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MICROCOIL DESIGN AND ANALYSIS FOR ACTUATION OF MICROSTRUCTURES AND DEVICES

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ABSTRACT

This technical brief presents an overview the design and analysis of planar microcoil designs for use in the actuation of magnetic microstructures and devices. The microcoil's feature sizes are in the range of microns with current loads less than 1 Ampere. The primary manufacturing method that is considered in modeling and designs of the micro coils is standard MEMS processes; processing method's limitations dictate design parameters that determine feature sizes and aspect ratios. Modeling consists of a variation in parameters of coil features, and an analytical computation of the theoretical electromagnetic field produced using Biot Savart's Law. Superposition is used to model microcoil interactions with varying center-to-center distances.

INTRODUCTION

The field of manipulating and actuating microstructures and devices is continuously developing. Methods for manipulating micro-objects include: grasping with miniature end-effectors; piezo-electric vibrations; electromagnetic fields; etc. The method that this paper explores is the use of electromagnetic fields to produce the driving force of actuation for micro-objects and devices.

Manipulating magnetic bodies through electromagnetic fields can be done by two main methods: large, external electromagnetic fields, or small, localized magnetic fields. For example, the use of four Helmholtz coils, external to the staging area, can be used to control the motion of a single magnetic structure. The advantage to this design is the manipulation of micro devices with a large macro-scaled apparatus. The disadvantage, however, is that it becomes difficult to control more than one structure or device as the EMF will influence all bodies within the staging area. The second method, which is explored in this paper, is to have a substrate of small planar microcoils (Figure 1) that can produce localized electromagnetic field to control the structures or devices. In conjunction with a vision system and associated controls, micromanipulation of structures and devices can be achieved simultaneously and independently. By way of analogy: the external electromagnetic fields method is similar to tilting a sphere on a single large platform, while the localized microcoils method is similar to a tilting small tiled divisions of a large platform. There has been some recent work on using a wire-bonder to create 3D micro-coils for similar applications [3]. This is a serial process while we are interested in developing a low-cost, parallel process, using standard fabrication processes that can scale to large substrates.

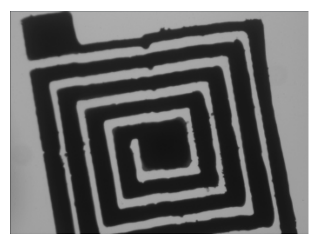

Fig. 1. *Square Planar Microcoils Realized on a Flexible Substrate using Conductive Ink. Coil Width: 300μm*

DESIGN

The design of the micro-scaled electromagnet can either be a single current carrying loop, or meandering coil of multiple loops. The advantage of a single loop design is its simplicity, however in order to supply the loop with a sufficiently large current to generate a strong magnetic potential, the cross-sectional area must be increased to compensate the current load. Microcoils created with multiple loops, with a similar cross-sectional area can generate a greater field potential due to superposition while maintaining a low current load.

The initial design parameter of the inner coil diameter (20 μm) used for the coils are based off of previous work in [1], which successfully created microcoils using photolithography and electrodeposition processes. The microcoils' height thickness) in this work were in the order of 20μm, due to the limitations of the photoresist used in the fabrication process. To overcome this limitation, the MEMS process for the preliminary development of the planar microcoils considers using an SU-8 mold, which can yield aspect ratios greater than 15:1 [2], which allows the design freedom to increase the cross-sectional area to support greater current loads; other insulating layer molds can be considered in future development. The preliminary micro-fabrication process developed for an example coil, shown schematically in Fig. 2, consists of seed layering, electroplating, photolithography, SU-8 molds, and a protective polymer sputtering layer.

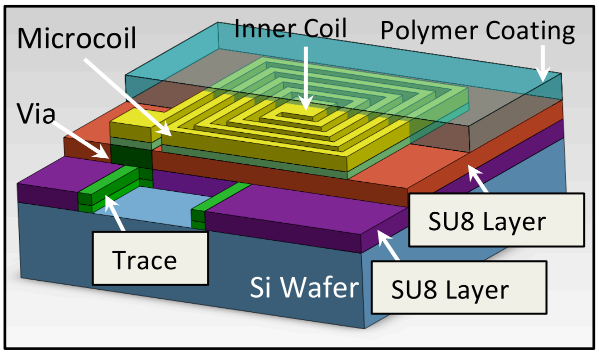

Fig. 2. Isometric View of Square Coil Design

The initial choice of design of a square shaped coil was due to the limitation of feature shape and sizes of an available metallic inkjet printer, (FUJIFILM Diamatix Materials Printer DMP-2800); curvilinear features can be realized with better precision with more advance printer models. However, since MEMS processes easily allow for curved features, a circular coil shape is chosen as the final design. The circular design is chosen for three primary reasons: (1) A greater uniformity of the field generated about the center, as a square shape has a non-continuous radius about the center; (2) To simplify the modeling process, due to the symmetric design about the center axis of the coil; and (3) To allow for a uniform and close-packed arrangement of multiple coils on a substrate – as opposed to a square grid pattern that would have varying center to center distances.

MODELING

The electromagnetic field strength produced by the coils is modeled using MATLAB. Biot Savart's Law, shown below, is used to determine the field strength in the z direction (perpendicular to the surface of the coil), at a given height along a plane parallel to the surface of the planar coil.

$$B_z = \frac{\mu_0 I}{2\pi} \frac{EllipticK[k] + \frac{EllipticE[k](R^2 - r^2 - z^2)}{(R-r)^2 + z^2}}{[z^2 + (R+r)^2]^{0.5}}$$

$$k = \frac{4Rr}{(R+r)^2 + z^2}$$

where μ_0 is the permeability constant, equal to $4\pi * 10^{-7}$, I is the current in the coil in A, R is the radius of the coil, r is the cylindrical (radius) coordinate of the point relative to the center of the coil, z is the (cylindrical) height coordinate above the surface of the coil, and the embedded, Symbolic Toolbox, Elliptic Functions are used.

A sample plot of the potential generated by a single coil with a current of 0.15 A, is shown in Fig. 3a, producing a peak field intensity of 1.2mT. A similar plot of the potential generated by multiple, adjacent, coils, with varying currents and direction, is shown in Fig. 3b. The cluster coils produce a peak field intensity of 1.5mT, with a non-uniform, directional, potential well; note that a similar peak can be obtained with less current to each coil. The geometric design parameters for the simulations are the following: # of turns = 10; inner coil diameter = 20 μm; trace width = 7 μm; trace spacing = 7 μm.

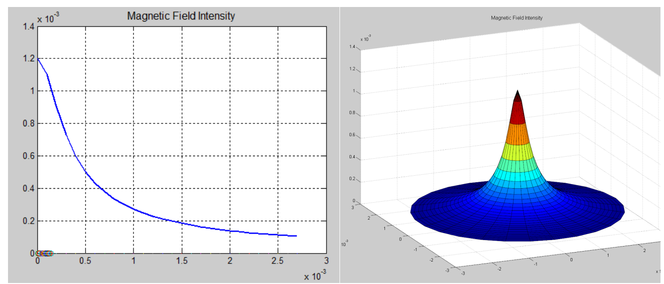

Fig. 3a. Planar micro-coil modeling results. Z-direction magnetic field intensity vs. distance from center of coil (left); 3D representation for entire coil (right).

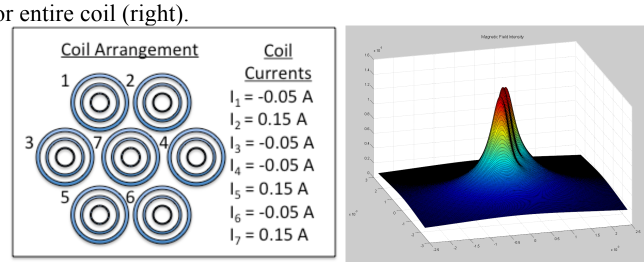

Fig. 3b. Multiple planar micro-coil modeling results. Cluster of coil arrangement, with respective current loads (left); 3D representation of Z-direction magnetic field intensity vs. distance from center of cluster (right).

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