PWR SOC 12

Palace Hotel, San Francisco, CA
Nov. 16-18, 2012

Integration of Magnetic Thin Films into On-chip Inductor: NiFe vs CoZrTaB

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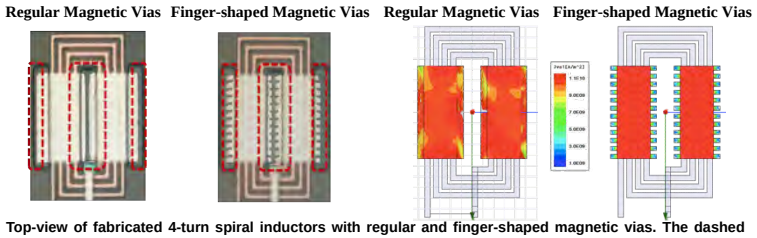
Motivation

- **On-chip inductors are a critical element in power circuit for PwrSoC/SiP.**
  - Need high inductance density -> Reduces chip area -> Reduces cost.
  - High quality factor -> Reduces loss -> Reduces power supply.
- **On-chip inductors with magnetic materials**
  - High permeability, high resistivity, high FMR for GHz applications.
  - CMOS compatibility: low process temperature, stable properties.

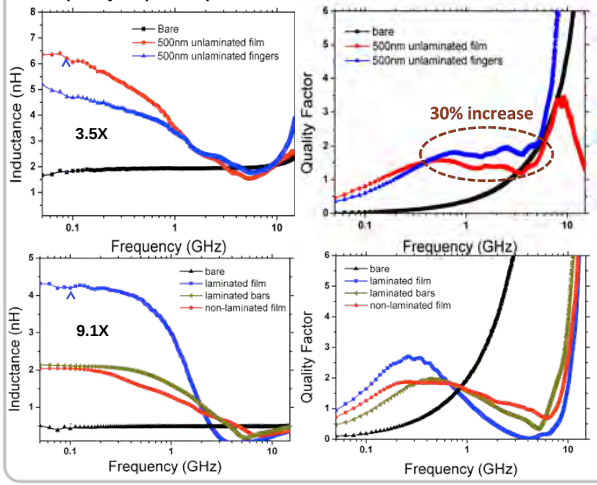
On-chip Inductors with Patterned Co-Zr-Ta-B Films

- **4-turn rectangular inductors with finger-shaped magnetic vias**
  - W: 88 µm, L:160 µm, elongated to take advantage of the uniaxial magnetic anisotropy.
  - Normal magnetic vias region: W: 7.5 µm, L: 86 µm, have high level of eddy current density.
  - Finger-shaped magnetic vias: W: 5 µm, L: 4 µm×13, designed to suppress eddy current.



Top-view of fabricated 4-turn spiral inductors with regular and finger-shaped magnetic vias. The dashed lines indicated magnetic via regions. Eddy current density in magnetic film at 1GHz was simulated by HFSS 3D EM simulator.

- **Measurement results**
  - With Co-Zr-Ta-B film, a maximum 3.5X inductance increase and a 3.9X increase in the Q-factor at 1 GHz were achieved, and by using laminations, up to a 9.1X inductance increase with good frequency response up to 2 GHz can be achieved.



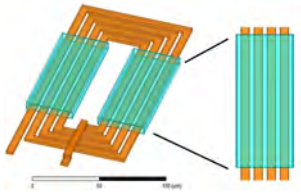
Top: Inductance and quality factor measurements from 4-turn rectangular spiral inductors with regular and finger-shaped magnetic vias. The Co-Zr-Ta-B film is 500nm thick without laminations.

Bottom: Inductance (a) and quality factor (b) measurements from stripline inductors with 5×100nm laminated versus unlaminated Co-Zr-Ta-B films. The "bare" represents the same inductor without magnetic materials.

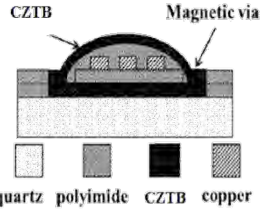
Wu, et al., IEEE Trans. Mag. 48, 4123 (2012).

Device Fabrication

- Spiral (W: 88 µm, L:160 µm) and stripline (W: 9 µm, L: 450 µm) inductors were fabricated on quartz substrates.
- Electron Beam Lithography (EBL) used for pattern definition.
- Magnetic films and 2 µm thick copper wires deposited by magnetron sputtering.
- Low-k polyimide for insulator.



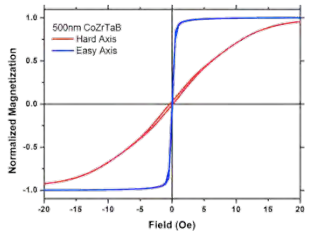
Schematic of on-chip 4-turn spiral inductor with magnetic materials.



Cross-section veiw of fabricated devices, copper coils were wrapped around by magnetic material Co-Zr-Ta-B.

Material Characterizations

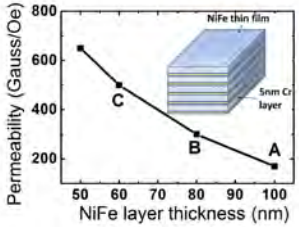
- DC magnetron sputter deposition: 80%Ni-20%Fe and Co-4%Zr-4%Ta-8%B (at.%).
- Co-Zr-Ta-B shows superior magnetic properties.
  - Low coercivity < 0.1 Oe
  - High DC permeability ~1070 and high resistivity ~ 115 µΩ·cm
  - High FMR frequency measured by PIMM ~1.6GHz



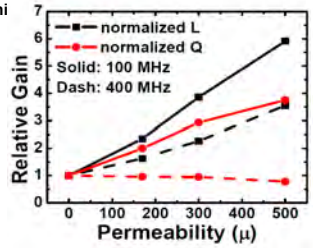
M-H magnetic hysteresis loops of hard and easy axis of magnetization for 500 nm thick as-deposited Co-Zr-Ta-B film

Inductance Enhancement Of On-chip Inductors With Ni-Fe

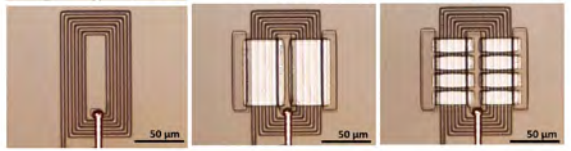
Spiral inductors with patterned NiFe rings at 100 m scale achieving enhancements of 6X in inductance and 3X in Quality factor at frequencies as high as 200 MHz. An inductance density around 770 nH/mm² is achieved, which is higher than other reported values of Ni-Fe based inductors.



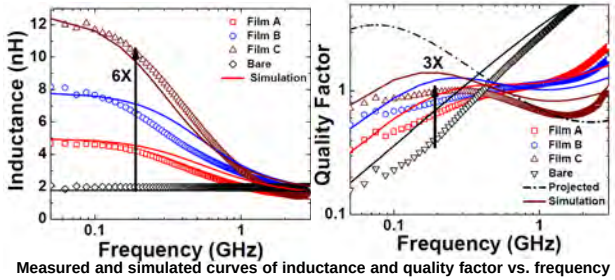
The measurement of layer thickness dependence of permeability. Inset shows schematic of lami



Measurement result showing relative gain in L and Q at low and high frequencies.



Optical images of the fabricated rectangular and square inductors (a) without NiFe (bare), (b) with NiFe thin film enclosed, (c) with patterned NiFe rings.



Measured and simulated curves of inductance and quality factor vs. frequency for 4-turn spiral inductors with Ni-Fe. Devices with film A (=170), B (=300) and C (=500) were investigated. L increase up to 6X is measured from device C at 200 MHz.

Xu, IEEE EDL 32, 69 (2011); Xu, IEEE EDL 31, 207 (2010); Tawab, APL 97, 162506 (2010).