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Method for forming an electromagnetic motor with an air bearing

Field of the invention

The present invention relates to an electromagnetic motor having an air bearing between a stator and a rotor.

5 Background of Invention

In recent years there has been intense research in the field of micro-mechanical devices, such as those fabricated using techniques borrowed from the field of semiconductor fabrication. Among the devices which can now
10 be created are micro-rotating devices (such as micro-pumps and motors).

Rotating micro-machinery usually comprises a rotating structure (a "rotor") that spins about a spindle axis on a stator. The rotor is typically no larger than 2cm or 3cm in diameter, and often much smaller. A common such structure is
15 shown in cross-section in Fig. 1. The rotor 101 includes a permanent magnet 103 which generates a magnetic field, while the stator includes a shaft 102 and multiple coil windings 104. When electrical current flows in the coil 104 an induced torque rotates the rotor. The multiple coil windings 104 are placed near to the surface of the magnet 103 to maximize the induced energy for the
20 rotation. The clearance between the rotating magnet 103 and stationery coil winding 104 is low, so the two surfaces may come into contact when there is an imbalance in the rotation, or if a load is applied to the rotor 102 load in the direction towards the stator.

25 It is known to provide a micro-bearing within the micro-device. Unless this is done there is generally high resistance to motion at the interface where the moving parts come into contact with the stationary parts. This resistance causes abrasion, which lowers the driving efficiency of the mechanism and

also causes an increase in temperature at the interface surfaces. Due to the tight spacing along the relatively long pivoting shaft, physical contact frequently occurs, particularly when the micro-device is subjected to shocks, resulting in undesirable loss in power. Furthermore, when the rotor is
5 subjected to axial loading, it is important that the rotation does not break down due to friction at the contact surfaces. In this regard, a robust bearing system is essential to keep up the mechanical balancing of the rotating elements, and attain a lifting capability so as to overcome the static and kinetic friction.

10 Fabricating a roller bearing in the restricted space is difficult, so instead the micro-bearing is conventionally fabricated to include a fluid film between the stator and the rotor to act as a lubricant, e.g. to balance a sleeve of the rotor in a correct position in relation to a shaft of the stator.

15 One possibility is to use a liquid lubricant, such as oil, but for this sealing is necessary to avoid leakage or evaporation of the liquid due to heating, since loss of the liquid bad interferes with the performance of the micro-device. Unfortunately, tiny sealing materials are not easily fabricated and integrated into the device.

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Summary of the Invention

The present invention aims to provide a new and useful electromagnetic motor, and preferably one which at least partially alleviates the problems
25 referred to above.

In general terms, the invention proposes that a formation is provided between the rotor and stator which, upon rotation of the rotor, generates an air bearing. The formation is provided over a large portion (such as at least 50%, at least

75%, at least 90% or even substantially the whole) of the area of the respective opposing surfaces of between the rotor assembly and the stator.

5 In particular, the formation may extend over a portion of the rotor which, when viewed along the rotational axis of the motor, overlaps with the area occupied by a permanent magnet of the rotor.

10 Such an architecture can be fabricated at micro-scale geometry accurately so it is suitable for a thin-type rotating mechanism, and it has enhanced rotary stability. In this regard, a consistent and uniform clearance between the components is preferred, and it can be achieved in embodiments of the invention by the air bearing system generated by the formation, which separates the surfaces by a thin air film generated during the rotation.

15 The formation which generates the air bearing preferably consists of a spiral patterned profile that helps in developing gas film lubrication during the spinning motion. The profile is designed with curved geometry to create uniform distributed air pressure at the surfaces, and thus minimize the surface contact. The grooves may be on either one of the stator and the rotor (or
20 conceivably on both), and face towards a surface (preferably a substantially flat surface) of the other.

For this purpose, the permanent magnet of the rotor is preferably provided on a surface of the rotor facing away from the stator. Alternatively, the permanent magnet may be formed embedded within the rotor so that it is not exposed in
25 the axial direction of the shaft. This makes it easier to arrange that the surfaces of the rotor at both longitudinal ends of the shaft are made substantially flat or provided with grooves.

With conventional machining technology would be difficult to create such a small geometry accurately. It is a feature of the present invention that Silicon

wafers are used to provide smooth and flat surfaces as the contact surfaces of the rotor and stator of the motor (although, forming the wafers of another material, especially another semiconductor material, is not excluded).

5 The motor of the invention may be formed by semi-conductor technology to attain highly precise dimension control (a precision which is hardly achievable by conventional workshop machining). Thus, this is an MEMS device. Embodiments of the structure may be able to carry a light load with sufficient torque to perform at a required rotation.

10 A preferred embodiment of the invention comprises of a rotor disc provided with a permanent magnet in the form of an adhered thin ring-shaped magnetic alloy, and a disk-shaped stator base provided with copper coils winding, and typically affixed to a printed circuitry board. Alternatively, these copper windings can also be constructed on a silicon substrate by an electro-plating process.

15 A first expression of the invention is an electromagnetic motor comprising:
a rotor assembly including a ring-shaped magnetic magnet and defining a central aperture;
a pin element comprising a shaft extending through the aperture; and
a stator supporting the shaft,
20 the rotor assembly including a substantially planar rotor bearing surface spaced from and facing a stator bearing surface of the stator, at least one of the rotor bearing surface and stator bearing surface including a formation which generates an air bearing between the rotor assembly and stator upon rotation of the rotor relative to the stator,
25 the formation extending over at least 50% of the total planar surface area of the rotor assembly in the direction as viewed parallel to the length direction of the shaft.

A second expression of the invention is an electromagnetic motor comprising:

a rotor assembly including a ring-shaped magnet and defining a central aperture;

a pin element comprising a shaft extending through the aperture; and
a stator supporting the shaft,

5 the rotor assembly including a substantially planar rotor bearing surface spaced from and facing a stator bearing surface of the stator, at least one of the rotor bearing surface and stator bearing surface including a formation which generates an air bearing between the rotor assembly and stator upon rotation of the rotor relative to the stator,

10 the formation and magnetic material overlapping as viewed in the direction along the shaft.

A third expression of the invention is an electromagnetic motor comprising:

a rotor assembly including a ring-shaped magnet and defining a central aperture;

15 a pin element comprising a shaft extending through the aperture; and
a stator supporting the shaft,

the rotor assembly including a substantially planar rotor bearing surface spaced from and facing a stator bearing surface of the stator, at least one of the rotor bearing surface and stator bearing surface including a
20 formation which generates an air bearing between the rotor assembly and stator upon rotation of the rotor relative to the stator,

the magnet being formed from provision of magnetic material within a pocket of the rotor assembly facing away from the stator.

These aspects of the invention are freely combinable. Also, the invention can
25 be expressed as corresponding methods of fabricating such devices, e.g. by MEMS techniques.

Brief Description of The Figures

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

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

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

FIG. 3 is a cross-sectional view of a structure used to form the rotor assembly of the embodiment of FIG. 2;

10 FIG. 4 is a cross-sectional view illustrating plasma etching on one surface of the structure of FIG. 3;

FIG. 5 is a cross-sectional view of a magnet plating process performed on the structure of FIG 4;

FIG. 6 is a cross-sectional view of a magnet adhesion process which is an alternative to the plating process of FIG. 5;

15 FIG. 7, which is composed of Figs. 7(a) to 7(d), is a top view of spiral grooves for producing an hydrodynamic bearing;

FIG. 8 is a cross-sectional view of a second embodiment of the micro-motor;

20 FIG. 9 is a cross-sectional view illustrating a step performed to aid bonding of a pin element to the stator in the fabrication of the embodiment of FIG 2.

FIG. 10 is a cross-sectional view illustrating the bonding of the rotor assembly to the stator to form the embodiment of FIG. 2;

25 FIG. 11 illustrates an application of an embodiment of the invention, as a motor for rotating a propeller of a centrifugal fan; and

FIG. 12 shows the performance of the arrangement of FIG. 11 as an application for the micro-motor.

Detailed Description of the embodiments

A first embodiment of the present invention is shown in Fig. 2. This embodiment generates an air bearing which provides active damping. The motor is suitable to be put inside a portable device that runs on a low-power dry cell. A consistent torque (which is essential to drive the motor effectively throughout the required operation) can be overcome since the air bearing overcomes all resistance in motion, and minimizes the risk of unintended collision of the rotating surface effectively, without external separation means.

The system includes a rotor assembly 210, a pin element 202 including a straight shaft which forms the axle of the motor (in FIG. 2 this element 202 has a T-shaped cross-section as discussed below) and a stator which is shown including a shaft base 203 and a thin electrical circuitry segment 204. Each of these elements is rotationally symmetric about the axis of the shaft of the element 202. The system includes a formation (described below) to generate a hydrodynamic air bearing to keep the rotor assembly 210 in position constantly throughout the rotation, and create a lubricating layer 206 between the facing bearing surfaces of the rotor assembly 210 and stator that cushions any possible collision, without the use of supplementary lubricant. For such application, load lifting capacity is generated by the spiral surface contours, to support the rotor assembly 210 axially in the operation, hence help stabilizing the spin motion at the contact interface.

The fabrication process of the embodiment requires a high precision approach to carefully reduce the thickness of each component with good dimensional controls and good rigidity. For this reason, this micro-fabrication is achieved using a semiconductor fabrication process to create selectively the required profile, and to control accurately the required geometry of the motor's bodies.

Semiconductor fabrication techniques also make it possible to fabricate an array of multiple identical motor components on single substrate concurrently, which reduces the construction cost and time. In this proposal, chemical plasma etching is used to create required contours on a plain surfaced disc, which is not attainable using conventional machining technology.

Typically, from cost considerations, a Silicon (Si) wafer is used as the base material for its high flatness and lightweight material properties. As in a conventional semiconductor fabrication process, this wafer is loaded into a vacuum chamber, and a series of a multiple masking and lithography processes are performed to achieve the intended structure by removing unwanted portions of the Si wafer. Photo-resist masking is prepared on every intended surface of the Si wafer, to cast the profile needed in the succeeding chemical plasma etching with precise specifications. Subsequently, a residual photo-resist layer (see Singapore patent application no. 200207479-7, corresponding to US patent application no 10/730472 the disclosure of which is incorporated herein by reference) during the etching is removed using a chemical solvent, such as by dipping in Acetone.

For further improvement to reduce friction, additional thin layers of conforming coating film, of a few micrometers in thickness (e.g. up to 3 microns, or 5 microns), are deposited on all surfaces of each component, including curved walls of the spindle. Deposition of a thin layer, preferably Diamond-Like-Carbon (DLC) film, provides a lubricating effect due to its high hardness material property, which covers the entire surfaces, with good adhesion and chemical inert property. It has extremely high mechanical hardness that reduces the wear and resistance at the contact that is desirable for high-speed mechanism. For such methodology, the probable deposition technique comprises sputtering or chemical vaporization as well as, in this proposal, Filtered Cathodic Vapor Arc (FCVA) methods where a low-temperature

conformal film can be achieved with uncomplicated control of the required film thickness.

Alternatively, a thin Self-Assembled-Monolayer (SAM) layer is also good for
5 reducing the contact friction (refer to the article in Thin Solid Films 423, 2003, p77-87). This can be achieved economically by immersing each component into a bath solution of organic chemical, such that the polymer chains become attached to the surface in a form of chemical bonding. In this regard, the contact surface becomes hydrophobic, which lowers the friction resistance to
10 large extent.

Details of the assembly sequence of the fabrication process of the embodiment of Si motor are explained as follows in terms of a single device, but it should be understood that these steps are preferably performed in a
15 batch process which creates many units of the motor concurrently.

The moving body of the motor, that is the rotor assembly 210, consists of a rotor disc 201 that has a ring-shaped trench 205 for housing a permanent magnet, as well as a through sleeve hole 209 in line with the spindle axis, as
20 shown in FIG. 2. It is made through etching a polished Silicon (Si) wafer, so multiple rotors can be fabricated at the same time on a wafer.

The fabrication process for appending the permanent magnet to the rotor assembly will now be explained. The magnet is intended to have a thickness
25 in the range of hundreds of micrometers, and used to provide the magnetic field required for inducing the rotation of the rotor assembly 210.

First, as shown in Fig. 3, a thin electrical conductive layer 301, for example, Titanium (Ti), Nickel-Iron (Ni-Fe), Cobalt (Co), Copper (Cu), Gold (Au), or their
30 composites, etc, is deposited and sandwiched between two thin Si wafers

301, 303 by a polymer bonding process (for implementation details see the article in the Journal of Micromechanics and Microengineering No. 12, 2002, 187-191 entitled "A low temperature bonding technique using spin-on fluorocarbon polymers to assemble microsystems").

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Following that, as shown in Fig. 4, a ring-shaped through hole (a "ring pocket") 205 is formed in wafer 303 by Deep Reactive Ion etching (DRIE), exposing the thin conductive layer 301 (see also patent application Singapore patent application no. 200207479-7 referred to above). Magnetic layer deposition is then established on the wafer level, by inserting the structure into a chemical bath solution and supplying electric current to the thin conductive layer 301 to attract and accumulate metallic ions. The ring pockets 205 on the rotor disc 201 fill up with a hard magnetic layer 501, such as Cobalt-Nickel-Manganese-Phosphorus (Co-Ni-Mn-P) composite. This deposition both accurate and uniform (refer to IEEE Transaction on Magnetics, Vol. 32, No. 5, September 1996, 5154-5156 entitled "Micromachined thick permanent magnet arrays on silicon wafer"). Subsequently, a thin metallic layer 502, such as Ni-Fe, Ni-Fe-Co, etc, is plated on top of the magnetic layer 501 by changing to a metallic bath. The layer 502 functions as a yoke for enhancing the rotation behaviour of the motor. Next, magnetization for the magnetic layer 501 is performed by means of external coils after the deposition. When the plating processes are completed, the rotor disc assemblies 201 are carefully handled for subsequent DLC coating on all surfaces.

25 Note that an alternative possible fabrication process within the scope of the invention would be to insert a pre-formed ring-shaped bond magnet 601, such as Samarium-Cobalt (Sm-Co) composite magnetic alloy with uniform thickness, into the etched hollow trench 205 on the disc 201. As illustrated in FIG. 6, such ring magnets 601, with a machined thin iron yoke plate 602, can

be put into the trench 205 in the rotor disc 210 individually using instant adhesive.

As mentioned above, another component of the motor assembly is a
5 cylindrical shaft base 203, which functions as a stationary platform that
detains the rotor assembly 210 during the rotation. Similarly, the shaft bases
203 for multiple respective electromagnetic motors may also be prepared
through a batch etching process on a Si wafer. The shaft base includes a disk
of hundreds of micrometer in thickness and same outer diameter as the
10 rotating rotor disc 201.

The embodiment includes a spiral groove thrust bearing on the lower (as seen
in Fig. 2) surface of the rotor assembly 210 for axial loading-carrying capacity.
Axial load-carrying capacity can be developed by pressure generated within a
15 lubricant film due to the wedge action between varying gaps of two surfaces
during relative motion. To produce the wedge action some pattern of varying
gap is engraved in one or other of the two opposing surfaces: the upper
surface of the shaft base 203 and the lower surface of the rotor assembly 210.
For example, an additional step may be included in the etching process of the
20 fabrication process of the rotor assembly 201, for creating spiral ridge and
groove profiles 207 of several micrometers depth on the upper surface of the
shaft base 203 which faces the flat surface of the rotor disc 201. This is
illustrated in FIG. 7(a). These thrust bearings created on the structure surface
rely on hydrodynamic pressure to support the load.

25 Three commonly occurring examples of annular, spiral-grooved, thrust
bearings that are the "pump-in", "pump-out" and "herringbone" designs.
These are shown respectively in Figs. 7(b) to (d). From the steady-state
bearing performance, the pressure generated by the "pump-in" design is
30 found to provide much higher load carrying capacity than the other two

designs, and thus it is been utilized for the proposed structure (refer to Technical guides published by RPI-MTI entitled "Gas Bearing Design" for further information on these designs). Thus, the "pump-in" spiral-grooved thrust bearing is preferred for the proposed structure (as shown in Fig. 7(a)).

5 The spiral-grooved thrust bearing 207 consist of a series of uniformly spaced shallow grooves which extends radially inwards and leaving a radial border encircling a centre opening of the bearing. The depth of each groove is up to several times the bearing clearance. The sides of the grooves are spiral lines. During the relative sliding motion between the spiral grooved surface and the

10 flat surface, in a direction inclined to the grooves, air flow along the grooves is induced because the hydraulic resistance along the grooves is smaller than that across the grooves. Due to the inclination of the grooves, the flow also has a component normal to the sliding direction. In this manner, the shallow inclined grooves function as a viscous pump. Capillary blockage of the

15 induced flow causes the pressure in the gap to rise above ambient pressure and thereby enables the bearing to carry load. The pressure gradient in the gap of this type of bearing is primarily in the direction normal to that of sliding.

It is important to ensure the reliability and stability during the rotation of the

20 motor in even reverse orientation. Thus, additional spiral grooves may be formed on either one of the top surface of rotor assembly 210 (in the area marked 214) of FIG. 2, or the underside of the step of T-shaped shaft 202 (in the area marked 215) to attain an effective air bearing on both planar surfaces of rotor assembly 210.

25 This possibility motivates the suggestion of an additional embodiment shown in FIG. 8, where identical reference numerals are used to indicate elements corresponding to the embodiment of FIG. 2. In contrast the embodiment of FIG. 2 the embodiment of FIG. 8 includes an added thin Si plate 1001

30 attached on the top surface of the rotor assembly 210, and the diameter of the

step of the shaft 202 is preferably enlarged. Grooves can be provided on either of the upper surface 214 of the plate 1001, or the lower surface 215 of the shaft 202. As the load capacity is strongly dependent on the area of the grooves, the air pressure can be greatly increased.

5

We now return to an explanation of the fabrication of the embodiment of FIG. 2 (which applies equally to the fabrication of the embodiment of FIG. 8).

Attached to the shaft base 203 is a thin electrical circuitry segment 204. The shaft base 203 and segment 204 form the stator assembly in the motor body.

10 The segment 204 has a thickness slightly less than that of the shaft base 203, and contains plated copper coil windings, which generate electrical field to induce the electro-magnetic torque needed for the rotation. Such circuitry 204 can be manufactured by plating technology on an Si wafer, or alternatively on a conventional printed circuit board (PCB). Uniform thickness is maintained
15 throughout the coils' area to keep a consistent spacing between the rotor assembly 201 and the PCB during the rotation.

The last item of the embodiment is the pin element 202 including a straight shaft which functions as the spindle axis for the rotation. A T-shaped circular
20 profile (i.e. a profile which is T-shaped in cross-section, though still circular when viewed from an end of the axis of the shaft) can easily be fabricated on a Silicon wafer by the previously mentioned etching process, and multiple units may be fabricated simultaneously. Alternatively, the pin element 202 can be fabricated more conventionally, e.g. from steel rod by a precision
25 machining method. The pin element 202 is made with adequate matching tolerances off the sleeve of the rotor disc 201, in order for the revolution to have low eccentricity. The shafts 202 are also coated with DLC to reduce the probable contact resistance during the spinning.

Advantageously, a low-temperature wafer bonding technique is employed to attach the shaft 202 to the shaft base 203. Preferably at this time the pin element 202 is one of many substantially identical pin elements on a first wafer, and the shaft base 203 is one of many shaft bases on a second wafer.

5 Thus, this bonding is preferably performed concurrently in many respective motor units on wafer level.

First, as shown in FIG. 9 a thin film of few micrometers in thickness of polymer adhesive 801 is spin-coated with appropriate masking on the center surface

10 portion of shaft base 203 (i.e. where the respective pin 202 is to be attached). Then, as shown in FIG. 10 the shaft of the pin element 202 is passed through the shaft aperture 209.

Finally, a further dicing process is carried to detach the assembled motors

15 from the Si wafer set.

One application for the MEMS motor which is an embodiment of the present invention is as a micro-cooler fan to dissipate heat in a portable device. It can be constructed by adhering a 1mm thick etched Si fin-like-disc ("propeller")

20 901 on the top surface of the rotor assembly 210, such that it forms a propeller for air convection. As shown in FIG. 11, the propeller 901 is fitted on the rotor assembly 210 and housed in a volute 903, to give a centrifugal fan assembly. Operation of the motor rotates the propeller 901, which in turn draws in air towards the planar face of propeller 901, and projects the air out

25 along the circumference of propeller 903. The size of propeller 901 is preferably larger area than that of rotor assembly 210 by 50% in order to expand the airflow during the rotation.

The performances of such fan, with outer diameter of 12mm and total

30 thickness of less than 2mm, are summarized in FIG. 12. It was observed that

the performance of air propulsion could be improved by varying the fin design of the propeller. By changing the curvature of the fins' shape (from design 1 to design 2), the flow rate generated rise two-fold, because the resistance along the air stream is reduced. Further enhancement could again be obtained by
5 increasing the number of fins on the propeller (from design 2 to design 3), which increases the flow rate to at least four times above that of first design, and maintaining the power capacity of the intended motor.

Although only a few embodiments of the invention have been described in
10 detail, many variations are possible within the scope of the invention as will be clear to a skilled reader.

Claims

1. An electromagnetic motor comprising:
 - a rotor assembly including a ring-shaped magnet and defining a central aperture;
 - 5 a pin element comprising a shaft extending through the aperture; and
 - a stator supporting the shaft,
 - the rotor assembly including a substantially planar rotor bearing surface spaced from and facing a stator bearing surface of the stator, at least one of the rotor bearing surface and stator bearing surface including a
 - 10 formation which generates an air bearing between the rotor assembly and stator upon rotation of the rotor relative to the stator,
 - the formation extending over at least 50% of the total planar surface area of the rotor assembly in the direction as viewed parallel to the length direction of the shaft.
 - 15
2. An electromagnetic motor according to claim 1 in which the formation extends over at least 75% of the total planar surface area of the rotor assembly in the direction as viewed parallel to the length direction of the shaft.
- 20 3. An electromagnetic motor according to claim 1 in which the formation extends over substantially all the planar surface area of the rotor assembly in the direction as viewed parallel to the length direction of the shaft.
4. An electromagnetic motor comprising:
 - 25 a rotor assembly including a ring-shaped mmagnet and defining a central aperture;
 - a pin element comprising a shaft extending through the aperture; and
 - a stator supporting the shaft,

the rotor assembly including a substantially planar rotor bearing surface spaced from and facing a stator bearing surface of the stator, at least one of the rotor bearing surface and stator bearing surface including a formation which generates an air bearing between the rotor assembly and stator upon rotation of the rotor relative to the stator,

the formation and magnetic material overlapping as viewed in the direction along the shaft.

5. An electromagnetic motor comprising:
- a rotor assembly including a ring-shaped magnet and defining a central aperture;
- a pin element comprising a shaft extending through the aperture; and
- a stator supporting the shaft,
- the rotor assembly including a substantially planar rotor bearing surface spaced from and facing a stator bearing surface of the stator, at least one of the rotor bearing surface and stator bearing surface including a formation which generates an air bearing between the rotor assembly and stator upon rotation of the rotor relative to the stator,
- the magnet being formed from provision of magnetic material within a pocket of the rotor assembly facing away from the stator.

6. An electromagnetic motor according to claim 5 in which the pocket of the rotor assembly is closed by an element of the rotor assembly extending over the pocket.

7. An electromagnetic motor according to any preceding claim in which the formation is grooves provided on the rotor assembly.

8. An electromagnetic motor according to any of claims 1 to 6 in which the formation is grooves provided on the stator.

9. An electromagnetic motor according to claim 7 or claim 8 in which the grooves have a spiral patterned profile.
10. An electromagnetic motor according to claim 9 in which substantially all
5 the grooves spiral inwardly in the same circumferential direction.
11. An electromagnetic motor according to claim 9 in which the spiral patterned profile includes radially inner and radially outer portions, the grooves of the radially inner portion spiralling inwardly in an opposite circumferential direction from the grooves in the radially outer portion.
- 10 12. An electromagnetic motor according to any preceding claim in which the rotor assembly comprises a body of silicon.
13. An electromagnetic motor according to any preceding claim in which the pin element comprises a body of silicon.
14. An electromagnetic motor according to any preceding claim in which
15 the stator comprises a body of silicon.
15. An electromagnetic motor according to any preceding claim in which the stator is disk-shaped.
16. An electromagnetic motor according to any preceding claim in which the stator includes a coil winding.
- 20 17. An electromagnetic motor according to any preceding claim in which the stator is affixed to a printed circuitry board.
18. An electromagnetic motor according to any preceding claim in which the coil windings are formed on the stator by an electro-plating process.

19. An electromagnetic motor according to any preceding claim in which the pin element comprises a bearing surface on the other side of the rotor assembly from the stator and facing a surface of the rotor assembly, a formation being provided to generate an air bearing between the surface of
5 the rotor assembly and the bearing surface of the pin element.

20. An electromagnetic motor according to claim 19 in which the grooves are formed on the bearing surface of the pin element and the opposing surface of the rotor assembly is substantially smooth.

21. An electromagnetic motor according to any preceding claim in which at
10 least one protective film selected from the group consisting of Diamond-Like-Carbon (DLC) or Self-Assembled-Monolayer (SAM), such as octadecyl-trichloro-silane (OTS), is provide on contact surfaces of any one or more of the rotor assembly, pin element and stator.

22. A fan motor comprising an electromagnetic motor according to any
15 preceding claim, and a propeller attached to the rotor assembly, the propeller including a formation for generating air flow upon rotation of the rotor assembly.

23. A fan motor according to claim 22 in which the propeller is an etched Si propeller onto the above-mentioned motor.

20 24. A method for forming an electromagnetic motor comprising:
forming a rotor assembly including a ring-shaped magnet and defining a central aperture;
forming a pin element comprising a shaft extending through the aperture; and
25 forming a stator supporting the shaft,
the rotor assembly including a substantially planar rotor bearing surface spaced from and facing a stator bearing surface of the stator, at least

one of the rotor bearing surface and stator bearing surface including a formation which generates an air bearing between the rotor assembly and stator upon rotation of the rotor relative to the stator,

5 the formation extending over at least 50% of the total planar surface area of the rotor assembly in the direction as viewed parallel to the length direction of the shaft.

25. A method according to claim 24 in which the formation extends over at least 75% of the total planar surface area of the rotor assembly in the
10 direction as viewed parallel to the length direction of the shaft.

26. A method according to claim 24 in which the formation extends over substantially all the planar surface area of the rotor assembly in the direction as viewed parallel to the length direction of the shaft.
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27. A method of forming an electromagnetic motor comprising:
forming a rotor assembly including a ring-shaped magnet and defining a central aperture;

forming a pin element comprising a shaft extending through the
20 aperture; and

forming a stator supporting the shaft,
the rotor assembly including a substantially planar rotor bearing surface spaced from and facing a stator bearing surface of the stator, at least one of the rotor bearing surface and stator bearing surface including a
25 formation which generates an air bearing between the rotor assembly and stator upon rotation of the rotor relative to the stator,

the formation and magnetic material overlapping as viewed in the direction along the shaft.

30 28. A method of forming an electromagnetic motor comprising:

forming a rotor assembly including a ring-shaped magnet and defining a central aperture;

forming a pin element comprising a shaft extending through the aperture; and

5 forming a stator supporting the shaft,

the rotor assembly including a substantially planar rotor bearing surface spaced from and facing a stator bearing surface of the stator, at least one of the rotor bearing surface and stator bearing surface including a formation which generates an air bearing between the rotor assembly and
10 stator upon rotation of the rotor relative to the stator,

the magnet being formed from provision of magnetic material within a pocket of the rotor assembly facing away from the stator.

29. A method according to claim 28 in which the pocket of the rotor
15 assembly is closed by an element of the rotor assembly extending over the pocket.

30. A method according to any of claims 24 to 29 in which the formation is grooves provided on the rotor assembly.

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31. A method according to any of claims 24 to 29 in which the formation is grooves provided on the stator.

32. A method according to any of claims 30 or 31 in which the grooves
25 have a spiral patterned profile.

33. A method according to claim 32 in which substantially all the grooves spiral inwardly in the same circumferential direction.

34. A method according to claim 32 in which the spiral patterned profile includes radially inner and radially outer portions, the grooves of the radially

inner portion spiralling inwardly in an opposite circumferential direction from the grooves in the radially outer portion.

35. A method according to any of claims 24 to 34 in which the rotor assembly is formed by etching at least one wafer of silicon.

5 36. A method according to any of claims 24 to 35 in which the pin element is formed by etching a silicon wafer.

37. A method according to any of claims 24 to 36 in which the stator is formed by etching a silicon wafer.

10 38. A method according to any of claim 37 which includes a step of affixing the stator to a printed circuitry board.

39. A method according to any of claim 37 which includes a step of forming the coil windings by an electro-plating process.

15 40. A method according to any of claim 24 to 39 in which the pin element comprises a bearing surface on the other side of the rotor assembly from the stator and facing a surface of the rotor assembly, the method including providing a formation to generate an air bearing between the surface of the rotor assembly and the bearing surface of the pin element.

20 41. A method according to claim 40 which includes a step of forming grooves on the bearing surface of the pin element, the opposing surface of the rotor assembly being substantially smooth.

25 42. A method according to any of claims 24 to 41 which includes a step of forming at least one protective film selected from the group consisting of Diamond-Like-Carbon (DLC) or Self-Assembled-Monolayer (SAM), such as octadecyl-trichloro-silane (OTS), on a contact surface of any one or more of the rotor assembly, pin element and stator.