Multilayered ferromagnetic-polymer composite structures for integrated, high-density power supply inductors

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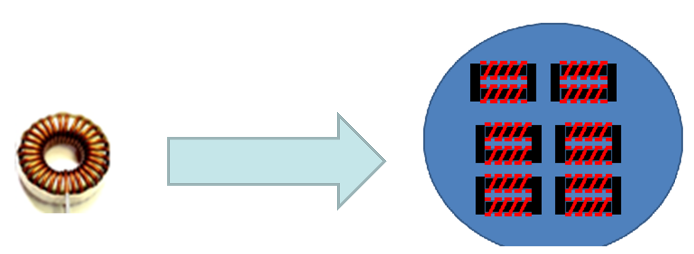
Objectives

Develop and demonstrate multilayered ferromagnetic-polymer composites as cores for miniaturized and integrated power inductors with:

- Inductance density: 100-1000 nH/mm^2
- Current-handling :0.5-1A
- Operation frequency: 1-10 MHz

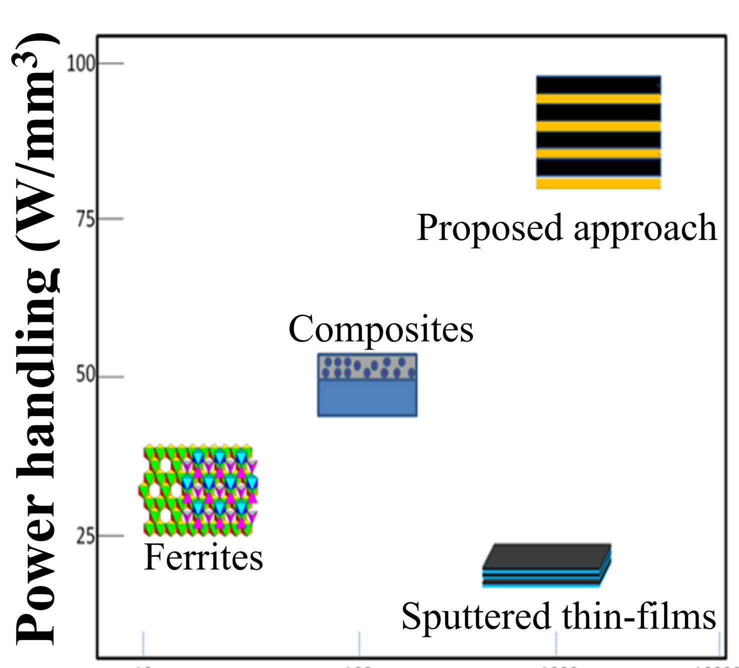
Magnetic Core - Targets

Property	Target
Permeability (@10MHz)	>250
Coercivity	<5 Oe
Core thickness	50-100 microns
Saturation Magnetization	0.5-1 Tesla



Prior Art

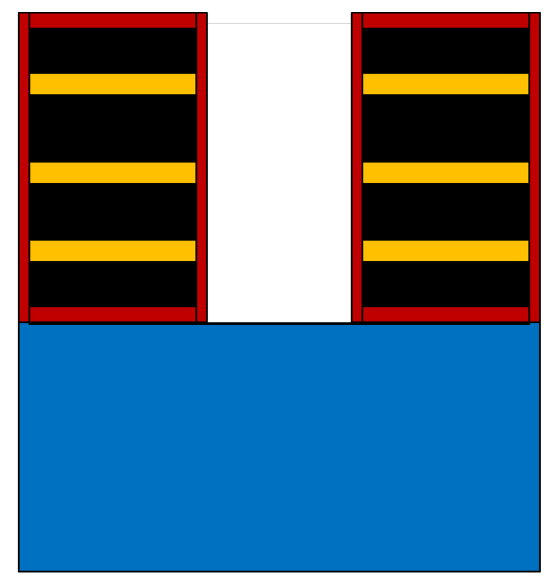
	Ferrites	Composites	Thin-films	Proposed approach
Thickness (µms)	500-800	200-500	10	50-100
Permeability	<200	<200	>500	>500
M_s	<0.5T	<0.5T	0.5-1T	0.5-1T
Frequency (MHz)	<10	<1	>100	1-10



Current material limitations:

1. **Ferrites**
   - Low Ms
2. **Composites (Amorphous/ nanocrystalline)**
   - High loss and low μ_r at f=1-10 MHz
3. **Nanogranular thin films**
   - Low power handling due to low Vcore

Proposed approach



Multilayered ferromagnetic-polymer dielectric composite structure

- High µ at desired frequency due to thin magnetic layer (Layer thickness ~skin depth)

$$\delta = \sqrt{\frac{\rho}{\pi f \mu}}$$

- Multilayer film-stacking using ultra-thin polymer dielectric layers as adhesives to maintain high Ms in ultra-thin form factor

$$Ms_{eff} = qMs_i$$

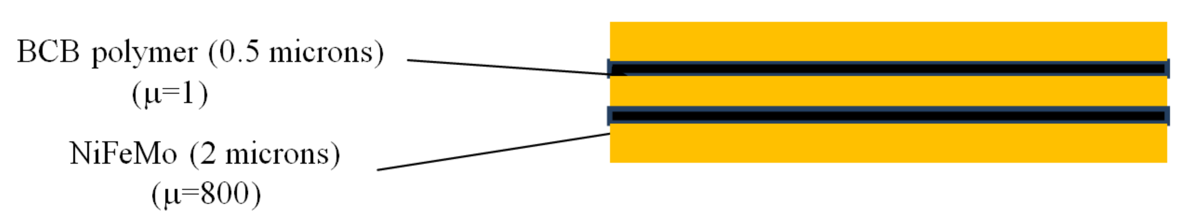
- Pattern multilayer film and form coils around it to fabricate ultra-thin inductor structures

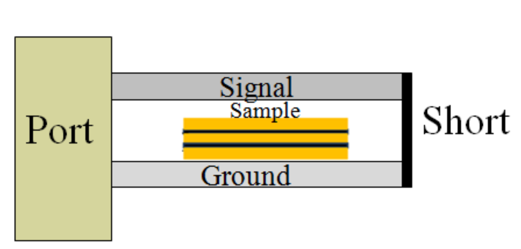
Modeling approach

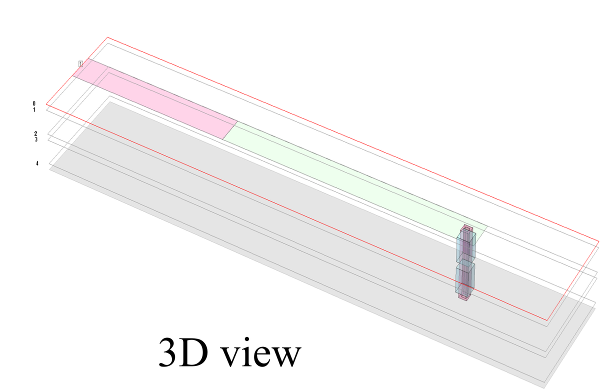
Computation of skin depth for different materials(@10MHz)

Material	Permeability	Resistivity (micro-ohm-cms)	Skin depth (microns)
NiFe	1000	20	2.25
NiFeMo	800	59	4.83
CoZrO	200	200	27.57

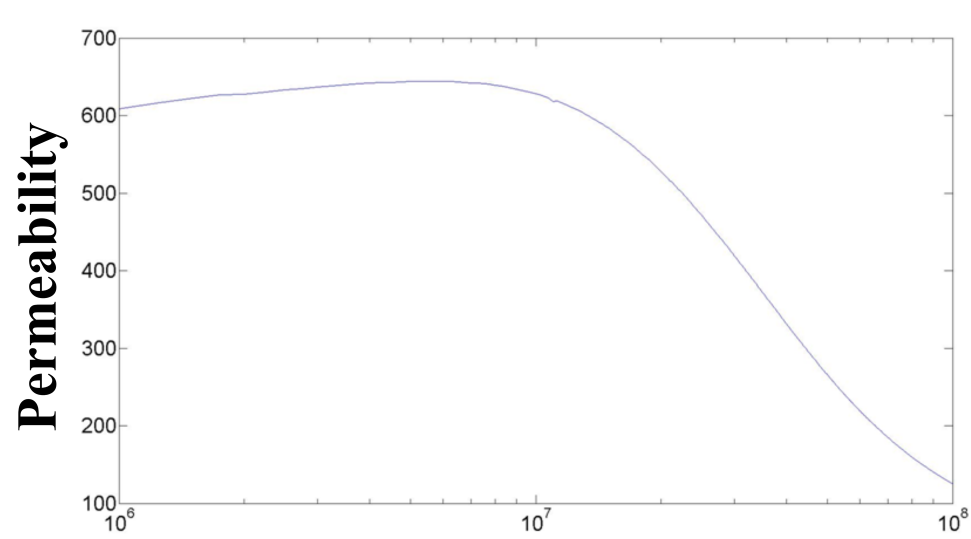
Electromagnetic (EM) simulation of shorted strip-line structures using SONNET to extract frequency dependent permeability



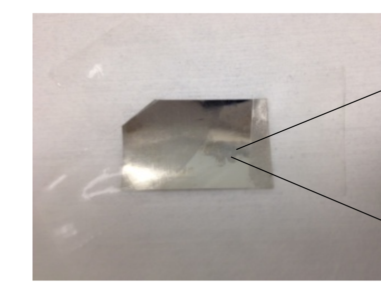




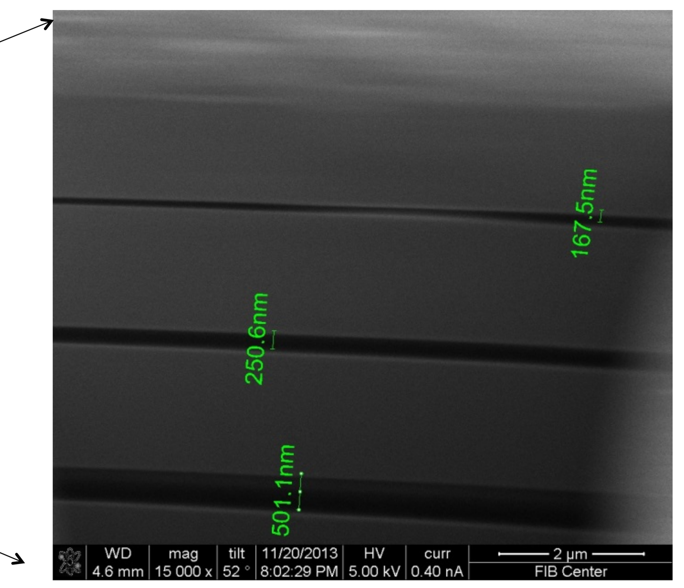
3D view



Fabrication and characterisation of multilayered composite

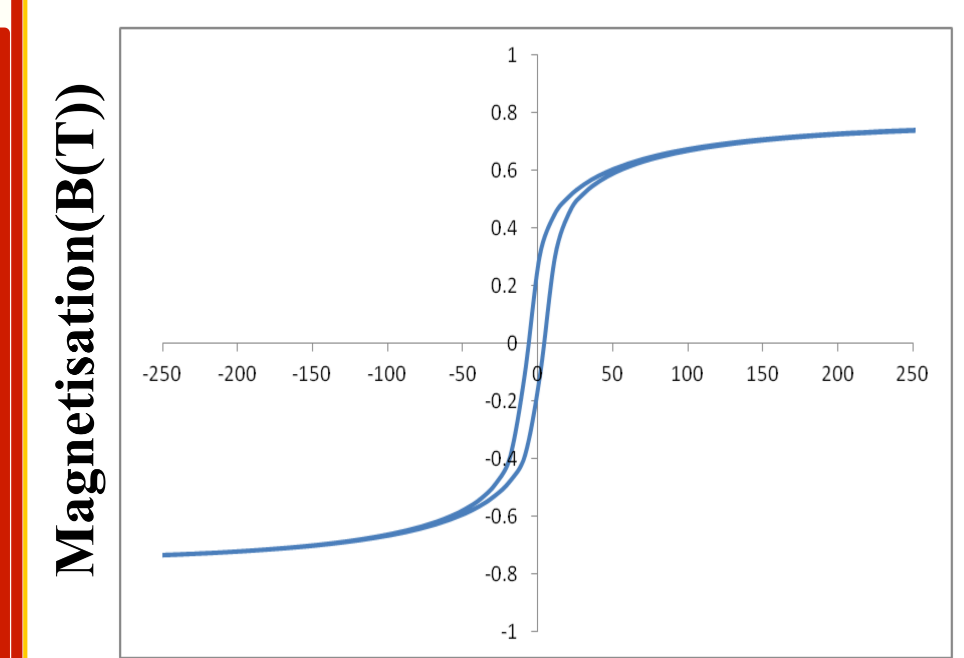


Multilayered composite film (thickness~50 microns)

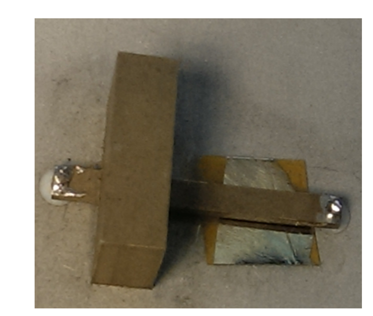


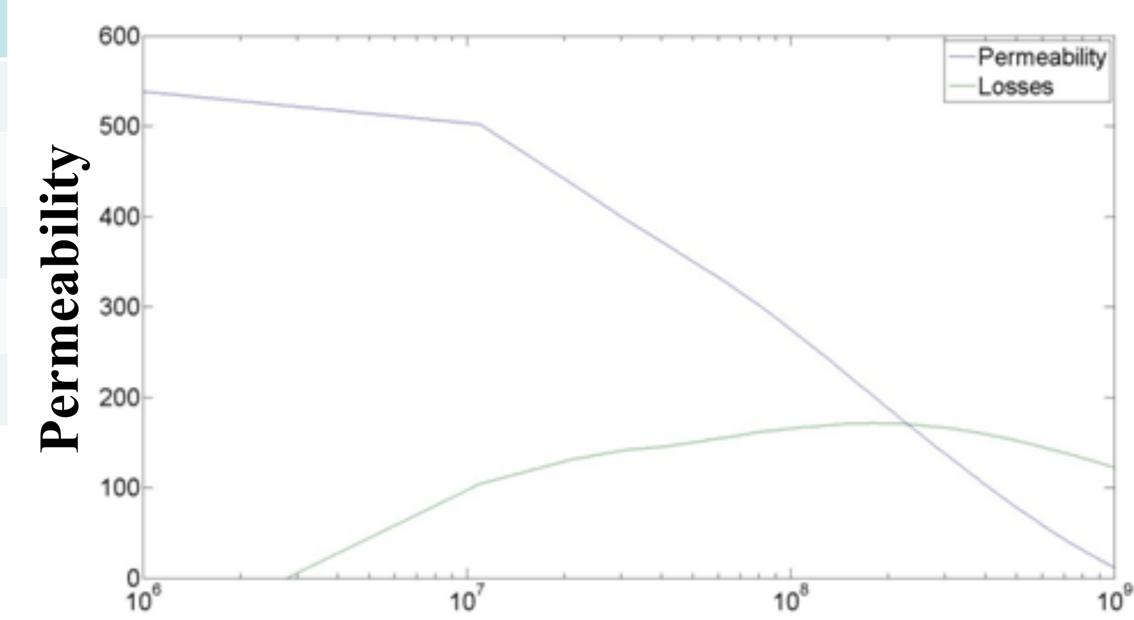
- Cross-section analysis shows multilayered composite structure with ultra-thin polymer of thickness:0.2-0.5 microns

(b) Magnetic properties characterisation



B_{sat}	**0.75 T**
Coercivity	4.4 Oe
Hk	15 Oe
Permeability	525
Q@1MHz	120
Q@10 MHz	10



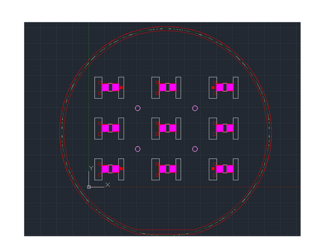


Extraction of frequency dependent permeability using shorted strip-line structure

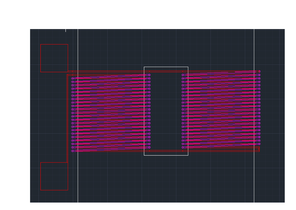
Excellent permeability and Q-factors obtained with composite structure for frequencies of 1-10 MHz

(d)Inductor design

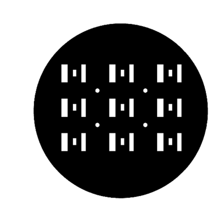
- Toroid inductors designed
- Number of turns ,N=30
- 40 microns vias
- Four-inch masks obtained



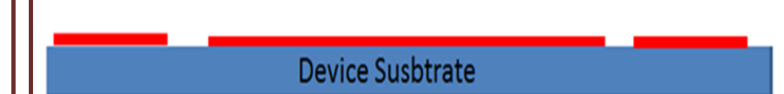
4-inch layout



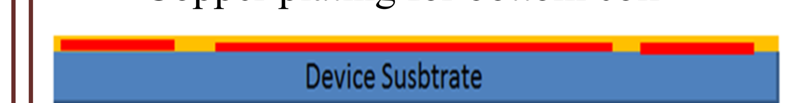
Single coupon



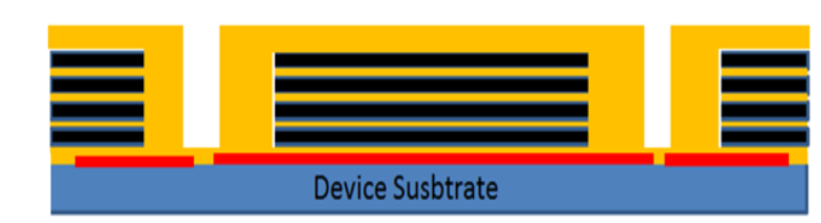
(e) Inductor fabrication process flow



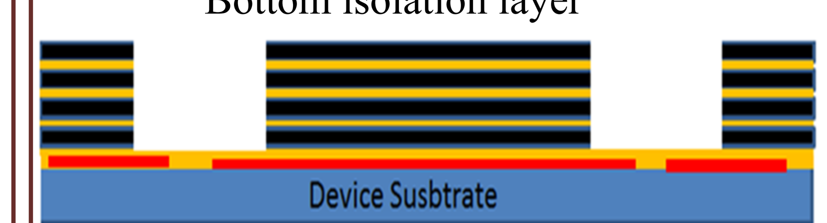
Copper plating for bottom coil



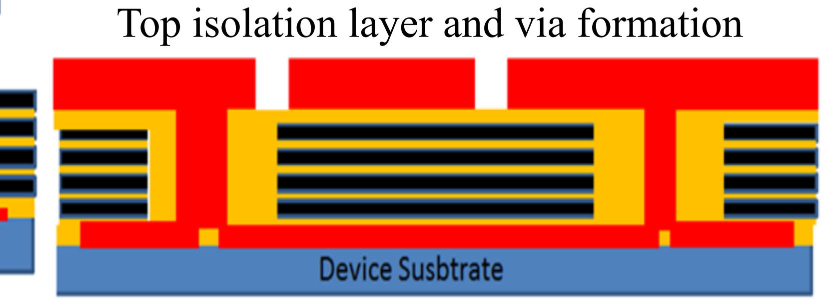
Bottom isolation layer



Top isolation layer and via formation

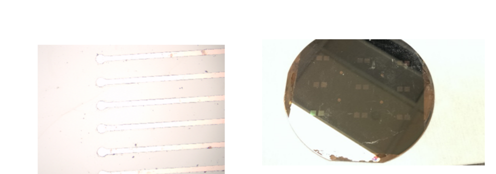


Magnetic layer formation and patterning

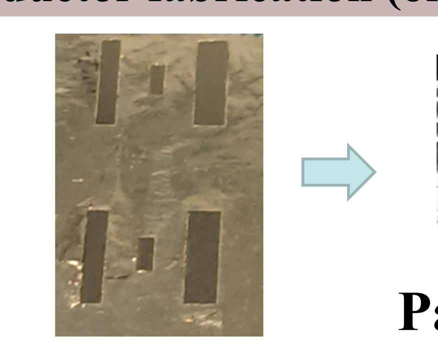


Via filling and top coil formation

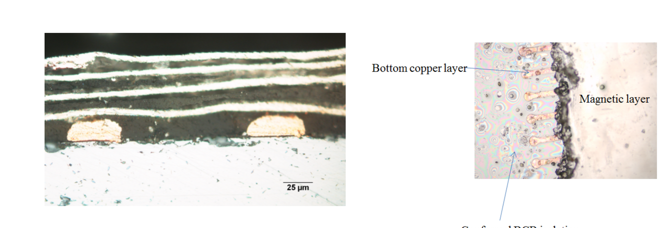
(e) Inductor fabrication (ongoing)



Bottom coil formation



Magnetic layer patterning



Patterned Magnetic layer on bottom coil

Summary

The proposed research describes a novel multilayered metal-polymer composite with high permeability and saturation magnetization at desired frequencies and anapproach to integrate composite structure in inductor devices.