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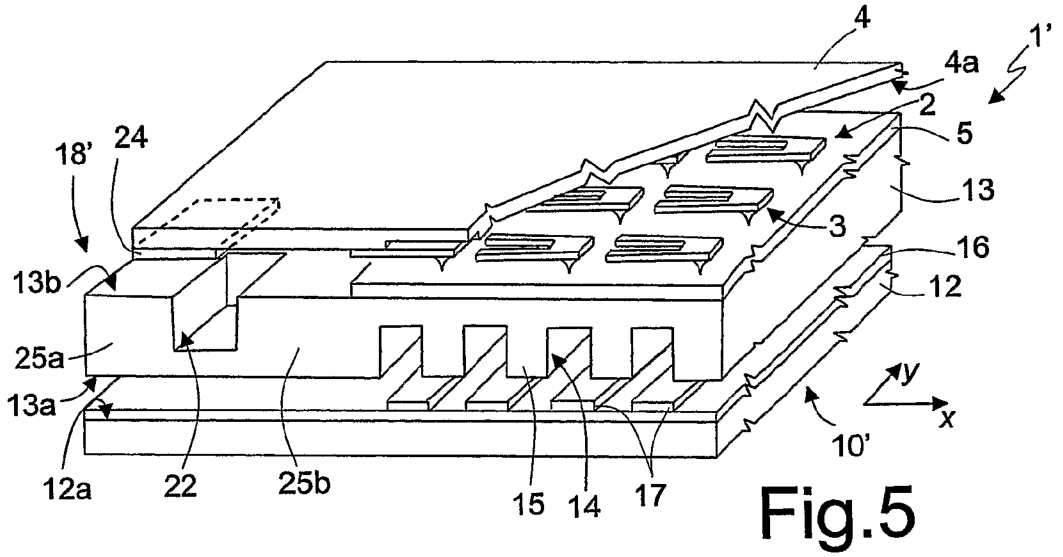

Fig.5

(57) Abstract: An electrostatic micromotor (10') is provided with a fixed substrate (12), a mobile substrate (13) facing the fixed substrate (12), and electrostatic-interaction elements (14, 15, 17) enabling a relative movement of the mobile substrate (3) with respect to the fixed substrate (2) in a movement direction (x); the electrostatic micromotor is also provided with a capacitive position-sensing structure (18') configured to enable sensing of a relative position of the mobile substrate (13) with respect to the fixed substrate (12) in the movement direction (x). The capacitive position-sensing structure (18') is formed by at least one sensing indentation (22), extending within the mobile substrate (13) from a first surface (13a; 13b) thereof, and by at least one first sensing electrode (24), facing, in at least one given operating condition, the sensing indentation (22).

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CAPACITIVE POSITION SENSING IN AN ELECTROSTATIC MICROMOTOR

TECHNICAL FIELD

The present invention relates to capacitive position sensing in an electrostatic micromotor, in particular for atomic-level storage systems (generally known as "probe storage" systems), to which the ensuing treatment will make reference without this implying any loss in generality.

BACKGROUND ART

As is known, storage systems exploiting a technology based on magnetism, such as, for example, hard disks, suffer from important limitations as regards the increase in the data-storage capacity and the read/write rate, and the reduction in their dimensions. In particular, there is a physical limit, the so-called "superparamagnetic limit", which constitutes an obstacle to the reduction in the dimensions of the magnetic-storage domains below a critical threshold, if the risk of losing the information stored is to be avoided.

Consequently, in the last few years, alternative storage systems have been proposed, amongst which the so-called "probe storage" systems have assumed particular importance. These systems enable high data-storage capacities to be achieved with reduced dimensions and with low manufacturing costs.

As illustrated in Figure 1, a storage device 1 of the probe-storage type comprises an array 2 of transducers (or probes) 3, arranged in rows and columns and fixed to an active substrate 4, made for example of silicon in CMOS technology (conveniently used also for providing a control electronics for the storage device). The array of transducers is arranged above a storage medium 5 (for example, made of polymeric material, ferroelectric material, phase-change material, etc.), and is relatively mobile with respect thereto. Each transducer 3 comprises a supporting element 6 made of semiconductor material, suspended in cantilever fashion above the storage medium 5, and an interaction element 7 (or tip), facing the storage medium 5, and carried by the supporting element 6 at a free end thereof. The interaction element 7 is able to interact locally with a portion of the storage medium 5, for writing, reading, or erasing individual information bits.

The relative movement between the storage medium 5 and the array of transducers is generated by a micromotor 10 coupled to the storage medium 5. The micromotor 10 is of a linear electrostatic type, made with semiconductor technologies, and bases its operation on capacitive variations.

In detail, the electrostatic micromotor 10 comprises a stator substrate 12, and a rotor substrate 13 arranged in use above the stator substrate 12 (the term "rotor" is used herein, as usually occurs in this technical field, to indicate a mobile element without necessarily referring to a rotary movement). Typically, both the rotor substrate 13 and the stator substrate 12 are made of semiconductor material, for example, silicon.

The rotor substrate 13 is suspended above the stator substrate 12 by means of elastic elements (not illustrated herein), and has, at a facing surface 13a facing the stator substrate 12, a plurality of rotor indentations 14; the rotor indentations 14 are obtained, for example, by anisotropic chemical etching and extend towards the inside of the rotor substrate 13. The rotor indentations 14 are set at a regular distance apart from one another by a first pitch P_1 in a sliding direction x. The rotor indentations 14 define between them rotor projections 15, extending towards the stator substrate 12.

The stator substrate 12 has, on a respective facing surface 12a facing the rotor substrate 13, an insulation layer 16, made, for example, of silicon oxide, on top of which a plurality of stator electrodes 17 is provided. The stator electrodes 17 are arranged at a regular distance apart from one another by a second pitch P_2 in the sliding direction x. The second pitch P_2 is different from, for example smaller than, the first pitch P_1, and the stator electrodes 17 are staggered with respect to the rotor projections 15 in the sliding direction x.

Each pair constituted by a rotor projection 15 and by the underlying stator electrode 17 forms a plane parallel plate capacitor with misaligned plates. When a voltage is applied between the misaligned plates, a force is generated, which tends to bring them back into an aligned position. Consequently, by appropriately biasing the stator electrodes 17 (with the rotor substrate 13 set generally at a reference potential) with biasing voltages conveniently out-of-phase with respect to one another, it is possible to generate an electrostatic interaction force, which brings about a relative linear movement of the rotor substrate 13 with respect to the stator substrate 12 in the sliding direction x. In particular, due to the presence of the rotor indentations 14, the capacitance C of the aforesaid capacitor is variable with the relative displacement between the stator substrate and the rotor substrate, and in particular is maximum when the stator electrode 17 is aligned to a rotor projection 15, and minimum when the stator electrode 17 is aligned to a rotor indentation 14. The electrostatic interaction force, which causes the relative movement of the rotor substrate 13 with respect to the stator substrate 12, is proportional to the resultant capacitive variation in the sliding direction x (in particular to the derivative of this variation).

The storage medium 5 is set on an external surface 13b of the rotor substrate 13, opposite to the facing surface 13a facing the stator substrate 12. In this way, actuation of the electrostatic micromotor 10 causes a corresponding movement of the storage medium 5 in the sliding direction x, and a relative displacement thereof with respect to the transducers 3. In particular, by appropriately driving the electrostatic micromotor 10, it is possible to control positioning of the transducers 3 at desired points of the storage medium 5, where it is desired to carry out the operations of reading, writing, or erasure of the stored data.

As is shown schematically in Figure 2, a control servomechanism is generally associated to the electrostatic micromotor 10; the control servomechanism comprises a position-sensing structure 18 designed to detect the relative position of the rotor substrate 13 with respect to the stator substrate 12, and a control unit 19, designed to carry out a feedback control of the actuation of the electrostatic micromotor 10 (and of the consequent positioning of the transducers 3), on the basis of the aforesaid detection of position. An electronic circuitry 20 is moreover connected to the array 2 for addressing the various transducers 3 (for example, via row and column multiplexers), and hence carrying out appropriate operations on the data stored in the storage medium 5.

In detail, and as shown in Figure 3, the position-sensing structure 18, of a capacitive type, comprises: a first electrode 21a and a second electrode 21b, which are arranged above the insulation layer 16, laterally with respect to the stator electrodes 17 in the sliding direction x, for example in an area corresponding to an end portion of the stator substrate 12, and are biased at different voltages; and a third electrode 21c, set on the facing surface 13a of the rotor substrate 13 facing the stator substrate 12, which is set, in a rest position, between the first electrode 21a and the second electrode 21b. The first and second electrodes 21a, 21b form, with the third electrode 21c, a first sensing capacitor C_1 and a second sensing capacitor C_2, respectively. The area of mutual facing between the first and second electrodes 21a, 21b and the third electrode 21c varies as a function of the position of the rotor substrate 13 with respect to the stator substrate 12, during its displacement in the sliding direction x. From a differential reading of the capacitance value of the first and second sensing capacitors C_1 and C_2, it is possible to determine the direction and amount of the aforesaid displacement, and so the relative position of the rotor substrate 13 with respect to the stator substrate 12.

The sensing structure described is not, however, optimized, due to the presence of a parasitic capacitance (as regards the aforesaid detection of position), which is formed between the third electrode 21c and the stator substrate 12. This parasitic capacitance brings about a lower sensitivity of the sensing structure to the variations of position, thus reducing the capacitive variation of the first and second sensing capacitors C_1, C_2 due to the relative displacement of the rotor substrate 13.

DISCLOSURE OF INVENTION

The aim of the present invention is to provide an electrostatic micromotor, and a corresponding electronic device, that will represent an improvement with respect to the known art, and in particular that will enable the aforementioned problems and disadvantages linked to sensing of the relative position between the rotor and stator substrates to be overcome.

According to the present invention, an electrostatic micromotor and an electronic device comprising the electrostatic micromotor are consequently provided, as defined in claims 1 and 11, respectively.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the present invention, preferred embodiments thereof are now described, purely by way of non-limiting example and with reference to the attached drawings, wherein:

- Figure 1 is a schematic perspective cross section of a portion of a storage device of a probe-storage type;
- Figure 2 is an overall block diagram of the storage device;
- Figure 3 shows an enlarged portion of the device of Figure 1, which highlights a position-sensing structure of a known type;
- Figure 4 shows a cross section of a portion of a storage device according to a first embodiment of the present invention;
- Figure 5 is a perspective cross section of the device of Figure 4;
- Figure 6 is a perspective cross section of a storage device in accordance with a second embodiment of the present invention;
- Figure 7 is a top plan view of a variant of the device of Figure 6;
- Figure 8 is a circuit block diagram of a position-sensing circuit of the storage device;
- Figure 9 shows a cross section of a storage device in a third embodiment of the present invention;
- Figure 10 is a graph showing the plot of an electrical quantity associated to the device of Figure 9;
- Figure 11 shows an overall block diagram of a servomechanism of the storage device;
- Figure 12 is a top plan view of a variant of the device of Figure 9; and
- Figure 13 is a perspective cross section of a storage device, according to a fourth embodiment of the present invention.

BEST MODE FOR CARRYING OUT THE INVENTION

Figures 4 and 5 show an electronic device 1′, in particular a probe-storage device comprising an electrostatic micromotor 10′, which differs from the one previously described substantially for a different construction of a corresponding capacitive position-sensing structure (for this reason, parts that are similar will be designated by the same reference numbers and will not be described again).

According to a first embodiment of the invention, a position-sensing structure 18′ comprises: at least one sensing indentation (or slot) 22, dug within the rotor substrate 13 to a given depth, for example, 30 µm, starting from its external surface 13b opposite to the facing surface 13a facing the stator substrate 12, in an area not covered by the storage layer 5; and at least one first sensing electrode 24, carried by the active substrate 4 and facing the external surface 13b, and in particular the sensing indentation 22. The first sensing electrode 24 is set on a facing surface 4a of the active substrate 4 facing the rotor substrate 13, in a distinct area with respect to the one carrying the array 2 of transducers 3, and has a shape that is as a whole elongated in an extension direction y, substantially orthogonal to the sliding direction x. In addition, the first sensing electrode 24 is made in the same metal layer in which the interaction elements 7 of the array of transducers are made. The sensing indentation 22 also has a shape elongated in the extension direction y and dimensions substantially corresponding to those of the first sensing electrode 24, and defines laterally in the rotor substrate 13 a first sensing portion 25a and a second sensing portion 25b. The sensing electrode 24 forms with the first and second sensing portions 25a, 25b (when they are in a position facing one another, on account of the displacement of the rotor substrate 13) a first capacitor C_1 and a second capacitor C_2, respectively, a value of capacitance of which varies as a function of the mutual position of the rotor substrate 13 with respect to the active substrate 4. In use, the rotor substrate 13 is biased at a reference potential (for example, at ground), and the first and second capacitors C_1, C_2 are connected in parallel, to form a resultant sensing capacitor.

The relative displacement of the rotor substrate 13 in the sliding direction x causes a capacitance variation of the resultant sensing capacitor, whence it is possible to determine the amount of the displacement. Advantageously, the presence of the sensing indentation 22, in which air is present, with unitary dielectric constant, reduces the value of the parasitic capacitance "seen" by the first sensing electrode 24 at rest, and consequently increases the amount of capacitive variations arising during displacement of the rotor substrate 13 and consequent alignment of the first sensing electrode 24 with the first or second sensing portion 25a, 25b. Thus, the sensitivity in the detection of position increases in the electrostatic micromotor 10'.

According to a second embodiment of the position-sensing structure 18' (Figure 6), the sensing indentation 22 extends throughout an entire thickness of the rotor substrate 13, separating vertically the first and second sensing portions 25a, 25b. In addition, the etch leading to formation of the sensing indentation 22 is extended also laterally with respect to the sensing portions, which thus assume a conformation projecting in cantilever fashion from the rotor substrate 13 in the extension direction y. In particular, the first and second sensing portions 25a, 25b are connected to the rotor substrate 13 only at one of their face, and are surrounded elsewhere by an empty space. Advantageously, in this case, there is a further reduction in the value of the parasitic capacitance between the first sensing electrode 24 and an underlying structure, when the first sensing electrode is not above the first or second sensing projection 25a, 25b, and consequently there is a further increase in the sensitivity of the capacitive detection of position.

A further variant of the present invention envisages the presence of a second sensing electrode 26, carried by the active substrate 4, and set on its facing surface 4a facing the rotor substrate 13. For example, in the rest condition, the first sensing electrode 24 is set between the first and second sensing portions 25a, 25b, whilst the second sensing electrode 26 is set laterally with respect to one between the first and the second sensing projections 25a, 25b in the sliding direction x (in the case illustrated in Figure 7, laterally with respect to the second sensing portion 25b). In Figure 7 elastic elements 27 may also be noted for suspension of the rotor substrate 13 with respect to the stator substrate 12.

In this variant, the first sensing electrode 24 forms, with the underlying sensing portions, a first sensing capacitor C_A (equivalent to the resultant sensing capacitor previously defined), whilst the second sensing electrode 26 forms, with the same sensing portions, a second sensing capacitor C_B. Advantageously, by appropriately processing the capacitive variations of the first and second sensing capacitors C_A, C_B, and in particular the difference between the respective capacitance values C_A-C_B, it is possible to determine not only the amount of the relative displacement of the rotor substrate 13, but also the direction of the relative displacement in the sliding direction x.

In this regard, Figure 8 shows a possible circuit embodiment of a position-reading circuit 30 in a control unit 19 of the electronic device 1′ (see, by analogy, Figure 2), designed for feedback control of the actuation of the electrostatic micromotor 10′. The position-reading circuit 30 supplies an output signal V_{out} indicating the position of the electrostatic micromotor, the value of which is a function of the difference C_A-C_B of the capacitances of the first and second sensing capacitors C_A, C_B.

In detail, the read circuit 30 comprises a first charge-amplifier stage 31a and a second charge-amplifier stage 31b, connected to the first and second sensing capacitors C_A, C_B, respectively. Each charge-amplifier stage 31a, 31b comprises an operational amplifier 32, receiving a supply voltage, for example, of 3.3 V, and having its inverting-input terminal connected to the respective sensing capacitor, its non-inverting-input terminal receiving an input sinusoidal signal, with an amplitude A_{in} and a first frequency, and its output terminal feedback-connected to the inverting-input terminal via a feedback capacitor 33 having a capacitance C_f.

The read circuit 30 further comprises: a mixer stage 34 having a first, non-inverting, input and a second, inverting, input, which are connected to the outputs of the first and second charge-amplifier stages 31a, 31b, respectively, and a third, mixing, input, receiving a mixing sinusoidal signal, having an amplitude A_{mix} and a second frequency different from the first frequency; and a low-pass filter stage 36, which is connected to the output of the mixer stage 34 and supplies at output the output signal V_{out}, of an analog type, with an amplitude proportional to the expression appearing below

$$V_{out} \propto \frac{1}{2} \cdot A_{in} \cdot A_{mix} \cdot \frac{C_A - C_B}{C_f}$$

and in particular, as is required, proportional to the difference C_A-C_B between the capacitances of the first and second sensing capacitors C_A, C_B.

The output signal V_{out} can then be converted from analog to digital by an analog-to-digital converter stage 38 operating on n bits, and is then supplied, for subsequent processing operations, to the control unit 19.

A third embodiment of the present invention (Figure 9) envisages provision of a plurality of sensing indentations 22 in the rotor substrate 13, and a plurality of first and second sensing electrodes 24, 26 carried by the active substrate 4. This structure, as will be clarified hereinafter, is advantageous for detecting large displacements between the rotor substrate and the stator substrate, partializing the total displacement into a plurality of equal stretches with repetitive pattern.

In detail, the sensing indentations 22 follow one another in the sliding direction x at a regular separation distance d_s, for example, 7 µm. Each indentation has the same width (measured in the sliding direction x), for example, 7 µm, and extends within the rotor substrate 13 for a depth of, for example, 30 µm. In addition, the sensing portions 25a, 25b have a width equal to that of the sensing indentations 22. The first and second sensing electrodes 24, 26 follow one another alternating in the sliding direction x, separated from the external surface 13b of the rotor substrate 13 by a distance of, for example, 1.5 µm. In addition, a gap g, smaller than the separation distance d_s, is provided between each of the first sensing electrodes 24 and one of the second sensing electrodes 26 adjacent thereto. In particular, the width of the sensing electrodes 24, 26 (in the sliding direction x) added to the gap g is equal to the width of the sensing portions 25a, 25b, and the first and second sensing electrodes 24, 26, respectively, are located all in a same relative position with respect to an underlying sensing indentation 25a, 25b. Furthermore, as shown schematically, the first sensing electrodes 24 are connected to one another and to a first terminal A, the second sensing electrodes 26 are connected to one another and to a second terminal B, and the rotor substrate 13 is connected to ground.

As is shown in Figure 10, an arrangement of the above sort for the electrodes and the sensing indentations causes the trend of the difference C_A-C_B between the capacitances of the first and the second sensing capacitors C_A, C_B to assume a periodic pattern constituted by the repetition of a number of equal stretches, as the displacement of the rotor substrate 13, designated by S, varies with respect to a resting position S_0. Advantageously, within each stretch, the values of the difference C_A-C_B are limited, so that it is not necessary to use, in the read circuit 30, an analog-to-digital converter operating on a large number of bits, at the same time ensuring a high resolution in the detection of position.

As is shown in Figure 11, the control servomechanism of the electrostatic micromotor 10′ comprises in this case a further position sensor 39 for a coarse detection of the position of the rotor substrate 13 with respect to the stator substrate 12, and in particular for identification of the stretch in the periodic pattern previously described corresponding to the effective displacement of the rotor substrate 13, in addition to the position-sensing structure 18′, which is designed to carry out a fine determination of the rotor substrate position within the identified stretch. For example, in a way not shown, the position sensor 39 can comprise a further sensing electrode, which is mobile fixedly with respect to the rotor substrate 13, and is coupled to further electrodes, which are fixed with respect to the active substrate 4 and are set at a distance apart from one another in the sliding direction x. The sensing electrode injects a signal towards ground, and the consequent identification of a high level of current at one of the electrodes coupled thereto enables coarse detection of the position of the rotor substrate.

The control unit 19 receives the information of position both from the further position sensor 39 and from the position-sensing structure 18′, so as to perform feedback control of the electrostatic micromotor 10′.

A further variant of the present invention envisages an increase in the linearity of the trend of the capacitive difference C_A-C_B, and consequently in the linearity of the capacitive position sensing.

As illustrated in Figure 10, the trend of the capacitive difference with respect to an ideal trend (represented with a dashed line) has a portion that is rounded off in the neighbourhood of a maximum/minimum thereof, with the consequence of a loss of resolution. This trend is a consequence of the presence of the gap g separating consecutive sensing electrodes, which causes a maximum value of the aforesaid capacitive difference not to vary as long as a further displacement of the rotor substrate 13 remains smaller than this gap.

To solve the above problem and to obtain an evolution of the capacitive difference that is more linear and practically equal to the ideal one, it is proposed (Figure 12) to make the sensing indentations 22 inclined with respect to the sensing electrodes 24, 26. For example, the first and second sensing electrodes 24, 26 extend once again parallel to the extension direction y, whilst the sensing indentations 22 extend at an inclination angle α with respect to this extension direction. In particular, in the example of Figure 12, the inclination angle α is equal to the arcsine of the ratio between the gap g and the length of the sensing indentations 22 (or, equivalently, of the sensing portions 25a, 25b). In this way, a situation does not arise in which the sensing electrodes 24, 26 are arranged entirely above an underlying sensing indentation 22 throughout a range of displacement equal to the gap g, and consequently the aforesaid rounded-off area of the capacitive trend is eliminated.

A fourth embodiment of the present invention (Figure 13) envisages that the first (and possibly the second) sensing electrodes 24 (26) are not carried by the active substrate 4, but by the stator substrate 12, in particular that they are arranged above the insulating layer 16 and the respective facing surface 12a towards the rotor substrate 13, in a position vertically corresponding to the sensing indentations 22 (which, in the case shown in Figure 13, extend once again throughout the thickness of the rotor substrate 13). The sensing capacitors are in this case formed between the sensing electrodes and the facing surface 13a of the sensing portions 25a, 25b. Advantageously, also in this case, the parasitic capacitance seen by the sensing electrodes in the rest condition is reduced, thanks to the presence of the sensing indentation 22 made in the rotor substrate 13.

From what has been described and illustrated above, the advantages of the capacitive position-sensing structure according to the invention are evident.

In particular, the presence of the sensing indentations facing the sensing electrodes enables minimization of the value of the parasitic capacitance, and hence maximization of the capacitive variation that arises between the sensing electrodes and the corresponding first/second sensing portions 25a, 25b due to displacement between the rotor substrate 13 and the stator substrate 12. In this way, it is possible to increase the sensitivity of the servomechanism controlling actuation of the electrostatic micromotor 10′ and increase the precision in the positioning of the transducers 3 for interaction with the storage medium 5.

It is to be noted that the provision of the sensing indentation 22 does not involve additional technologies or

process steps with respect to the ones required for providing the electrostatic micromotor 10', given that micromachining of the rotor substrate 13 is already envisaged, for example, for forming the rotor indentations 14 (instead, micromachining and corresponding process steps are not envisaged for the stator substrate 12).
The capacitive variation C_A-C_B, which is a function of the relative displacement between the rotor substrate 13 and the stator substrate 12, can be detected in a simple and effective way with the read circuit 30, independently of frequency and resistive spreads. In particular, it is advantageous for this purpose to connect the rotor substrate 13 to ground.

The presence of a plurality of sensing indentations 22 and of corresponding first and second sensing electrodes 24, 26 enables an increase in resolution in the case of large relative displacements between the rotor substrate 13 and the stator substrate 12.

In addition, the presence of a non-zero inclination angle α between the direction of main extension of the rotor indentations 22 and that of the sensing electrodes 24, 26 enables an increase in linearity in the detection of position.

From the standpoint of manufacturing flexibility, it is also advantageous to be able to position the first and second sensing electrodes 24, 26 either on the stator substrate 12 of the electrostatic micromotor 10' or on the active substrate 4 of the corresponding electronic device, in any case achieving the aforesaid advantage of reduction in the parasitic capacitance.

Finally, it is clear that modifications and variations can be made to what is described and illustrated herein, without thereby departing from the scope of the present invention, as defined in the annexed claims.

In particular, a different number of indentations and sensing electrodes can be provided, for detecting the relative position of the rotor substrate 13 with respect to the stator substrate 12.

In the fourth embodiment described, envisaging the arrangement of the sensing electrodes above the stator substrate, the sensing indentation 22 could not extend throughout the entire thickness of the rotor substrate 13, starting from the facing surface 13a towards the stator substrate 12 (in a way similar to what is shown in Figures 4 and 5 as regards the first embodiment), but only for a part of this thickness.

In addition, the read circuit 30 could have a different circuit architecture (of a known type), for example of the switched-capacitor type, with the possibility of avoiding the presence of a demodulation stage and of obtaining an optimization of the number of operational amplifiers.

It is evident that other uses can be envisaged for the capacitive position-sensing structure according to the invention, different from the storage device described. For example, the structure described can be implemented in an optical switch device, of a known type, in which the electrostatic micromotor 10′ is used for moving and orienting means for reflection of a light beam.

The active substrate that carries, in certain embodiments, the sensing electrodes, can finally be configured to perform different functions and integrate further circuits.

CLAIMS

1. An electrostatic micromotor (10′) comprising a fixed substrate (12), a mobile substrate (13) facing said fixed substrate (12), electrostatic-interaction elements (14, 15, 17) operable so as to enable a relative movement of said mobile substrate (13) with respect to said fixed substrate (12) in a movement direction (x), and a capacitive position-sensing structure (18′) configured to detect a relative position of said mobile substrate (13) with respect to said fixed substrate (12) in said movement direction (x); characterized in that said capacitive position-sensing structure (18′) comprises at least one sensing indentation (22) extending within said mobile substrate (13) from a first surface (13a; 13b) thereof, and at least one first sensing electrode (24), facing, in at least one given operating condition, said sensing indentation (22).

2. The micromotor according to claim 1, wherein said sensing indentation (22) defines laterally in said mobile substrate (13) a first sensing portion (25a) and a second sensing portion (25b), which are designed to face said first sensing electrode (24) in respective operating conditions so as to form with said first sensing electrode (24) a first sensing capacitor (C_A), a capacitance of which is variable as a function of a relative displacement of said mobile substrate (13) with respect to said fixed substrate (12).

3. The micromotor according to claim 2, wherein said sensing indentation (22) extends throughout a thickness of said mobile substrate (13) reaching a second surface (13b; 13a) of said mobile substrate opposite to said first surface (13a; 13b); and said first and second sensing portions (25a, 25b) are projections extending in cantilever fashion from said mobile substrate (13).

4. The micromotor according to claim 2 or 3, wherein said capacitive position-sensing structure (18') further comprises at least one second sensing electrode (26), facing said first surface (13a; 13b) and set alongside said first electrode (24) in said movement direction (x); said second electrode (26) forming, with said first and second sensing portions (25a, 25b), a second sensing capacitor (C_B), a capacitance of which is variable as a function of the relative displacement of said mobile substrate (13) with respect to said fixed substrate (12).

5. The micromotor according to claim 4, wherein said capacitive position-sensing structure (18') further comprises at least one further first electrode (24), electrically connected to said first sensing electrode, a further second sensing electrode (26), electrically connected to said second sensing electrode, and at least one further sensing indentation (22), said first electrodes alternating with said second electrodes (26) in said movement direction (x) separated from one another by a separation gap (g), and said sensing indentations (22) being set alongside one another in said movement direction.

6. The micromotor according to claim 5, wherein said sensing indentations (22) define between one another, in said mobile substrate (13), sensing portions (25a, 25b) having a first width, and said first and second electrodes (24) have a second width, in said movement direction (x); the sum of said second width and said separation gap (g) being substantially equal to said first width.

7. The micromotor according to claim 5 or 6, wherein said first and second sensing electrodes (24, 26) extend parallel to one another in a first extension direction (y), and said sensing indentations (22) extend parallel to one another in a second extension direction, inclined by a non-zero angle (α)

with respect to said first extension direction (y).

8. The micromotor according to any one of the preceding claims, wherein said sensing indentation (22) contains air, and wherein said mobile substrate (13) and said fixed substrate (12) comprise semiconductor material.

9. The micromotor according to any one of the preceding claims, wherein said electrostatic-interaction elements (14, 15, 17) comprise electrodes (17) arranged on a surface of said fixed substrate (12) facing said mobile substrate (13), and indentations (14), extending within said mobile substrate (13) starting from a respective surface facing said fixed substrate (12) and defining between one another projections (15) staggered with respect to said electrodes (17) in said movement direction (x).

10. The micromotor according to any one of the preceding claims, wherein said fixed substrate (12) has a facing surface (12a) facing said first surface (13a), and said first sensing electrode (24) is set above said facing surface (12a).

11. An electronic device (1′) comprising an electrostatic micromotor (10′) according to any one of the preceding claims.

12. The device according to claim 11 when dependent on any of claims 1-9, further comprising an active substrate (4) set above said mobile substrate (13) and having a respective facing surface (4a) facing said first surface (13b) of said mobile substrate (13); wherein said first sensing electrode (24) is set in contact with said respective facing surface (4a).

13. The device according to claim 12, wherein said electronic device (1′) is a storage device of a probe-storage type, comprising a storage medium (5) coupled to said mobile

substrate (13) so as to move, in use, in said movement direction (x), and an array (2) of transducers (3) arranged above, and for interacting locally with, said storage substrate (5).

14. The device according to claim 13, wherein said transducers (3) are carried by said active substrate (4), and said storage medium (5) is set on said first surface (13b), laterally with respect to said sensing indentation (22).

15. The device according to any one of claims 11-14, further comprising a control unit (19) connected to said capacitive position-sensing structure (18′) for implementing a feedback control of said electrostatic micromotor (1′); said control unit (19) and said capacitive position-sensing structure (18′) implementing a servomechanism of said electronic device (1′).

16. The device according to claim 15 when dependent on claim 4, wherein said control unit (19) comprises a read circuit (30) configured to determine a relative displacement of said mobile substrate (13) with respect to said fixed substrate (12) as a function of the capacitive difference between the capacitances of said first and second sensing capacitors (C_A, C_B).

17. The device according to claim 16, wherein said read circuit (30) comprises: a first charge-integrator stage (31a) and a second charge-integrator stage (31b), connected to said first and second sensing capacitors (C_A, C_B), respectively; a mixer stage (34), connected to the output of said first and second charge-integrator stages (31a, 31b); and a low-pass filtering stage (36), connected to the output of said mixer stage (34) and supplying an output signal (V_{out}), the value of which is a function of said capacitive difference.

18. The device according to claim 16 or 17, wherein said

capacitive difference has a periodic trend comprising the repetition of a plurality of substantially equal stretches; wherein said read circuit (30) is configured to detect said relative position within a given stretch among said stretches, and said control unit (19) further comprises determination means (39) configured to identify said given stretch within said periodic trend.

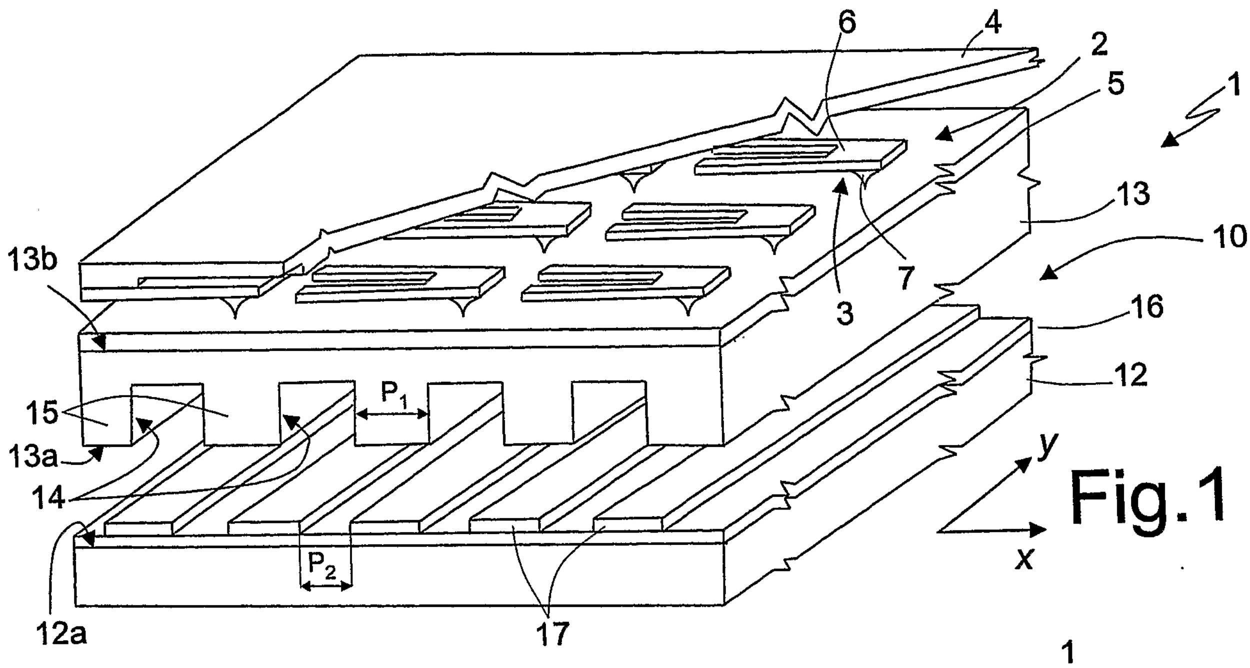

Fig.1

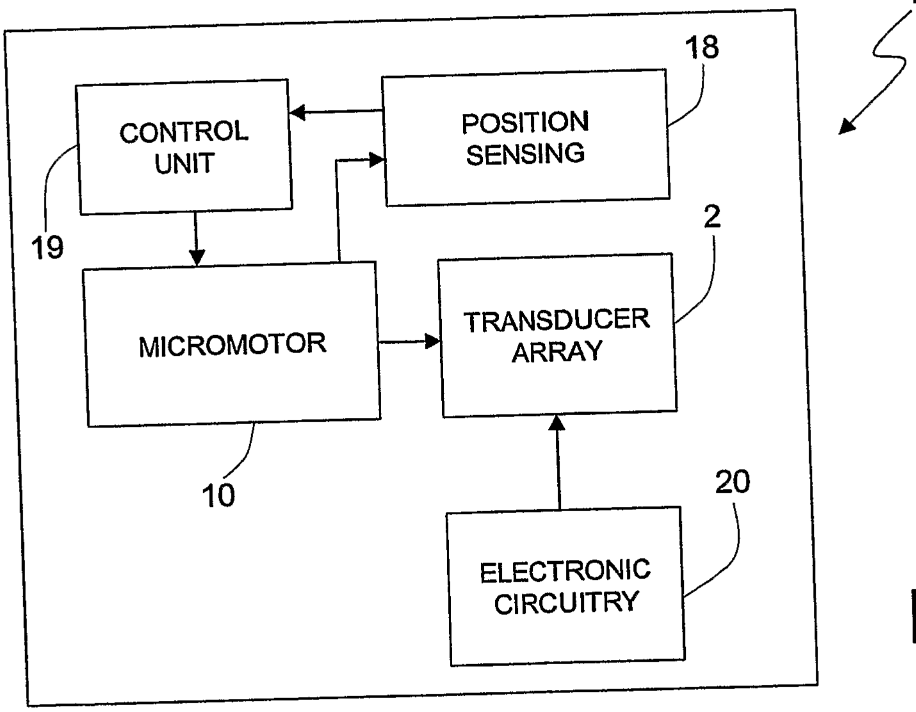

Fig. 2

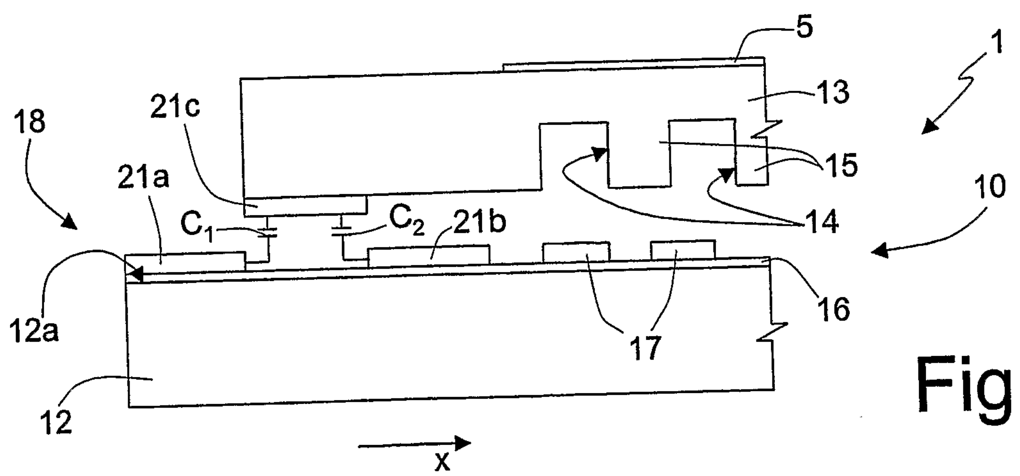

Fig. 3

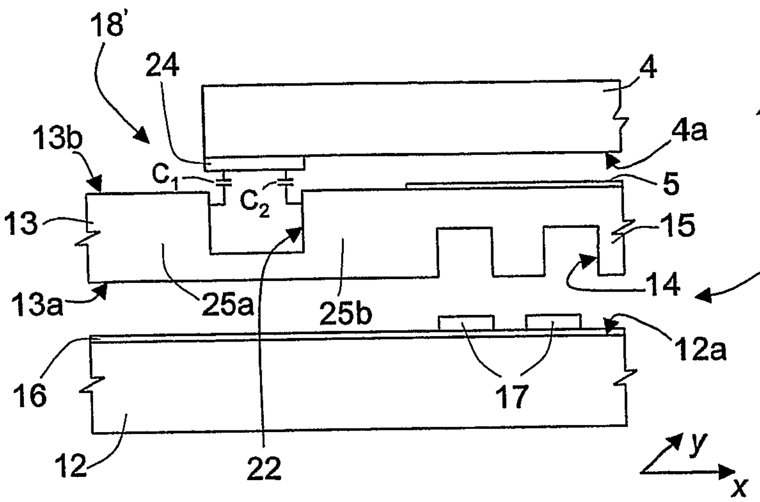

Fig.4

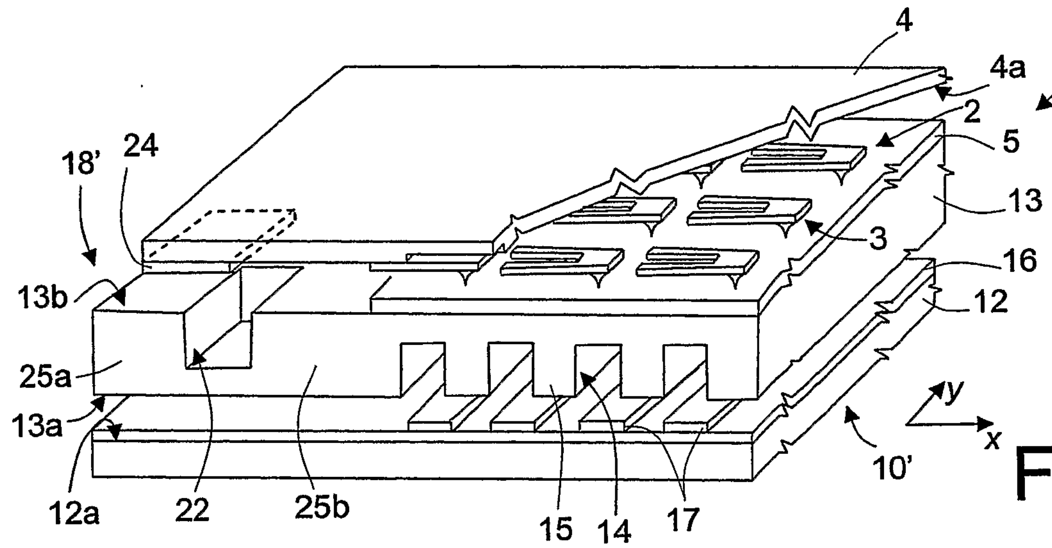

Fig.5

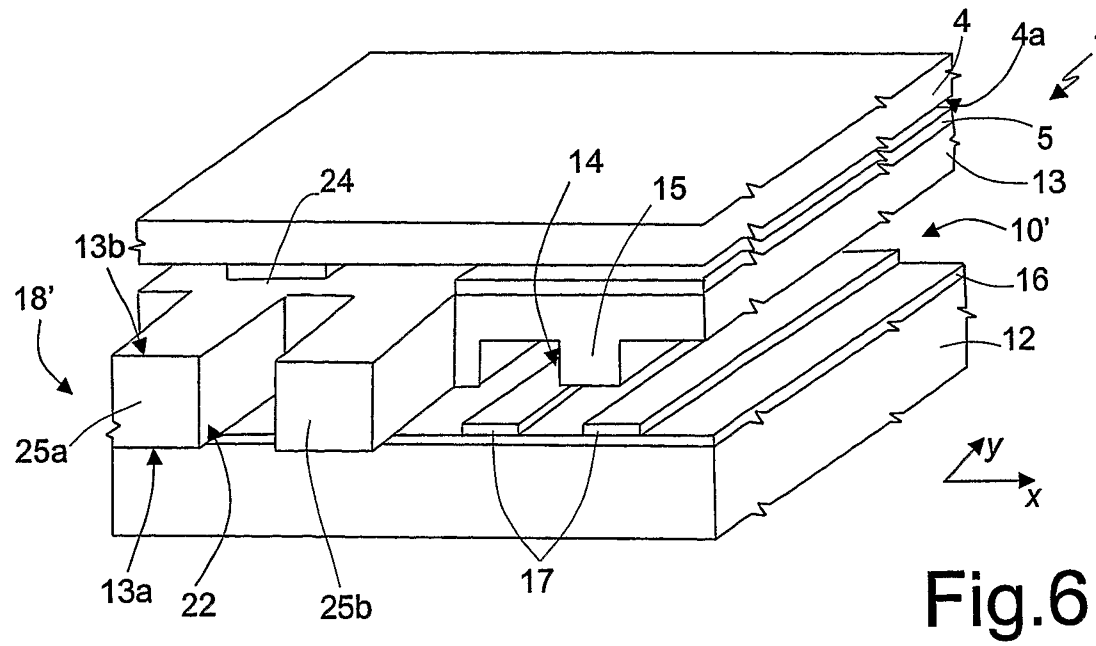

Fig.6

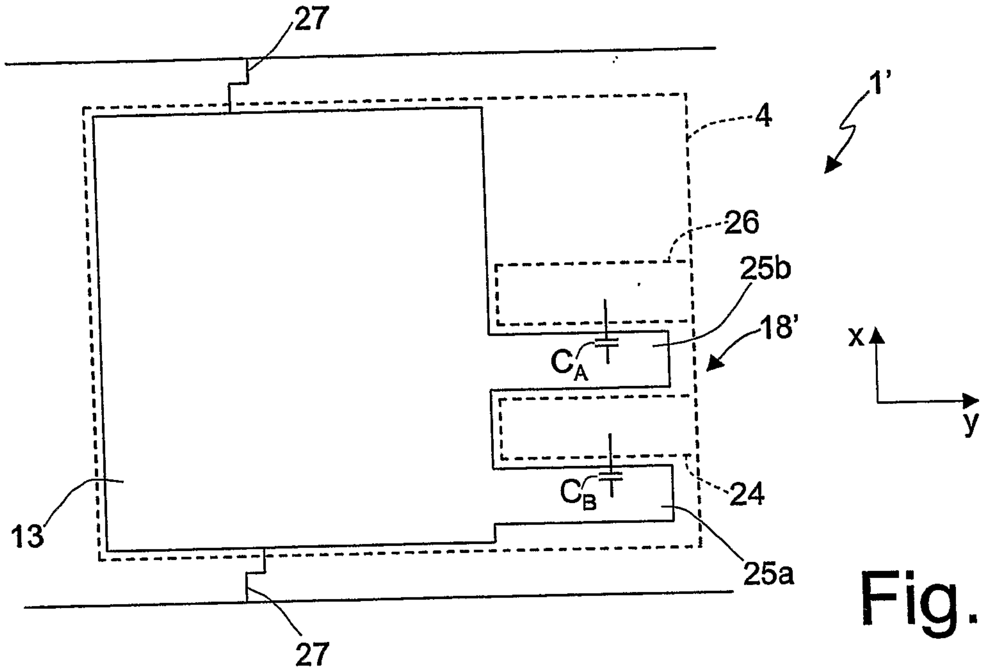
27
1'
4
26
25b
18'
C_A
x
y
C_B
24
13
25a
27

Fig. 7

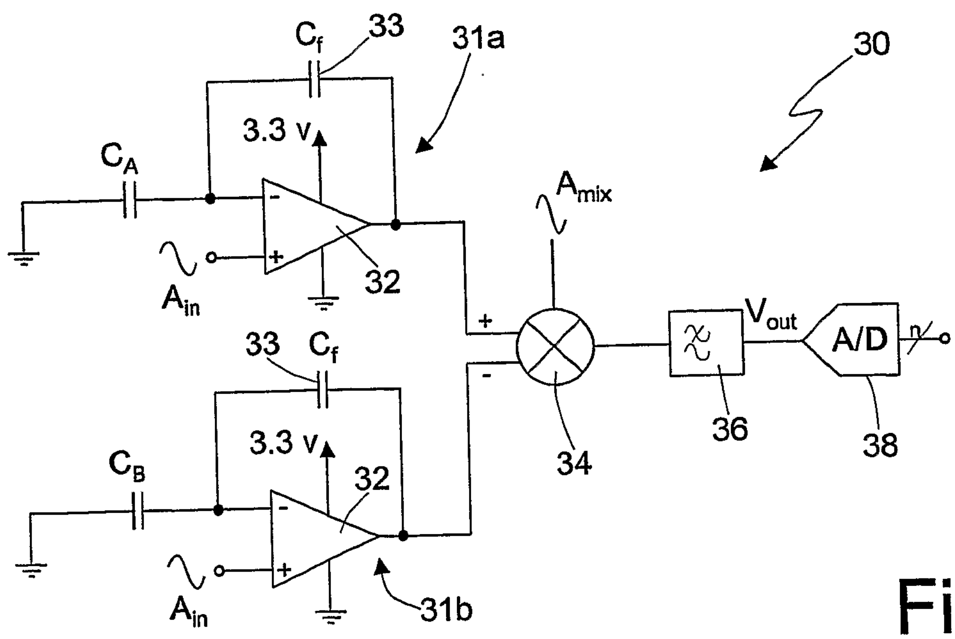
C_f
33
31a
30
3.3 V
C_A
A_{mix}
32
A_{in}
+
33
C_f
V_{out}
A/D
n
-
3.3 V
36
C_B
32
34
38
A_{in}
31b

Fig. 8

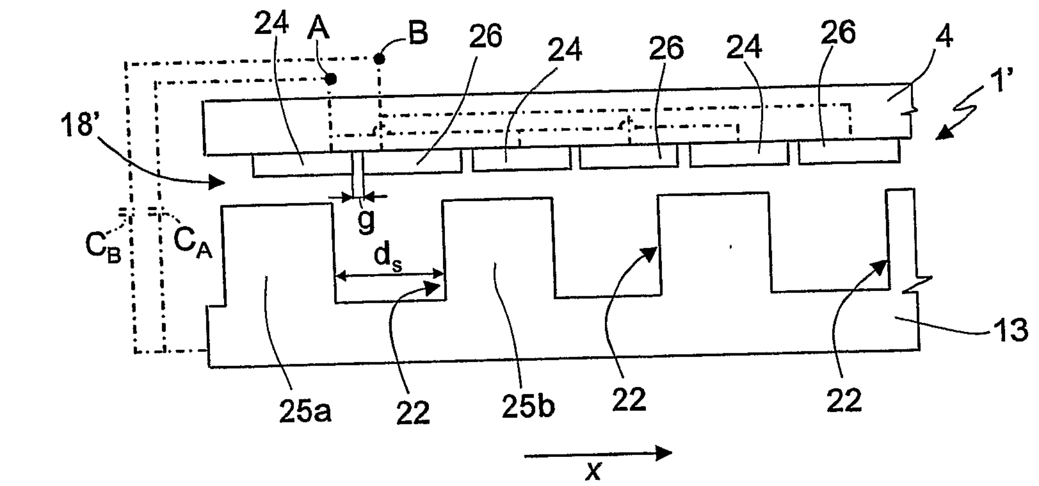

Fig.9

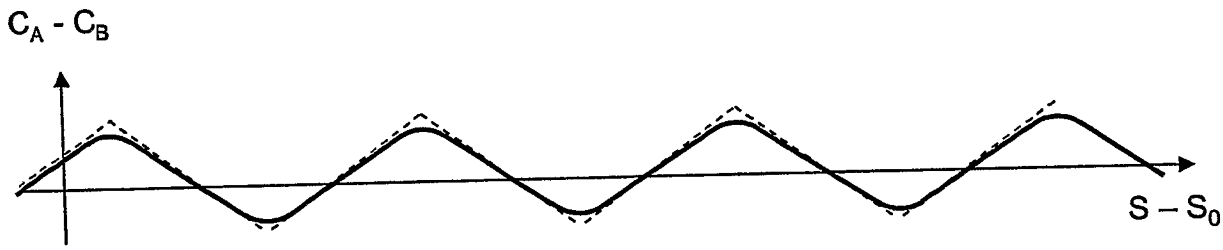

Fig.10

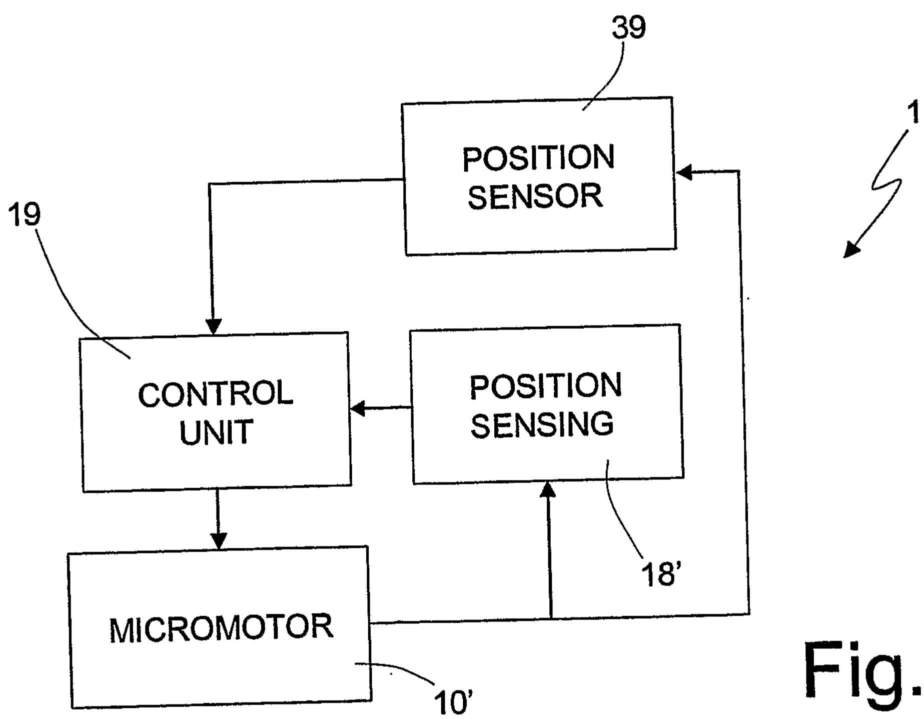

Fig.11

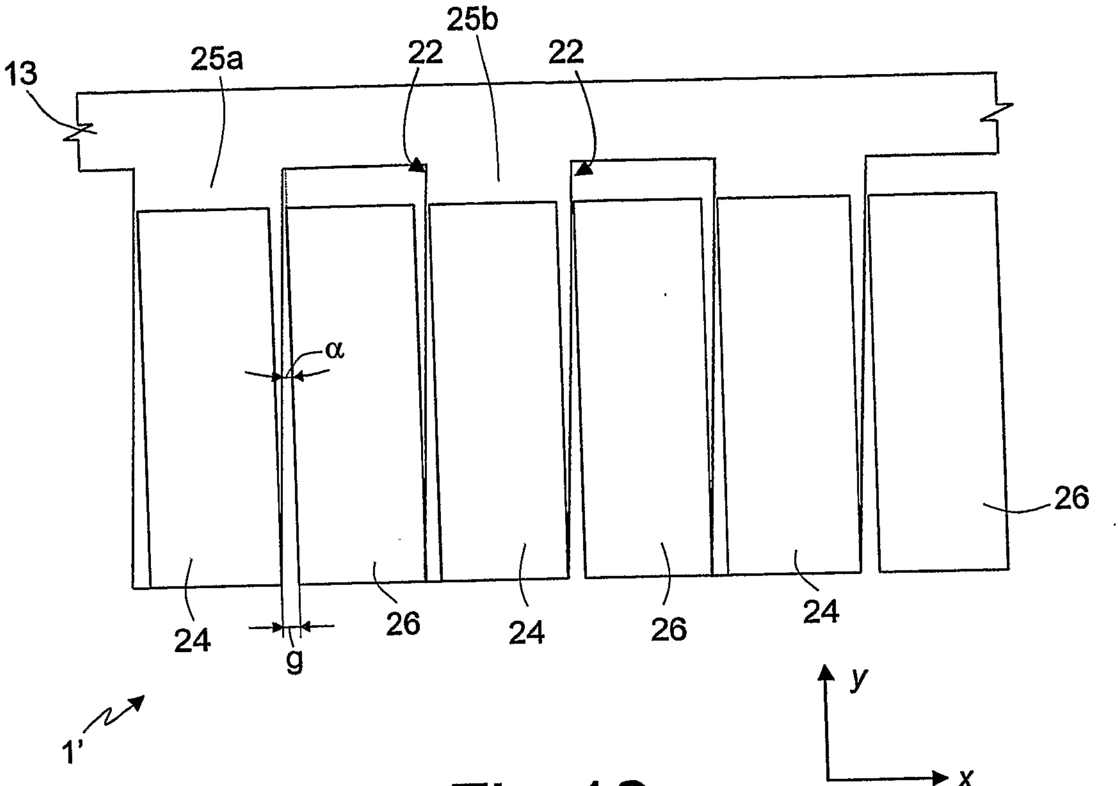
13
25a
25b
22
22
α
26
24
26
24
26
24
g
1'
y
x

Fig.12

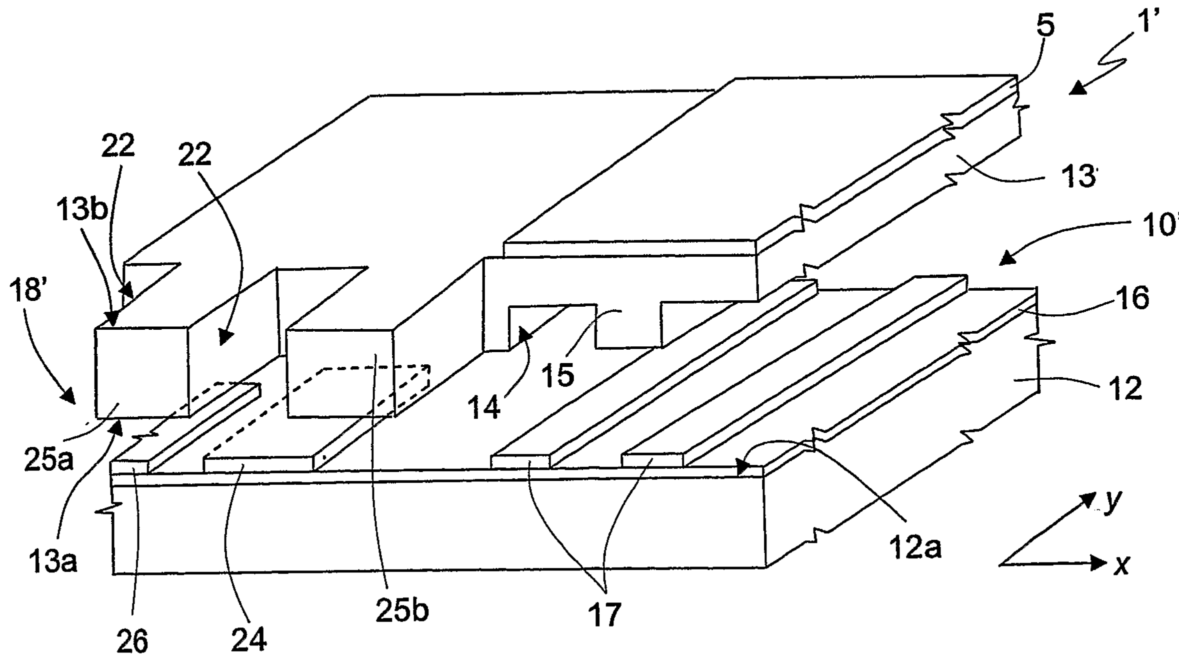
5
1'
13
10'
16
12
22
22
13b
18'
25a
13a
26
24
25b
14
15
17
12a
y
x

Fig.13

INTERNATIONAL SEARCH REPORT

International application No
PCT/IT2007/000252

A. CLASSIFICATION OF SUBJECT MATTER
INV. H02N1/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H02N G11B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2005/062362 A1 (YANG HONGYUAN [US] ET AL) 24 March 2005 (2005-03-24) abstract; figure 1 paragraphs [0007], [0016], [0017]	1-18
A	EP 1 263 123 A (HEWLETT PACKARD CO [US]) 4 December 2002 (2002-12-04) abstract; figures paragraphs [0006], [0021]	1-18
A	WO 97/04449 A (GEN NANO TECHNOLOGY [US]; KLEY VICTOR B [US]) 6 February 1997 (1997-02-06) abstract	1-18

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 December 2007	10/01/2008

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Ramos, Horacio

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IT2007/000252

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