Development of Micro-Trafos Using MCM and Electronic Packaging Technologies

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1. Abstract

Several electronic devices such as implants and sensors network could benefit from compact transformers (trafos). In this paper, the authors present the development of microtrafos on a MCM (Multi Chip Module) platform. The windings were completed using wirebonding of Au wires. Electrical characterization of the prototypes presented results as good as those from devices built with printed circuit boards, showing that this is a viable approach, with the advantage of smaller dimensions.

2. Introduction

Following the scaling trend on electronics, there has been a great interest for PwrSiP (Power Supply in Package) and PwrSoC (Power Supply on Chip) devices. In the PwrSiP, the magnetic elements are packed together with the converter circuit, while in PwrSoC these elements are integrated to the circuit, leading to integrated bias sources [1]. However, building magnetic components directly onto/together with the integrated circuit demands complex and expensive deposition techniques that limit its commercial use [2].

Another area that can use small volume transformers is energy harvesting. Ultralow voltage oscillators with magnetic circuits for this purpose are already found in the literature [3]. However, no such devices with adequate electrical and size characteristics are commercially available.

Macrelli et al. [1] built minitransformers using thinned commercial cores assembled onto Printed Circuit Boards (PCB's). The windings are made of gold wirebonds interconnected under the core through the PCB tracks. The wires do not comply onto the core and the air gap reduces the coupling factor.

Lu et al. [4] built the wirebond inductors covered with an epoxy resin and ceramic powder with magnetic properties. Even so, the coupling factor is not high, on the order of 0.6, probably because the high magnetic permeability of the compound leads to a significant non-concatenated magnetic flow outside the windings.

Macrelli et al. [5] also uses LTCC to build a core in a racetrack shape with a 50:1 winding ratio using Au wirebond. In this case, the effective winding voltage ratio was 20:1 and the coupling factor was 0.6.

All these studies, however, make use of PCB's substrates. This limits the track to the submilimetric scale, i.e., 0.1 mm wide tracks can only be achieved in very calibrated fabrication process. Working on such critical condition compromises the reproducibility of the final devices. The MCM approach presented on this paper allows overcoming this size restriction. The use of well known photolithographic technologies of the semiconductor industry leads to tracks that can scale down to micrometers. This allows to a much greater scaling compared to PCB technology and, thus, to much smaller microtrafos.

In this paper, the authors present a technological approach to build miniaturized magnetic circuits (i.e. a microtransformer or microtrafo) using MCM-D (Multi Chip Modules – Deposition of thin films) fabrication technologies.

MCM's are electronic assemblies where several integrated circuits are mounted onto a substrate (usually alumina) to behave as a single circuit. The Electronic Packaging Research Group (NEE - Núcleo de Empacotamento Eletrônico) at CTI has the ability to fabricate MCM tracks down to 40 µm. This technology leads to a considerable dimensional gain for building a microtrafo in terms of size and weight.

The differential of MCM is the use of lithography to define the conductive tracks instead of PCB technologies that allows submilimetric dimensions.

Using the technologies available at NEE, we designed and built prototypes of microtrafos. The trafo cores were made of commercially available ferrite cores on toroidal shape. The cores were thinned to <3 mm high in order to allow the windings to be made of Au wirebonding. The winding were constructed with 20x100 μm^2 ribbons and 25 µm diameter wires. These prototypes aim to energy harvesting applications. Such devices must supply adequate voltage levels to standard electronic circuits (i.e. 3-5 V) from sources that provide in the range of tens of mV. A high turns ratio is found and thus, a high coupling factor is necessary in order to minimize the amount of windings and the final volume of the microtrafo.

4. Assembling of the Prototypes on MCM

Microtrafos were built using MCM technologies onto a 1in.x1in. alumina substrate. A 3.5 µm thick gold layer were electrodeposited and the tracks defined using lithography and etching processes. The final device

(Fig. 1) has four winding sets, two with 16 turns and two with a single turn and test structures to help understand parasitic effects of the technological approach.

Two prototypes were built with this kind of substrate and solid ferrite cores ground to 2.5 mm high. The tracks were interconnected using 25 µm diameter gold wires (for the 16 turns sets) and 20x100 μm^2 gold ribbon (for the single turn sets).

On the first prototype A (Fig. 1) a conservative approach was used for wirebonding, placing the turns onto the specified pad area. On prototype B (Fig. 2), a more aggressive wirebonding was performed, pushing the equipment limits to weld the wires directly onto the tracks and as close to the ferrite core as possible.

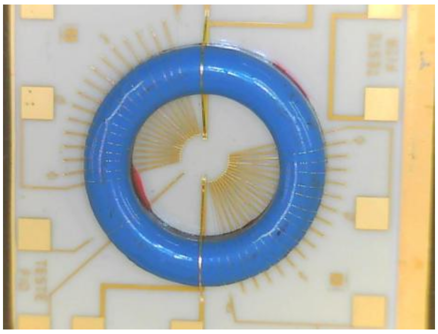

Fig.1. *MCM microtrafo prototype A.*

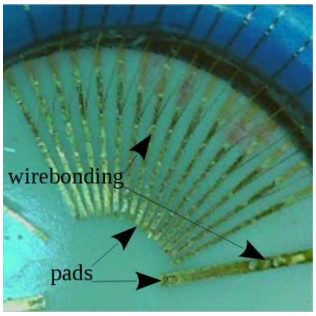

Fig.2. *Detail of MCM microtrafo prototype B. Wirebondig was performed closer to the ferrite core.*

5. Electrical Characterization of the Prototypes

Prototypes were characterized regarding the inductance electrical parameters, ohmic resistance of the turns and coupling factor, the main figure of merit to be considered for microtrafo performance.

Measurements were performed on a Cascade Summit microprobe, with shielded probes suited for high frequency operation. Results are shown on Table I and II.

Inductance and resistance were measured at 2 MHz, 1 V, while coupling factor was measured at 1 MHz, 10 Vpp and 10 MHz, 10 Vpp.

Best coupling factor are found for winding ratio 16:16 (> 80% for both prototypes and frequencies). Also, coupling factor is higher when the windings are packed closer to the ferrite core and at lower frequency, making prototype B at 1 MHz the highest coupling factor: 95.2%. Ohmic resistance however is still high and compromises the final voltage measured on the windings.

Table I. *Electrical characterization results of the MCM microtrafo prototypes (average values).*

Winding	Electrical parameter	Prot. A	Prot B
16 turns	DC Resistance	24.0 Ω	17.1 Ω
	Inductance	28.4 µH	41.5 µH
1 turn	DC Resistance	667 mΩ	679 mΩ
	Inductance	114 nH	158 nH

Table II. *Coupling factors of the MCM microtrafo prototypes.*

Frequency	Windings	Prot. A	Prot B
1 MHz	16 to 16 turns	95,0 %	95,2 %
	1 to 1 turn	---	50,3 %
	1 to 16 turns	37,2 %	47,1 %
10 MHz	16 to 16 turns	83,6 %	81,0 %
	1 to 1 turn	71,3 %	77,4 %
	1 to 16 turns	11,9 %	11,6 %

6. Conclusions

The fabrication of microtrafos using MCM technology was successful. Prototypes provided a coupling factor above 0.9 (90%), very close to the maximum found in literature for devices built on PCB.

The best result was at 1 MHz, indicating that the microtrafos are better suited for lower frequencies.

Initial results also points to improvement approaches, e.g. thicker tracks to reduce the ohmic resistance and more aggressive wirebond approach, to bring the bonds closer to the core.

Acknowledgments

The authors acknowledge CNPq and FINEP for the financial support; NEE/CTI and NMS/CTI for their help on the litho masks and substrate fabrication process, NAPE/CTI for helping on electrical measurements.

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