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Initial Revision Completion Date: 11-MAR-07

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Sponsor: VIRTUAL AEROSURFACE TECHNOLOGIES/ATLANTA, GA
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Contract #: AGR SIGNED 2/22/2007 **Contract thru:** GTRC
Project Director(s):
PDPI ALLEN, MARK G
Unit: ECE **Initiation Date:** 01-MAR-2007
Termination Perf Date: 01-SEP-2007 (Performance)
Termination Rpts Date:
Project Title: MAGNETIC MICROCOMPRESSOR

Note: Deliverables sorted on 'Due Date to Sponsor' column

Rev No (1)	Description of Deliverable	Deliv Id No (2)	Period	Covered	Due Date to Sponsor (3)	Copies reqd	Date Mailed^	Sat^
*0	FINAL REPORT	1	01-MAR-2007	01-SEP-2007	01-SEP-2007	0	30-SEP-2007	N

Total Count:1
* Satisfied

PLEASE NOTE:

1.An asterisk denotes this deliverable was changed or added by the mod.
2.The Deliverable Id No will remain associated with its originally assigned deliverable for the duration of the project.
Modifications to the project will no longer cause this number to be sequentially renumbered.
3.Blanks in the 'Due Date to Sponsor' indicate 'as appropriate' or 'as required'.
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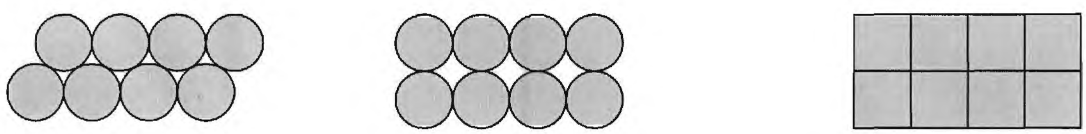
Prepare reports in accordance with:

Please review the schedule for accuracy and contact the CO if changes are necessary.

The conventional way of fabricating copper coils onto mm-scale, cylinder-like structures is to wind insulated magnet wires. However, such a method has some limitations. As the overall size of the device decreases, thinner wires must be used to pack more turns in the same volume. Hence, the thickness of the insulation layer represents a non negligible ratio of the total volume, contributing to a low packing density. This leads to a very non optimum design of the coils. Furthermore, cooling of the coils can not be self-integrated system.

At small-scale, these issues can be solved using MEMS fabrication technologies. First, square shape wires can be fabricated by electrodeposition. The use of square wires increases the packing density over conventional circular shape wires. Figure 1 shows the packing density of the different arrangements.



2 rows = 1.866D

Area = $7.464D^2$
Active Area = $2\pi D^2$
Packing density = 84.2%

2 rows = 2D

Area = $8D^2$
Active Area = $2\pi D^2$
Packing density = 78.5%

X = D

2 rows = 2D

Area = $8X^2$
Active Area = $8X^2$
Packing density = 100%

Figure 1: Arrangement schemes for circular and square wires

Secondly, the thickness of the insulation layer can be decreased down a few microns using chemically vapor deposited layers, such as parylene. Thirdly, integrated fluidic channels can be fabricated at the same time, and used for system cooling, and heat exchange.

MEMS fabrication:

We are proposing an innovative fabrication approach to build three-dimensional coil structures using conventional MEMS technologies. As depicted in Figure 2, the multi-turn coil is fabricated using a single layer of electroplated copper. It is then released from the substrate, insulated, and folded as envisioned in Figure 3.

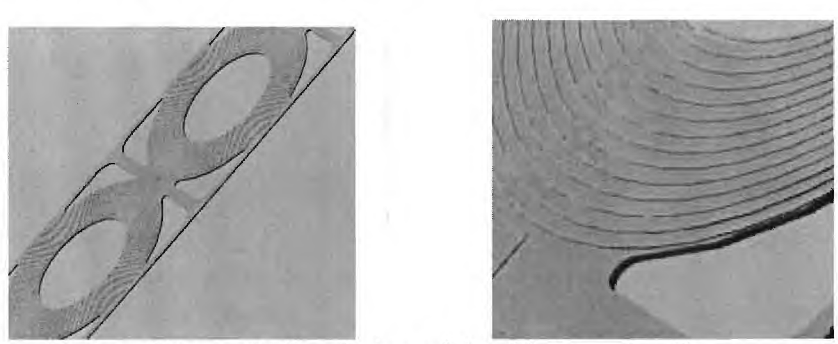


Figure 2: Rendering of the fabricated coil.

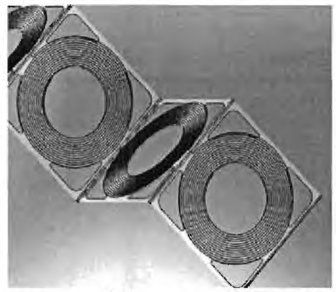


Figure 3: Rendering of the one-dimensional folded coil.

Using this technique, three-dimensional, MEMS fabricated, copper coil is achieved. For prototyping, the concept will be demonstrated using a limited number of layers. Multi-dimensional folding can also be implemented.

Testing:

Common fabrication and electrical characterizations will be performed such as yield test, resistance and inductance measurements, maximum current handling capacity… Finally, the coil will be integrated with permanent-magnets, and the magnetic actuation will be tested.

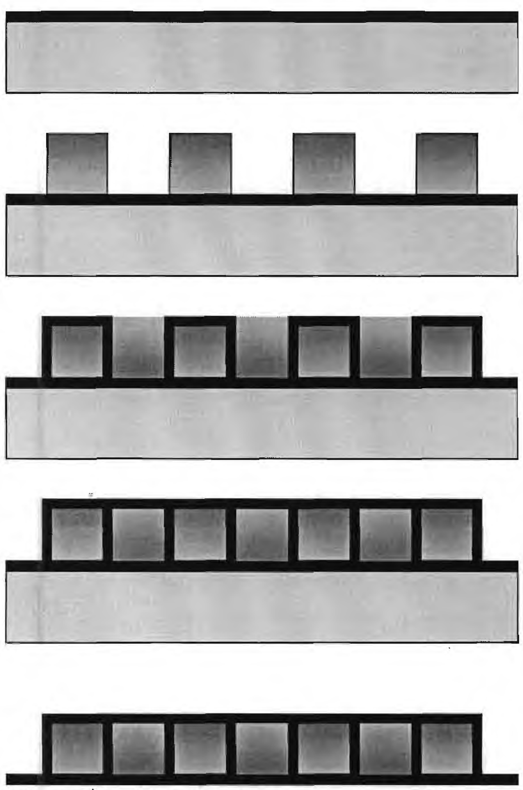


Figure 4. Fabrication sequence for ultracompact windings

In order to produce windings with maximal packing density, it is required to not only control the geometric shape and alignment of the individual conductors, but also to minimize the insulation surrounding each conductor. Unlike conventional wire wrapping, in which cylinders are stacked in a relatively inefficient fashion, and where insulation thickness (for fine magnet wire) is on the order of the thickness of the conductor itself, MEMS fabrication offers the possibility of efficient stacking and ultrathin, vapor-deposited insulation. Control of geometry as well as incorporation of cooling features has resulted in maximum current densities of MEMS-fabricated windings exceeding that of conventional wires by two orders of magnitude[1]. These approaches will be utilized to create ultracompact windings for the compressor actuators.

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[1] D. P. Arnold, F. Herrault, M.G. Allen et al., "Design optimization of an 8 W, microscale, axial-flux, permanent-magnet generator," *J. Micromech. Microeng.* 16 S290-S296 (2006)

To create ultracompact windings, an electroplating through resist mold coupled with a sidewall insulation scheme will be utilized[2]. The process is shown conceptually in Figure 4. An insulation layer such as polyimide or parylene deposited onto a rigid substrate such as a glass or silicon wafer and is cured. Using standard plating-through-resist techniques coupled with straight-sidewall photoresist processes, a first sequence of metal conductor lines is formed. The metal lines are coated with a vapor-deposited insulating material such as parylene (poly-p-xylylene) and are used as electroplating molds to deposit a second sequence of alternating lines conformally and exactly matched to the original spacing of the first sequence of lines. Because of the vapor deposition of parylene, as well as the low voltages used in magnetic excitation, the thickness of this insulation layer can be on the order of several microns or less. After planarization, the upper surfaces of the conductors are recoated with parylene and are separated from the substrate to form the final set of windings. For thicknesses of copper on the order of 100 microns and insulation thicknesses on the order of 5 microns, extremely efficient packing densities can be achieved.

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[2] F. Cros and M.G. Allen, "High Aspect Ratio Microstructures Using Sacrificial Conformal Costing," Proc. Solid State Sensors and Actuators Conference, Hilton Head, SC, June 1998.