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MEMS Technology for the Fabrication of RF Magnetic Components

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Abstract

MEMS technology can be utilized for the fabrication of magnetic structures in multiple frequency ranges, ranging from low-MHz metal-core devices for DC-DC converters to high-frequency dielectric or air core devices for RF application. They can also be fabricated in multiple locations: integral with silicon chips; in the interconnect layer between chip and board; and directly on the printed wiring board, in order to yield ultracompact magnetic microsystems. This paper describes examples of each of these fabrication approaches: high frequency dielectric-core inductors for CMOS power amplifiers integrated on-chip; high-frequency air-core inductors fabricated within the interconnect layer between chip and board; and low-frequency metal-core inductors for DC-DC power conversion.

On-Chip Devices: Dielectric-Core Inductors for High Frequency Power Amplifiers

Surface micromachined, epoxy-embedded, inductors and their integration with a foundry-fabricated CMOS RF power amplifier is described. The inductors combine the features of: (1) being supported both by electroplated posts and a deposited thick dielectric layer, thereby separating them from the lossy silicon substrate; and (2) being embedded in the epoxy molds from which they are formed, minimizing microphonics and allowing sufficient mechanical stability such that the chips bearing the inductors can be packaged using standard injection-molding processes. Such epoxy-embedded inductors can have large quality factors, indicating that dielectric losses associated with the epoxy material are small in the low GHz frequency regime. The embedded structure (Fig.1) is mechanically robust and compatible with standard chip packaging techniques. Here the solenoid coil is built with 50 um thick SU-8 elevation from the Si substrate. The large gap between the solenoid coil and the Si substrate helps to reduce coupling to the lossy substrate by keeping the flux path of the coil away from the Si substrate. The coil width is 20 um, the turn-to-turn pitch is 80 um, and the height of the solenoid core is 50 um. Q-factor and inductance are extracted from the measured S-parameters in the frequency range of 50MHz to 10GHz. An embedded inductor of 6 turns and 400 um wide solenoid core has a peak Q-factor of 20.5 at 4.45 GHz and an inductance of 2.6nH. To demonstrate the utility of these devices, a 2.4GHz integrated CMOS power amplifier is implemented in a 0.24-μm CMOS foundry technology; the power amplifier delivers 20-dBm output power with 31% PAE as biased at class AB. Four inductors have been integrated on the power amplifier, demonstrating the compatibility of this process with foundry CMOS technology.

Devices in the Interconnect Layer: Large Height, Air-Core Inductors

As the input-output requirement of silicon chips increases, mass-manufacturing interconnect such as flip-chip technology are being commonly used. When considering the expansion of this technique to large area arrays of interconnect, it is also possible to consider integrating MEMS structures within the interconnect layer itself. As a simple example, inductors or antennas can be fabricated from dense arrays of interconnect that extend from chip to substrate and back to chip. To illustrate the MEMS-in-the-interconnect-layer approach, an electroplating bonding technique was used to fabricate air-core solenoid–type inductors with large cross-sectional area. The inductors are 500um high with a 100um gap between posts (Fig.2). Inductances ranging from 1.2nH to 16nH depending on the number of turns were achieved. These devices illustrate the feasibility of fabricating dense arrays of interconnect-based passive-elements, as well as other MEMS, in the chip-board interconnect layer.

Packaging-Compatible Devices: Iron-Core Laminated Inductors for Power Conversion

In macro-scale magnetic devices, low-loss cores are typically achieved by laminating alternating layers of core material and insulating material. This work details a manufacturable approach allowing micron-scale (or smaller) laminations and large total core thickness without the need for interposing vacuum steps or sub-micron lithography. The approach is based on *sequential electroplating* to form densely alternating stacks of magnetic and nonmagnetic material, followed by selective etching and surface micromachining to insulate the magnetic cores. Using standard micromachining processes, coils are integrated with these cores to form inductors (Fig.3). To illustrate the improved characteristics of a laminated core, a solid core integrated inductor with the same cross-sectional core area was fabricated, and both devices were tested Although at low frequency both devices had comparable inductances, the inductance of the solid core inductor decreases faster than its counterpart, suggesting that eddy current effects are significantly reduced in the case of the laminated core inductor. The Q-factor of the laminated core inductor is approximately 2-3 times larger than that of the solid core inductor at 1MHz, indicating the beneficial effect of the highly laminated core.

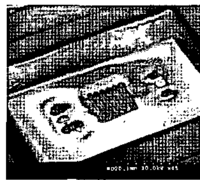

Fig. 1. Embedded Inductor

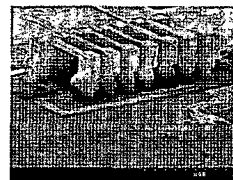

Fig. 2. Interconnect Inductor

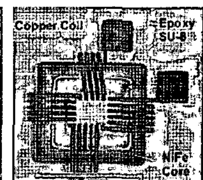

Fig. 3. Laminated core inductor

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