DTU Library

Design and Fabrication of Air-core Inductors for Power Conversion

Lê Thanh, Hoà; Mizushima, Io; Tang, Peter Torben; Ouyang, Ziwei; Knott, Arnold; Jensen, Flemming; Han, Anpan

Publication date:
2016

Document Version
Peer reviewed version

Citation (APA):
Lê Thanh, H., Mizushima, I., Tang, P. T., Ouyang, Z., Knott, A., Jensen, F., & Han, A. (2016). Design and Fabrication of Air-core Inductors for Power Conversion. Poster session presented at 5th International Workshop on Power Supply On Chip, Madrid, Spain.

Proposal for E-Poster Title

Design and Fabrication of Air-core Inductors for Power Conversion

Hoa Thanh Le [a, b], *Io Mizushima* [c], *Peter Torben Tang* [c], *Ziwei Ouyang* [b], *Arnold Knott* [b], *Flemming Jensen* [a], *Anpan Han* [a]

[a] *Danchip*, [b] *DTU Elektro Tech. Uni. Denmark*, [c] *IPU, Kgs. Lyngby, Denmark.*

e-mail: anph@dtu.dk

Abstract

Microelectromechanical systems (MEMS) inductors are used for e.g. RF MEMS and microelectronics. A new application is for power electronics in switched mode power supplies (SMPS). High-performance power inductors, which can be combined with integrated circuits (IC), are required for future power supply on chip (PwrSoC) [1]. Examples of PwrSoC applications are power adaptors for LED illumination and the “Internet of Things”. We report an air-core MEMS inductor. Our process is scalable and universal for making inductors with versatile geometries e.g. spiral, solenoid, toroid, and advanced inductors that are impossible to make by wire-winding technology. As all process temperatures are kept below 200 ^oC, the inductors can be integrated into CMOS wafers by MEMS post processing.

Brief Description and Figures

Our inductor design is optimized for very high frequency (30 to 300 MHz) SMPS with 12V, 1A output. For this application, the inductor is a suspended air-core toroid secured to the substrate by fixtures (Fig 1a). Our design has near-ideal performance because the electromagnetic flux is confined in the toroid, leading to minimal electromagnetic interference (EMI) cross-talk with active CMOS devices in case of wafer level integration or packaging. Furthermore, the air-core design also minimizes high-frequency eddy-current losses in the Si substrate that would otherwise be significantly larger than the conduction loss (10 times more at 100MHz) [2]. To implement end-user requirements such as inductance, efficiency, and ripple, we analytically modelled and simulated our toroidal inductor with COMSOL for an optimal inductor design. The models account for high frequency skin and proximity effects, and we studied the influences on resistance and inductance as a function of frequency between DC and 300 MHz.

The fabrication process includes 3 main stages, 12 steps and 4 lithography masks. Firstly, we create through silicon vias (TSVs) by deep reactive ion etch (DRIE). Copper (Cu) is then deposited using electroplating with three plating steps; plating top layer and to “close” the TSVs, bottom-up plating to fill the TSVs and plating 30 µm bottom layer. E-beam evaporated 10 nm Cr/100 nm Au is used as seed layers. The windings are patterned by Cu wet-etching using a resist mask. In stage 3, we selectively remove the Si core by DRIE. Because of the 30 µm height variation caused by the Cu winding structures, photoresist is spray-coated and patterned to etch SiO_2 and Al_2O_3. The Si is exposed and we remove the silicon core in the last 2 steps. The air-core inductor is held in place by Si fixtures (Fig 1b), that are fabricated by combining

DRIE, atomic layer deposition (ALD), and utilizing aspect ratio dependent etching effect (ARDE) [3].

Fabrication results are shown in Fig. 1b and Fig. 2. After releasing with buffered hydrofluoric acid (BHF), the windings are suspended on the silicon support and fixed by three silicon fixtures. Fig. 2b and 2c show a cross-sectional image of Cu-filled TSV, and copper windings, respectively. A selected result from our analytical model is shown in Fig. 2a. Efficiency (η) is presented as a function of toroidal geometry (turns, outer radius) with a η = 90 % plane. This was used as a design guideline for selecting inductor geometry so that η > 90 %.

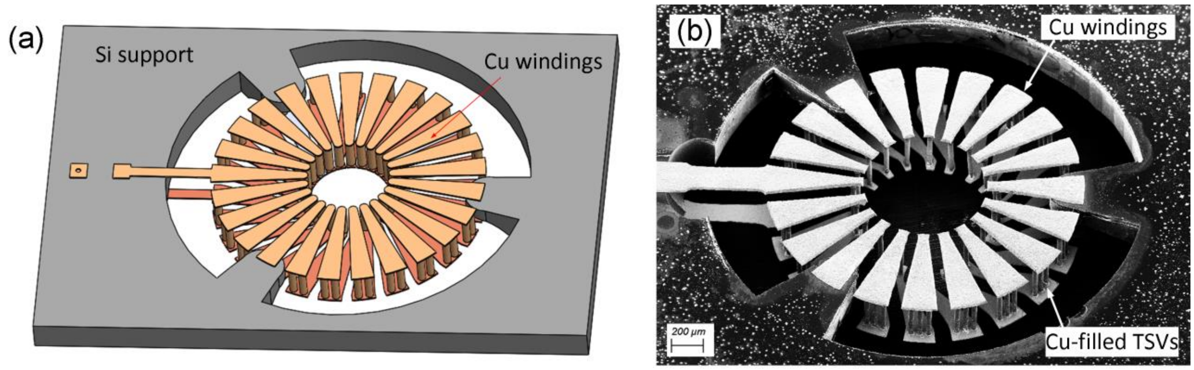

Figure 1: 3D Illustration of air-core toroidal inductor chip (a), and SEM micrograph of fabricated air-core inductor (b).

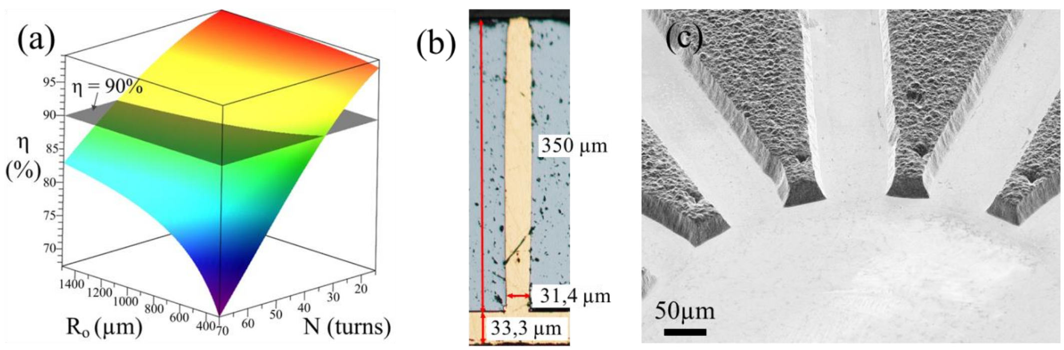

Figure 2: 3D plot of calculated efficiency as a function of number of turns (N) and outer radius (R_o) (a), (b) 30-µm-diameter, 350-µm-tall Cu-filled TSV, (c) wet-etched copper windings.

Key Contributions

We have developed a new process scheme to fabricate near-ideal air-core micro-inductors. Different inductive devices can be fabricated e.g. toroid, solenoid, spiral, transformers using the scheme. Our inductors can be integrated directly on processed CMOS wafers. An analytical model has been developed and numerical simulations has been used as design guidelines. In the near future, we will characterize our inductors.

[1] C. Ó. Mathúna et al. , IEEE Trans. Power Electron. 27(11) (2012) 4799-4816.
[2] M. Araghchini and J. H. Lang, APEC 2014 (2014) 519–526.
[3] Lai, S. L., D. Johnson, and R. Westerman, J. Vac. Sci. Technol. A 24 (2006) 1283.