

Method of producing a thin electromagnetic motor

Field of the invention

The present invention relates to MEMS (micro-electromechanical systems) devices, and in particular to MEMS devices which are axial-type
5 electromagnetic motors.

Background of Invention

The use of MEMS devices, including micro-rotating devices in which a rotor
10 element having a sleeve rotates around a spindle shaft, is becoming more widespread due to their portability and low power consumption. Examples of such micro-rotating devices include micro-pumps or motors.

A typical micro-rotating device is illustrated in cross-section in Fig. 1. It
15 comprises a rotor (rotating disc) 101 and a stator 105. The stator 105 is formed with a coil winding (not shown). The spindle shaft 102 extends from the stator 105, and passes through a central aperture 106 in the rotor 101. The inner surface of the aperture 106 constitutes the sleeve for the shaft 102. The rotor includes a cavity on its surface facing the stator 105. The cavity
20 encircles the aperture 106 and is filled with a permanent magnet 104 and a yoke 103. The rotor 101 rotates about the spindle shaft 102 when there is a continuous flow of electrical current into the coil winding on the stator 105. The micro-rotating device of Fig. 1 is easily constructed by placing the sleeve of the rotor disc 101 onto the shaft 102.

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In use, the portable device is subjected to shock, so a good cushioning is essential to protect the structure if the performance of the motor is not to be impaired. Also, as in all other micro-mechanical devices, frictional resistance to motion occurs when the surfaces of the moving parts come in contact with

those of the stationary parts. Unless measures are taken, the frictional resistance causes abrasion, which lowers the driving efficiency of the mechanism and also causes an increase in temperature at the interface surfaces.

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In micro-rotating devices the clearance between spindle shaft and sleeve is usually very narrow, so no mechanical bearing can be inserted. Thus, a lubricant, such as oil or powder, is often used as the substitute for the mechanical bearing. The lubricant creates fluid pressure to balance the shaft
10 against the sleeve. However, due to the tight spacing along the relatively long pivoting shaft, physical contact frequently still occurs particularly at high rotation speeds, resulting in undesirable loss in power. Furthermore, in the fabrication process for miniature devices, micro-machining technology has only a limited ability to create complex profiles on thin wafer structure, and it is
15 difficult to construct a lubricating gadget within the confined space. Hence, the sealing (which is necessary in micro-rotating devices employing a lubricant to avoid leakage of the lubricant, or evaporation of the lubricant due to heating) may lead to impaired device performance. Again, tiny sealing elements are not easily fabricated and integrated into the device.

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Summary of the Invention

The present invention aims to provide new and useful micro-mechanical rotating devices.

In general terms, the present invention proposes that the aperture of the rotor
25 has a stepped profile, that the shaft of the MEMS based micro-motor includes a portion which is wider than the narrowest part of the aperture and thus limits the distance which the rotor can move from the stator, and that the MEMS device includes an air-bearing system which creates a uniform hydrodynamic pressure between the rotor and the stator.

For example, the shaft may have a T-shape cross-section, i.e. it includes a shaft portion of uniform radius and a head portion of greater radius which retains the rotor within the required position, thereby limiting the clearance allowable for vertical displacement.

- 5 Preferably the shaft is formed of a polymeric material, which provides cushioning of the rotor during high-speed rotation.

The air bearing is created by forming curved grooves on the rotor facing the stator for generating a hydrodynamic air bearing to minimize the contact, and to improve the rotation stability.

- 10 Preferably, the rotor incorporates a magnetic alloy of desired thickness and shape to induce rotation when a magnetic field is generated by a coil associated with the stator.

- Preferably, a thin layer of Diamond-Like-Carbon (DLC) is provided coating the contact surfaces of the rotor to reduce the friction resistance during the
15 rotation. The DLC layer may be provided on all surfaces of the rotor.

Specifically, a first expression of the invention is a MEMS micro-motor device comprising:

a stator element;

- a rotor element having a sleeve, the sleeve having a profile including a
20 step-change between a first diameter in a first axial location and a second larger diameter in a second axial location, the second axial location being further from the stator element than the first axial location;

a shaft projecting from the stator and passing through the sleeve, the shaft having a profile including a first portion for contacting the sleeve at the

first axial location and a second portion of greater diameter for contacting the sleeve at the second axial location; and

an air-bearing system for creating a uniform hydrodynamic pressure between the rotor and the stator.

- 5 A further aspect of the invention is a method of fabricating this micro-rotating device. The rotor disc may be formed by a dry etching process, with appropriate lithography and masking on a single wafer substrate.

Brief Description of The Figures

Preferred features of the invention will now be described, for the sake of
10 illustration only, with reference to the following figures in which:

FIG. 1 is a cross-sectional view of a prior art micro-motor;

FIG. 2 is a cross-sectional view of a micro-motor which is an embodiment of the invention;

FIG. 3, which is composed of Figs. 3(a) to (h), is a cross-sectional view
15 of the intended fabrication procedure for the rotor disc.

FIG. 4 shows the top-down assembly sequence of the proposed micro-motor structure.

Detailed Description of the embodiments

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Referring to Fig. 2, a micro-rotating device which is an embodiment of the invention is shown in cross-section. The device includes a rotor 200 and stator 208. The rotor 200 is principally a silicon disk 201 having a central aperture. A shaft 202 projects from the stator 208, and the two are connected
25 by a shaft holder element 207.

The shaft 202 is rotationally symmetric about an axis 211. The shaft includes a first portion 210 of uniform diameter at all positions along the axis 211, and

a head portion 209 further from the stator 208 and which is of also of uniform diameter at all positions along the axis 211. The central aperture of the rotor 200 is defined by two cylindrical sleeve surfaces 212, 213. The cylindrical sleeve surface 212 is of smaller diameter than the cylindrical sleeve surface 213.

Of course, the figure is not to scale. Typically, the maximum diameter of the rotor device (in the sideways direction of Fig. 2) is at most 3cm, and more preferably less than 2cm. The thickness of the rotor 200 is preferably no more than 600 μm .

The 'T'-shaped shaft 202 constitutes a means to avoid tilting of the rotor 200, and keeps the rotor 200 in position constantly throughout the rotation. Thus, the shaft 202 provides an advantage compared to the regular pin-type shaft 102 of Fig. 1.

As in shown Fig. 2, the silicon body 201 includes a trench in its surface which faces the stator 208 and encircling the aperture, and the trench is substantially filled with a magnetic material 204 (e.g. an alloy) and a yoke layer 203. These materials induce a rotation motion when appropriate magnetic fields are generated by a coil (not shown) fixed to the stator 208.

Arcuate angled grooves 214 are provided on the surface of the rotor 200 facing the stator 208. These grooves create an air-bearing in the region 206, which helps improve the spin motion at the contact interface by reducing mechanical resistance. Likewise, the arcuate profiles 214 are also advantageous in generating air pressure along the circumference of the shaft 202 (due to the kinetic behaviour of gases) to minimize the eccentricity through the rotation. To produce the minute pattern 214 an etching process is

preferred, since this can achieve the required specifications without imposing other defects on the disc 201 since the Si material is relatively hard.

To reduce the total thickness of the motor assembly, the thin rotor structure
 5 200 is fabricated using a semiconductor process to selectively create the required profile, and to accurately control the required geometry of the intended rotor 200. Furthermore, the process allows an array of multiple rotor discs 201 to be made on single substrate concurrently, thereby cutting down on the construction cost and time. In this regard, micro-fabrication techniques,
 10 such as plasma etching, are used for producing a step profile, of micrometers in height, on the disc 201, which is not easily attainable from conventional machining technology.

The details for the etching sequence in the fabrication of the Si disc 201 are
 15 explained as follows, with reference to FIG. 3.

As shown in Fig. 3(a), a thin piece of double-side polished Si substrate 301 is first loaded into a furnace of high thermal heat to develop thin Silicon oxide (SiO_2) layer 302 on both its surfaces. This oxide layer functions as a
 20 protective mask in later steps of the method in cases when the surface is not coated with another protective material such as spin-coated photo resist. Considering the etching depth requirements, the thickness of SiO_2 layer 302 used is about $2\text{ }\mu\text{m}$ which is sufficient to stop the etching for a low-depth structure.

25 Next, the Si wafer is spin-coated on one side with a photo-resist masking layer 303 of about 7mm thickness of on one side above the SiO_2 layer 302, and the layer 303 is subsequently patterned with the required profile by means of conventional lithography. Chemical plasma etching (with gases

such as CF_4 and O_2) is then carried out, removing the unwanted portion of the SiO_2 layer 302, as shown in Fig. 3(b),

5 A further photo-resist masking layer 304 is applied to the same surface of the water 301, covering the remaining portions of the $2\mu\text{m}$ oxide layer. The layer 304 is patterned, and then chemical plasma etching is again performed, as illustrated in Fig. 3(c), to create another profile for succeeding etching steps.

10 Owing to the fact that ions travel straight towards the substrate during the plasma etching process, deep perpendicular walls can be formed subsequently, with polymer passivation, as in the Bosch process, that shields the walls from the bombarding ions. In the most etched portions of the Si substrate 301 about one-third of the total thickness remains, as shown in Fig. 3(d).

15 Following that, the residual photo-resist layer is removed using chemical solvent, such as dipping in Acetone. A further plasma etching is carried out to take out about 50mm from areas of the Si body 301 not covered by the remaining SiO_2 302. This forms a set of uniformly distributed surrounding
20 grooves 214 dedicated to the air-bearing function, illustrated in Fig. 3(e). Subsequently, the SiO_2 left behind is removed by dipping the Si body 301 in Hydrofluoric (HF) acid.

Following that, the Si body 301 is inverted. Etching methods are again
25 employed using another patterned masking layer 305 to make through-holes 306, 307 through the Si substrate 201 as shown in Fig. 3(f) and Fig. 3(g), in line with those earlier made cavities. Through hole 307 becomes the aperture of the disk 201, and through holes 306 singulate individual disks 201 from the substrate 301. To ensure that the etching of the holes 306, 307 is aligned on
30 both sides of the substrate 201, an optical aligning system is used, along with

the appropriate markings, to position the Si substrate when it is inverted in the etching chamber.

- The photo-resist layer 305 is also used to reduce the thickness of the substrate 301 in the region around the central aperture 306 before the discs 201 are detached from the wafer substrate 301. The dimension of the sleeve on the rotor disc 201 has a stepped profile, intended to accommodate the different dimensions of the T-shaped shaft 202 as mentioned earlier.
- At this point, the fabrication of the rotor disc 201 is completed. It has a shape of a flat round plate, with a through hole 306 at the centre. One side of the disc has a large, circular trench 308 removed, used in the later assembly process. When each of the rotor disc 201 is detached from the substrate, it carries a residual layer of polymer resulting from the Bosch polymer passivation during the etching. It is then desirable to remove this thin coat entirely from the surface by dipping into ultra-sonic mixture bath containing Hydrosulfuric acid (H_2SO_4). One half of the completed disk 201 is shown in perspective view in Fig. 3(h).
- For further improvement to reduce friction, an additional thin layer of conforming coating film 205 is deposited on all surfaces of the disc 201, including the sleeve hole 306 on the etched disc 201. The thin layer 205, which is preferably Diamond-Like-Carbon (DLC) film, provides a lubricating effect due to its high hardness material property. One possible deposition technique comprises sputtering or chemical vaporization as well as, in this proposal, Filtered Cathodic Vapor Arc (FCVA) methods where low-temperature conformal film can be achieved with uncomplicated control for the required film thickness.

A ring-shaped yoke plate 203 with high magnetic saturation property, for instance Nickel-Iron (Ni-Fe), of about 100mm thickness is added to the inner surface of the etched trench 308 on the rotor disc 201, by adhesive, to intensify the induced electromagnetic force. A ring-shaped bond magnet 204
5 hundreds of micrometers thick and composed of a magnetic alloy, such as Samarium-Cobalt (Sm-Co), is inserted over the yoke 203.

The thickness of each of the magnet 204 and yoke 203 is appropriately controlled during the fabrication to ensure that they fit entirely into the etched
10 hollow trench 308 on the disc 201, with good flatness at the base surface.

Another key component of the motor assembly of the embodiment is the T-shaped shaft 202 with adequate mating behaviour to soften any physical shock on the thin Si disc 201. The shaft 202 can be fabricated from polymeric
15 material, for example Polyimide composition, and can be prepared by a conventional grinding process to shape it into a cylindrical shape, and finished off by subsequent polishing to achieve the required surface smoothness. Alternatively, the T-shaped shaft 202 can be made using injection-moulding technology. Advantages of using a moulding process include the ability to
20 fabricate numerous shaft samples in a single mould run, a good surface finish and the ability to ensure that the shaft profile is free from undesirable deformations, which may arise if the shaft 202 is made by conventional machining techniques.

25 The polymer material selected for the shaft 202 in either of the possible fabrication processes has mechanical and thermal requirements which are suitable in view of the possible structural deformation of the shaft 202 during the rotation of the rotor 200. As the shaft 202 is subjected to wear, the polymeric material chosen for use may contain small content of graphite or

glass fiber, which would improve the mechanical strength as well as providing a lubricating finish on its surface.

5 Likewise, a cylindrical shaft holder 207 of similar material and finish is cut and polished to secure the shaft at the base of the motor assembly. This ring-like structure, having a thickness of hundreds of micrometers, functions as a support base for the shaft 202, which also detains the rotor disc 201 during the rotation.

10 The stator 208 may consist of a thin Printed Circuit Board (PCB). It has a thickness slightly less than that of the shaft holder 207, and contains plated copper coil windings, which generate electrical fields to induce the electro-magnetic torque needed for the rotation. A uniform thickness is maintained throughout the coils' area to keep a consistent air gap between the rotor 200
15 and the PCB 208 during the rotation.

Fig. 4 is a perspective view showing the assembly process. A position of the material 204 is treated as invisible to show the yoke 203. As illustrated in Fig. 4, the rotor structure of Fig. 2 can be assembled by hand, without the use of
20 optical alignment tool. The assembly of micro-motor is completed by plugging the shaft 202 through the sleeve of the rotor disc 201, and fully inserting the shaft 202 into the shaft holder 207 adhered to the PCB 208. A check is performed that the shaft 202 is perpendicular to the rotor 200 and stator 208, and that the rotor 200 is parallel to the stator 208, to ensure steady rotating
25 behaviour.

Claims

1. A MEMS micro-motor device comprising:
 - a stator element;
 - a rotor element having a sleeve, the sleeve having a profile including a
5 step-change between a first diameter in a first axial location and a second
larger diameter in a second axial location, the second axial location being
further from the stator element than the first axial location;
 - a shaft projecting from the stator and passing through the sleeve, the
shaft having a profile including a first portion for contacting the sleeve at the
10 first axial location and a second portion of greater diameter for contacting the
sleeve at the second axial location; and
 - an air-bearing system for creating a uniform hydrodynamic pressure between
the rotor and the stator.
2. A micro-motor device according to claim 1 in which the shaft has a T-
15 shaped axial cross-section consisting of a first portion of uniform radius and a
head portion of greater radius.
3. A micro-motor device according to claim 1 or claim 2 in which the shaft
is formed of a polymeric material.
4. A micro-motor device according to any preceding claim in which the air
20 bearing system comprises grooves formed on the surface of the rotor facing
the stator.
5. A micro-motor device according to any preceding claim in which the
rotor includes a magnetic element for inducing rotation when a magnetic field
is generated by a coil associated with the stator.

6. A micro-motor device according to any preceding claim in which the rotor includes a silicon body.

7. A micro-motor device according to any preceding claim in which a thin layer of Diamond-Like-Carbon (DLC) is provided on the rotor to reduce
5 frictional resistance during rotation of the rotor.

8. A method of producing a micro-motor device, the method including:

etching a substrate to form a rotor having a sleeve defining an axis, the sleeve having a profile including a step-change between a first diameter in a first axial location and a second larger diameter in a second axial location;

10 inserting a shaft through the sleeve, the shaft having a profile including a first portion for contacting the sleeve at the first axial location and a second portion of greater diameter for contacting the sleeve at the second axial location; and

securing the shaft to a stator with the first portion of the shaft closer to
15 the stator than the second portion.

9. A method according to claim 8 in which the shaft has a T-shaped axial cross-section consisting of a first portion of uniform radius and a head portion of greater radius.

10. A method according to claim 8 or claim 9 in which the shaft is formed of
20 a polymeric material.

11. A method according to any of claims 8 to 10 in which grooves are formed on the surface of the rotor which is to face the stator, the grooves being for generating an air bearing upon rotation of the rotor around the shaft.

12. A method according to any of claims 8 to 11 in which the etching of the
25 rotor includes forming a circular trench on the surface of the rotor which is to

face the stator, and inserting at least one magnetic element into the trench for inducing rotation when a magnetic field is generated by a coil associated with the stator.

13. A method according to any of claims 8 to 12 in which the substrate is
5 silicon.

14. A method according to any of claims 8 to 13 comprising forming a thin layer of Diamond-Like-Carbon (DLC) on the rotor to reduce frictional resistance during the rotation of the rotor.