Optimization of magnetic enhancement layers for high-frequency transmission line micro-inductors

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Background

- Minimization leading to increased consideration of integrated passives on-Si or in-package
- Soft ferromagnetic thin-films play a key part for inductance enhancement effects and low loss at high frequencies
  - Inductance enhancements of up to 28\%
  - Current capacities of up to 10 A\r
- Ideal Magnetic thin-film will provide
  - High inductance enhancement
  - High saturation current
  - Low losses at high frequency (>100 MHz)

Devices to effectively close the core between the top and bottom magnetic layers are commonly used in transmission-line structures.

- Simulations show a good correlation with Finite Element Analysis (FEA)

\begin{align*}
\mu &= \frac{2\delta}{(1 + \delta^2) \tan \left( \frac{1 + \delta^2}{2\delta} \right)}
\end{align*}

Where:
- \( \mu \) = relative permeability
- \( \delta \) = depth of the thin film
- \( \delta \) = thickness

Simulations show a good correlation with Finite-Element Analysis (FEA)

Objectives

- Inductance model based on series of reluctance elements to calculate inductance enhancement
- Resistance model based on \( R_L + R_{\text{res}} \)
- High-frequency complex permeability modelled using analytical equations:

\begin{align*}
\mu &= \frac{2\delta}{(1 + \delta^2) \tan \left( \frac{1 + \delta^2}{2\delta} \right)}
\end{align*}

Three common materials for transmission-line micro-inductors were compared:

- \text{CoP}
- \text{NiFe}
- \text{CoTaZr}

Sputtered materials (CoTaZr)
- Good magnetic properties
- Time-consuming to produce above a few µm

Electrodeposited materials (CoP, NiFe)
- Similar properties to sputtered materials
- Improved deposition rate

Results

- The device Q-factor illustrates the relationship between inductance and resistance at a particular frequency and geometry
- Device Q-factor peaks can be seen for each material, indicating an optimal material thickness for a particular frequency, not shown in thin-film measurement
- Inductance enhancement at the Q-factor peak can be used to determine the material with the greatest inductance enhancement capability at a given frequency
- High-Bias current handling of a device is a function of anisotropy field, however initial bias is influenced by more than low-frequency permeability
- Inductance enhancement as a function of frequency directly related to relative permeability and resistivity, CoP shows inductance retention to a high frequency

Inductance enhancement as a function of DC bias field

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References


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