Micro Helmholtz coil pair towards cellular applications

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Introduction

Micro Helmholtz coils are needed in medical technology for high-resolution magnetic resonance imaging (MRI) or for nuclear magnetic resonance (NMR) spectroscopy at the micro level. The coil sensitivity, and therefore the desired signal, is maximized when the size of the coil matches that of the sample [1, 2]. Small sample analysis with micro Helmholtz coils shows exceptional performance compared to planar coils and allows for advanced chemical analysis. Due to their 3-D shape, the B_{1unit} field is stronger and more uniform [3]. Among NMR applications, modified micro Helmholtz coils (Maxwell coils) are used for the creation of high magnetic field gradients [4, 5]. So far, difficult 3-D processes prevent the production of suitable coils and only few publications exist. Up to 10 process steps [3] or coils made by hand [4] are insufficient for reproducible coils and make successful measurements very difficult or impossible. As devices are often single use, low-cost solutions are most promising. We present **Helmholtz coils made with a wire bonder with included sample containers in microliter range**, which are **cheap and reproducible** in a mass production sense.

Micro Helmholtz coil manufacturing process

We have developed a full mass production compatible process with **550 µm high SU-8 posts** on a silicon substrate. Because of its excellent mechanical properties [6] SU-8 is a suitable choice: high adhesion strength as well as high stability ensure a stable winding process. SU-8 pillars with **outer diameters from 100 µm to 1000 µm** with varying sidewall thicknesses down to 20 µm have been manufactured. In figure 1 some posts are pictured, each one of them can be seen as a sample container for **high throughput parallel cell analysis**. In a previous publication [7] we introduced the technology of fabricating micro coils exploiting the basic capabilities of an automatic wire bonder. By **wrapping wire in two well-defined heights** around a SU-8 post, we rapidly fabricate micro Helmholtz coils. In figure 2, a picture of the coil including cell container is shown. All coils presented here are wound with standard non-insulated gold bond wire (32 µm diameter) and a sufficient distance (1 wire diameter) between adjacent windings to avoid short circuits. Research on insulated bond wire is in progress [8]; we expect to incorporate insulated gold wire within the next months to achieve higher winding densities. Wire bonder Helmholtz coils are being fabricated with extremely high speed (< **200 ms**), very precisely, and fully batch-process compatible in a **simple single step process**. Here, the end connection of the lower part shares a bond pad with the start connection of the upper part. The magnetic field, simulated with *FEMM* [9], is found to be **0.9 mT** when passing a current of 0.1 A. In figure 3, the simulated magnetic field is homogeneous in the center of the coil. A **homogeneous region of 100 µm** is large enough to hold several cells. Because of the small dimensions, we have not been able to do magnetic field measurements for comparison.

Qualification of the Helmholtz coils

The DC resistance and inductance of a Helmholtz coil with a radius of 200 µm is measured with an impedance analyzer (*Agilent E4991A*) to be **0.3 Ω and 7.4 nH**, respectively. In figure 4, a frequency sweep of the electrical properties is depicted. The resistance increases due to skin and proximity effects whereas the inductance stays constant. Due to a long wire feed and low resistivity silicon, a relatively small ***Q* factor of 5 at 400 MHz** has been achieved.

Conclusion

We are able to produce micro Helmholtz coils in an easy, single step process in a mass production way and guarantee cheap on-chip manufacturing. By using SU-8 as post material and UV-lithography as structuring step, we assure not only high precision and batch fabrication but also are able to include cell containers into the coils.

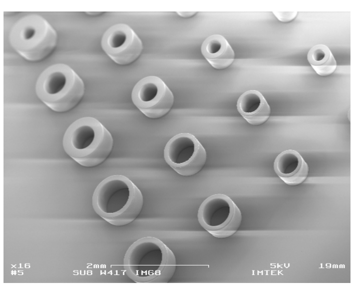

Figure 1: SU-8 pillars on a silicon substrate. Each pillar is capable of receiving cells for highly parallel bio analysis.

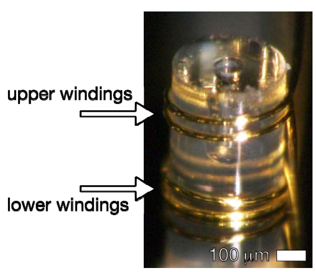

Figure 2: Helmholtz coil made with a wire bonder around a SU-8 pillar. One can clearly see the distance of one coil radius between upper and lower windings.

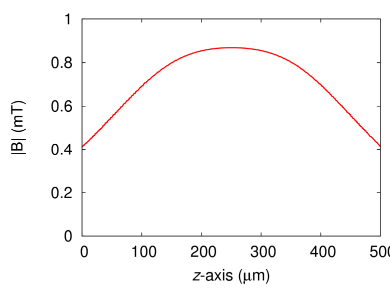

Figure 3: Calculated magnetic field along the centerline of the Helmholtz coil. $z = 0$ denotes the bottom of the coil (substrate level).

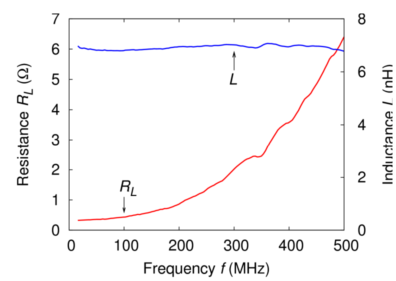

Figure 4: Resistance and inductance of the micro Helmholtz coil as a function on frequency.

References

[1] A. G. Webb: *Radiofrequency microcoils in magnetic resonance*. PROG NUCL MAG RES SP, 31:1–42, 1997. [2] D. I. Hoult and R. E. Richards: *The SNR of the NMR experiment*. J MAGN RESON, 24:71–85, 1985. [3] Ehrmann et al.: *Microfabricated solenoids and Helmholtz coils for NMR spectroscopy of mammalian cells*, LAB CHIP, 7:3732–380, 2007. [4] Seeber et al.: *Triaxial magnetic field gradient system for microcoil magnetic resonance imaging*, REV SCI INSTR, 71(11):4263-42721, 2000. [5] Syms et al.: *MEMS Helmholtz coils for magnetic resonance imaging*, J MICROMECH MICROENG, 15(7):S1–S9, 2005. [6] Lorentz et al.: *SU-8: a low-cost negative resist for MEMS*, J MICROMECH MICROENG, 7(3):121–124, 1997. [7] Kratt et al.: *Solenoidal out-of-plane micro coils for MR analysis manufactured with a wire bonder*, ISMRM, ID:2983, 2008. [8] R. L. Lyn et al.: *Overview of* X-Wire™ *insulated bonding wire technology*, IMAPS, 2006. [9] D. C. Meeker, *Finite Element Method Magnetics*, Version 4.2 (23May2008 Build), http://femm.foster-miller.net.

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