

ONE-PIECE DOUBLE BALANCE SPRING AND
METHOD OF MANUFACTURING THE SAME

FIELD OF THE INVENTION

The invention concerns a double balance spring and the method of manufacturing the same and, more specifically, a double balance spring formed in a single piece.

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BACKGROUND OF THE INVENTION

The regulating member of a timepiece generally includes an inertia wheel, called a balance, and a resonator called a balance spring. These parts have a determining role as regards the working quality of the timepiece. Indeed, they regulate the movement, i.e. they control the frequency of the movement.

In the case of a double balance spring, materials have been tested in order to limit the influence of a temperature change on the regulating member in which it is integrated, without resolving difficulties regarding assembly or resonance adjustment.

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SUMMARY OF THE INVENTION

It is an object of the present invention to overcome all or part of the aforecited drawbacks, by providing a double, one-piece balance spring whose thermo-elastic coefficient can be adjusted and which is obtained using a manufacturing method that minimises assembly difficulties.

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The invention therefore concerns a double balance spring that includes, made in a layer of silicon-based material, a first balance spring coaxially mounted on a collet, the collet including one extending portion that projects from said balance spring and which is made in a second layer of silicon-based material, characterized in that said extending portion extends
5 into a third layer of silicon-based material coaxially with a second balance spring in order to form a one-piece, double balance spring made of silicon-based materials.

According to other advantageous features of the invention:

- 10 - the collet has approximately the same section in each of said layers so as to facilitate adjustment of said double balance spring;
- the collet has an approximately different section over at least one of the layers,
- the balance springs include coils that wind in the same direction or pitch,
- 15 - the ends of the outer curves of each of the balance springs are plumb with each other so that single means can be used for pinning said double balance spring up to the collet,
- the balance springs have the same angular stiffness or pitch,
- at least one of the balance springs has at least one part made of silicon
20 dioxide to make it more mechanically resistant and to adjust its thermo-elastic coefficient,
- the inner coil of at least one of the balance springs has a Grossmann curve so as to improve the concentric development of said coil,
- the collet has a metal part into which an arbour is driven.

25 More generally, the invention relates to a timepiece, characterized in that it includes a double balance spring in accordance with any of the preceding variants.

Finally, the invention relates to a method of manufacturing a double balance spring that includes the following steps:

- a) providing a substrate including a top layer and a bottom layer of silicon-based materials,
- b) selectively etching at least one cavity in the top layer to define the pattern of a first part of a collet, made of silicon-based material, of said double balance spring, 5
- c) joining an additional layer of silicon-based material to the etched top layer of the substrate,
- d) selectively etching at least one cavity in the additional layer to continue the pattern of the collet and to define the pattern of a first balance spring, made of silicon-based material, of said double balance spring, 10

characterized in that it further includes the following steps:

- selectively etching at least one cavity in the bottom layer to continue the pattern of the collet and to define the pattern of a second balance spring, made of silicon-based material, of said double balance spring, 15
- releasing the double balance spring from the substrate.

According to other advantageous features of the invention:

- after step d), it includes step g): oxidising the first balance spring made of silicon-based material so as to make it more mechanically resistant and to adjust its thermo-elastic coefficient, 20
- after step e), it includes step g'): oxidising the second balance spring made of silicon-based material so as to make it more mechanically resistant and to adjust its thermo-elastic coefficient,
- prior to step e), it includes step h): selectively depositing at least one metal layer on the bottom layer to define the pattern of a metal part on the collet, 25
- step h) includes step i): growing said deposition by successive metal layers at least partially over the surface of the bottom layer, so as to form the metal part for receiving an arbour, which is driven therein,

- step h) includes steps j): selectively etching at least one cavity in the bottom layer for receiving the metal part and step k): growing said deposition by successive metal layers at least partially in said at least one cavity so as to form the metal part into which an arbour will be driven,
- step h) includes a last step l): polishing the metal deposition,
- several double balance springs are made on the same substrate, which allows batch manufacture.

10 BRIEF DESCRIPTION OF THE DRAWINGS

Other peculiarities and features will appear more clearly from the following description, which is given by way of non-limiting illustration, with reference to the annexed drawings, in which:

- Figures 1 to 5 show successive view of the manufacturing method according to the invention,
- Figures 6 to 8 show views of the successive steps of alternative embodiments,
- Figure 9 shows a flow chart of the method according to the invention,
- Figures 10 and 11 are perspective diagrams of a one- piece, double balance spring according to a first embodiment.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The invention relates to a method, generally designated 1, for manufacturing a double balance spring 21 for a timepiece movement. As illustrated in Figures 1 to 9, method 1 includes successive steps for forming at least one type of one-piece, double balance spring, which can be entirely formed of silicon-based materials.

With reference to Figures 1 and 9, the first step 100 consists in providing a silicon-on-insulator (SOI) substrate 3. Substrate 3 includes a top layer 5 and a bottom layer 7 each formed of silicon-based material.

Preferably, in this step 100, substrate 3 is selected such that the
5 height of bottom layer 7 matches the height of one part of the final double balance spring 21.

Preferably, top layer 5 is used as spacing means relative to bottom layer 7. Consequently, the height of top layer 5 will be adapted in accordance with the configuration double balance spring 21. Depending
10 upon said configuration, the thickness of top layer 5 may thus fluctuate, for example, between 10 and 200 μm .

In a second step 101, seen in Figure 2, cavities 8 and 10 are selectively etched, for example by a DRIE (deep reactive ionic etch) process, in top layer 5 of silicon-based material. These cavities 8 and 10
15 can preferably form a pattern 9 that defines the inner and outer contours of one part of the collet, made of silicon-based material, of the double balance spring.

In the example illustrated in Figures 10 and 11, pattern 9 forms the median part of collet 27 of double balance spring 21. As Figure 2 illustrates,
20 pattern 9 is approximately cylinder-shaped with a circular section. However, advantageously according to method 1, the etch on the top layer 5 leaves complete freedom as regards the geometry of pattern 9. Thus, it might not necessarily be circular, but, for example, elliptical and/or have a non-circular inner diameter.

25 In a third step 102, shown in Figure 3, an additional layer 11 of silicon-based material is added to substrate 3. Preferably, additional layer 11 is secured to top layer 5 by means of silicon fusion bonding (SFB). Thus, step 102 advantageously covers top layer 5 by binding the top face of pattern 9, with a very high level of adherence, to the bottom face of

additional layer 11. Additional layer 11 may, for example, have a similar thickness to that of bottom layer 7.

In a fourth step 103, shown in Figure 4, cavities 12 and 14 are selectively etched, for example, by a DRIE process similar to that of step 5 101, in additional silicon layer 11. These cavities 12 and 14 form two patterns 13 and 15, which define the inner and outer contours of the silicon parts of double balance spring 21.

In the example illustrated in Figure 4, pattern 13 is approximately cylindrical with a circular section, and pattern 15, is approximately spiral- 10 shaped. However, advantageously according to method 1, the etch on additional layer 11 allows complete freedom for the geometry of patterns 13 and 15. Thus, in particular, pattern 15 may, for example, include more coils or an open outer curve.

Preferably, pattern 13 made in additional layer 11 is of similar shape 15 and plumb with pattern 9 made in top layer 5. This means that cavities 10 and 12, respectively forming the inner diameter of patterns 9 and 13, communicate with each other and are substantially one on top of the other. In the example illustrated in Figures 10 and 11, patterns 13 and 9 respectively form the upper and median parts of collet 27 of double balance 20 spring 21.

Preferably, at least one bridge of material 16 is formed to hold double balance spring 21 on substrate 3 during manufacture. In the example illustrated in Figure 4, it can be seen that a bridge of material 16 is left 25 11. between the outer curve of pattern 15 and the rest of the non-etched layer

Advantageously, as patterns 13 and 15 are etched at the same time, they form a one-piece part in additional layer 11. In the example illustrated in Figures 10 and 11, patterns 13 and 15 form respectively the top part of collet 27 and the first balance spring 23 of double balance spring 21.

After this fourth step 103, it is clear that patterns 13 and 15 etched in additional layer 11 are connected by the bottom of pattern 13, with a high level of adherence, above pattern 9, which is etched in top layer 5 and laterally, by the outer curve of pattern 15, to additional layer 11.

5 Preferably, as shown in dotted lines in Figure 9, method 1 can include a fifth step 104 that consists in oxidising at least pattern 15, i.e. the first balance spring 23 of the double balance spring so as to make said first balance spring more mechanically resistant and to adjust its thermo-elastic coefficient. This oxidising step is explained in EP Patent No. 1 422 436,
10 which is incorporated herein by reference.

Advantageously, according to the invention, after fourth step 103, or preferably, after fifth step 104, method 1 may include three embodiments A, B and C, as illustrated in Figure 9. However, each of the three embodiments A, B and C ends in the same final step 106, which consists in
15 releasing the manufactured double balance spring 21 from substrate 3.

Advantageously, release step 106 can be achieved simply by applying sufficient force to double balance spring 21 to break bridges of material 16. This force may, for example, be generated manually by an operator or by machining.

20 According to a first embodiment A, in a sixth step 105, shown in Figure 5, cavities 18 and 20 are selectively etched, for example by a similar DRIE process to that of steps 101 and 103, in bottom layer 7 of silicon-based material. These cavities 18 and 20 form two patterns 17 and 19, which define the inner and outer contours of silicon parts of double balance
25 spring 21.

In the example illustrated in Figure 5, pattern 17 is approximately cylinder-shaped with a circular section and pattern 19 is approximately spiral-shaped. However, advantageously according to method 1, the etch in bottom layer 7 leaves complete freedom as to the geometry of patterns 17

and 19. Thus, in particular, pattern 19 may, for example, have more coils or an open outer curve.

Preferably, pattern 17, made in bottom layer 7, is of similar shape and substantially plumb with pattern 9 made in top layer 5. This means that
5 cavities 18, 10 and 12 respectively forming the inner diameters of patterns 17, 9 and 13, communicate with each other and are approximately one on top of the other. In the example illustrated in Figures 10 and 11, patterns 13, 9 and 17 form the one-piece collet 27 of double balance spring 21.

Preferably, at least a second bridge of material 16 is formed to hold
10 double balance spring 21 on substrate 3 during manufacture. The example illustrated in Figure 5 shows that one bridge of material 16 is left between the outer curve of pattern 19 and the rest of the non-etched layer 7.

Advantageously, as patterns 17 and 19 are etched at the same time, they form a one-piece part in bottom layer 7. In the example illustrated in
15 Figures 10 and 11, patterns 17 and 19 form respectively the bottom part of collet 27 and the second balance spring 25 of double balance spring 21.

After this sixth step 105, it is clear that patterns 17 and 19 etched in bottom layer 7 are connected by the top of pattern 17, with a high level of adherence, above pattern 9, which is etched in top layer 5 and, laterally, by
20 the outer curve of pattern 19 to bottom layer 7.

After final step 106, explained above, first embodiment A thus produces a one-piece double balance spring 21, formed entirely of silicon-based materials, as shown in Figures 10 and 11. It is thus clear that there are no longer any assembly problems, since assembly is performed directly
25 during manufacture of double balance spring 21. The latter includes a first balance spring 23 and a second balance spring 25, which are joined coaxially to each other by a single collet 27.

As explained above, collet 27 is formed by the three successive patterns 13, 9 and 17 by etching the successive respective layers 11, 5 and
30 7. It is thus clear that median pattern 9 is useful as spacing means between

the first balance spring 23 and the second balance spring 25, but also as guide means for said balance springs. Advantageously, according method 1, it is thus possible, via the choice of thickness of top layer 5, to define directly the space between the two balance springs 23 and 25 and the
5 guide quality thereof.

Similarly, the height of balances springs 23, 25 and, incidentally, those of top and bottom parts 13 and 17 of collet 27, which are not necessarily equal, can be directly defined by the choice of thickness of additional layer 11 and bottom layer 7.

10 Moreover, the etches carried out in steps 103 and 105 of method 1 allow complete freedom as to the geometry of balance springs 23, 25 and collet 27. Thus, in particular, each balance spring 23 and 25 can have its own number of coils, its own geometrical features in proximity to collet 27, its own coil winding direction and also its own curve geometry, particularly
15 as regards the external part. By way of example, one and/or the other of balance springs 23, 25 can thus have an open outer curve so as to cooperate with an index assembly or have, on the end of the outer curve, a bulge portion that can be used as a point of attachment.

In accordance with the same reasoning, collet 27 can have uniformly
20 peculiar or different dimensions and/or geometries at least over one of bottom 17, median 9 and/or top 13 parts, . Indeed, depending upon the arbour on which collet 27 will be mounted, the inner diameter can have a complementary shape over all or part of the height of collet 27. Likewise, the inner and/or outer diameters are not necessarily circular but may be, for
25 example, elliptical and/or polygonal.

In the example illustrated in Figures 10 and 11, balance springs 23 and 25 have the same height, i.e. they are etched in layers 7 and 11 of the same thickness and they have the same number of coils. The ends of their outer curve are shifted relative to the collet by an angle of approximately
30 180°. Finally, the coils of balance springs 23 and 25 have opposite winding

directions. Moreover, collet 27 is of entirely uniform height and it is approximately cylinder-shaped with a circular section.

As explained above, because of the manufacturing freedom allowed by method 1, things could be different, i.e. the ends of the outer curve of each balance spring 23, 25 could be plumb with each other which would advantageously enable single means to be used for pinning the two balance springs 23 and 25 up to the collet.

It should also be noted that the very good structural precision of deep reactive ionic etching decreases the start radius of each of balance springs 23 and 25, i.e. the external diameter of collet 27, which means that the internal and external diameters of collet 27 can be miniaturised. It is thus clear that double balance spring 21 can advantageously receive, via its cavities 18, 10 and 12, an arbour of smaller diameter than is currently usually manufactured.

Preferably, said arbour can be secured to the internal diameter 18 and/or 10 and/or 12 of collet 27. Tightening can be achieved using resilient means etched in silicon collet 27. Such resilient means may, for example, take the form of those disclosed in Figures 10A to 10E of EP Patent No. 1 655 642 or those disclosed in Figures 1, 3 and 5 of EP Patent No. 1 584 994, said Patents being incorporated herein by reference.

According to a second embodiment B, after step 103 or 104, method 1 includes a sixth step 107, shown in Figure 6, consisting in implementing a LIGA process (from the German "röntgenLithographie, Galvanoformung & Abformung"). This process includes a series of steps for electroplating a metal on the bottom layer 7 of substrate 3 in a particular shape, using a photostructured resin. As this LIGA process is well known, it will not be described in more detail here. Preferably, the metal deposited may be, for example, gold or nickel or an alloy of these metals.

In the example illustrated in Figure 6, step 107 may consist in depositing a cylinder 29. In the example illustrated in Figure 6, the cylinder

29 is for receiving an arbour, which is advantageously driven therein. Indeed, one drawback of silicon is that it has very few elastic and plastic zones, making it very brittle. The invention thus proposes to fit an arbour, for example a balance staff, not against the silicon of collet 27, but to the
5 inner diameter 28 of metal cylinder 29, which is electroplated during step 107.

Advantageously, according to method 1, the cylinder 29 obtained by electroplating allows complete freedom as regards its geometry. Thus, in particular, the inner diameter 28 is not necessarily circular, but for example
10 polygonal, which could improve the transmission of stress in rotation with an arbour of matching shape.

In a seventh step 108, similar to step 105 shown in Figure 5, cavities are selectively etched, for example by a DRIE method, in bottom layer 7 of silicon-based material. These cavities allow patterns to be formed for a
15 second balance spring and a collet similar to patterns 19 and 17 of the first embodiment A.

After final step 106, explained above, the second embodiment B thus produces a one-piece, double balance spring formed of silicon-based materials with the same advantages as embodiment A, with the addition of
20 a metal part 29. It is thus clear that there is no longer any assembly problem since assembly is carried out directly during manufacture of the double balance spring. Finally, advantageously, an arbour can be driven against the inner diameter 28 of metal part 29. One could therefore envisage cavities 10 and 12 including sections of larger dimensions than
25 that of inner diameter 28 of metal part 29, so as to prevent the arbour being in push fit contact with collet 27.

According to a third embodiment C, after step 103 or 104, method 1 includes a sixth step 109 shown in Figure 7, consisting in selectively etching a cavity 30, for example, by a DRIE process, to a limited depth in bottom
30 layer 7 of silicon-based material. Cavity 30 forms a recess to be used as a container for a metal part. As in the example illustrated in Figure 7, the

cavity 30 obtained can take the form of a disc. However, advantageously according to method 1, the etch of bottom layer 7 allows complete freedom as to the geometry of cavity 30.

5 In a seventh step 110, as illustrated in Figure 8, method 1 includes implementation of a galvanic growth or LIGA process for filling cavity 30 in accordance with a particular metal shape. Preferably, the deposited metal may be, for example, gold or nickel.

10 In the example illustrated in Figure 8, step 110 may consist in depositing a cylinder 31 in cavity 30. Cylinder 31 is for receiving an arbour, which is advantageously driven therein. Indeed, as explained above, one advantageous feature of the invention consists in tightening the arbour, for example the balance staff, not against the silicon-based material of collet 27, but on the inner diameter 32 of metal cylinder 31, which is electroplated during step 110.

15 Advantageously according to method 1, cylinder 31 obtained by electroplating allows complete freedom as to its geometry. Thus, in particular, the inner diameter 32 is not necessarily circular but, for example, polygonal, which could improve the transmission of stress in rotation with an arbour of matching shape.

20 Preferably, method 1 includes an eighth step 111, consisting in polishing the metal deposition 31 made during step 110, in order to make said deposition flat.

25 In a ninth step 112, similar to step 105 shown in Figure 5, cavities are selectively etched, for example, by a DRIE process, in bottom layer 7 of silicon-based material. These cavities form patterns of a second balance spring and a collet similar to patterns 19 and 17 of the first embodiment A.

30 After final step 106 explained above, third embodiment C produces a one-piece, double balance spring formed of silicon-based materials with the same advantages as embodiment A, with the addition of a metal part 31. It is thus clear that there are no longer any assembly problems, since

assembly is carried out directly during manufacture of the double balance spring. Finally, advantageously, an arbour can be driven against inner diameter 32 of the metal part. One could therefore preferably envisage cavities 10 and 12 including sections of larger dimensions than that of the inner diameter 32 of metal part 31, to prevent the arbour being in push fit contact with collet 27.

According to the three embodiments A, B and C, it should be understood that the final double balance spring 21 is thus assembled prior to being structured, i.e. prior to being etched and/or altered by electroplating. This advantageously minimises the dispersions generated by current assemblies of two balance springs and, consequently, improves the precision of a regulator member on which it will depend.

Advantageously, according to the invention, it is also clear that it is possible for several double balance springs 21 to be made on the same substrate 3, which allows batch production.

Moreover, it is possible to make a driving insert of the same type as metal depositions 29 and/or 31 also, or solely from additional layer 11 and/or top layer 5. One could also envisage the two balance springs 23 and 25 being oxidised to make them more mechanically resistant and to adjust their thermo-elastic coefficient. A conductive layer could also be deposited on at least one part of double balance spring 21 to prevent isochronism problems. This layer may be of the type disclosed in EP Patent No. 1 837 722, which is incorporated herein by reference. Finally, a polishing step like step 111 may also be carried out between step 107 and step 108 as shown in dotted lines in Figure 9.

CLAIMS

1. Double balance spring (21), which comprises, made in a layer of silicon-based material (11), a first balance spring (23) coaxially mounted on a collet (13, 27), characterized in that the collet (13, 27) includes one extending part (9) projecting from said balance spring, which is made in a
5 second layer (5) of silicon-based material, said extending part extending (17) into a third layer (7) of silicon-based material coaxial with a second balance spring (25) to form a one-piece double balance spring (21) made of silicon-based materials.

2. Double balance spring according to claim 1, characterized in
10 that the collet (13, 9, 17, 27) has approximately the same section in each of said layers so as to facilitate adjustment of said double balance spring.

3. Double balance spring according to claim 1, characterized in that the collet has a substantially different section across at least one of the layers (5, 7, 11).

15 4. Double balance spring according to any of the preceding claims, characterized in that the balance springs (23, 25) include coils wound in the same direction.

5. Double balance spring according to any of claims 1 to 3, characterized in that the balance springs (23, 25) include coils wound in
20 different directions.

6. Double balance spring according to any of the preceding claims, characterized in that the ends of the outer curves of each of the balance springs (23, 25) are plumb with each other to allow single means to be used for pinning said double balance spring up to the collet.

25 7. Double balance spring according to any of the preceding claims, characterized in that the balance springs (23, 25) have the same angular stiffness.

8. Double balance spring according to any of claims 1 to 6, characterized in that the balance springs (23, 25) each have distinct angular stiffness.

9. Double balance spring according to any of the preceding
5 claims, characterized in that at least one of the balance springs (23, 25) has at least one silicon dioxide-based part so as to make said balance spring more mechanically resistant and to adjust the thermo-elastic coefficient thereof.

10. Double balance spring according to any of the preceding
10 claims, characterized in that the inner coil of at least one of the balance springs (23, 25) has a Grossmann curve so as to improve the concentric development of said double balance spring.

11. Double balance spring according to any of the preceding
15 claims, characterized in that the collet (27) has one metal part (29, 31) for receiving an arbour that is driven therein.

12. Timepiece characterized in that it includes a double balance spring according to any of the preceding claims.

13. Method (1) of manufacturing a double balance spring (21) including the following steps:

20 a) Providing (100) a substrate (3) including a top layer (5) and a bottom layer (7) of silicon-based materials,

b) selectively etching (101) at least one cavity (8, 10) in the top layer (5) to define the pattern (9) of a first part of a collet (27), made of silicon-based material, of said double balance spring,

25 characterized in that it further includes the following steps:

c) joining (102) an additional layer (11) of silicon-based material to the etched top layer (5) of the substrate (3),

d) selectively etching (103) at least one cavity (12, 14) in the additional layer (11) to continue the pattern of the collet (27) and to define the

pattern (15) of a first balance spring (23), made of silicon-based material, of said double balance spring,

5 e) selectively etching (105, 108, 112) at least one cavity (18, 20) in the bottom layer (7) to continue the pattern of the collet (27) and to define the pattern (19) of a second balance spring (25), made of silicon-based material, of said double balance spring, and

f) releasing the double balance spring (21) from the substrate (3).

14. Method according to claim 13, characterized in that, after step d), it further includes the following step:

10 g) oxidising the first balance spring (23), made of silicon-based material, so as to make said balance spring more mechanically resistant and to adjust the thermo-elastic coefficient thereof.

15. Method according to claim 13 or 14, characterized in that, after step e), it further includes the following step:

15 g') oxidising the second balance spring (25), made of silicon-based material, so as to make said balance spring more mechanically resistant and to adjust the thermo-elastic coefficient thereof.

16. Manufacturing method according to any of claims 13 to 15, characterized in that, prior to step e), it further includes the following step:

20 h) selectively depositing (107, 110) at least one metal layer on the bottom layer (7) to define the pattern of a metal part (29, 31) on the collet (27).

17. Manufacturing method according to claim 16, characterized in that step h) includes the following phase:

25 i) growing (107) said deposition by successive metal layers at least partially over the surface of the bottom layer (7) so as to form the metal part (29) for receiving an arbour that is driven therein.

18. Manufacturing method according to claim 16, characterized in that step h) includes the following phases:

j) selectively etching (109) at least one cavity (30) in the bottom layer (7) for receiving the metal part (31);

k) growing (110) said deposition by successive metal layers at least partially in said at least one cavity so as to form the metal part (31) for receiving an arbour, which is driven therein.

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19. Manufacturing method according to any of claims 16 to 18, characterized in that step h) includes the following last phase:

l) polishing (111) the metal deposition (29, 31).

20. Manufacturing method according to any of claims 13 to 19, characterized in that several double balance springs (21) are made on the same substrate (3).

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