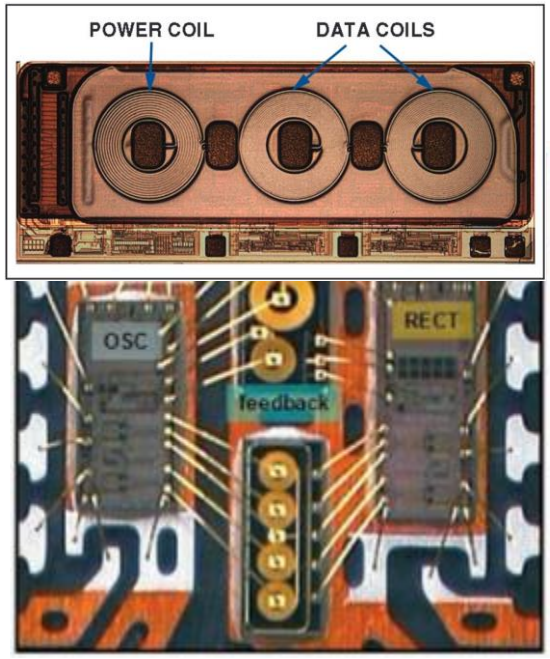


- Core Materials: High B_{sat} allows for size reduction
- Output Power: High F_{sw} allows for size reduction
- High F_{sw} increases system losses due to core material limitations and IC switching losses
- Multi-layered laminated cores required for meaningful integration of magnetics



Wafer Level Magnetics
(Core technology options)

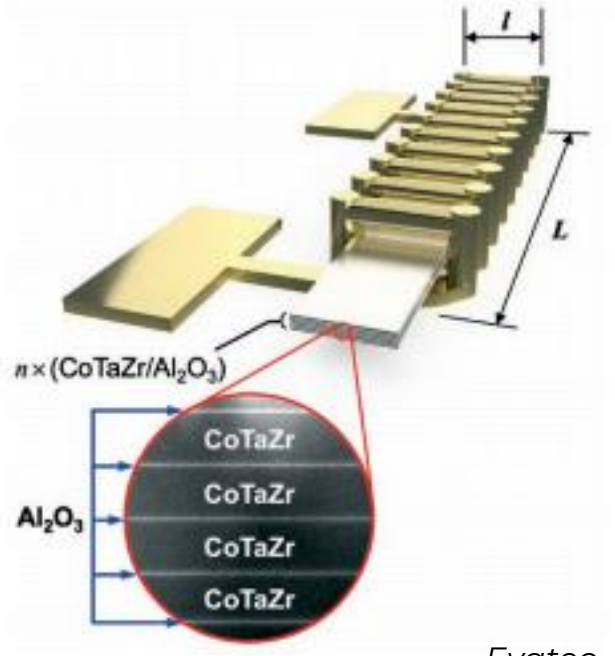
Aircore WLM



iCoupler, ADI

Electroplating windings

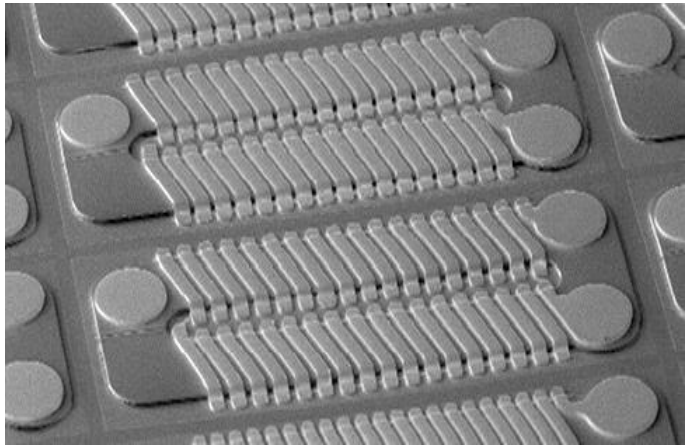
Multilayered thick film sputtered core



Evatec

Electroplating windings

Electroplated thick film core



Enpirion

Electroplating windings

Wafer Level Magnetics
(Core technology comparison)

Aircore WLM

- ⬆ Easy to fabricate
- ⬆ Low cost
- ⬆ Low power loss
- ⬇ High near magnetic fields
- ⬇ Low inductance
- ⬇ Requires high F_{sw}

Multilayered thick film sputtered core

- ⬆ High performance
- ⬆ Process/thickness control
- ⬆ FEOL compatible
- ⬇ Slow (.1um/min)
- ⬇ High-cost process (~10-20x of the plating)
- ⬇ High capital costs (>5X over electroplating)
- ⬇ Limited alloy selection
- ⬇ Thickness/Stress limitations
  (<20L, <3 um)
  Power ≈ core thickness

Electroplated thick film core

- ⬆ Fast deposition (1um/min)
- ⬆ Low cost process
- ⬆ Intrinsically low stress → No. layers (>100)
- ⬆ Low capital costs (BEOL-OSAT)
- ⬆ Highly scalable
- ⬇ Metallic high μ crystalline films have low ρ → small skin depth → higher loss
- ⬇ Multi-layer laminations needed for high currents >1A
  Complex multi-layer/multi-mask **cost prohibited process**

Enachip's Technology Platform

Enachip addresses the electroplating core shortcomings to enable a high performance WLM cost competitive solution

Electroplated core

- ↑ Fast deposition process (1um/min)
- ↑ Low cost process
- ↑ Intrinsically low stress → No. layers (>100)
- ↑ Low capital costs (BEOL-OSAT)
- ↑ Highly scalable
- → ↓ Metallic high μ crystalline films have low ρ → small skin depth → higher loss
- → ↓ Multi-layer laminations needed for high currents >1A

Complex multi-layer/multi-mask **cost prohibited process**

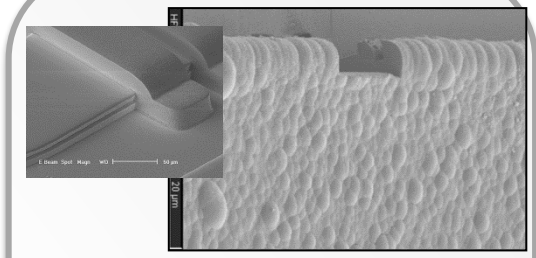
EnaChip : Enabling Technology Platform
(Multiple Market Verticals)

Post Process (BEOL-OSAT) compatible
INDEPENDENT of Si node!

Unique high-performance magnetic materials

Utilizes highest speed integrated electronic circuits

Innovative wafer fabrication processes



Unique Magnetic Alloys
- New Compositions of mater
- Unique formulations to meet performance
- Enachip Proprietary
- CMOS compatible

Miniaturization / Cost

Addressable Market Verticals

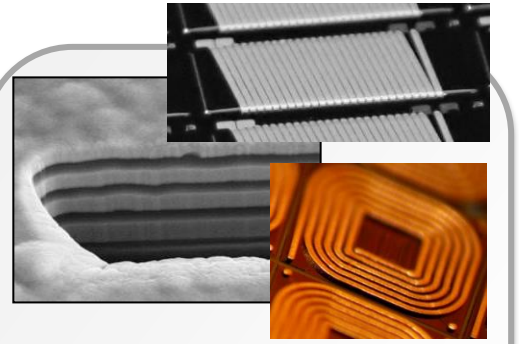
Voltage Regulation
- DC/DC Voltage Regulators
- Integrated Power Management IC
- LED Drivers

Signal Conditioning
- Low Pass Filter
- Band Pass Filter
- Tuner
- RF Suppression (Beads)

Magnetic Field Sensing
- Magnetic field -> Electric Signal

Power Harvesting
- RF→DC
- Solar -> DC/AC
- Mechanical -> DC/AC

Electromagnetic Actuation
- Moving Beams
  *(**Reed switches**, **Relays**)*
- Electromagnetic Separation
  (Bio-medical devices POC Lab on Chip)
- Moving membranes
  (micro Pumps, micro Valves)



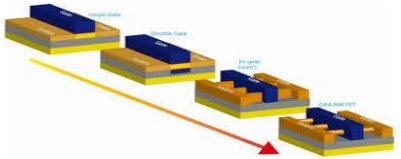
Innovative Mfg. Processes
- Game changing low-cost magnetic core laminations
- Copper windings
- Integrated circuit compatible

Performance / Cost

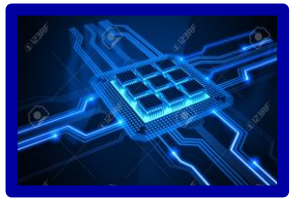
More than Moore : Added Functionality at Chip Level

Moore's law reaching physical limitations

Transistors shrinking



Increased Performance/Cost



Investment

*Technical progress & industry's confidence in **Moore's Law** feeds into a virtues cycle!*

Market Growth

Smaller, powerful, cheaper devices

Next

Added functionality on chip level

System Integration

Increased Functionality/cost

Investment

*Increased functionality at chip level feeds into a **More than Moore** virtues cycle!*

Market Growth

Smart Home

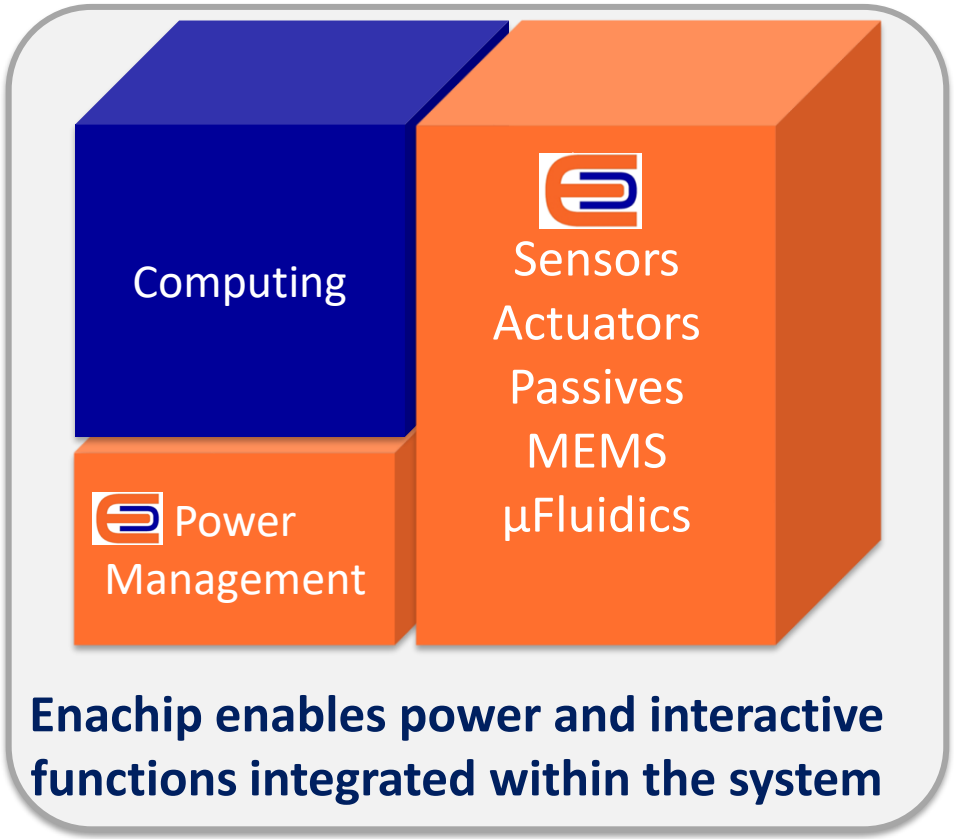
Smart Cars

Smart Health

Smart Power Integration is needed in All Systems

ENACHIP WLM platform enables power and interactive functions in system

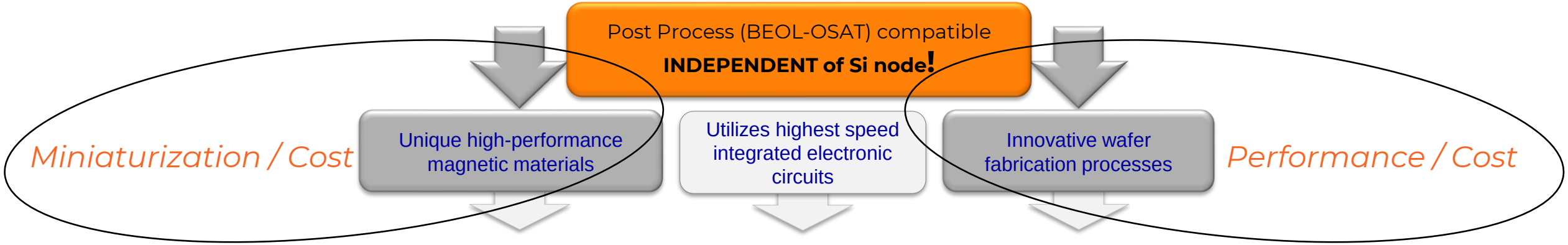
System Integration at chip level



Enachip enables power and interactive functions integrated within the system

Devices are “talking” to environment and to the users

EnaChip : Enabling Technology Platform
(Multiple Market Verticals)



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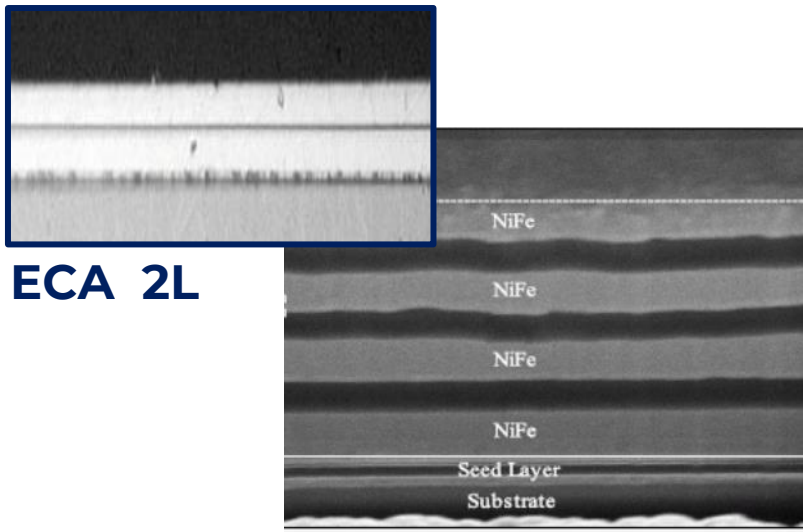
High Performance proprietary Mag. Alloys

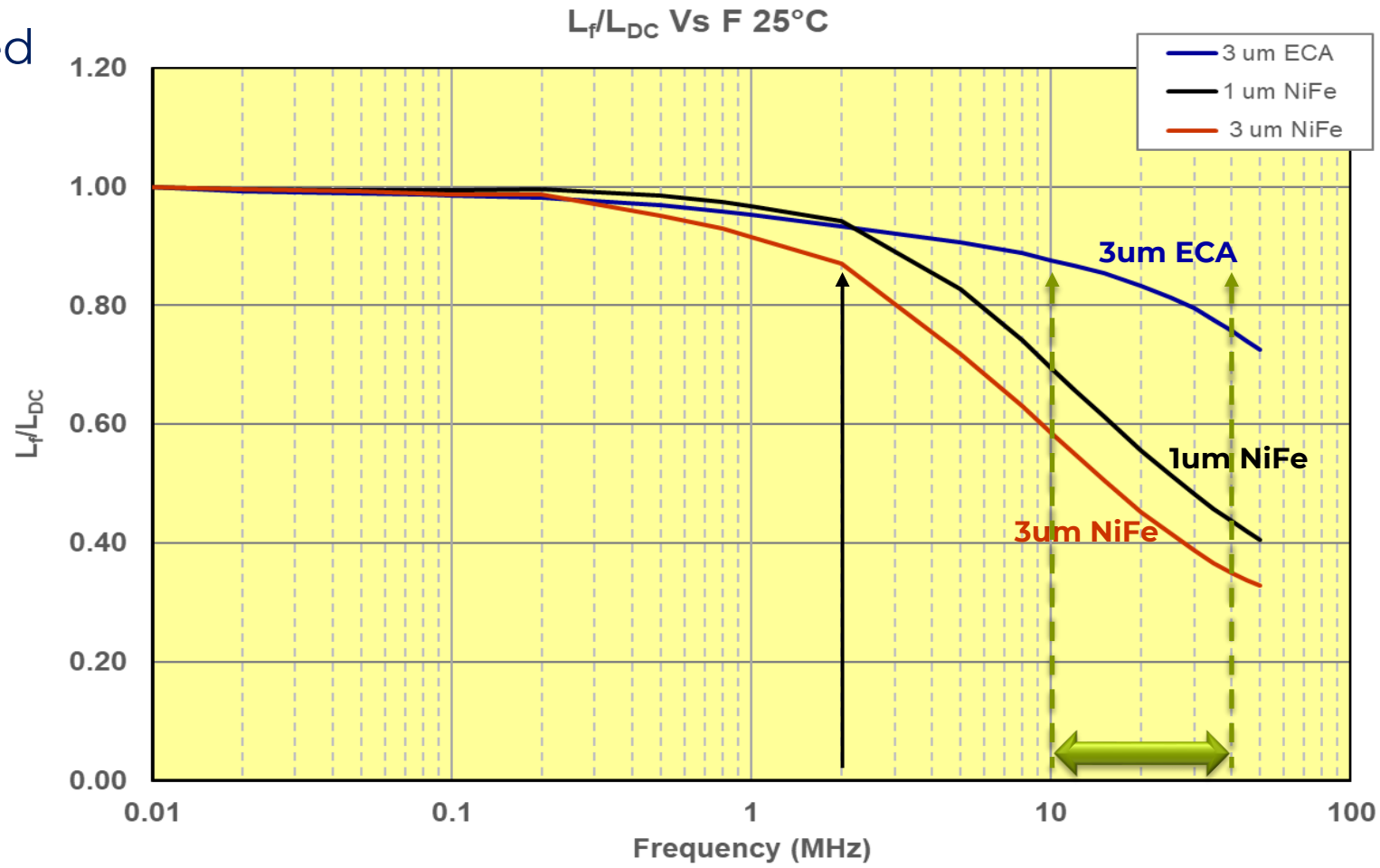
EnaChip Alloy (ECA)

- Amorphous Electroplated
- 3x NiFe resistivity
- F_{sw} up to 30MHz



ECA 2L

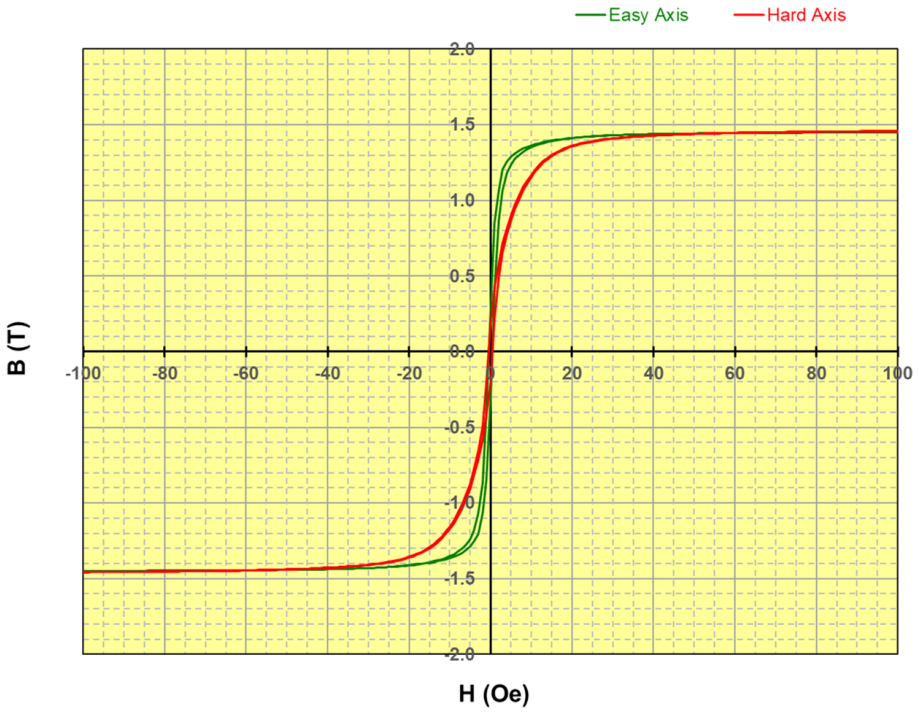
NiFe 4L



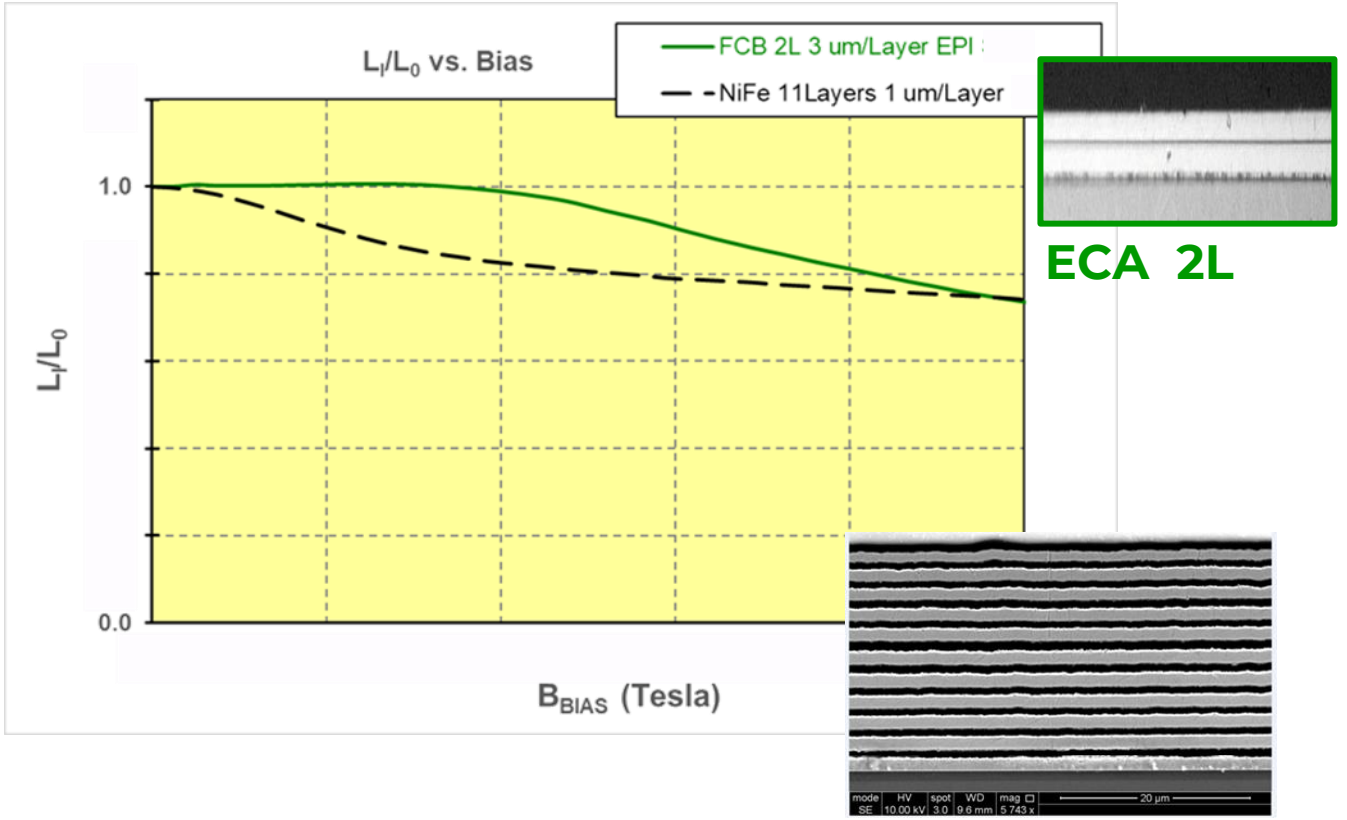
High Performance Proprietary Mag. Alloys

EnaChip Alloy (ECA)

- Permeability 900
- $B_{sat} \geq 1.5$ T



ECA Bias operational range >> NiFe



ECA 2L

NiFe 11L/1µm ea

Game Changing Multilayer Cost Reduction !

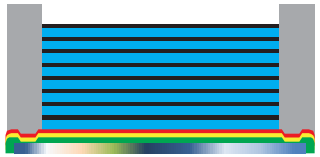
EnaChip

base Wafer - bottom copper & insulation

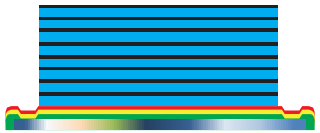
1 Sputter Seed Layer

2 Thick

8 Core Layers
5 main steps
1 mask !



3 Sequentially electroplate 8 layers of magnetic core and insulation



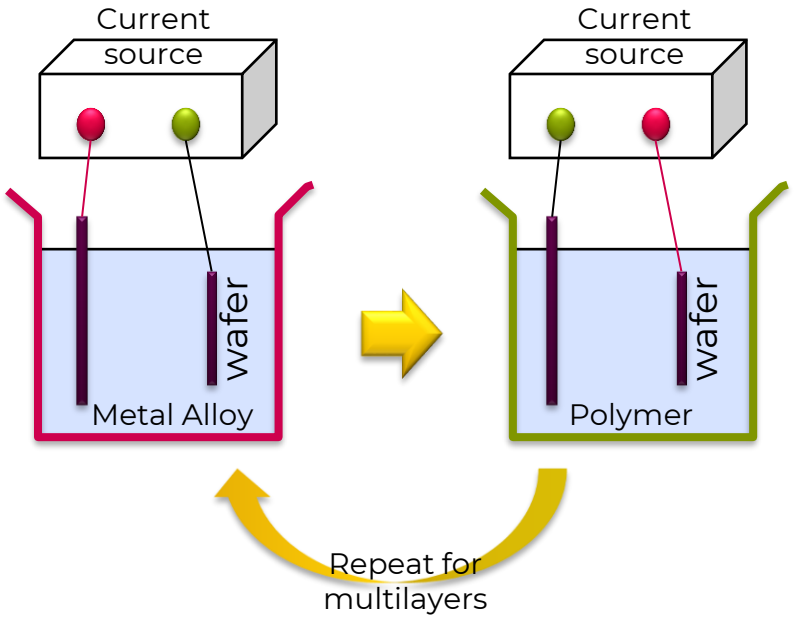
4 Strip photoresist

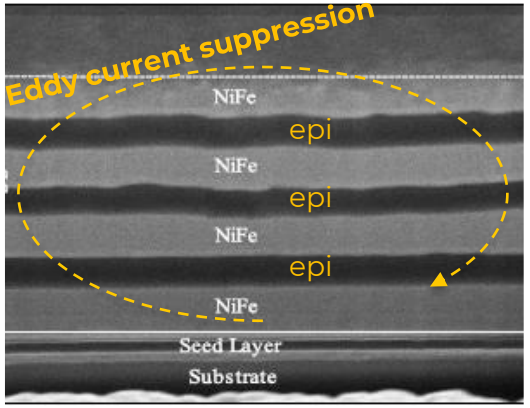
5 Etch seed layers

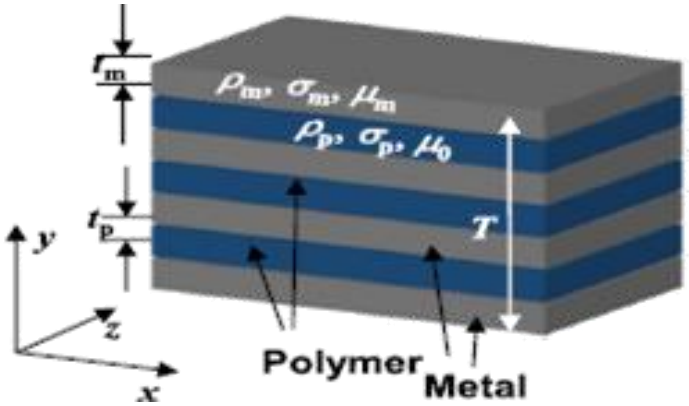
Standard

Multi Layer process incorporates electroplated insulator (epi)

- Electrochemically synthesized insulator
  - Conjugated polymer based
- Conductivity < 1S/m



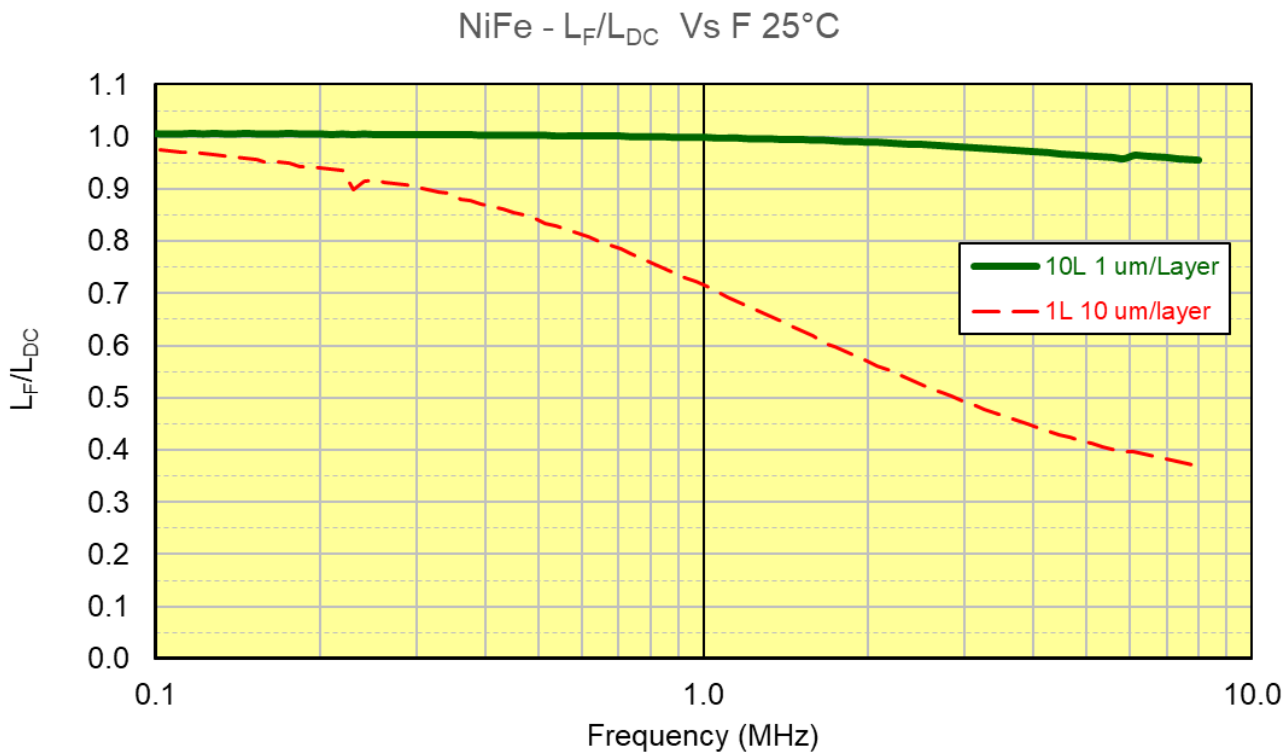


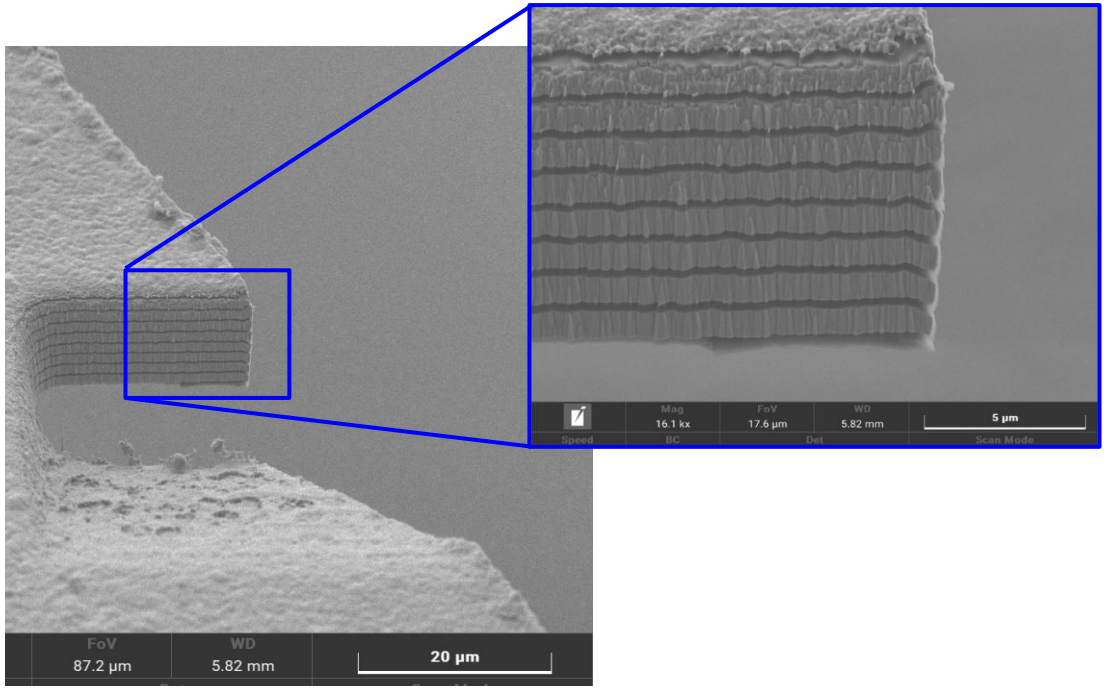


Vertical conductivity is important for Eddy current suppression

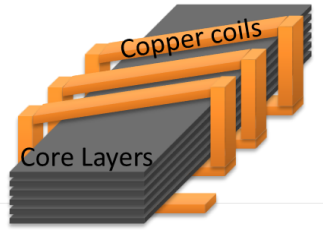
Multi Layer process Thin Insulator !

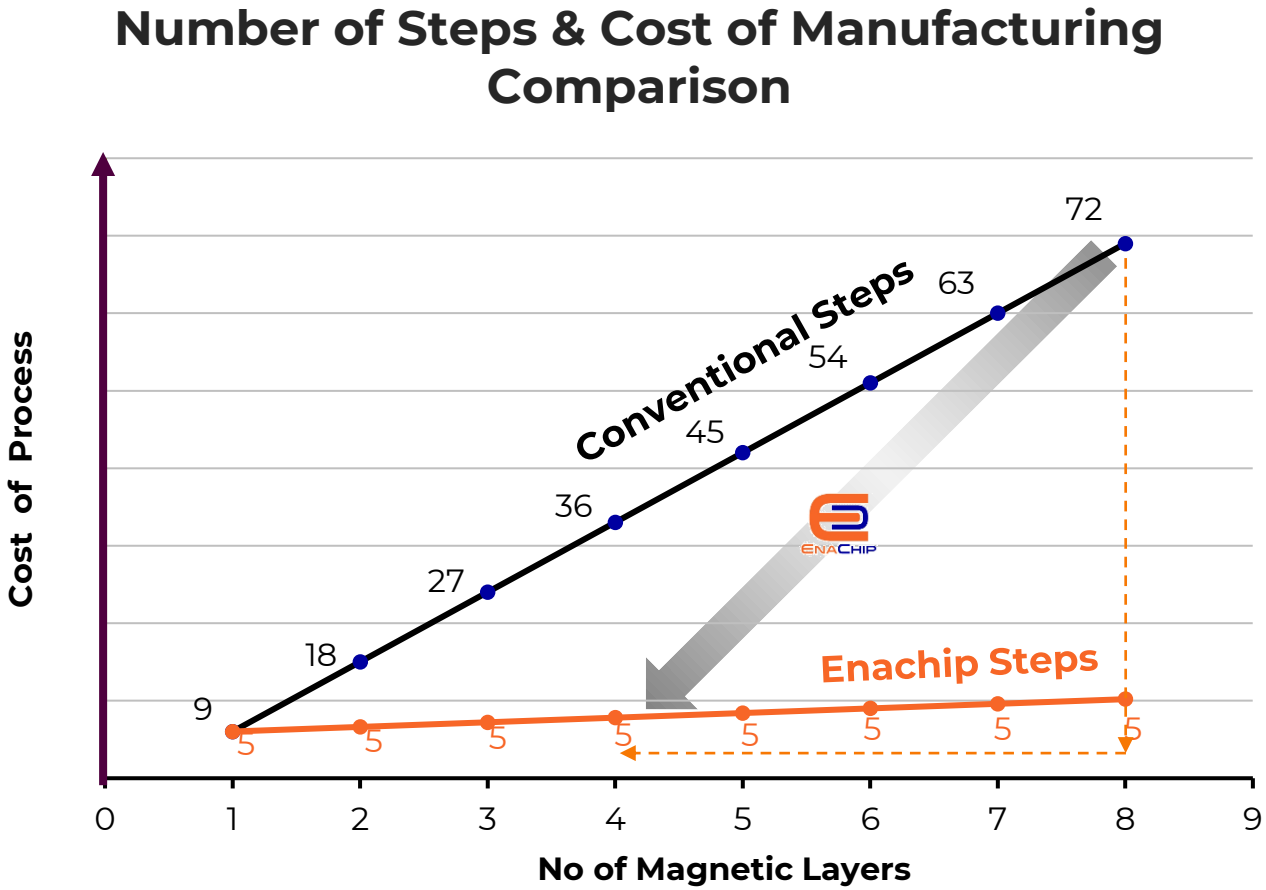
- Multiple layer with thin Insulator → Very high layer packing coefficient → Low profile cores
- EPI performance is comparable to ideal insulator with ability to suppress Eddy Current Loss





Combination of performance alloys and cost reduction manufacturing process → Competitive WLM commercialization



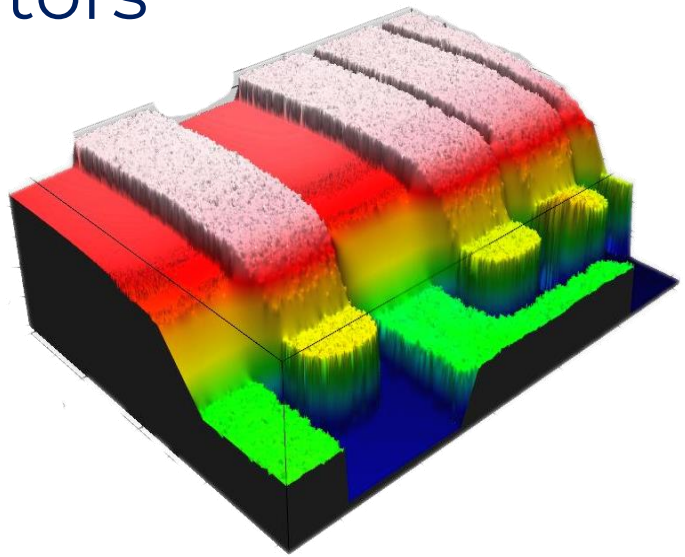


Example Multi Layer Process:
Build a high current MEMS inductor
e.g. requires 8 Core layers
Conventional: **72 steps**
Enachip: **5 steps**
→ 14x less steps
→ game changing cost reduction

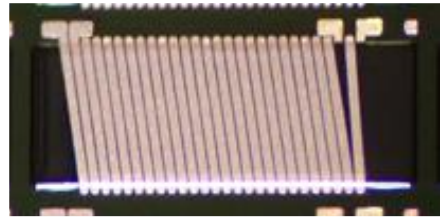
Enachip' s Alloy:
Reduces the required layers by 2x
→ Reduce process time by 50%

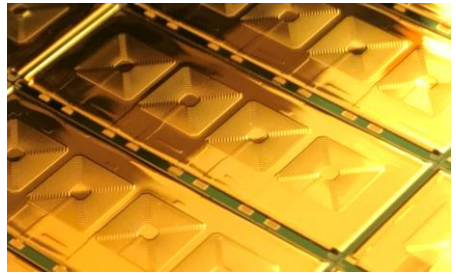
Device Examples

- Thick Cu toroid micro-inductors
- Multi-core toroids
- Spiral coils
- Electromagnets/Actuators
- Transformers
- Sensors



High aspect ratio lithography and electroplating!

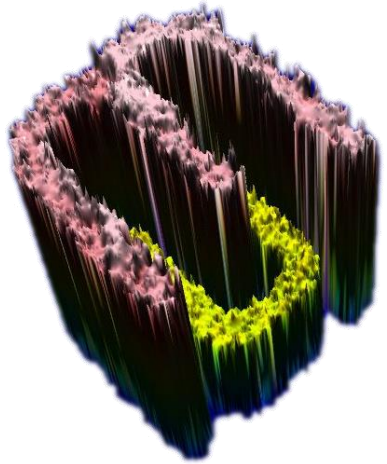




Summary

- New amorphous high resistivity magnetic alloys
- Single-mask multi-layer core electroplating laminations

- Potential game changing Wafer Level Magnetic integration for PwrSoC
- Post process technology platform – independent from Si nodes can address multiple PwrSoC applications
  - Low current (I_{out}<3A), Low profile <0.3mm
  - Moderate current (3A<I_{out}<6A), DCR < 30 mΩ, Low profile <0.5mm
  - High current (6A< I_{out}<10A), DCR < 1 mΩ, Low profile <0.6mm



Thank you

More to come at Live PwrSoc 2021 in Philadelphia !