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5.5 INTEGRATED MICROMOTOR CONCEPTS

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Abstract

The concept of an integrated micromotor is introduced and the philosophy of operation and fabrication are discussed. The motor considered has a working surface which covers a circular area of 200 microns radius. The final device has an eddy current driven free rotor floating on spiral groove bearings and is processed on a silicon chip using monolithic and compatible thin film fabrication techniques.

"He who would do good to another must do it in Minute Particulars" [1, p. 66, quoted from Blake].

I. Introduction

With the advent of integrated circuit techniques engineers have been able to implement many ideas which previously were just visions, as for example that of reliable large scale computation. And though basically integration as a concept is independent of small size, anyone working in the laboratory with monolithic techniques soon learns of their general applicability to minitiarized systems. But as yet such integrated systems are not basically capable of motion. Since one of man's visions is the construction of complete systems in microminature form, we have considered the basic problem of obtaining rotary motion in microelectrinic structures. Here we report the concepts arrived at after our various investigations and experimentations.

Although an investigation of the phenomena of motion on a miro-scale and in systems compatible with monolithic integrated circuits seems warranted in its own right, one of the questions most frequently asked of the authors is "To what use can you put your micromotor?". Thus it seems worthwhile listing a few uses as we see them. One of the primary reasons of conceiving of the micromotor was that of supplying a tape drive for an integrated Turing machine; this still seems a strong motivation. But with the presence of a micromotor some new and exciting fields are opened up. One of these is that of microminiature fluidic systems constructed by integrated circuit methods. For such systems the micromotor could act as the fluid pump changing electrical energy, stored for example in a battery, into fluid motion. Such a system could possibly be a fluidics computer, useful over large temperature ranges, of a size to fit in the hand. Because of its size the micromotor could possibly find many biological system uses, for example as implanted synchros or blood flow pumps to assist when partially clogged arteries are present. Of course more standard applications are possible, as a microminiature lathe drive for a micro-factory, and we imagine that our readers can think of other profitable uses.

We next discuss the principle of operation decided upon.

II. Principles of Operation

The principles used in the operation of the micromotor are probably best grasped through a visualization of the actual layout used for its construction. This layout is shown sketched in Fig. 1 where the rotor is shown as a circle of 185μ radius. This rotor is completely floating with, however, a center indentation to keep it centered. The principle of driving the rotor is that used for watt-hour meters [2] where a rotating electromagnetic field induces currents in the rotor upon which forces are created by proper phasing of the inducing fields. These inducing fields are set up by currents flowing in the five drive coils sitting over the rotor and connected to the ten contact pads located around the outside of the structure. Proper phasing of the driving currents is obtained by using a single signal generator and supplying the various drive coils from it through RC phase-shift circuitry.

Under the rotor lie a set of spiral groove bearings, these acting to give aerodynamical lift for contact free bearings [3]. These bearings consist of ten grooves set into the substrate at a variable pitch which however is chosen as close as possible with the fabrication methods to the optimal 16° pitch. To initially lift the rotor a single turn lift coil is also set into the substrate directly outside of the rotor; this can be seen attached to the two center-bottom contact pads in Fig. 1. By passing an initial current through the lift coil, again through electromagnetic induction, a vertical force is exerted on the rotor to allow it to be free to rotate in the first instance. After rotation the lift coil can be turned off, but its presence is thought to be valuable in supplying stability to the motion.

In summary, spiral grooves are used to supply frictionless bearings for the rotor whose motion is induced by eddy current interaction with a rotating electromagnetic field, as in a watt-hour meter. Initial

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contact friction is overcome through the use of an electromagnetic lift.

With these principles in mind we can discuss fabrication techniques.

III. Processing Methods

The fabrication methods incorporated in the design basically stem from those used in the making of resonant gate transistors [3]. After appropriate etching of the Silicon substrate various metallic surfaces are deposited by thin film techniques with a spacer metal finally etched to free the rotor. Integrated circuit masking techniques are used to obtain the various necessary patterns. Many steps are involved with the critical choices having to do with obtaining selective etchants in conjunction with compatible metals which will adhere to each other.

Figure 2 shows a side view of a device fabricated using the steps of Table I. In this method aluminum is used as a spacer for the nickle-gold rotor. And although this procedure may prove satisfactory in the end, the authors have had some trouble due to fusing of nickle and aluminum such that as yet a rotor has not been freed.

As a consequence present planning has the device constructed by using aluminum for all final metallic parts with photoresist as the spacer; for this positive photoresist appears optimal though as yet our laboratories have not been sufficiently equipped to handle it.

IV. Conclusions

An integrated micromotor has been described in concept. Such a device can be constructed in conjunction with other integrated circuit components and hence should allow for reliable and mass-produced microsystems. Applications include the construction of microfactories, microfluidic computers, and biological repair functions. Preliminary testing of all stages of fabrication indicate the good possibility of device construction.

'Science confronts the work of one man with that of another, and grafts each on each; and it cannot survive without justice and honor and respect between man and man'!
[1, p. 63]

References

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[3] Muijderman, E. A., 'New Forms of Bearing: the Gas and Spiral Groove Bearing", Philips Technical Review, Vol. 25, No. 10, October 1954, pp. 253-288.

[4] Nathanson, H.C., W.E. Newell, R.A. Wickstrom, and J.R. Davis, Jr., "The Resonant Gate Transistor", IEEE Transactions on Electron Devices, Vol. ED-14, No. 3, March 1967, pp. 117-133.

Table 1, Processing Steps

Step	Purpose	Process
1	Etch protectant	SiO_2 growth
2	Spirals	SiO_2 etch
3	Lift coil attract	P diffusion
4	Drive-in, etch protectant, rotor release	SiO_2 growth
5	Center hole	SiO_2 etch (KTFR mask) Si etch (SiO_2 mask)
6	Etch protectant	SiO_2 growth
7	Lift coil, drive coil attach	SiO_2 etch
8	Lift coil, drive coil base	Ni deposition; electroless Au deposition, electroless
9	Rotor spacing	Al deposition, evaporation
10	Rotor material	Ni deposition; evaporation
11	Rotor	Ni etch, Ni deposition; electroless Au deposition; electroless Ni deposition; electroless
12	Drive coil spacing	Al deposition; evaporation
13	Drive coil contact exposure	Al etch
14	Drive coil material	Ni deposition; evaporation
15	Drive coil	Ni deposition; electroless Ni etch, Ni deposition; electroless Au deposition; electroless Ni deposition; electroless
16	Rotor release	Al and SiO_2 etch

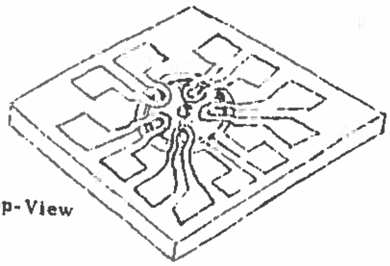

Figure 1

Micromotor Top-View Sketch

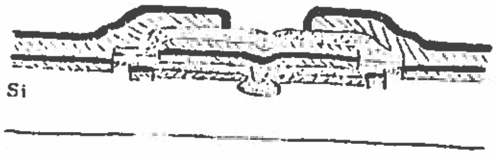

Figure 2

Processing, Cross-Section