ULTRA-LOW-PROFILE MICROMACHINED POWER INDUCTORS WITH HIGHLY LAMINATED NiFe CORES: APPLICATION TO LOW MHz DC-DC CONVERTERS

Jin-Woo Park and Mark G. Allen
School of Electrical and Computer Engineering, Georgia Institute of Technology
791 Atlantic Dr. Atlanta, GA 30332 USA

Abstract
Micromachined inductors with sub-mm profiles and comparable electrical performance to thicker, commercially-available surface-mount devices, have been fabricated and characterized for low MHz DC-DC converters. The fabrication approach involves micron-scale lamination of nickel-iron cores, combined with 3D-micronachined copper windings. The dimensions of the fabricated inductor are 11.5 mm x 5.7 mm x 0.65 mm, and the DC resistance is 190mΩ. Use of this inductor in a prototype DC-DC boost converter circuit (6V – 9V) yielded 1.6 W power output at 84% efficiency.

Introduction and fabrication

NiFe has advantages over many ferrites for high power density micro-magnetic devices because of its high relative permeability (~800) and saturation flux density (~1T). However, since these films are electrically conducting, increasing eddy current loss as operating frequency increases requires such cores to be laminated. Due to the relatively high permeability of these films, the laminations must be exceedingly fine (1-5 microns) for operation in the low MHz regime. Although such thin laminations are difficult to achieve using conventional machining technology, they are achievable using micromachining. Previous approaches, such as those based on sputtering, to produce highly laminated films in this size regime have not been able to produce the total magnetic cross-sectional area (e.g., many tens to hundreds of microns) necessary to achieve large inductor saturation currents. In this work, a simple, manufacturable laminated core fabrication technique has been developed for reducing eddy currents in the MHz operating regime while simultaneously preserving large total magnetic cross-sectional area. This approach is illustrated by fabrication and testing of an inductor consisting of 40 laminated layers of 1μm thick electroplated NiFe films. The manufacturing approach is based on an alternating, conformal sequential electroplating of layers of NiFe and Cu, followed by selective sacrificial etching of the Cu [1]. Since the copper sacrificial interlayer is itself conducting, it can act as a plating base for the subsequent deposition of NiFe without the necessity of multiple vacuum steps, multiple coating of insulating layers, or multiple photolithography steps. Highly laminated structures can therefore be achieved merely by alternating plating baths during fabrication, followed by selective removal of the Cu layers to provide electrical insulation between the magnetic layers. Electrodeposition of NiFe layers has been performed in a DC magnetic field (20mT) to introduce anisotropy. To save total core electroplating time, 5 cores (each having 8 layers of lamination) are stacked to achieve the desired total core thickness. The core is combined with standard MEMS-based toroidal conductor winding fabrication [2]. Since only CMOS-compatable fabrication is used, this inductor can be directly fabricated on top of silicon circuitry. Fig. 1 shows a photomicrograph of a laminated core and a complete inductor.

Experimental Results

The inductance and Q-factor of the fabricated inductor are shown in Fig 2(a). A maximum Q of 7.5 was obtained at the 0.5V excitation voltage of the measurement instrument (HP4194A). This Q-value is approximately 3 times higher than previous inductors [1]. The fabricated inductor has been utilized in a DC-DC boost converter along with a commercially available switching regulator chip (LT1930A) operating at 2.2MHz, a Schottky diode, and resistors. The demonstrated converter has a 1.6W output with 84% efficiency converting from 6V to 9V as shown in Fig 2(b).

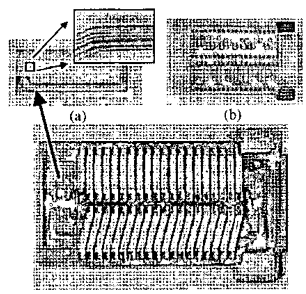

Fig 1. (a) Laminated core (8 layers of 1um film); (b) windings prior to core integration; (c) completed device

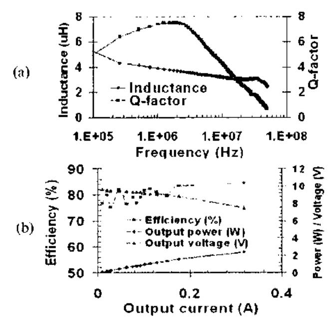

Fig 2. (a) Electrical properties of inductor as a function of frequency; (b) inductor performance in DC/DC converter (input voltage - 6V)

References
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[2] C. H.Ahn, M. Allen, IEEE Trans. Industrial Electron., vol. 45, pp.866-876, 1998