

AN ELECTROMAGNETIC MOTOR

Field

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The present invention relates to an electromagnetic motor, particularly though not solely to an axial electromagnetic micromotor.

Background

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As electronic devices become smaller, there is increasing demand for smaller actuators. For example micro machines are increasingly being used in electronic devices, such as micro fans in mobile telephones, or micro pumps in medical applications. Typically such micro-motors include a stator having windings, a rotor with magnets and a shaft / bearing arrangement to couple the rotor to the stator.

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In some portable applications a motor may be subjected to vibration, shock loads and different orientations. Consequently it may be desirable that the bearing prevents the rotor from impacting the stator, which would otherwise reduce the life of the motor and cause undesirable speed variations.

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Summary

In general terms in a first aspect the invention proposes a Tetrahedral Amorphous Carbon (TAC) layer as an axial and/or thrust bearing. This may have the advantage of reduced coefficient of friction, increased surface hardness and/or increased wear resistance.

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In a specific expression of the invention there is provided an electromagnetic motor comprising

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a stator,

a rotor configured to rotate about the stator, and

a Tetrahedral Amorphous Carbon (TAC) layer on a least one bearing surface between the stator and the rotor.

The rotor may comprise a bushing, the stator comprises a shaft and the motor may be an axial type micromotor with the bushing configured to rotate about the shaft.

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The TAC layer may be provided on a contact surface of the bushing.

The bushing may comprise a polymer.

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The TAC layer may be provided on a contact surface of the shaft.

The shaft may comprise a metal or metallic alloy.

The motor may further comprise a conductive layer under the TAC layer.

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The conductive layer may be elemental titanium.

Brief description of the drawings

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In order that the present invention may be more readily understood and put into practical effect, there shall now be described, by way of non-limitative example only, one or more embodiments of the inventions, with reference to and as illustrated by the accompanying drawings, in which:

Figure 1 is a perspective view of a motor according to an exemplary embodiment,

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Figure 2 is a flow diagram of a method of manufacturing a bearing according to an exemplary embodiment, and

Figure 3 is a perspective view of apparatus for depositing the thin film bearing layer on the bushing in Figure 1.

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Detailed description

An axial type electromagnetic micro motor 100 is shown in Figure 1 according to an exemplary embodiment, having a rotor 102 and a stator 104. The stator includes a plurality of windings or coils 106 and the rotor includes a plurality of

magnets or poles 108. When current is flowing through the windings 106 in a specific sequence, a rotating magnetic field is induced in the air-gap 110 between the rotor 102 and the stator 104. The magnets 108 rotate in synchronism with the rotating magnetic field. Thus the speed of rotation can be controlled by the frequency of the current in the windings 106.

The stator 104 includes a base 112 and a shaft 114 extending axially from the base. The shaft 114 is generally perpendicular to the base 112. The windings 106 are located on or in the base 112. The rotor 102 includes a thin flat disk 116 and a central, cylindrical bushing 118 extending axially from the disk 116. The bushing 118 is generally perpendicular to the disk 116, and is parallel to the shaft 114 and co-axial with the shaft 114. In use, with the rotor 102 in place on the stator 104, the bushing 118 has a tight axial clearance on the shaft 114 and a tight thrust clearance on the base 112 to allow smooth rotation, but where, undesirable vibration of the rotor 102 may be minimised. The bushing 118 has a curved bottom edge 124 which contacts the base 112. The curved profile minimises the area of surface contact, and hence, reduces the frictional resistance. In most applications, the motor 100 will be oriented with the shaft 114 generally vertically upwardly directed.

A thin layer of conformal coating may be provided on the bearing surfaces between the rotor 102 and the stator 104, as a protective and/or lubrication layer. For example, a Diamond Like Carbon (DLC) layer may be provided on the bearing surfaces, for example the inner surface 122 of the bushing 118, the end 124 of the bushing, the curved outer surface 126 of the shaft 114, and/or the contact portion 128 of base 112 around the shaft 114. The DLC layer may protect the components from damage and reduce friction.

For example, the base 112 and shaft 114 may be made from a hard metallic material, such as steel, for providing a rigid axis of rotation. The base 112 and shaft may have a TAC layer 130 to protect against abrasive wear.

The bushing 118 may be made from a polymer, such as poly-carbonate (PC). A thin film bearing layer 120 may be deposited on the axial 122 and thrust 124

bearing surfaces of the bushing 118. The thin film bearing layer 120 may be a multi layer coating, for example with an inner conductive layer such as titanium or gold of about 0.1 μ m thickness, and an outer DLC layer, such as Tetrahedral Amorphous Carbon (TAC) of 1-3 μ m thickness.

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We have experimentally observed that a motor similar to the example embodiment described above, survived at least 10⁹ cycles of radial abrasion. The following improvements were also recorded:

10 Table 1:

Property	Non-Coated	TAC coated
Hardness	0.36 GPa	4.5 ~ 6.3 GPa
Elastic Modulus	4.8 GPa	24.8 ~ 25.6 GPa
Coefficient of Friction (Initial)	0.27	0.15
Critical Scratch Load	17 g	25 g
Water Contact Angle	79°	80°

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The bearing 120 on the rotor 102 or the bearing 130 on the stator 104 may be manufactured according to the method 200 shown in Figure 2. Manufacturing may be done in a batch process where multiple motors are formed simultaneously. At 202 the disk 116 and the bushing 118 are cleaned. At 204 the disk 116 is masked. At 206 a titanium layer is deposited on the bushing 118. At 208 a Tetrahedral Amorphous Carbon (TAC) layer is deposited on the titanium layer. Then the other rotor and stator components may be assembled and coupled together. The same or similar equipment may be used in a similar fashion to deposit the bearing 130 on the stator 104. For example the deposition equipment may be a Large Batch Coating System as marketed by Nanofilm Technologies International Pte. Ltd. of Singapore; modified according to the exemplary embodiment.

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Cleaning 202 the disk and the bushing may include rinsing the disk 116 and the bushing 118 in acetone, then rinsing in a distilled water bath, followed by blow drying using Nitrogen gas. This cleaning process may remove most surface contaminants, for promoting good adhesion of thin film on the axial 122 and thrust
5 124 contact surfaces of the bushing 118.

Masking 204 the disk may include securing the disk 116 and the bushing 118 onto a holder 300 as shown in Figure 3. The holder 300 is mounted on a movable platform 302, which can be rotated so that the bushing 118 faces the plasma
10 emission. The holder 300 is made of two opposed metallic plates, such as, aluminium or steel, which are bolted together sandwiching the disk 116. The bushing 118 is exposed through an aperture 303 at the centre of the plates. The plates may function as a heat shield during the deposition to mask the disk 116 from thermal heat from the plasma, and to limit the deposition of the thin film
15 bearing layer to the bushing 118.

Depositing 206 the titanium layer may include directing titanium plasma towards the holder 300 using Filtered-Cathodic-Vacuum-Arc (FCVA) deposition. The thickness of the titanium layer can be selected by duration of exposure to the
20 plasma.

Depositing 208 the Tetrahedral Amorphous Carbon (TAC) layer may include applying a negative electrostatic potential to the holder 300. The titanium layer then becomes negatively charged which attracts the positively charged DLC
25 plasma 304. Carbon ions are pulled towards the polymer surface at high approaching energy due to the negative voltage bias, and they penetrate into the soft polymer surface upon impact. Strong binding of DLC ions and polymer surface occurs so that the subsequent discharged densely packed DLC ions form a hard smooth surface.

30 In order to deposit a uniform layer of TAC on the inner axial bearing surface 122, it may be necessary to provide plasma from two or more directions. This may be achieved with plasma sources from more than one direction and/or relative movement of the bushing and the plasma source during deposition.

As seen in Figure 3, two FCVA plasma sources 306,308 are positioned towards a first open end 310 of the bushing at different tilted angles. The bushing has a longitudinal axis 312 about which the plasma sources are opposite spaced. Each plasma source is tilted towards the bushing at an acute angle to the longitudinal axis 312. The discharging plasma 304 from the plasma sources 306, 308 covers the upper and lower portions of the axial bearing surface 122 concurrently and thus may achieve a uniform thickness film.

The platform may be rotated (for example using a position controllable electric motor) so that the discharging plasma 304 from the plasma sources 306, 308 can be directed to a second opposite end of the bushing, which may further improve the uniformity of the film. That is the platform has a first position with the plasma 304 directed through the first end 310 and a second position with the plasma 304 directed through the second end.

The TAC film thickness may be selected by the duration of exposure to the plasma. The thickness of the TAC film may be chosen according to the application and/or the required wear resistance performance.

In batch processing, the stator base 300 of a large number of motors may be a silicon substrate. In this case, the substrate may be diced to singulate each separate motor.

One application for an embodiment of the present invention is as a MEMS micro-cooler fan to dissipate heat in a portable device. For example an etched silicon fin-like-disc ("propeller") may be attached by adhesive to the top surface of the rotor, such that it forms a propeller for air convection. Alternatively the fins could be moulded directly into the upper surface of the disk 116. The propeller and rotor may rotate within a housing, which in turn draws in air towards the propeller, and projects the air out. For example, a 6 coil 8 pole configuration might be controlled to rotate at between 5000-8000RPM. The fan and the motor together might be 2mm thick and 12mm in diameter.

Notable features of the exemplary embodiment may include:

the TAC layer may be 1-3 μ m thick;

the TAC layer may have a surface hardness of at least 4.5GPa;

the TAC layer may have an elastic modulus of at least 24.8GPa;

5 the TAC layer may have a critical scratch load of at least 25g;

the bearing may be manufactured by a method comprising:

providing a bearing surface on a rotor or a stator, and

directing a source of Diamond Like Carbon (DLC) plasma at the bearing surface from two or more directions;

10 directing a source of DLC plasma may comprise directing two sources of DLC plasma at the bearing surface, wherein the bearing surface has a longitudinal axis, and the sources are spaced on opposite sides of the longitudinal axis and oriented at an acute angle to the longitudinal axis towards the bearing surface;

the method may further comprise rotating the bearing surface relative to the source of DLC plasma;

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the method may further comprise cleaning the bearing surface before directing the source of DLC plasma at the bushing;

the method may further comprise directing a source of titanium plasma at the bearing surface after cleaning the bearing surface and before directing the source

20 of DLC plasma at the bearing surface;

directing the source of DLC plasma at the bearing surface comprises applying a negative voltage to the bearing surface;

the method may further comprise heat shielding and/or masking a non bearing surface and exposing the bearing surface before directing the source of DLC

25 plasma at the bearing surface;

the DLC plasma may be Tetrahedral Amorphous Carbon (TAC) plasma;

the source of DLC plasma may be Filtered Cathodic Vacuum Arc (FCVA);

the bearing surface may be a polymer;

the bearing surface may be a bushing on the rotor;

30 the bushing may be oriented at a first position wherein the DLC plasma is directed through an opening at a first end of the bushing and subsequently oriented at a second position wherein the DLC plasma is directed through an opening at a second opposed end of the bushing;

the bearing surface may be a metal;

the bearing surface may be a shaft on the stator;

the motor may be an axial type micromotor; and/or

a plurality of motors may be manufactured together in batches, with a stator of each motor being part of a substrate, and further comprising singulating the

5 substrate to separate each motor.

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

LIST OF REFERENCES

	100	motor
5	102	rotor
	104	stator
	106	windings
	108	poles
	110	air gap
10	112	base
	114	shaft
	116	disk
	118	bushing
	120	bearing layer
15	122	axial bearing surface of 118
	124	thrust bearing surface of 118
	126	curved outer surface of 114
	128	contact portion of 112
	200	method of manufacturing
20	202	cleaning
	204	masking
	206	deposit Ti
	208	deposit TAC
	300	holder
25	302	platform
	304	plasma
	306	upper plasma source
	308	lower plasma source
	310	aperture
30	312	longitudinal axis

Claims:

- 5 1. An electromagnetic motor comprising
 a stator,
 a rotor configured to rotate about the stator, and
 a Tetrahedral Amorphous Carbon (TAC) layer on a least one bearing
surface between the stator and the rotor,
10 wherein the rotor comprises
 a bushing, the stator comprises a shaft and the motor is an axial type
micromotor with the bushing configured to rotate about the shaft.
2. The motor as claimed in claim 1 wherein the TAC layer is provided on a
15 contact surface of the bushing.
3. The motor as claimed in claim 2 wherein the bushing comprises a polymer.
4. The motor as claimed in any one of claims 1 to 3 wherein the TAC layer is
20 provided on a contact surface of the shaft.
5. The motor as claimed in claim 4 wherein the shaft comprises a metal or
metallic alloy.
- 25 6. The motor as claimed in any one of the preceding claims further comprising
a conductive layer under the TAC layer.
7. The motor as claimed in claim 4 wherein the conductive layer is elemental
titanium.