Scalable Integrated Magnetics: A Cost-Effective and Efficient Solution for Vertical Power

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Special Acknowledgement: **Prof. Mark Allen, UPenn-USA (co-Founder)**

ENERGY SAVINGS 

SIZE REDUCTION 

PERFORMANCE ENHANCEMENT 

MANUFACTURING SAVINGS 

MISSING LINK 

Concentrated Functionality

Electrification - Autonomy

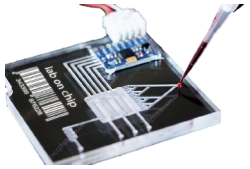
The Problem:

World needs

MORE power in SMALLER spaces:

High Power Density

Advanced Health



Aerospace - Defense

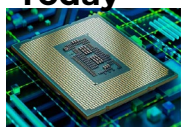
IoT – Edge Computing

Computing

90's

3 million transistors

Today



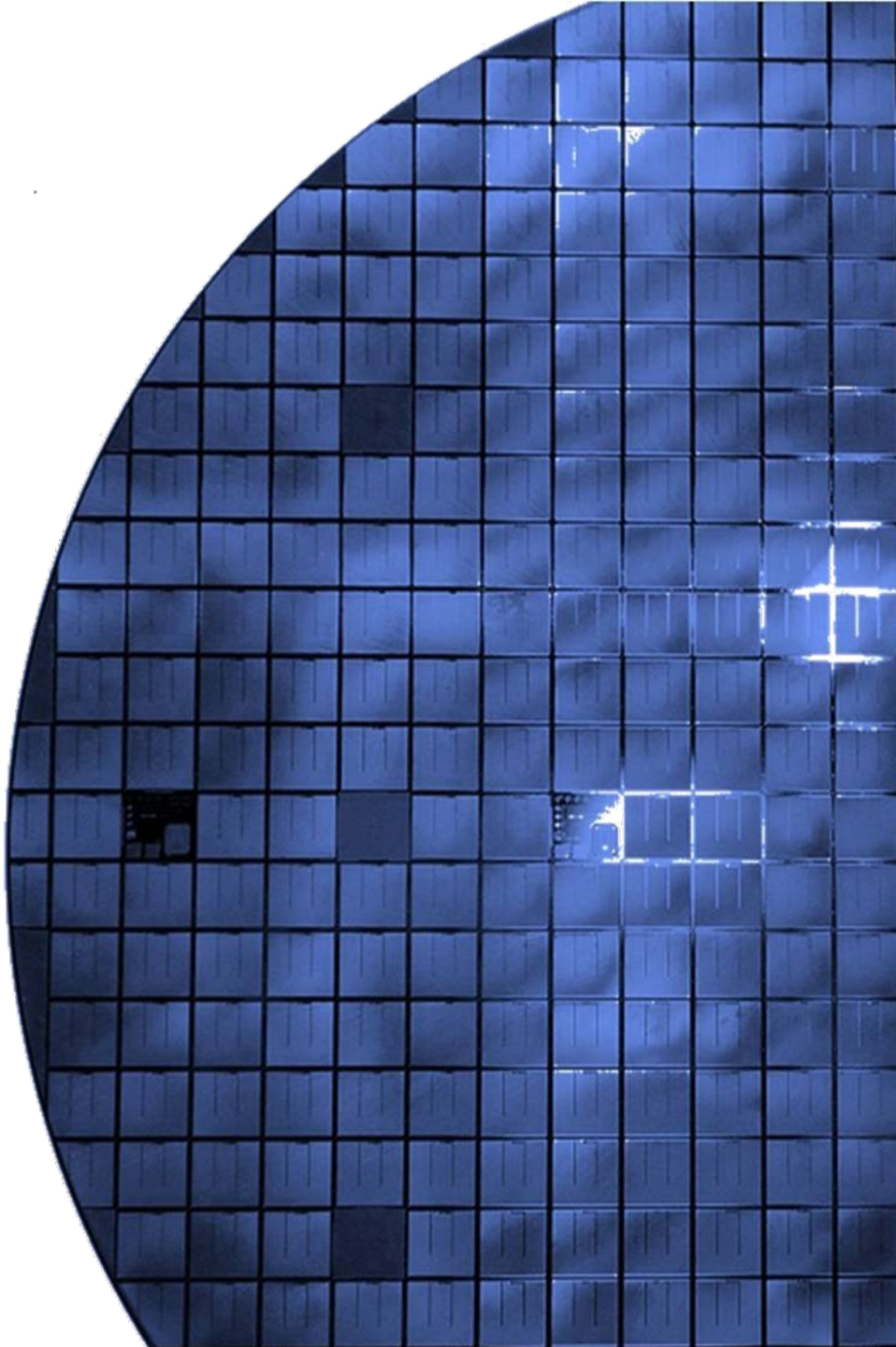
7 billion transistors

THE ROOT CAUSE of POWER INEFFICIENCIES

Power

Is Separate From

Silicon



Breaking Down the Problem

Megatrends:

- **A.I.**
- **Age of everything/everyone connected**
- **High performance computing**
- **Instantaneous access & processing of information**

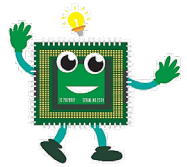
Drive→

Needs:

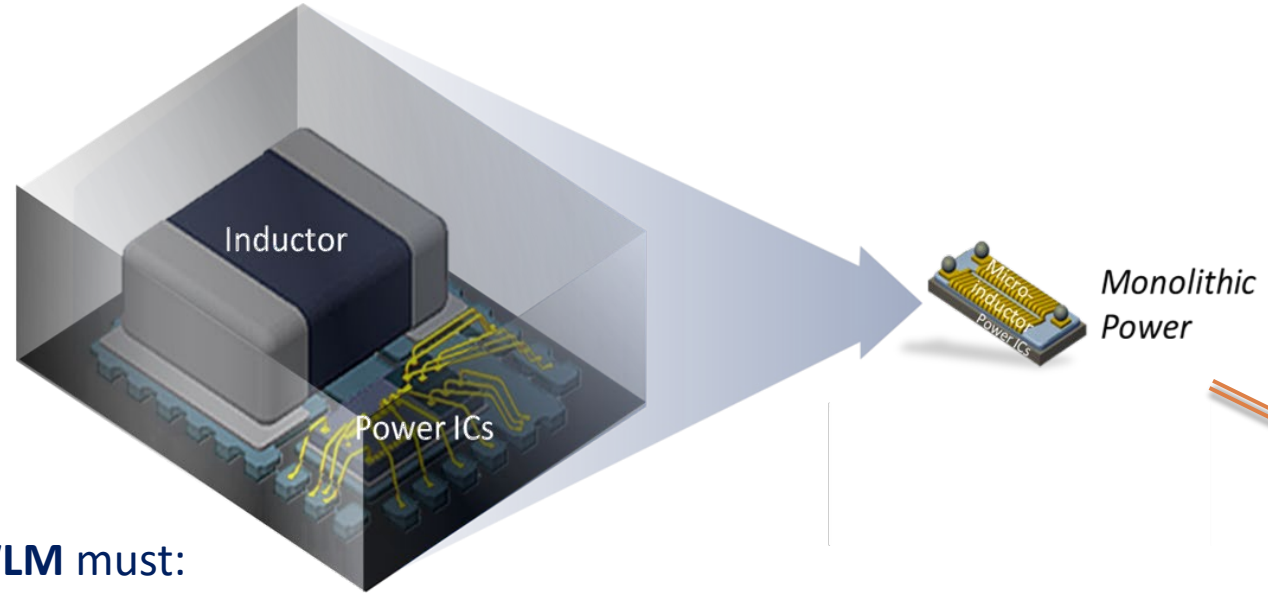
- **Small form factors**
- **High power density**
- **Efficiency**
- **Easy implementation**
- **Low cost**

- *Legacy technologies are not enough!*
- *Recent state-of-the-art technologies are expensive, exclusive, and limited*

EnaChip's electroplated Wafer Level Magnetics (eWLM)
means affordable integrated magnetics for every chip!

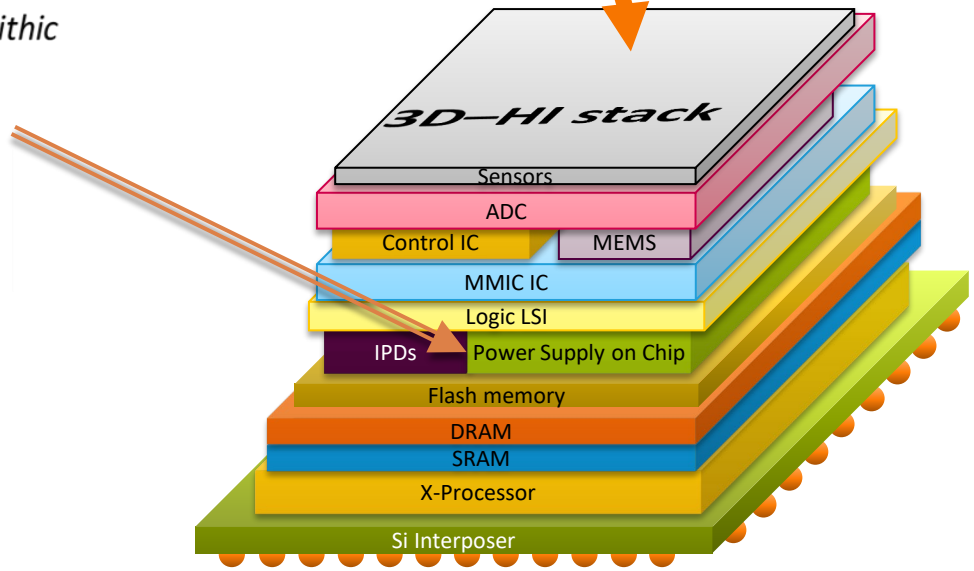


eWLM – Monolithic Integration



Monolithic Power

System Architecture



3D Heterogeneous Integration

eWLM must:

Meet cost – manufacturing and packaging

Meet form factor – footprint and thickness

Meet quality and reliability – demanding applications

Meet performance – efficiency and functionality

Meet the intangibles – near field noise, thermals, integration compatibility

EnaChip's Transformative Technology Trifecta

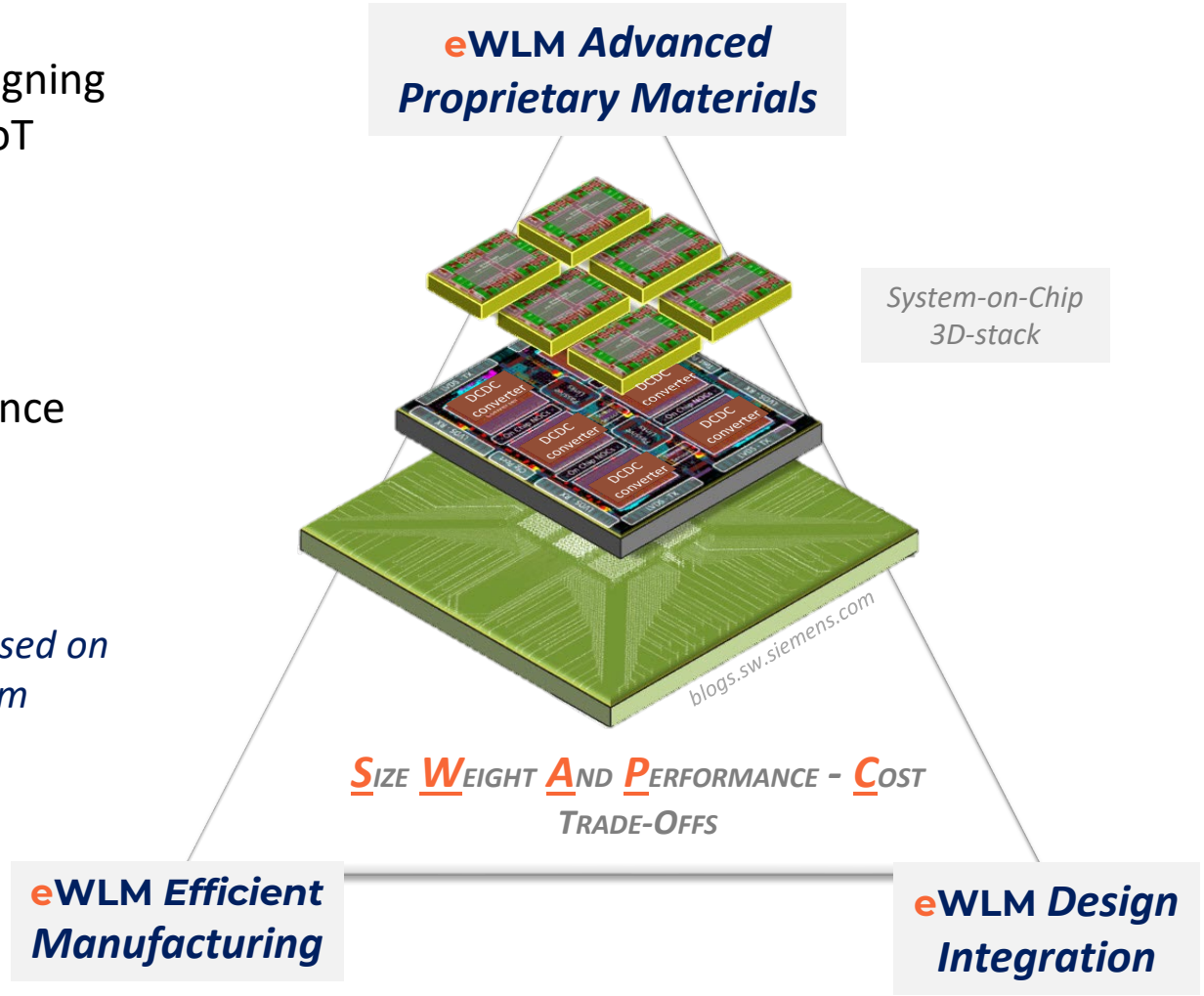
Problem:

Industry is facing SWAP-C necessary trade-offs when designing Systems-on-Chip for HPC, AI, portables, wearables, and IoT

EnaChip's eWLM Solution: Materials, Process, Design

is a cost-effective customizable convergence of performance and desired form factors without SWAP-C trade-offs

- *Using existing infrastructure*
- *Node agnostic processes*
- *Fast & low-cost electroplating processes*
- *Ease of design*
- *System design optimization based on EnaChip platform*

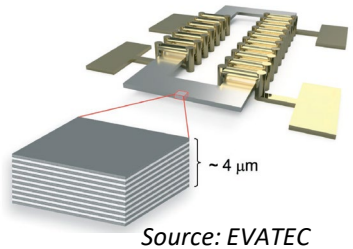


EnaChip's eWLM Competitive Advantage

Today's Industry:

- High cost
- Slow process
- Limited thickness

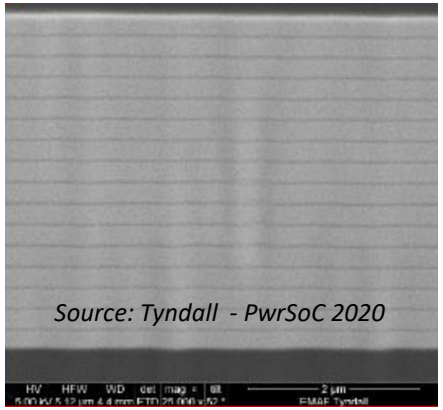
Sputtered Laminated Cores



Source: EVATEC

20-40 Layers CZT **TOTAL 5um**

Estimated deposition time **many hours !**

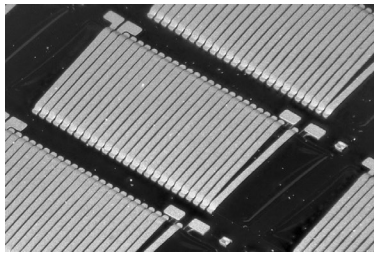


(max achievable thickness ~5um)

Continuously Electroplated Laminated Cores

EnaChip

- Simple process
- Ultra low cost
- Ultra fast process
- On any wafer, any node!

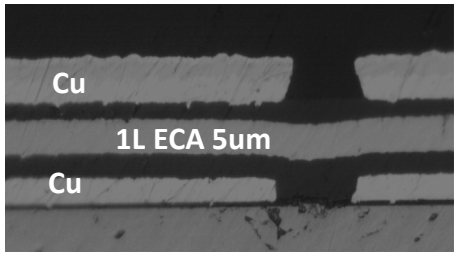


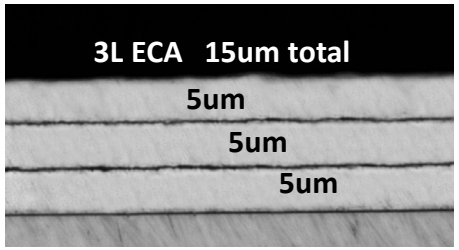
Microtransformer
(1.7mm x 4.0mm)

1 Layer ECA **TOTAL 5um**

Deposition time **20 min !!**

(100X Faster)

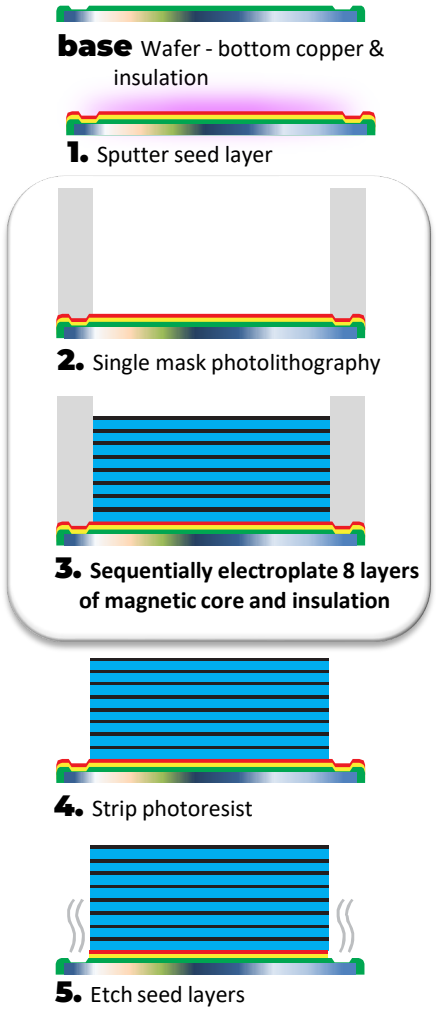




(max achievable thickness 20um)

Game Changing Cost Reduction !

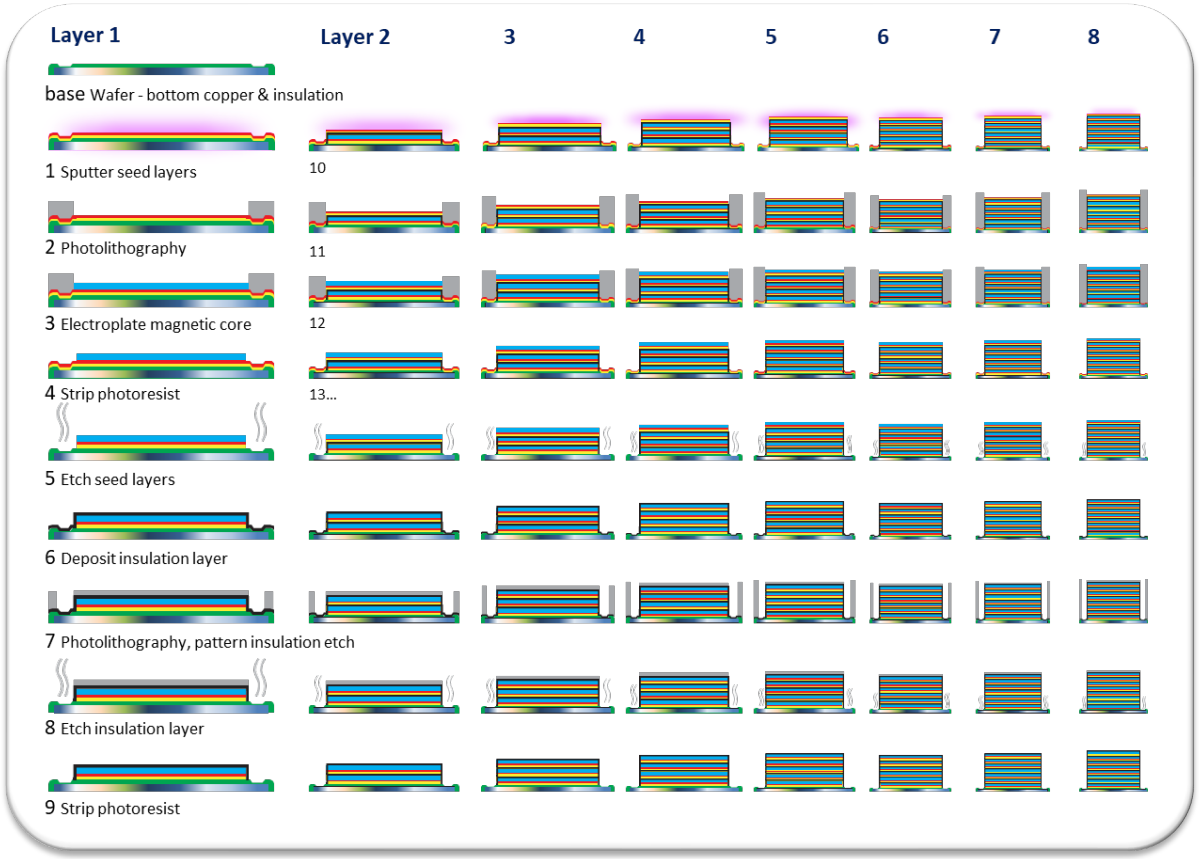
EnaChip process for 8 core layers
Using **electroplated EPI** as insulator



5 main steps
1 mask

Today's process for 8 core layers using **sputtered SiO_2** as insulation

72 main steps
16 masks

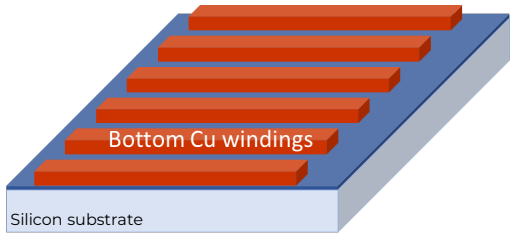


Key Process Modules
(Electroplated micro-coils)

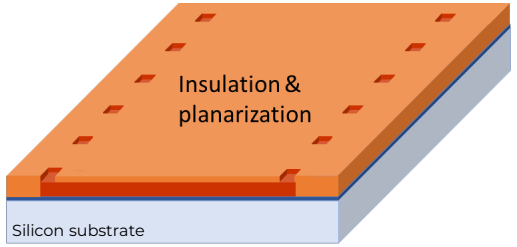
- Thick electroplated Cu (5um – 80um)
- Dielectric insulation/planarization
- Electroplated high frequency magnetic alloy laminations

EnaChip's electroplated Wafer Level Magnetics process flow

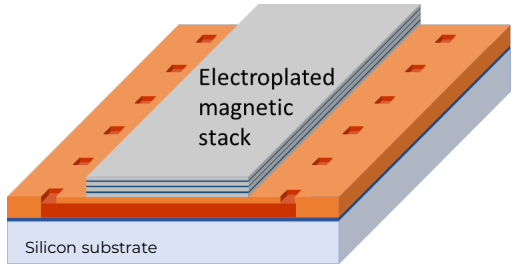
A. Electroplate thick Cu



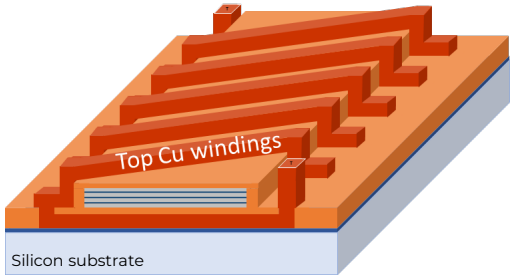
B. Spin thick photoresist, cure to insulate and planarize



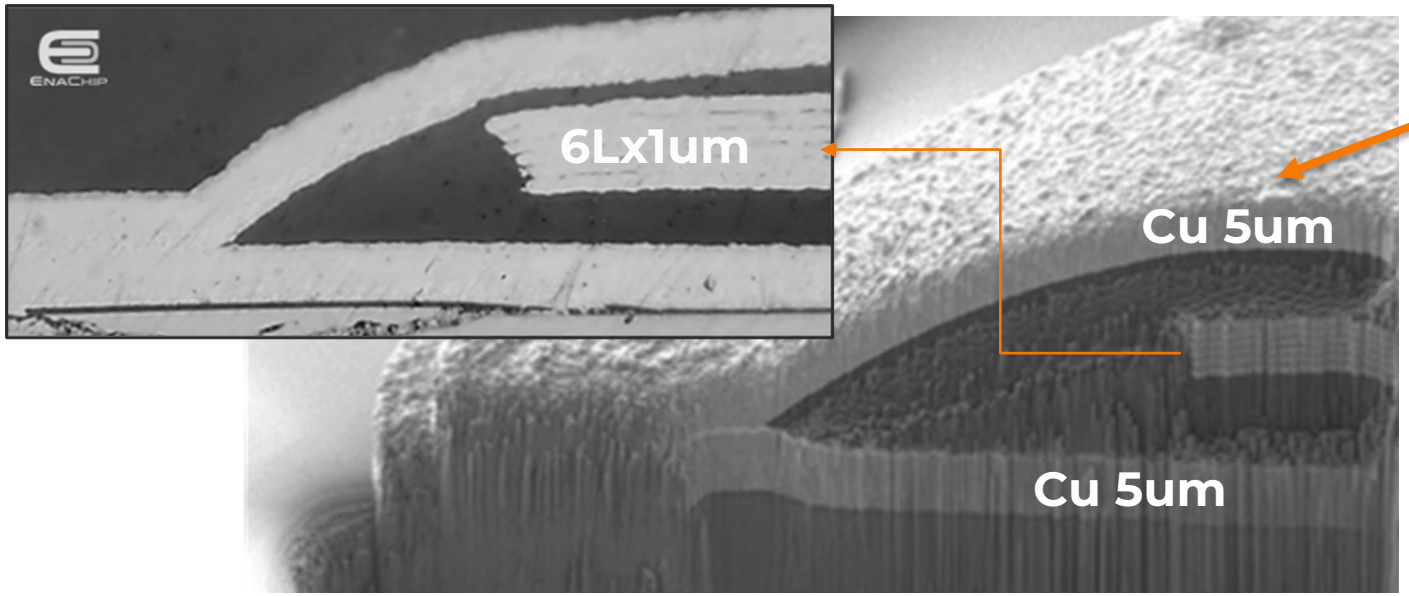
C. Electroplate laminated magnetic core

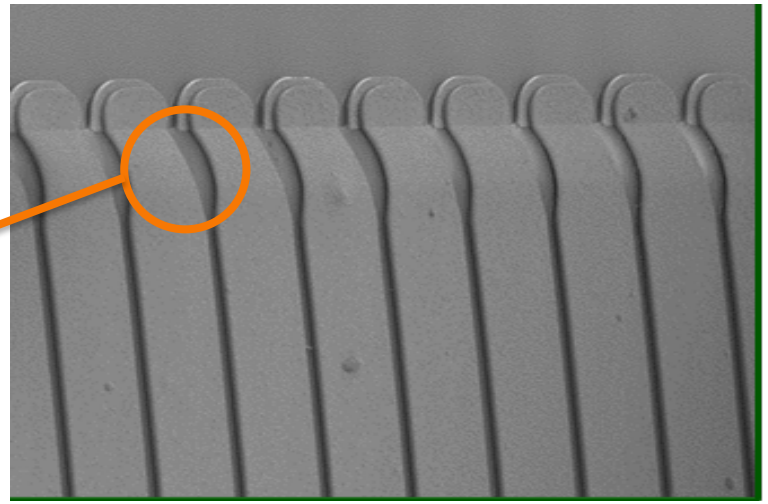


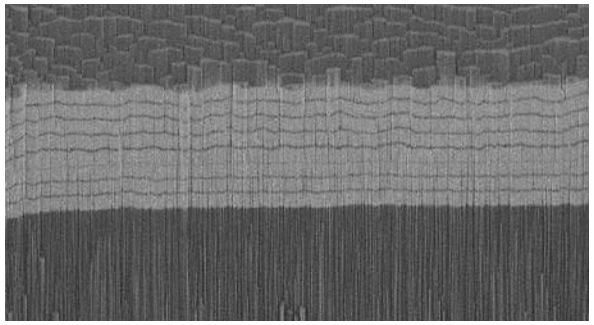
D. Insulate core & electroplate top Cu to complete coil windings

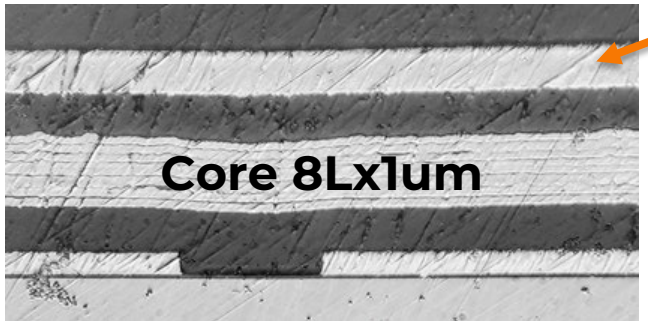


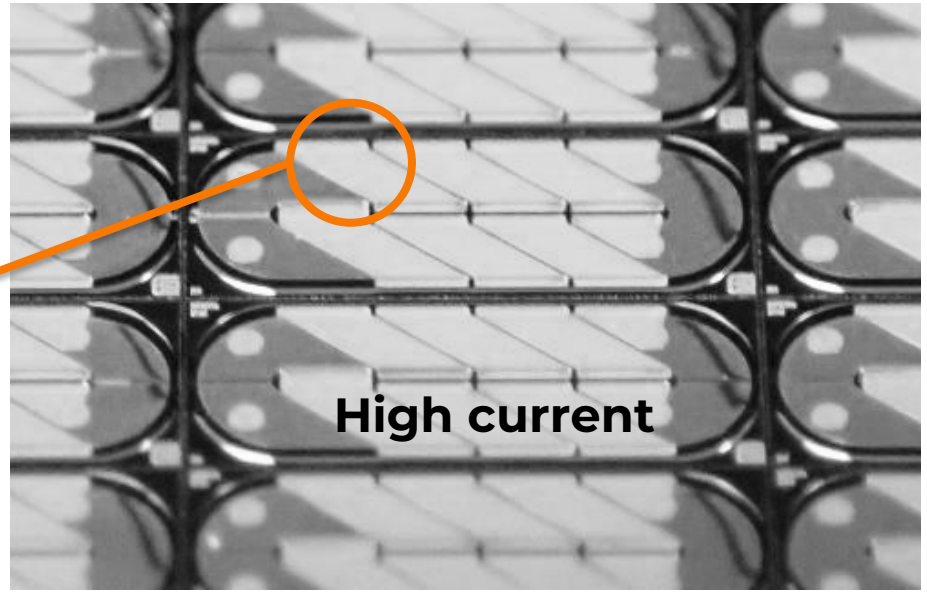
Device Structure



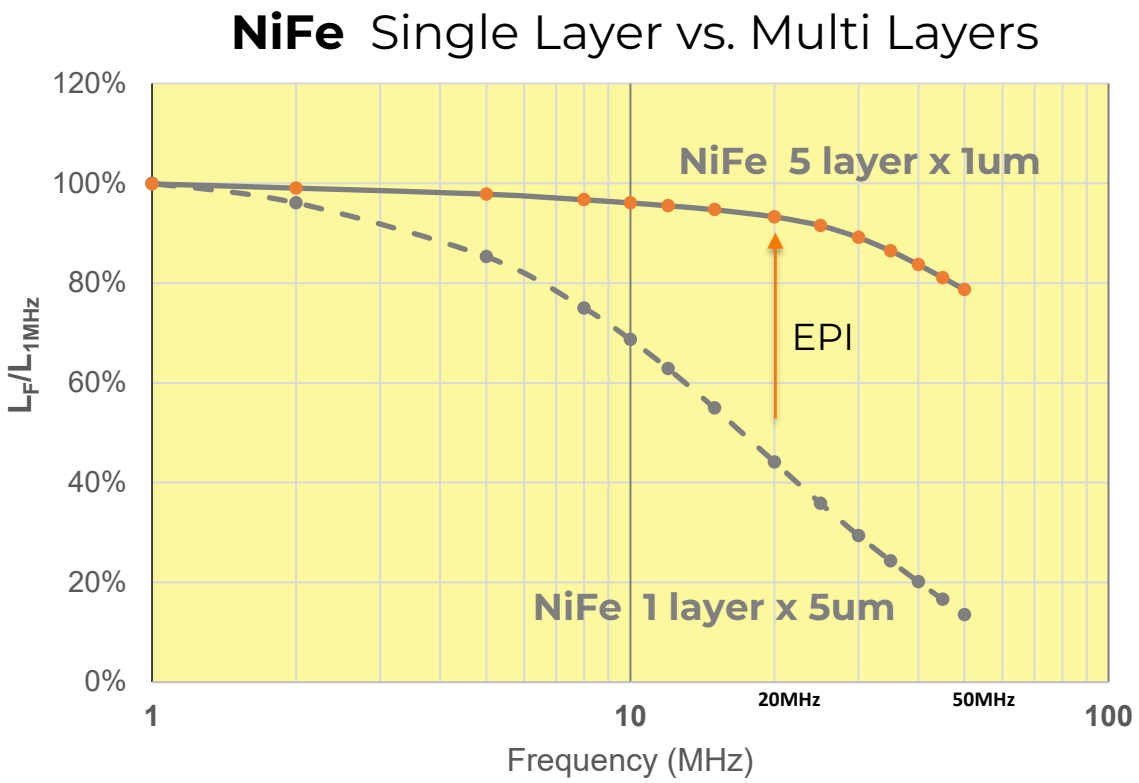


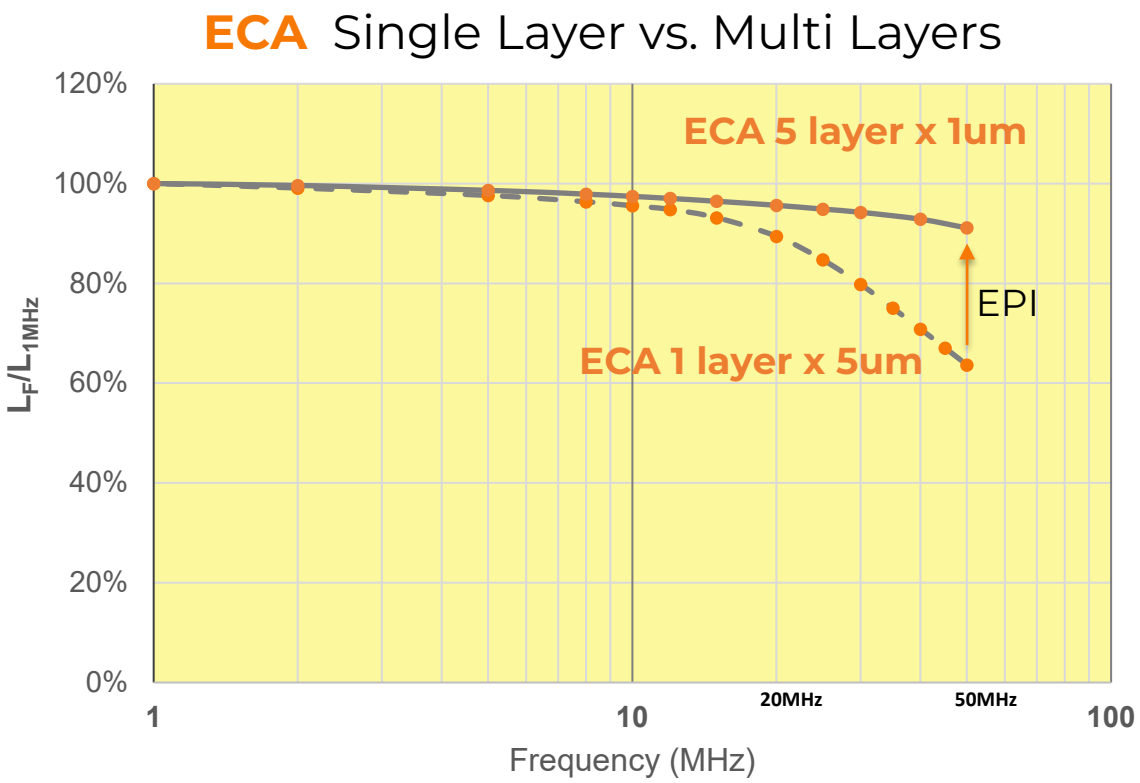




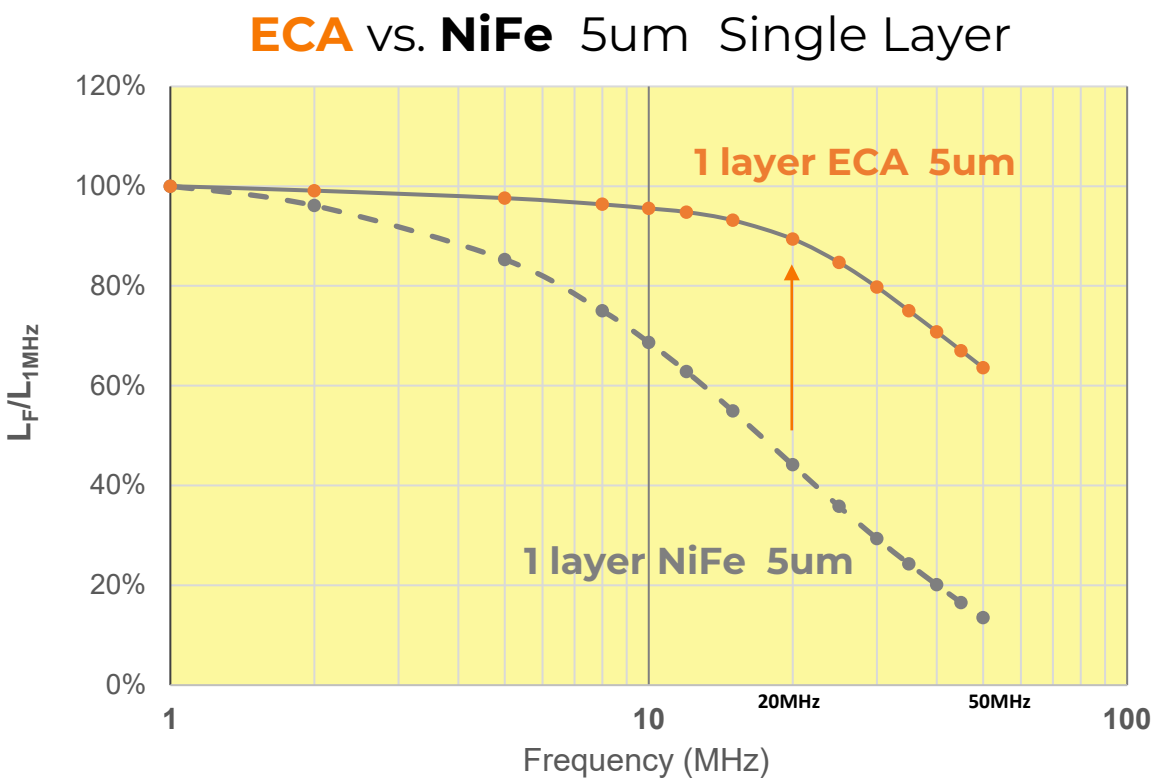


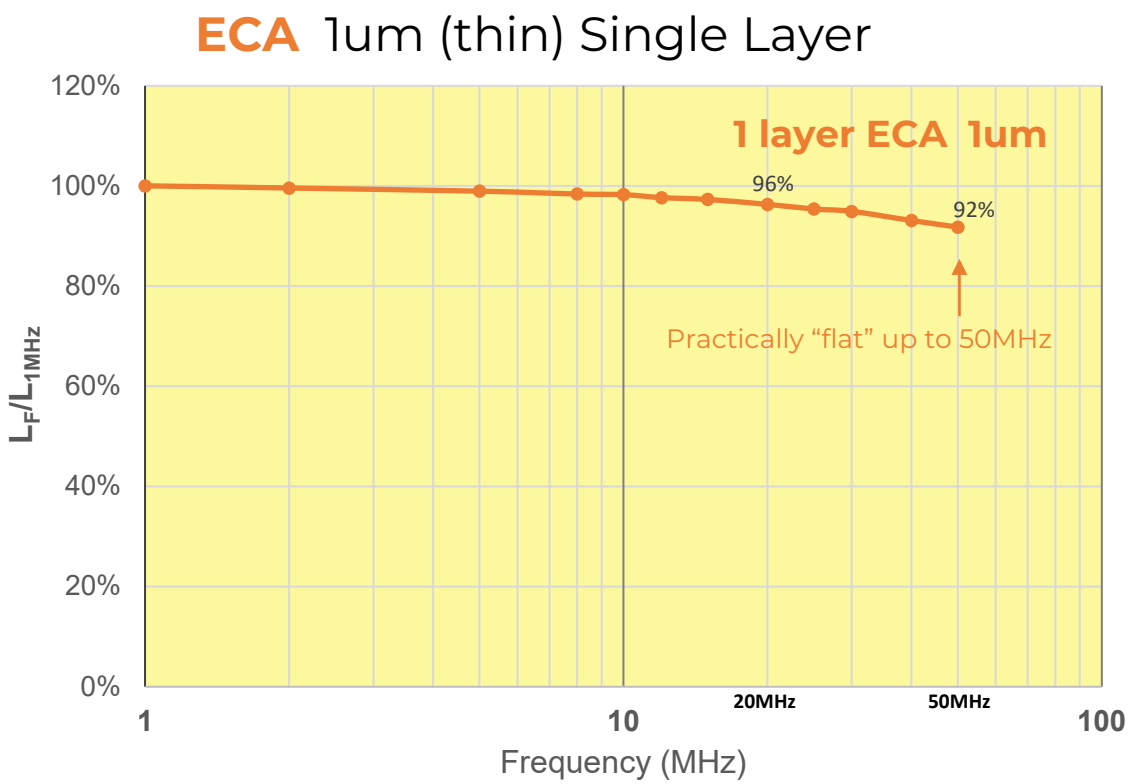
EnaChip's Electroplated "insulator" (EPI) Does it work?



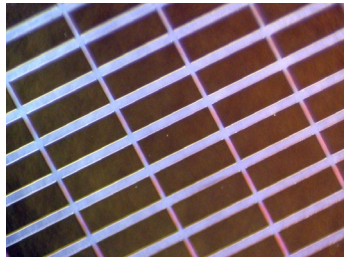


EnaChip's Electroplated Alloy ECA vs. NiFe



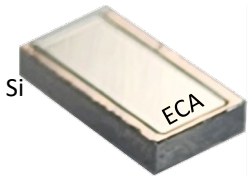


Testing ECA Films – Wire Wound vs. Integrated Device

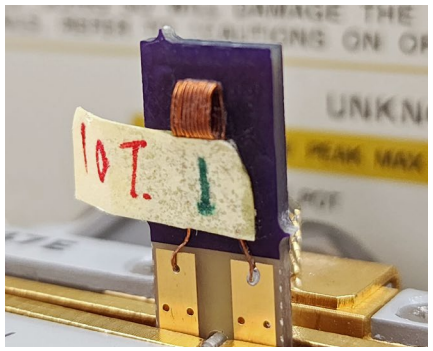


Electroplated ECA cores
(single or multi-layers)

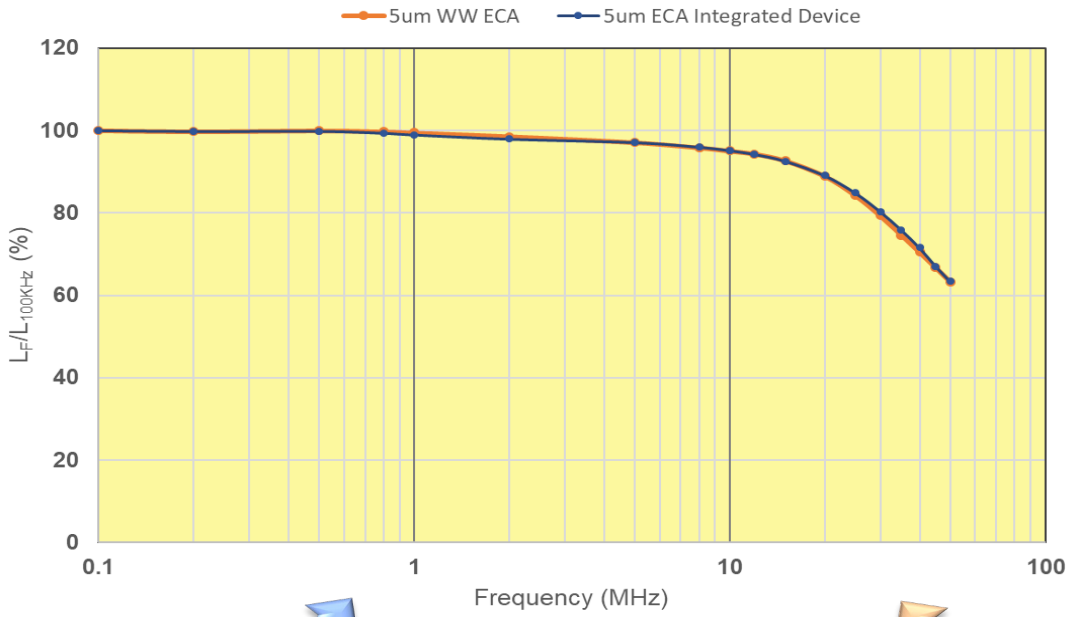
ECA on blank Si die



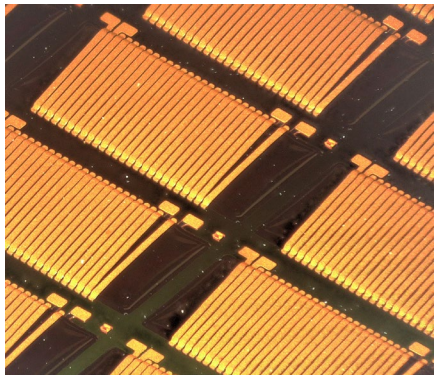
Insert test bar in
the fixed test coil

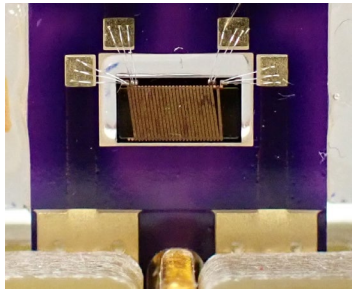


Fixed 10T **W**ire-**W**ound test coil



Fabricate integrated inductor





Package and test
eWLM

Programable ECA Material Intelligence

Tunable Magnetic Materials for target applications: System Level → Power Integration

System Architecture

Application

e.g. Wearables

e.g. Performance Computing

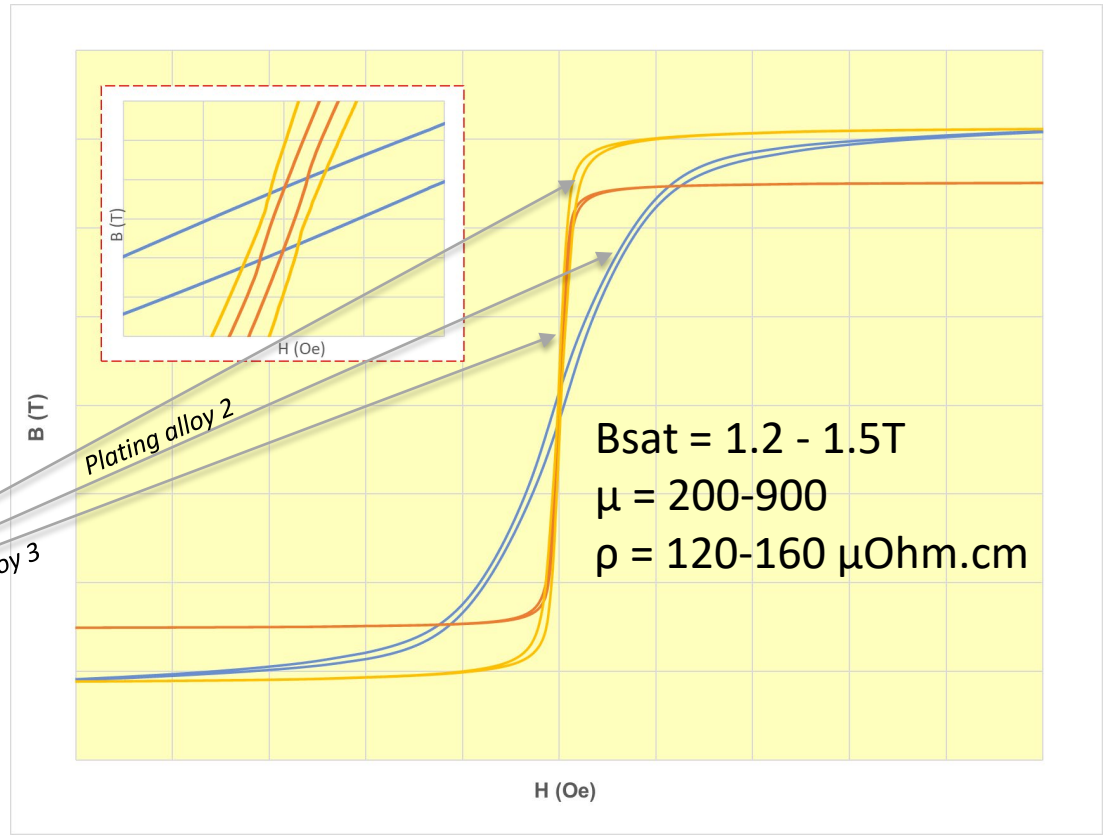
Recipe 1

Recipe 2

Fabrication

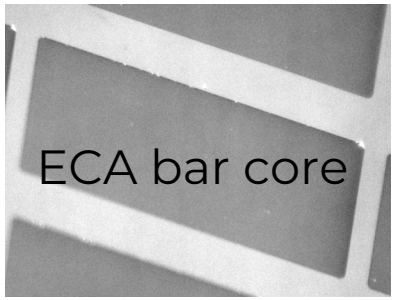
Process Intelligence: Alloy plating

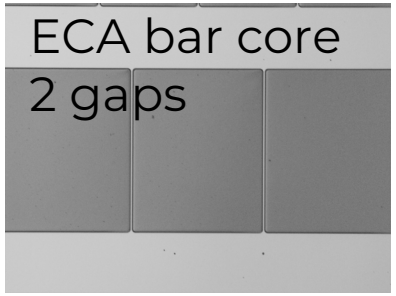
Same Chemistry

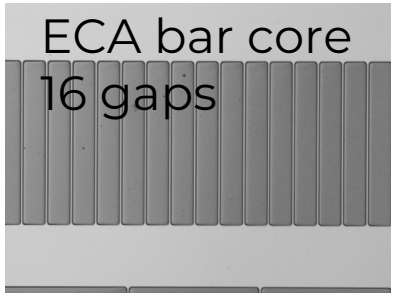


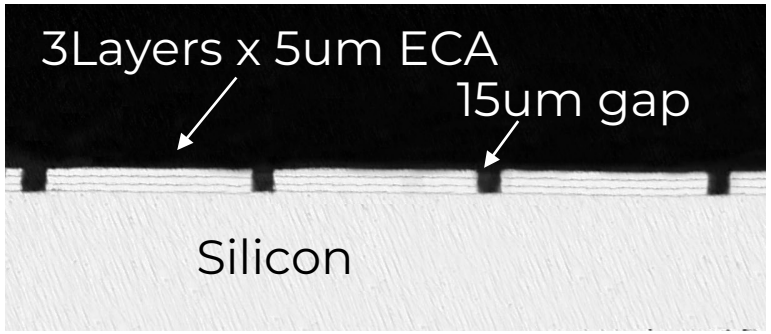
eWLM - Unique Design Flexibility to Control Performance

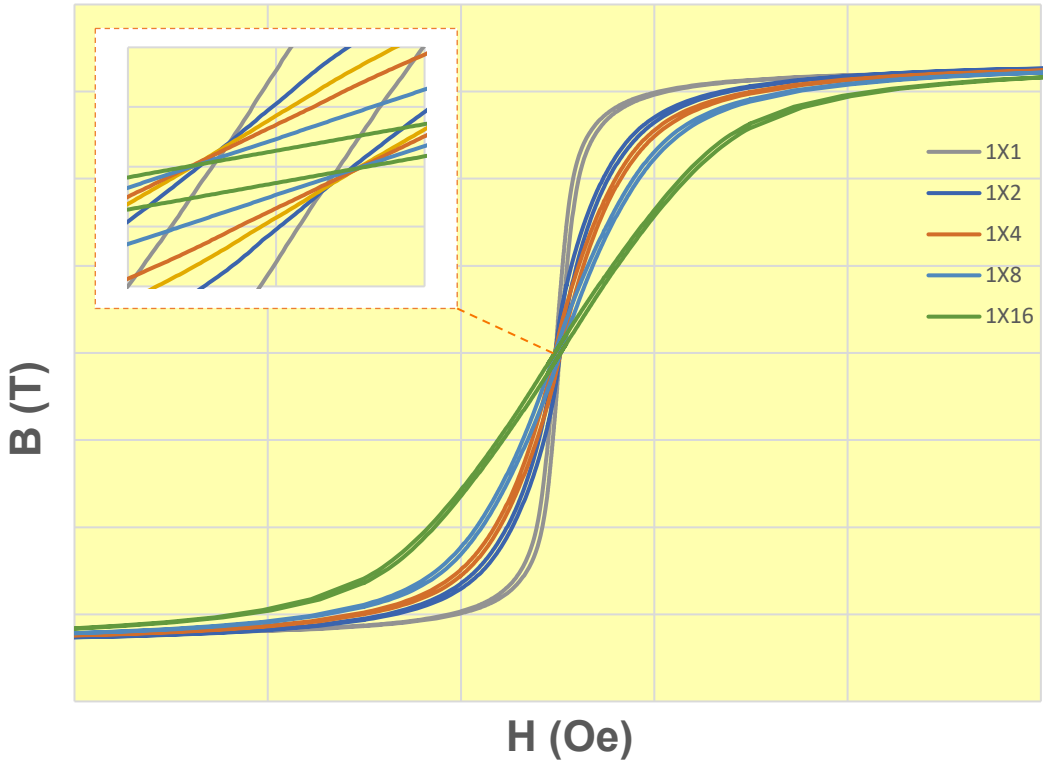
1 mask, single or multilayer core **plating** allows for precise gap control → Performance flexibility



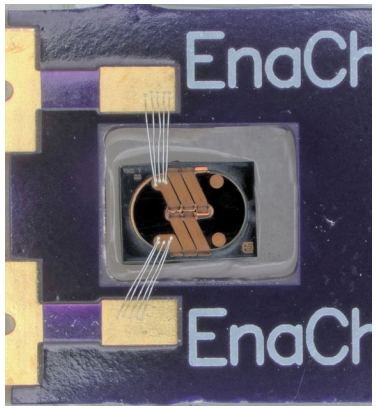


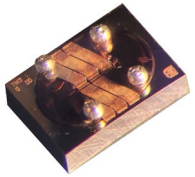




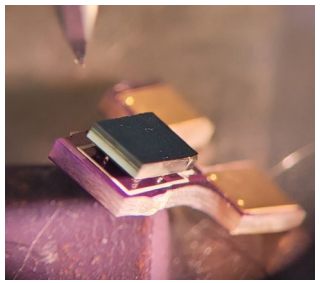


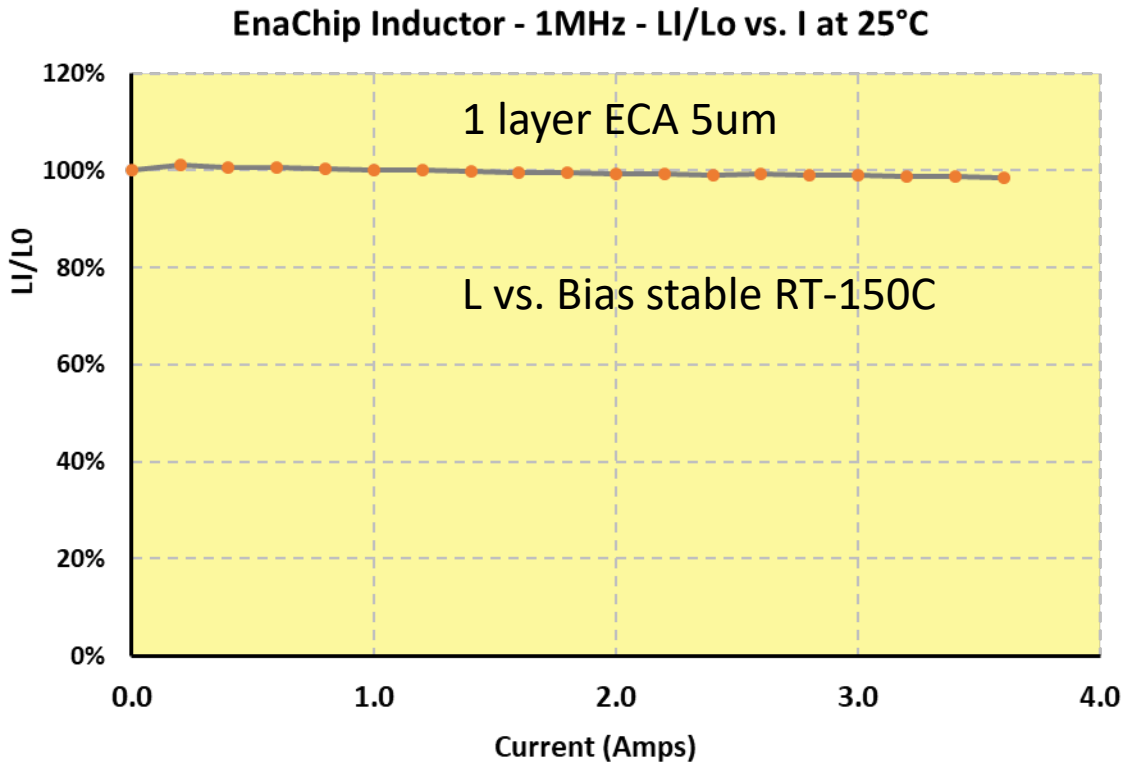
High current capability and closed path design





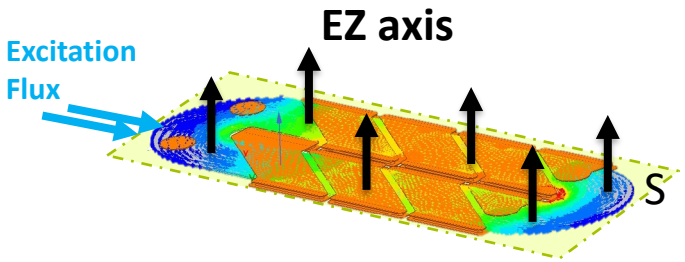
Flip chip



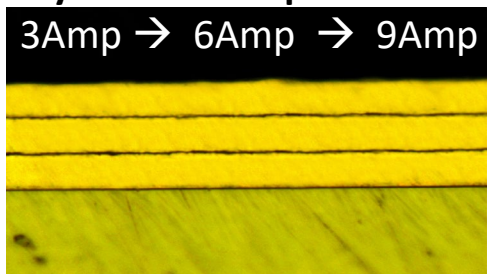


15um Cu
1Layer x 5um ECA
I_{max} = 3.5Amps
F_{sw} = 20MHz

L scalable ~ 3nH/ layer



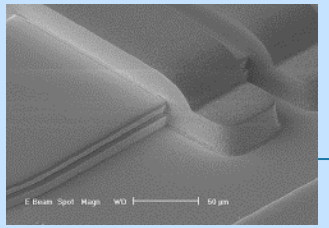
1 year Roadmap



Note:

ECA Magnetic Anisotropy control on Z-axis !!

EnaChip develops an Enabling Technology Platform eWLM



Unique high-performance magnetic materials

Innovative wafer fabrication processes

Silicon Based Control Circuits
(node independent)

Current Roadmap Focus

Power Management
DC/DC Voltage Regulators
PMIC
LED Drivers

Signal Conditioning
Filters
Tuners

Multiple Addressable Market Verticals

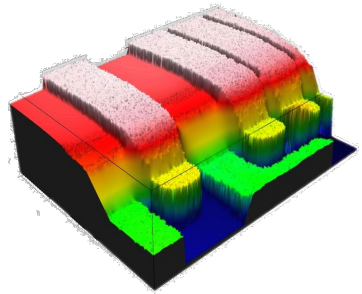
Intelligent Sensors - Automotive and IoT
- Current sensing
- Magnetic Field Sensing

Connected and Smart Health
- Electromagnetic Separation
- Micropumps, Microvalves, Relays

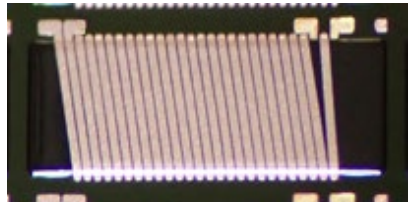
Microdevices
Electromagnetic Actuators
Power Harvesting
Switches

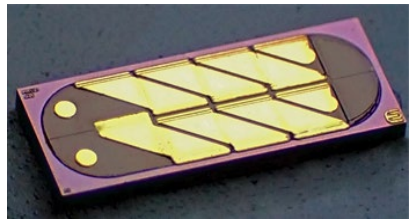
Walk Away Message

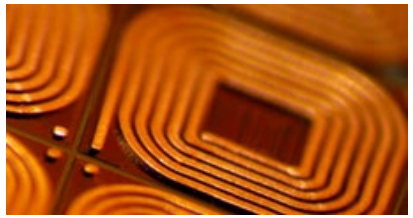
- EnaChip is commercializing a thin film electroplated Wafer Level Magnetics technology platform: Materials - Processes - Design
  - Thick Cu toroid micro-inductors
  - Multi-core toroids
  - Spiral coils
  - Electromagnets/Actuators
  - Transformers
  - Sensors

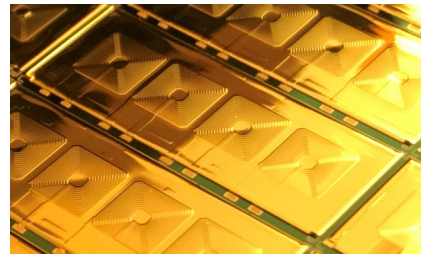


3D topography



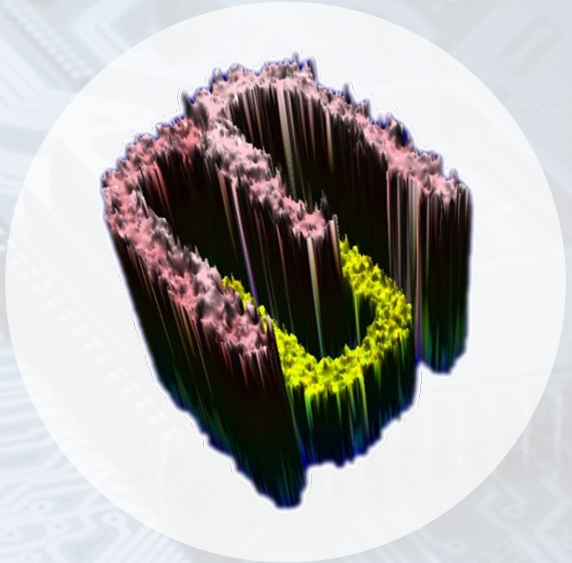






- EnaChip Gen-1 specs:

Inductance density:	100nH/mm^2, 2nH/mΩ
Power Throughput:	0.5W ≤ P ≤ 15W
Current range:	0.5A ≤ I ≤ 5A
Operational V_{IN}:	$1.8V_{DC} \leq V_{IN} \leq 18V_{DC}$
Operational V_{OUT}:	$0.6V_{DC} \leq V_{OUT} \leq 5V_{DC}$
Working Voltage:	$50V_{DC}$
Frequency Range:	5MHz ≤ f ≤ 30MHz (roadmap 50MHz)
Typical Device Profile:	40um ≥ T ≤ 200um



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