3D ULTRA-FAST MANUFACTURED MICRO COILS ON POLYMER OR METAL CORES

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Abstract: We present high aspect ratio 3D solenoidal micro coils manufactured in a serial, high speed and fully MEMS compatible winding procedure using an automatic wire bonder. The coils are wound on steel, glass, or polymer cores with a diameter ranging from 100 µm to 1 mm. The applications of these coils are manifold: as semi-integrated inductors for electronics, for energy harvesting purposes, and for sensors and actuators.

Key words: micro coil, manufacturing, wire bonder, SU-8.

1. INTRODUCTION

The development of 3D high aspect ratio micro solenoids and Helmholtz micro coils proved to be a challenging task for the MEMS community mainly because the traditional microfabrication techniques inherently generate 2D structures. Many groups have focused their research efforts towards obtaining 3D micro coils in the past decade. Peck et al. [1] and Seeber et al. [2] have used a hand-winding technique to produce micro coils by wrapping a wire around a capillary. This procedure is not compatible with batch-fabrication since each coil must be treated individually, with consequences on the yield and reproducibility of the manufactured coils. An interesting but rather complicated technique reported by Rogers et al. [3] involved micro-contact printing combined with a rolling process and subsequent electroplating to define coils around a capillary tube. An innovative approach by Dohi et al. [4] combines surface micromachining and a post-release folding process to create freestanding micro coils. Ehrmann et al. recently reported [5] a MEMS-compatible technology to create micro solenoids and Helmholtz micro coils using three electroplated copper layers and vias through SU-8 isolation layers. While this is a batch-fabrication technique, due to the planar nature of the processes involved, the aspect ratio of the coils, therefore their 3D character is rather limited.

We have has recently reported [6] a method to fabricate coils with sub-millimeter dimensions on PCB substrates exploiting the unique capabilities of an automatic wire bonder. However, this is not compatible with wafer-scale fabrication, therefore unsuitable for MEMS applications.
Here, we report a fully MEMS-integrated process for micro coil fabrication using the automatic wire bonder in conjunction with traditional microfabrication techniques: CrAu evaporation on Si or Pyrex substrate together with UV photolithography is used to define the metal pads for coil winding. Cylindrical posts to support the micro coils are defined using thick SU-8 photolithography. Although the wire-bonder based technique to manufacture the micro coils is a serial technique, it is compatible with the previously mentioned standard batch-fabrication techniques due to the fact that it is very fast and reproducible.
In addition to this cleanroom process, we introduce a PCB based technology as a substrate for the coils. In the following these two aspects are described in more detail.

2. MICRO COIL WINDING

Modern automatic wire bonders allow the user to define 3D coordinates, to which the bondhead moves consecutively. Our method for solenoidal coils is the following: we locate the first contact ("ball") next to a core and move circularly around the core whereas the wire plastically deforms to the core's shape. The trajectory then is terminated with the second ("wedge") bond. A schematic of the used trajectory is shown in Figure 1.
The method eliminates the loose wire end issue of other winding methods, and hence the need for manual re-soldering of the micro coils.

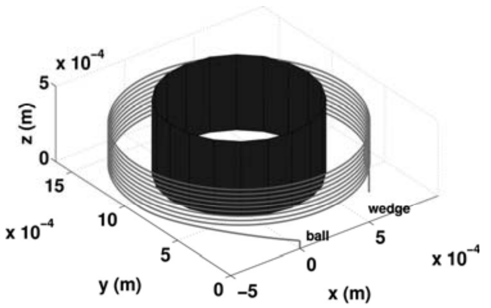


Figure 1: Wire bond trajectory.

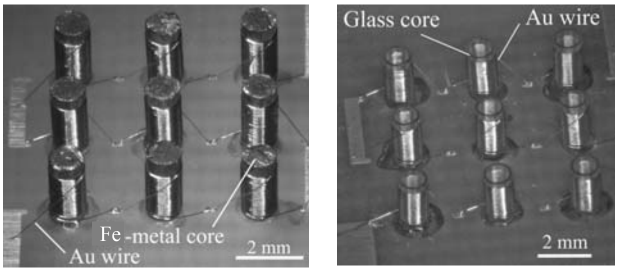
We are thus able to wind large arrays of 3D micro coils in an easy and reproducible process with an accuracy of better than 3 µm, taking 200 ms to wind a single coil. We use insulated gold wire (X-Wire™ from Microbonds) with a diameter of 25 µm.
Figure 2 is a microscope photograph taken during the coil winding process.

Figure 2: Capture of the wire bonder head in movement during the micro coil winding process.

3. SUBSTRATE PROCESSING

In this paper we present two possible substrates for micro coils: a printed circuit board (PCB) with metal or glass cores, and a fully MEMS compatible process with Pyrex or silicon wafers and SU-8 cores.

The first approach is based on PCB technology: A 1 mm thick PCB with the necessary holes and gold pads was commercially fabricated [7]. Coil cores with a total length of 3 mm were glued into the holes in the PCB, so the length of the cores above the PCB is 2 mm. Two different coil core materials were used: iron cores and hollow glass cores. Iron cores were manufactured by EDM (electrical discharge machining) erosion. The glass cores were sawed. The diameter of both cores was 1.0 mm. In Figure 3 photos of a coil array with iron cores and glass cores, respectively, is shown. The non-insulted gold bond wire is 28 µm thick. In order to avoid short-circuits a pitch of 25 µm was introduced separating the windings form each other. The number of windings is thus mainly defined by the wire diameter, the pitch, and the height if the posts.

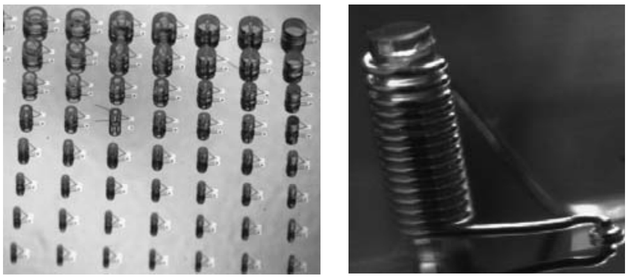


(a) (b)

Figure 3: PCB board with an array of coils around Fe-metal cores (a) and hollow glass cylinders (b).

In the second approach we first have to define the metal pads for the connection of the wire ends of the micro coils: a chromium/gold layer of 50/500 nm thickness was evaporated on the substrate. AZ 1518 photoresist was UV patterned and the chromium/gold metal was subsequently wet-etched to define the pads.

For polymer cores a thick photoresist, SU-8, was deposited onto the substrate and lithographically structured with high aspect ratio. We were able to fabricate structures with a diameter down to 100 µm and a height of up to 650 µm, resulting in an aspect ratio of 6.5:1.
In figure 4(a) a large array of micro coils wound around SU-8 posts with diameters from 1000 µm (upper line) to 200 µm (bottom line) is pictured. Figure 4(b) shows a side view of a micro coil with 150 µm diameter and 15 windings. The SU-8 post is 650 µm high. Here, we used insulted wire of 25 µm thickness.



(a) (b)

Figure 4: Micro coils around SU-8 cores.

Figure 5 shows an overview of the process steps of the wire bonded coils around SU-8 structures.

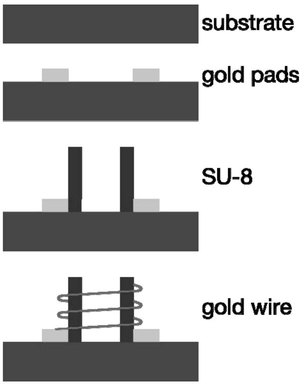


Figure 5: Process flow.

4. MEASUREMENT RESULTS

With the micrometer positioning precision of the wire bonder head, we have good control over each axis. In particular, the *z*-axis movement can be used to start the coil winding process at different heights. Figure 6 shows coils produced with different *z*-start heights. In figure 6(a) the starting height was 50 µm, what is the minimal *z*-start height. In figure 6(b) the start is 350 µm.
The pictures show that the angle of the wire between the ball and winding is almost 90° in both cases. In the case of larger starting heights, the first winding is needed to reach the desired height. Afterwards the coil is wound regularly.

(a) (b)

Figure 6: Coils with different z-start heights.

For electrical characterization of the coils we used an Agilent E4991A impedance analyzer. The measured real and imaginary part of the complex impedance Z correspond to the resistance R = real(Z) and the inductance L = imag(Z)/ω of a straight forward R-L series inductor model, where ω is the angular frequency. The quality factor Q of a coil described by this model is given by Q = imag(Z)/real(Z).

In Figure 7 the measured data for an example coil with a diameter of 100 µm, 5 windings, and a pitch of 50 µm manufactured on a glass substrate is shown. The inductance is constant at 41 nH in this frequency range. The resistance increases due to skin and proximity effects. The quality factor at 400 MHz is 41.

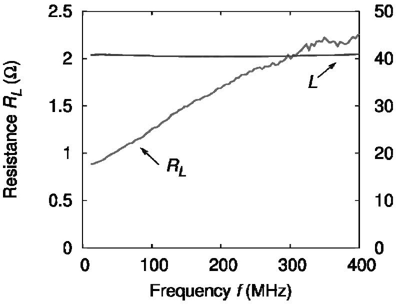


Figure 7: Frequency dependent resistance and inductance of a coil with a diameter of 100 µm, 5 windings, and a pitch of 50 µm, manufactured on a glass substrate.

5. CONCLUSION

We have manufactured coils on iron, polymer, and glass cores. Iron and glass cores were up to 2 mm high with a diameter of 1 mm, polymer cores up to 650 µm tall with a minimal diameter of 100 µm. These small cores carry up to 15 windings of 25 µm diameter gold wire.

The introduced production method for micro coils is not only compatible with standard micro manufacturing processes, we also believe that it is competitive with SMD technology. The possibility of adapting the inductance by the free choice of the number of windings as well as the relatively free choice of the core diameter, combined with the fact that no subsequent soldering is required, offer a flexibility and a semi-integration level which provides a tremendous advantage for microelectronics, RF technology, measurement technique, and sensors.

6. ACKNOWLEDGMENTS

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