

Thin Passive Components (TPC)

presented by

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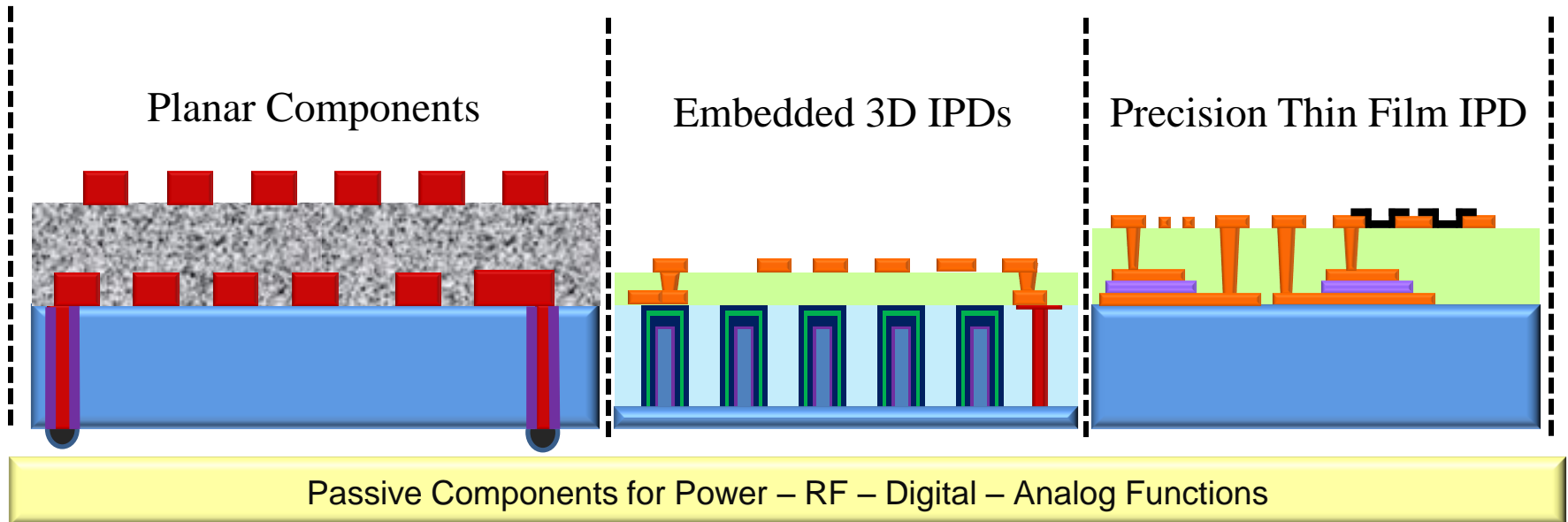
Atlanta, Georgia
May 25, 2011

Research Focus

Magnetics

High-Density Capacitors

Supercapacitors



Planar Components

Embedded 3D IPDs

Precision Thin Film IPD

Passive Components for Power – RF – Digital – Analog Functions

Thin Power Components

Integrated Power Sources

RF Components

RF Components

EMI Isolation

Thin Film Batteries



Research Focus and Targets

<i>TPC Technology</i>	<i>State-of-the-Art</i>	<i>Proposed Research Objectives</i>
<i>Power Supply Capacitors</i>	<ul style="list-style-type: none"> • 40-100 $\mu\text{F}/\text{cm}^2$; 250 microns • Self-healing only with high ESR 	<ul style="list-style-type: none"> • 100-200 $\mu\text{F}/\text{cm}^2$ • 50-100 microns • Self-healing with low ESR
<i>Power supply Inductors</i>	<ul style="list-style-type: none"> • 100 nH/cm²; 300-500 microns • High losses at high current and frequency 	<ul style="list-style-type: none"> • 100-1000 nH /cm²; 100 microns • Lower losses
<i>RF Components</i>	<ul style="list-style-type: none"> • Permittivity of 8-10 • Non-magnetic • Tolerance with discrete processes 	<ul style="list-style-type: none"> • Permittivity of 20-80 • Permeability of 10-20 • Tolerance and tunability when integrated

Power Supply Capacitors: Proposed Research Vs State-of-the-Art

	<i>State-of-the-Art</i>	<i>Proposed Research Objectives</i>
<i>Capacitance Density</i>	<ul style="list-style-type: none"> • 40 $\mu\text{F}/\text{cm}^2$ 	<ul style="list-style-type: none"> ▪ 100-200 $\mu\text{F}/\text{cm}^2$
<i>Thickness</i>	<ul style="list-style-type: none"> • 250 microns 	<ul style="list-style-type: none"> ▪ 50-100 microns
<i>Leakage Current</i>	<ul style="list-style-type: none"> • 0.1 $\mu\text{A}/\mu\text{F}$ 	<ul style="list-style-type: none"> ▪ 0.03 $\mu\text{A}/\mu\text{F}$
<i>Conformal Electrodes</i>	<ul style="list-style-type: none"> • Self-healing only with high ESR 	<ul style="list-style-type: none"> ▪ Self-healing with low ESR
	<ul style="list-style-type: none"> • Temperature constraints with certain conformal electrodes 	<ul style="list-style-type: none"> ▪ No temperature constraints
<i>Cost</i>	<ul style="list-style-type: none"> • High-Cost for thin IPDs 	<ul style="list-style-type: none"> ▪ Low-cost

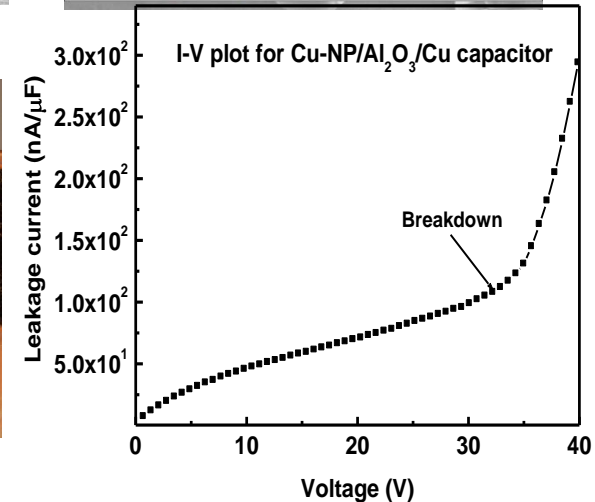
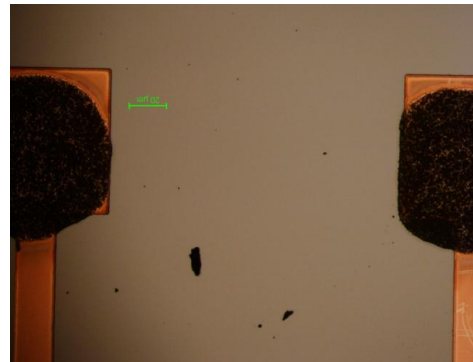
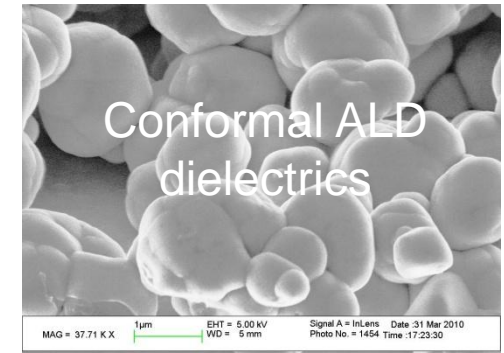
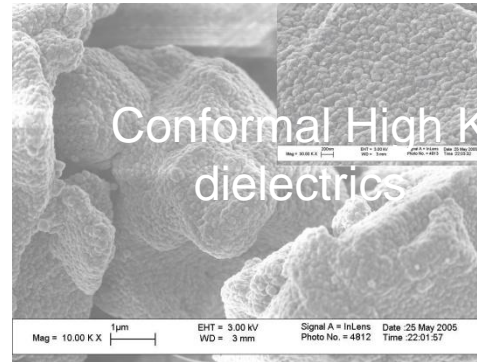
Thin Power Capacitors - Challenges

- **Material challenges:**
 - Volumetric efficiency hitting fundamental material and process limits;
- **Integration Options Challenges:**
 - Usually 100s of microns thick; difficult to embed in the package;
 - Materials and processes not compatible with glass, silicon or organic packages
- **Manufacturing Challenges:**
 - Thin film capacitors are prone to yield issues from defects;
 - Lack of reparability in the integrated passive component can affect good dies and packages



Background Research in thin IPDs

- High Surface area electrodes with thin conformal dielectrics
- Self-healing of defects for low leakage, yield and reliability
- Conformal top electrodes
- Package compatible integration processes



Capacitance density:

Nanoelectrodes: 60 µF/cm² ; 32 V BDV

Foil Capacitors: 9 µF/cm²; 10 V BDV;

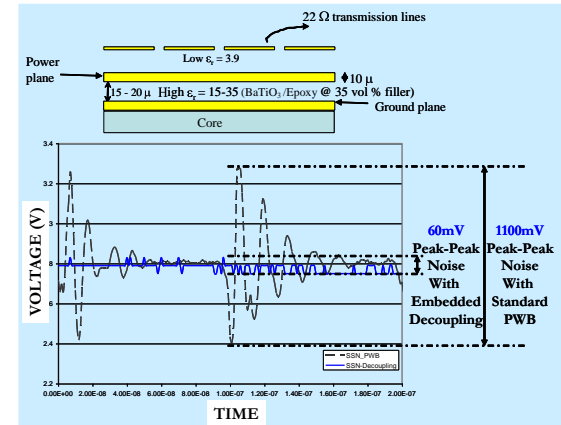
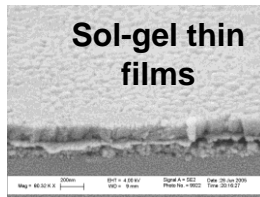
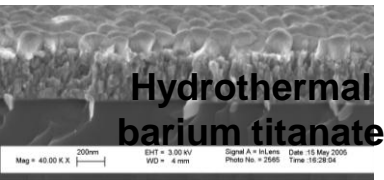
More than 5 Patents Filed in High-Density Capacitors and Integration

Approach for High-Density Capacitors

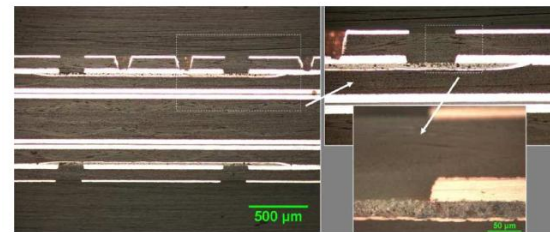
- Metal-based top electrodes
 - Low ESR (10X smaller than conducting polymers)
 - High-temperature (> 400 C)
- Self-healing with low ESR electrodes:
 - Post-processing to heal the defects
 - Top-electrode based self-healing without conducting polymers
- Conformal High K Dielectrics
 - Capacitance density 5-10X above tantalum capacitors
 - Self-healing with high-K dielectrics
 - Conformal High K crystallization

Background Research

Thin Film Decoupling Capacitors



Industry Prototypes
System-Level Function
Enhancement



Large area demonstration of embedded thin film capacitors on organic board;

Nano-Composites & Nano-scale Thin Film High K Materials

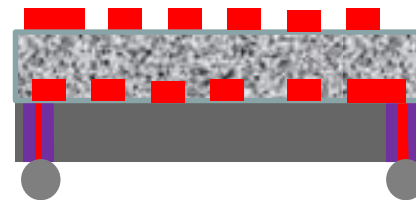
*J. Amer. Ceram. Soc., August, , 93 (9), 2764-2770, 2010 ,
IEEE CPMT Transactions on Adv. Pkg, Dec. 2007, pp. 585-594.*

II. Thin Power Inductor Targets

Objectives:

Thin power inductors using nanomagnetic materials

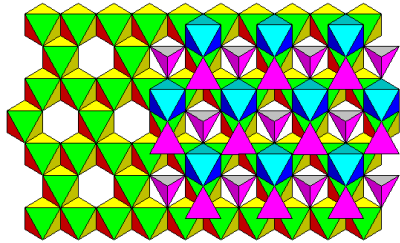
- Inductance to :
 - 1 000 nH/mm²
 - 50-100 micron device
 - Q of 20-50
 - 0.1-1 GHz
- Low-cost process for easier integration
- Integration process that easily enables planar toroid structures for highest inductance density



Power Supply Inductors – Proposed Research Vs State-of-the-Art

	State-of-the-Art	Proposed Research
Inductance Density	<ul style="list-style-type: none"> • 50 -100 nH/cm² 	<ul style="list-style-type: none"> ▪ 100-1000 nH/cm²
Thickness	<ul style="list-style-type: none"> • 500 microns 	<ul style="list-style-type: none"> ▪ 100 microns
Current-Handling	<ul style="list-style-type: none"> • 1-3 A for thicker cores 	<ul style="list-style-type: none"> ▪ 1-3 A for thinner cores
Power efficiency	<ul style="list-style-type: none"> • 70-80% for high currents (>1 W/cc) 	<ul style="list-style-type: none"> ▪ 80-90% for high currents (100 mW/cc)

Thin Power Inductors: Challenges

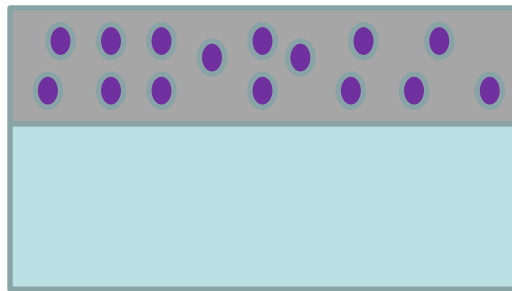


Ferrites

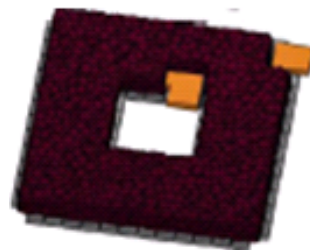


Ferrites :

- Limited frequency of operation
- Low saturation magnetization
- Low volumetric efficiency



Metal polymer composites

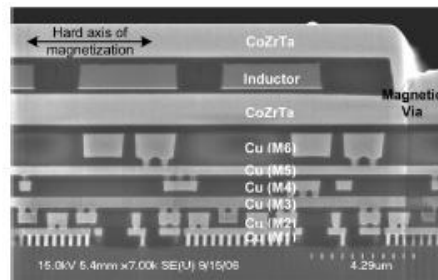


Metal-polymer microcomposites:

- Limited frequency of operation
- Lower permeability beyond 1 MHz



Layered magnetics



Intel

Layered magnetics:

- Complex and expensive processes
- Difficulty scaling up the thickness

Soft Inductor Core with Nanomagnetics

Approach:

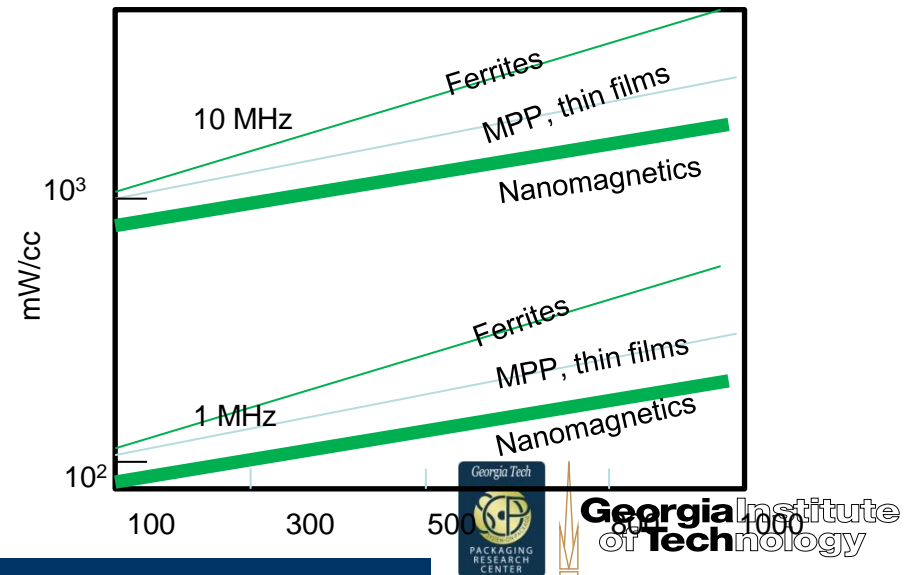
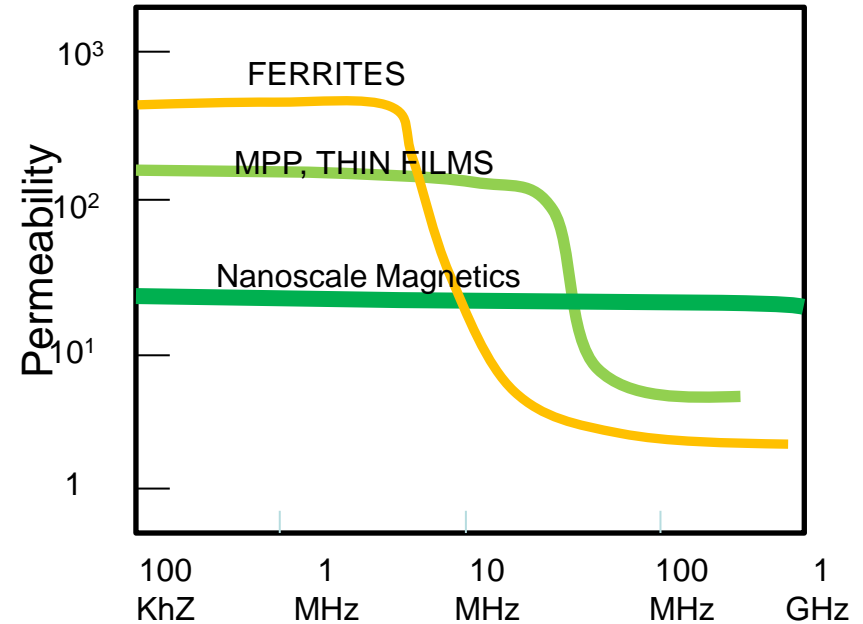
- Stable properties with frequency using nanomagnetic films

- Permeabilities of above 100 till 2 GHz;
- FMR of 20 GHz demonstrated
- Lower domain wall and eddy current losses

- Innovative processing to achieve adequate thickness

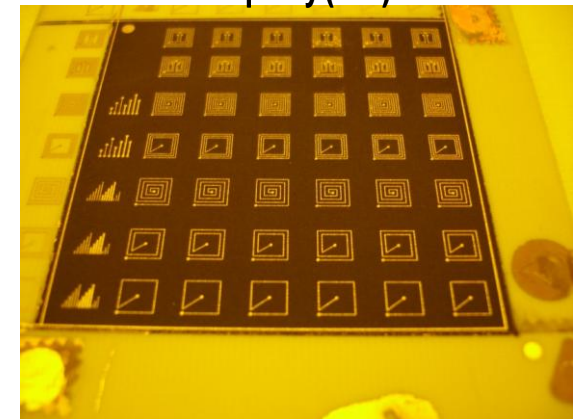
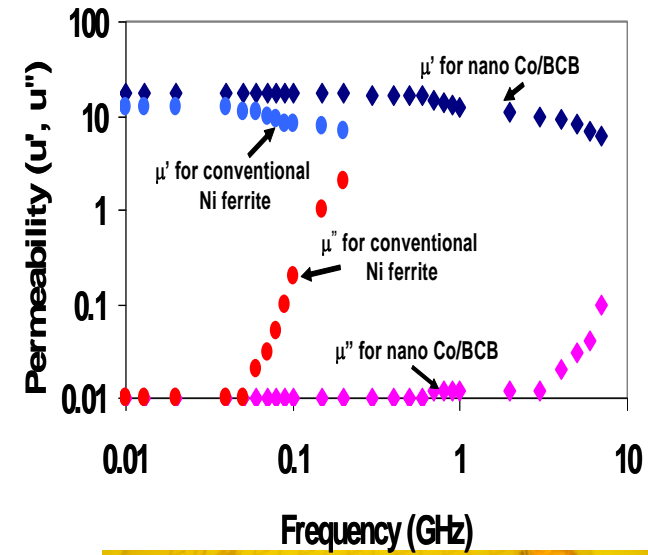
- Orientation of magnetic domains to induce paramagnetic behavior in the hard-axis

- Lower losses at higher magnetic fields



Background Research in Nanomagnetism

- Nanomagnetic films with low hysteresis losses and high M_s
- Metal nanocomposites for printable silicon-compatible inductor core
- Polymer paste technology for organic compatible high-density inductors
- Low-cost integrated coil technologies with magnetic thick films core



High-density inductors with magnetic paste:

PRC-Inframat Collaboration



Georgia Institute of Technology

VI. RF Components

Objectives:

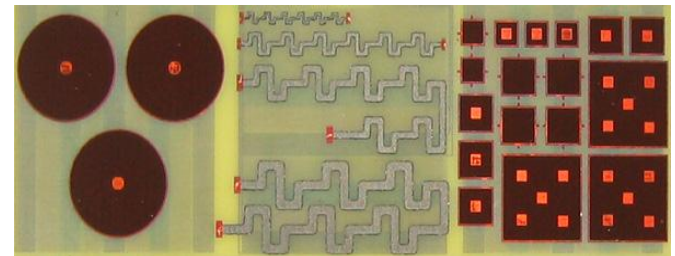
- Novel high K dielectrics:
 - Permittivity: 10-80
 - Permeability: 10-100
 - Dielectric Loss tangent: < 0.005
 - TCC < 30 ppm/C
 - Tolerance of 5%
- Precision R, L and C
- Design of RF and mixed signal components

Challenges:

- Existing RF dielectrics are expensive and not scalable (LTCC) and have limited permittivity of ~ 8 (polymer composites)
- Higher permittivity leads to thermal and frequency instability, and high loss;
- Tolerance from processing and material variations;

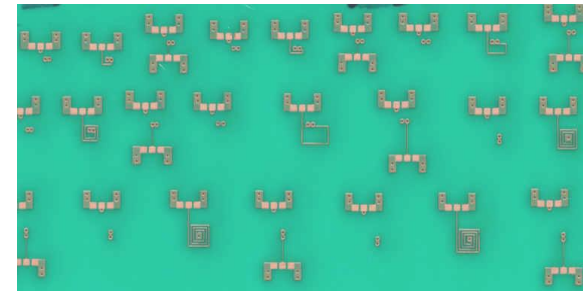
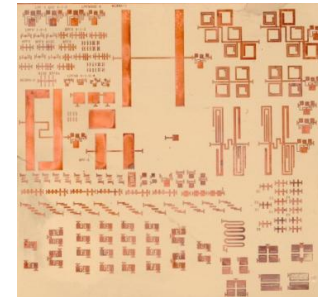
Proposed R&D:

- Organic substrates or organic build-up layer process compatible
- Polymer and glass matrix composites or thin film capacitors with engineered properties
- Tolerance from:
 - Thickness control
 - Lateral dimension control



RF Dielectrics: Challenges

- Existing RF dielectrics are expensive and not scalable (LTCC) and have limited permittivity of ~ 8 (polymer composites)
- Higher permittivity leads to thermal and frequency instability, and high loss;
- Tolerance from processing and material variations;
- Thick and stable dielectrics do not allow for tunability (material limitations)



RF passives on LCP, FR4 (PRC)

Novel High K RF Materials

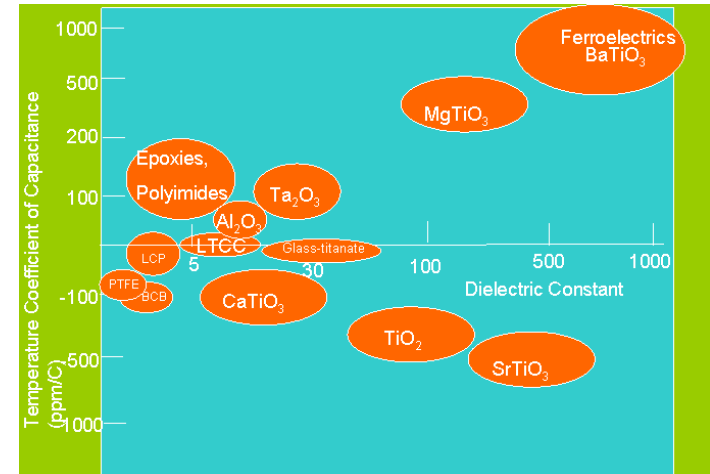
Nanoscale ferroelectrics
(superparaelectrics)

- Enhanced stability with voltage and temperature by engineering the film chemistry and structure

- Layered structures with positive and negative TCC;

- Composites of different filler materials that compensate TCC

- Same concept for voltage stability: Combine materials with positive or negative voltage dependence



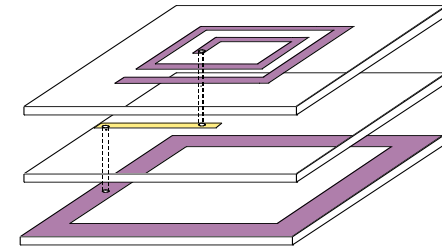
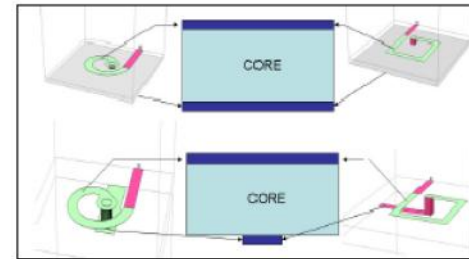
PRC INVENTION: ORGANIC BASED
DIELECTRIC MATERIALS AND METHODS
FOR LOW TCC AND HIGH PERMITTIVITY,

US PATENT APPLICATION: 11/429,780

- Jin-Hyun Hwang, **P. Markondeya Raj**, Isaac Robin Abothu, Chong Yoon, Mahadevan Iyer, Hyung-Mi Jung, Jong-Kuk Hong and Rao Tummala, "Temperature dependence of the dielectric properties of polymer composite based RF capacitors", *Journal of Microelectronic Engineering*, [Microelectronic Engineering Volume 85, Issue 3](#), Pages 553-558, March 2008.

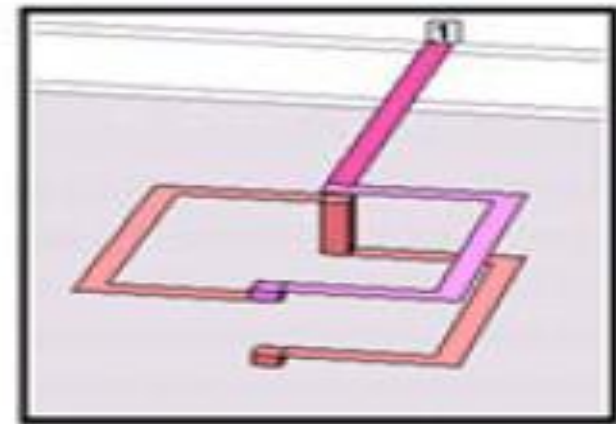
Design Approaches to High Q

- Create ground plane opening under inductor footprint;
- Circular loops instead of rectangular



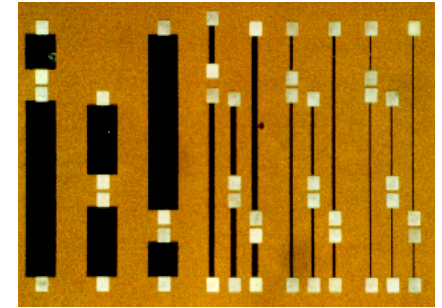
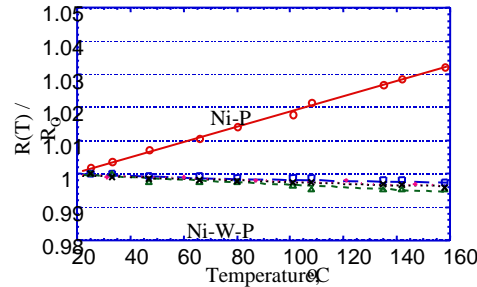
Hollow ground

- Increase spacing and create off-set between half loops; Decrease series capacitance with increased spacing between the loops
- Optimize line-width and spacing for high Q and inductance density



Thin Film Resistor Examples

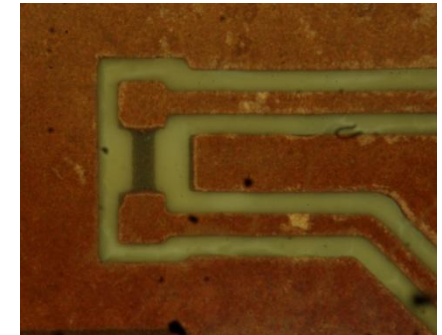
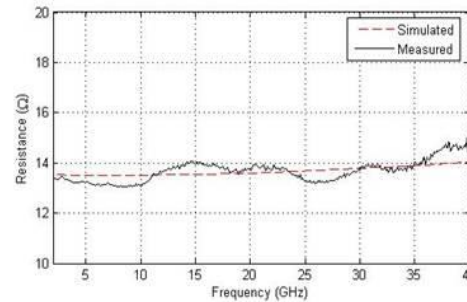
Electroless Plated Resistor Process



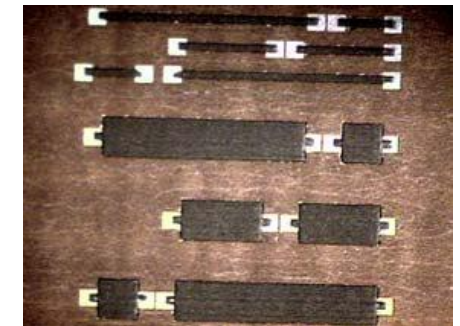
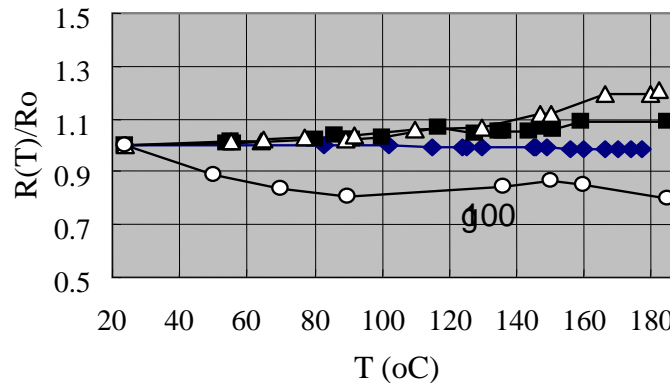
Electroless Ni alloy resistors
50-100 ohms/square

Foil transfer process
1-10 k Ohms/square
TCR 100 ppm/C

Foil Transfer Process



Polymer thick film (PTF) Printing Process



Printed polymer thick film resistors
500 – 10K ohms
TCR 300 ppm/C

Research Focus and Targets

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<i>RF Components</i>	<ul style="list-style-type: none"> • Permittivity of 8-10 • Non-magnetic • Tolerance with discrete processes 	<ul style="list-style-type: none"> • Permittivity of 20-80 • Permeability of 10-20 • Tolerance and tunability when integrated



TPC Workshop

MAY 25, 2011

Thank you for attending.