High Efficiency Si Integrated Micro-transformers for Power and Signal Isolation

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Background

Context : Integrated micro-transformer for signal isolation and power transfer

- Isolation is required to protect human and sensitive components from high voltages.
- Power needs to be transferred from non-isolated side to isolated side.
- Technology further developed to achieve higher inductance density and higher efficiency.
- Provide a complete solution for achieving isolated signal and power transfer with a high integration level.

Design & Modeling

- Use magnetic mateirals to achieve
  - o A high magnetizing inductance
  - o A good coupling factor
- Racetrack shape is employed:
  - o Easy to induce uniaxial anisotropy in the core
  - o Relatively less complex to fabricate
- Two types of structure used to realize racetrack micro-transformers
  - o Single layer metal
  - o Double layer metal

Fig. 1. Top view of a SLM racetrack micro-transformer

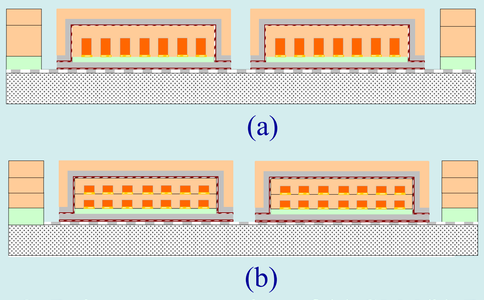


Fig. 2. Deivce cross-section of (a) SLM(b) DLM

Specs of two types of μ-transformer

Transformer Prototype	SLM	DLM
Winding width, μm	40	40
Winding thickness, μm	30	15
Winding spacing, μm	20	15
Turns ratio,	4:4	6:6
Core thickness, μm	4.5	4.5
Core length, mm	1.09	1.32
Device length, mm	2.59	2.6
Device width, mm	1.35	1.15
DC resistance, Ohm	0.34	1.1
Inductance at 20MHz, nH	80	240

Fabrication

- MEMs fabrication process [5]
- Electroplated Cu coils between magnetic cores
- Electroplated thin film Ni45Fe55 cores
- Extreme low profile

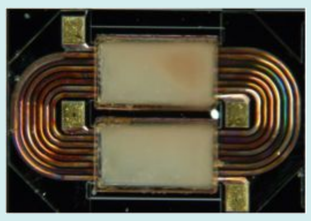


Fig. 3. Top view of a fabricated SLM racetrack micro-transformer

DLM Process

NiFe - Bottom core

ILD - Insulator

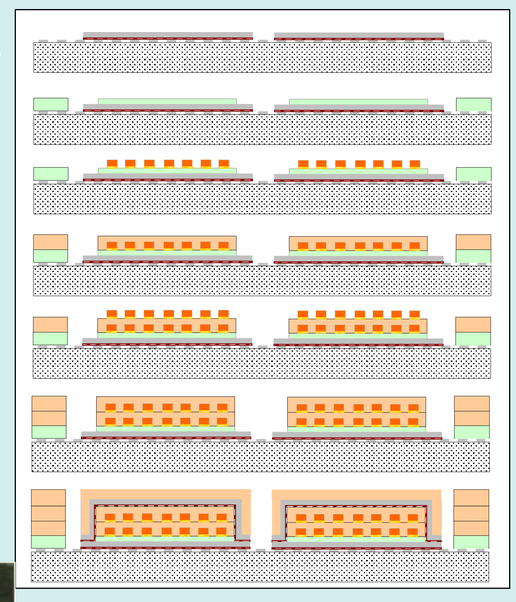
1st Copper coils

IMD1 -Insulator

2nd Copper coils

IMD2 -Insulator

NiFe - Top core



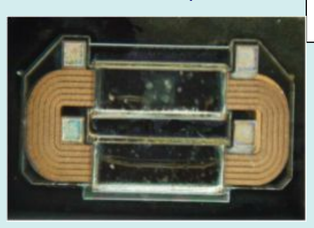


Fig. 4. Top view of a fabricated DLM racetrack micro-transformer

Characterization & Analysis

Fig. 5. Cross section of (a)SLM device (b)DLM device

- Characterization was carried out using an R&S Vector Network Analyzer, Model ZRVE
- De-embedding method [6] was applied for the correction of the parasitics associated with the test set-up
  - o Impedance matrix of DUT, Z_{DUT} was measured
  - o A dummy device was prepared and Z_{Dummy} was measured
  - o Impedance of transformer was separated from Z_{DUT}

$$[Z_{Transformer}] = [Z_{DUT}] - [Z_{Dummy}]$$

- V_{out} and voltage gain can be obtained using

$$\begin{bmatrix} V_{in} \\ V_{out} \end{bmatrix} = [Z_{Transformer}] \begin{bmatrix} I_{in} \\ -I_{out} \end{bmatrix} \qquad Gain = 20 \times Log_{10}[V_{out} / V_{in}]$$

- One port measurement was used to obtain the open circuit characteristic of the transformer.
- Only measured inductance (Loc) and resistance (Roc) from primary side with secondary open are shown in Fig. 6.
- Higher inductance density achieved using DLM structure[from 18nH/mm² to 80nH/mm²[7]
- Efficiency improved by using DLM from 63% to 78%

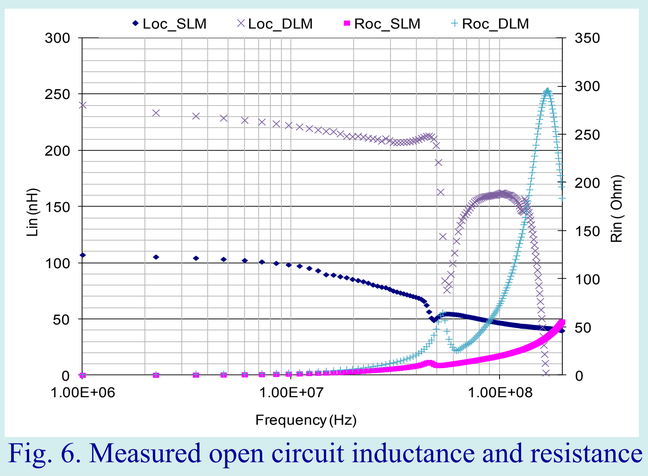


Fig. 6. Measured open circuit inductance and resistance

- The measured voltage gains for with 50 Ω load condition are shown in Fig. 7.
- For a 5V peak input, the maximum efficiency of the micro-transformer can be estimated to be 78% at 20MHz

Advantages over integrated air-core transformers:

- Requires significantly lower operating frequency compared to air-core micro-transformers
- Achieve much higher converter efficiency (>60%)

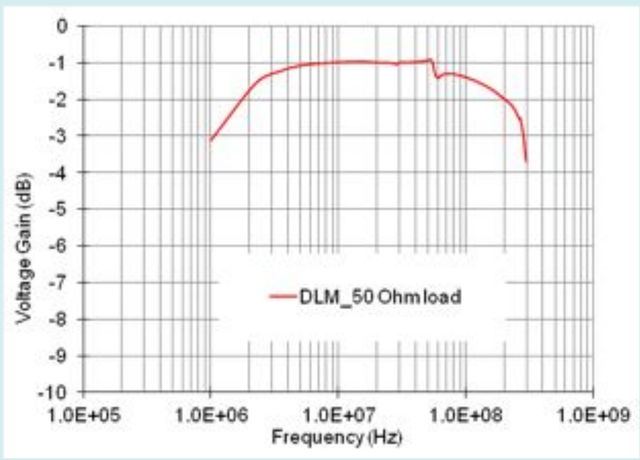


Fig. 7. Calculated and measured voltage gain

Conclusions & Acknowledgements

- Batch micro-fabricated transformers with advanced double layer metal process
- High Voltage Gain >-1dB at 10~40MHz
- High efficiency of 78% at 20MHz
- Higher converter efficiency @ 20MHz (> 60%) than air-core based solutions
- Small footprint area (<3mm²)
- Extreme low profile (<100um)

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