Micro Magnetic Resonance *x,y*-Gradient System for Microscopic Samples

Markus V. Meissner[1], Robert Ch. Meier[1], Peter T. While[1], Ali Moazenzadeh[2], and Jan G. Korvink[1,3]

[1]*Lab. for Simulation, IMTEK - University of Freiburg, Freiburg, Germany,* [2]*Lab. for Microactuators, IMTEK - University of Freiburg, Freiburg, Germany,* [3]*Freiburg Institute for Advanced Studies – FRIAS, University of Freiburg, Freiburg, Germany*

Magnetic resonance imaging of microscopic samples (≈100µm in diameter) requires strong, fast switchable magnetic field gradients to suppress diffusion-related artifacts and to reduce the acquisition time. One approach for achieving a higher magnetic gradient strength is to bring the gradient coils physically closer to the sample. A novel micro manufactured *x,y*-gradient system based on multiple straight, wire-bonded conductors is presented in this work.

Introduction to the gradient concept: Before the concept of magnetic resonance imaging was discovered, Anderson [2] reported a variety of shimming coils to correct magnetic field non-linearity. More recently, the Anderson shimming coils have been combined to define miniaturized bi- and triaxial linear gradient systems, to perform magnetic resonance microscopy or flow imaging.[1,3] The *x*- and *y*-gradient coils are both comprised of 8 straight parallel conductors, arranged in the planes $z=\pm z_0$ in such a way as to maximize gradient strength at the origin and to eliminate higher order terms (see fig. 3 shown in [2]). In fig. 1, a homogeneity contour plot of the paired Anderson linear *y*-gradient is presented to provide a spatial view of the gradient linearity. The size of the volume of interest for a given field error depends on the gradient conductor *z*-spacing, 2 z_0. For a conductor *z*-spacing of 2 z_0 = 800µm, a gradient strength of approx 3.2 T/(m A) is achievable.[1,2] It is possible to increase the gradient strength further by considering additional conductors on the two planes. Furthermore, this has the added benefit of extending the usable volume of interest. For example, an extended model with 32 conductors was considered, which is capable of generating a gradient strength of 8.3 T/(m A) (by using conductors of 25µm in diameter).

Fabrication: A standard *x,y*-gradient system, shown in fig. 3 was manufactured in a MEMS clean-room. (i) A bare Pyrex wafer was gold-metalized via electroplating to implement supply tracks and bond pads. (ii) A 250µm SU8 epoxy-resist offset structure was added to allow planar bond wire positioning. (iii) Another resist layer (50µm PerMX 3050, DuPont) was laminated [4] and defined 40-75µm wide channels to enable bond wire *x,y*-alignment. (iv) An automatic wire-bonder was employed to wind 25µm thick insulated gold wires. Bond wires were aligned within the alignment channels. (v) Gradient conductors and bond pads were encapsulated via dry film resist (50µm PerMX 3050, DuPont). This allowed a statically determined conductor alignment. (vi) Flip chip bonding was performed using two component epoxy resin.

Fabrication of an additional *y*-gradient is done by repeating the process with 90 degree rotated alignment channels and wire bonds. Single *x*-gradient alignment is shown in fig. 4 & 5. A conventional Anti-Helmholtz *z*-gradient can be added externally to the chip setup (see fig. 2).

Results: The bond wire alignment was measured optically (Zeiss Axion microscope) and a total translation of 17-36µm was measured for different alignment methods. However, the bond wires remain straight. Hall probe (MPT-141, Group3) based field mapping of a single chip (see fig. 4.) was performed to provide approximate confirmation of the simulated gradient linearity. However, to evaluate such small gradient field variations, a high resolution measurement setup is required (e.g. GMR-sensor, etc.). Four terminal resistivity measurement showed no significant difference to the expected wire resistance.

Discussion and Conclusion: A low cost, miniaturized gradient system was fabricated to extend the concept of [1] with regards to increasing achievable gradient strength and miniaturization. The fabricated *x,y*-gradient system can be supplied by a constant current of 400mA without major heat up of the gradient conductors, suitable for first order shimming. Furthermore, the individual conductors can be driven independently to provide fine tuning of the induced field, as well as field focusing.

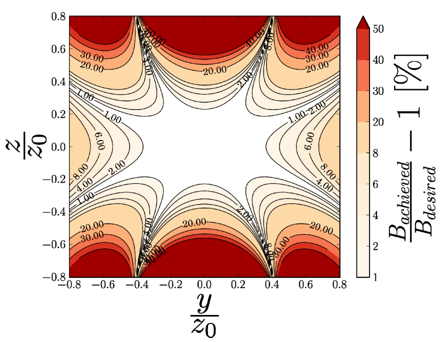

Fig. 1: Gradient homogeneity plot of Anderson's paired *y*-gradient coil. [2] Desired gradient field based on evaluated first order field derivative in the center. The gradient conductor configuration is according to the maximum achievable gradient strength discussed in [2] (see figure 4 & 5 in [2], w=1.55, y_c=1.19). Plot is generalized to 2 z_0 layer spacing, separating the conductors between the top and bottom layers.

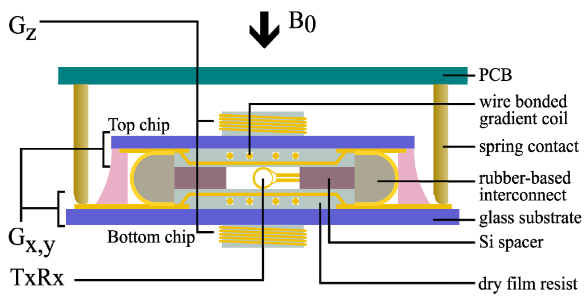

Fig. 2: Gradient flip-chip concept, *z*-gradient based on conventional Anti-Helmholtz coil pair

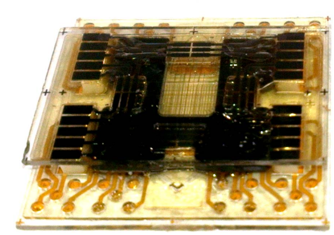

Fig. 3: Flip-chip bonded micro *x,y*-gradient system. Interconnection via conductive rubber-stripes (total chip size 2 x 2cm)

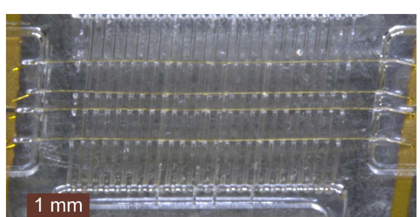

Fig. 4: In PerMX embedded gold wire bonds with vertical cooling channels. (test structures)

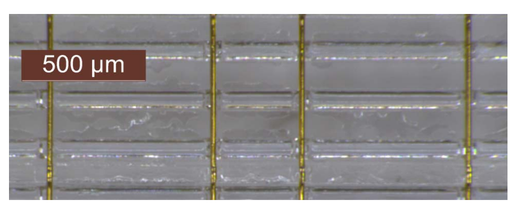

Fig. 5: Bond wire alignment via permanent, dry film photo-resist. Conductor pair in the center differs from the desired wire position by 17µm. *x*-gradient conductors embedded into liquid cooling system.

Acknowledgment:
The authors gratefully acknowledge the funding through the European Research Council (ERC), contact no. 290586.

References:
[1] D.A. Seeber, et al., Triaxial magnetic field gradient system for microcoil magnetic resonance imaging. Rev. Sci. Instrum.,71(11):4263, 2000
[2] W.A. Anderson., Electrical current shims for correcting magnetic fields. Rev. Sci. Instrum., 32(3):241–250, 1961
[3] A.G. Goloshevsky, et al., Integration of biaxial planar gradient coils and an RF microcoil for NMR flow imaging. MST, 16(2):505–512, 2005
[4] R.Ch. Meier, et al., Complex three-dimensional high aspect ratio microfluidic network manufactured in … . Biomicrofluidics, 5(3):034111, 2011