

“PROCESS FOR MANUFACTURING MICROMECHANICAL DEVICES
CONTAINING A GETTER MATERIAL AND DEVICES SO MANUFACTURED”

The present invention relates to a process for manufacturing micromechanical
5 devices containing a getter material and to the devices manufactured through this
process. In particular, the invention relates to a process for manufacturing said devices
comprising a step of joining together two wafers by melting at the interface
therebetween, one of the wafers being silicon made and the other one being made of a
semiconductor, ceramic or oxidic material; the invention relates as well to the final
10 devices and to particular getter materials capable of withstanding the process conditions.

Micromechanical devices are generally known as “MicroElectroMechanical
Systems” or “MicroOptoElectroMechanical Systems”, and with their abbreviations
MEMS and MOEMS (in the following reference will only be made to MEMS, by that
also meaning MOEMS). These devices are formed of a sealed cavity, inside which
15 micromechanical parts capable of carrying out preset movements or parts capable of
interacting with electromagnetic radiation are present, in addition to auxiliary parts and
electrical feedthroughs for both the power supply of the device and the transmission of
the signal generated by the device to the outside. Examples of such devices are
microaccelerometers, described in numerous patents such as US 5,594,170, US
20 5,656,778 and US 5,952,572; miniaturized resonators, used in the field of
telecommunications and particularly in the manufacture of mobile phones, described in
patents US 5,821,836 and US 6,058,027; or IR miniaturized sensors, an example of
which is described in patent US 5,895,233.

At the end of the manufacturing process, various gases are contained in the cavity
25 of a MEMS, being residual of the process or due to the degassing of the same cavity
walls, which may interfere with the MEMS operation: for example, they can modify the
thermal conduction in the system thus altering the temperature measure in the case of an
IR sensor, that thus need the best possible degree of vacuum in the cavity. Other MEMS
devices do not have such a stringent requirement for extremely high vacuum levels. For
30 instance, in accelerometers a low pressure of gas in the cavity helps to dampen the
vibration of the moving part after it's been placed in motion; this allows fast recovery of

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the "rest" status of the device, making it more quickly ready for further movement detections; to this end, the manufacture of some MEMS foresees the backfilling of the cavity, prior to its sealing, with a given gas (e.g. a noble one) at pressures in the order of thousands of Pascal (Pa). In these cases too, however, it is necessary that the atmosphere in the cavity has a constant pressure and chemical composition, because variations in these parameters could alter the viscosity of the medium around movable parts, thus altering the measurements.

The achievement of very high vacuum degrees or of a constant atmosphere throughout the life of a MEMS device can be assured by introducing into the cavity a getter material, that is, a material capable of removing most non-noble gases. Getter materials usually employed are metals such as zirconium, titanium or alloys thereof; preferred is the alloy having weight percent composition zirconium 80% - cobalt 15% - Rare Earths 5%, sold by the applicant under the name St 787. The use of getter materials in MEMS devices is described, for instance, in US patents nos. 5,952,572, 6,499,354, 6,590,850, 6,621,134, 6,635,509 and 6,923,625.

MEMS are manufactured with technologies derived from the manufacturing of integrated semiconductor circuits, typically consisting in localized depositions of desired materials onto planar supports of glass, of quartz, of a ceramic material (e.g. silicon carbide) or of a semiconductor material (silicon is preferred), and selective removals of parts of layers of different material. In particular, the last generation MEMS, described in the following with reference to Fig. 1, are normally manufactured by welding two parts together, a first part 10 being commonly formed of a planar support, generally of silicon, on which the functional elements 11 and the auxiliary ones (these ones not shown in the drawing) are built, and a second part 12, which may be made of glass, quartz, ceramic or a semiconductor material, and generally has only the function of closing the device in order to protect the inner elements. As this second part is generally free from functional elements and thereby provides more free space, the getter material 13 is preferably arranged on this part, as described for instance in patent US 6,897,551. The preferred technique for the deposition of getter material layers in this application is the cathodic deposition, commonly known as "sputtering". As it is known, in this technique, a body, generally having a short cylinder shape (called "target"), made

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of the material intended to be deposited and the support on which to form the deposit are arranged in a sealed chamber; the chamber is filled with a noble gas, generally argon, at a sub atmospheric pressure; by applying a potential difference of the magnitude of thousands of volts (or lower, depending on the configuration used) between the target (held at cathodic potential) and an anode, the noble gas is ionized and the ions so produced are accelerated towards the target, thus eroding it by impact; the eroded material deposits on the available surfaces, including the support; by employing masking systems provided with suitable openings it is possible to restrict the area of the support where the deposit has to be formed. As an alternative, sputtering can be carried out under reactive conditions, namely, adding to the noble gas small percentages of a reactive gas, oxygen for instance, which reacts with the particles eroded by the target in gaseous phase producing a deposit of the material that results from the reaction of the reactive gas with said particles. Once all the elements needed for the operation of the MEMS have been formed on the two parts, these are joined together by welding them along a line enclosing the elements of the device. The micro-device is thus sealed in a closed space 14 and is mechanically and chemically protected from the outer environment.

The welding can be accomplished by numerous techniques, known with the common definition of "bonding". A first possibility consists in inserting between the two parts a malleable metal such as indium, lead or gold is placed, and causing this to melt and solidify, possibly while exerting pressure ("pressure bonding"); however, this technique results in not completely reliable weldings from the mechanical strength point of view. Another type of bonding is the anodic one (mainly employed where one of the supports is made of glass or quartz and the other one is of silicon), wherein a potential difference of about 1000 V is applied between the two parts kept at a temperature of about 300 – 500 °C; in these conditions there is a migration of positive ions from the support kept at positive potential (e.g. sodium ions from the glass), towards the support kept at negative potential, and a migration of negative ions (e.g. oxygen from silicon) to the opposite direction; this material migration between the two supports results in the mutual welding thereof. Another possible technique is the eutectic bonding, wherein a layer of metal or alloy, able to form an eutectic composition with the material of at least

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one of the two supports, is interposed between the two supports, so to cause a localized melting in the welding area by means of a suitable thermal treatment. However, the eutectic bonding is not generally used when there are dangers of metallic contamination, e.g. when the eutectic bonding is carried out together with CMOS manufacturing processes. The getter materials presently available are those compatible with MEMS manufacturing processes which use the hereinabove described bonding techniques.

Another possible MEMS sealing technique is direct bonding, requiring the localized melting of the material of the supports; the achievement of a stable bonding through this way generally requires high temperatures, e.g. about 1000 °C in the case of silicon. This technique can also use an intermediate layer, e.g. silicon oxide when bonding two silicon parts. Compared to the previously cited techniques, direct bonding allows to obtain a better bonding between the two parts to be welded, increasing both the adhesion force and the stability with respect to stress conditions as thermal and mechanical shocks, vibrations or thermal cycles. With such a type of bonding, the mechanical characteristics of the welding area are comparable with those of the material forming the welded parts. This type of bonding is used for the devices which must have a great reliability and durability (e.g. avionic applications).

However, it has been verified that getter materials used at present are not capable of withstanding the thermal treatments required by direct bonding. Firstly, during these thermal treatments most getter materials undergo strong structural and morphological rearrangements, which may result in the melting of the material deposit (e.g. in the case of the cited St 787 alloy); the minimum consequence observed is the nearly total loss of the gas sorption ability by the getter, while in the case of melting the getter material can "wet" the functional parts of the device and, after solidification, it can completely alter or prevent the operation thereof. In some cases a partial evaporation and new condensation of the getter material on the adjacent surfaces has also been observed, with negative consequences on the device operation. Another problem that has been observed with all the getter materials is that, if the deposit is formed on silicon, it detaches from the support during the cooling that follows the bonding operation, so that solid fragments can come into contact with the functional parts, thus jeopardizing the device efficiency.

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Object of the present invention is to provide a process for manufacturing micromechanical devices comprising a step of direct bonding of two support parts on which functional elements, accessories and a getter material are present, as well as to provide final micromechanical devices and a family of getter materials capable of withstanding the manufacturing process.

These objects are achieved according to the present invention with a process for manufacturing micromechanical devices comprising a step of direct bonding of two support parts, one of which is made of silicon and the other one is made of silicon or of a semiconductor, ceramic or oxidic material, wherein functional elements and possible auxiliary elements of the device are present on at least one of the support parts, and wherein a getter material deposit is present on a silicon support part, comprising the steps of: providing a first support part where functional elements and possible auxiliary elements of the device are built; providing a second support part; said first and second support parts being formed such that, when mating, they form a cavity wherein said functional elements, auxiliary elements and getter material deposit are housed; approaching said two support parts so as to form said cavity and welding said two support parts by direct bonding; said process being characterized in that said getter material deposit is formed on said silicon support part by means of a first operation of forming on the silicon support part an intermediate layer of a vitreous, ceramic or oxidic material having thickness of at least 50 nanometers, and a second operation of depositing a getter material layer having thickness not higher than 10 micrometers onto said intermediate layer; and in that the getter material employed is an alloy containing zirconium and at least a second element chosen among molybdenum, niobium, tantalum and tungsten, wherein zirconium is present in percentages comprised between 70 and 97% by weight.

The invention will be illustrated in the following with reference to the drawings, wherein:

- Figure 1, already described with reference to the prior art, schematically shows a sectional view of a MEMS device;
- Figure 2 shows the main steps of the operation characterizing the process of the invention.

The inventors have found that it is possible to prevent the getter material deposits on silicon supports from detaching during a direct bonding process if some particular getter materials are used, if between the getter material and silicon is interposed an intermediate layer being made of a vitreous, ceramic or oxidic material, and if the getter and intermediate layers have particular thickness values; as the process of the invention is characterized by the presence of the intermediate layer and by the definition of said thicknesses, while for the remainder operations it is completely similar to other MEMS manufacturing processes with direct bonding, only the innovative features of the process will be described in detail in the following.

As previously described, due to available space reasons, it is preferable to produce the getter layer on the support opposite to the one where MEMS functional and auxiliary elements are built; thereby, in the rest of the description reference will be made to this embodiment, but it will be evident to those skilled in the art that the invention can also be applied where the getter deposit is obtained on the same support carrying the functional and auxiliary elements.

The formation of the intermediate layer and of the getter material layer thereon can be carried out by means of various techniques. For example, the intermediate layer may be made of a vitreous or ceramic silicon compound, e.g. oxide or nitride; in this case, such layer can be let to grow starting from the silicon support by reaction with oxygen or nitrogen at a sufficient temperature, or alternatively it is possible to adopt the technique of oxygen or nitrogen ion implantation into silicon, followed by thermal treatments of diffusion (known in the field as "annealing") to render the so formed layer homogeneous as to structure and characteristics.

However, the preferred technique for the growth of the various layers is sputtering, possibly reactive, offering a high control of the geometric and structural characteristics of the layer under formation at a limited cost. Further, with respect to the previously cited techniques, sputtering gives the additional advantage of being able to form intermediate layers suitable for the purposes of the invention with materials different from silicon compounds, such as e.g. metal nitrides or carbides.

The preferred way of carrying out the process of the invention (deposit by sputtering of both intermediate and getter material layers on the support free from

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functional elements) is described in the following with reference to Figure 2, wherein the elements are shown in a schematic sectional view.

Figure 2a shows a support 20, similar to support 12 of Figure 1 but having an upside-down orientation with respect thereto.

5 Figure 2b shows the forming operation of the intermediate layer onto support 20. The deposition is preferably carried out on a restricted area of support 20, by positioning a mask 21 over the support, the mask having an opening 22 defining the area of support 20 where the deposit is to be formed; the arrows in Figure 2b indicate the direction of the particles of the material chosen for the formation of the intermediate
10 layer 23. The thickness of the intermediate layer can be controlled, as it is well known in the field, by adjusting the process time, the power applied between anode and target and the distance between the target of the material to be deposited and support 20. The thickness of layer 23 must be at least 50 nanometers (nm), because it has been observed that with lower thicknesses the detachment of the getter layer subsequently formed can
15 not be prevented; preferably, this thickness is lower than 2 μm , in order to minimize the time of deposition of the intermediate layer, still ensuring optimal functional characteristics. The deposition of layer 23 by sputtering can also be carried out under reactive conditions, for instance in the presence of small amounts of oxygen in the noble gas, yielding an oxide as the material forming such layer.

20 The forming operation of the intermediate layer can be carried out also in other ways, for example without using the mask 21 in the deposition phase, by uniformly depositing the material of layer 23 onto support 20 and then selectively removing it in order to obtain the desired geometry; in this case, the use of a mask may be required for the operation of selective removal of portions of the thus deposited layer.

25 The subsequent operation is the deposition of the getter material layer. Also this operation can be carried out without using maskings, by uniformly depositing the material on support part 20 (where layer 23 is already present) and then selectively removing the getter, so as to leave it only in correspondence to layer 23. However, also in this case the getter material layer deposition is preferably carried out by using a
30 masking system, so that the getter material deposits only onto the intermediate layer. The mask may have an opening that is smaller than that employed in the operation

shown in Figure 2b, but preferably the size, shape and alignment of the opening are the same as those of the previous operation, in order to maximize the getter deposit area (and thereby its gas sorbing ability); these preferred conditions are accomplished in the most convenient way by employing the same mask, kept in constant alignment with respect to support part 20 in the two operations, thus simplifying the whole process. By using the same mask for the two deposition operations, these are consecutively carried out during the same manufacturing step by simply replacing the target of the intermediate layer material with the getter material target, by adjusting the time of using the two targets on the basis of the desired thicknesses for the two layers of different materials. This mode is represented in Figure 2c, wherein the same mask 21 of Figure 2b, with opening 22, is used to deposit the getter material layer 24; also in this case the arrows indicate the direction of the getter material particles being deposited.

In Figure 2, mask 21 is represented as a physical object laid over support part 20. This choice is possible when the deposits to be formed have lateral dimensions not lower than about 200-300 micrometers; below these dimensions it is necessary to resort to lithographic masks, obtained by deposition on the support of films of UV-sensible organic materials, exposure to UV light and selective removal with chemicals of exposed (or non-exposed) portions of said films, according to a procedure well known in the field of microelectronics and that can be applied to the deposition of getter materials as described in the international patent application WO 2006/109343 in the applicant's name.

The getter material compatible with the direct bonding operation is an alloy containing zirconium and at least a second element chosen among molybdenum, niobium, tantalum and tungsten, wherein zirconium is present in percentages comprised between 70 and 97% by weight. Preferably, the second element is chosen between niobium and tantalum, and in this case zirconium is present in percentages comprised between 85 and 95% by weight.

The thickness of the getter material layer must not exceed 10 μm , because the inventors have experimentally observed that for higher thicknesses the getter deposit detaches from the support during direct bonding (in particular, during the cooling following the bonding), despite the presence of the intermediate layer and independently

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from the thickness of this latter; the thickness of this layer is preferably larger than 0.1 μm , as for lower thicknesses the gas sorbing ability becomes too low.

The so-prepared support part 20, with the addition of layers 23 and 24, then undergoes the subsequent operations of the MEMS manufacturing process, in particular the direct bonding with a support like support part 10. As known in the field, in order to ensure a good quality of the direct bonding, it is preferable that the two surfaces to be welded together are preliminary subject to cleaning and surface modification treatments, such as mechanical polishing, lapping or chemical washings. These treatments are preferably carried out before the deposition steps of the intermediate and getter layers, but they could also be carried out after said deposition steps, as described in the international patent application WO 2005/047558 in the applicant's name. The sealing step can also be carried out in the presence of a given gas (e.g., a noble gas) at sub-atmospheric pressure, in order to obtain a MEMS device having a fixed gas pressure in the cavity, for the reasons explained before.

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CLAIMS

1. A process for manufacturing micromechanical devices comprising a step of direct bonding between two support parts, one of which (12, 20) is made of silicon and the other one is made of silicon or of a semiconductor, ceramic or oxidic material, wherein functional elements (11) and possible auxiliary elements of the device are present on at least one of these support parts, and wherein a getter material deposit (13, 24) is present on one silicon support part, comprising the steps of: providing a first support part (10) on which the functional elements (11) and possible auxiliary elements of the device are built; providing a second support part (20); said first and second support parts being formed such that, when mating, they form a cavity (14) wherein said functional elements, auxiliary elements and getter material deposit are housed; approaching said two support parts so as to form said cavity and welding said two support parts by direct bonding; said process being characterized in that said getter material deposit is formed on said silicon support part by means of a first operation of forming on the silicon support part an intermediate layer (23) of a vitreous, ceramic or oxidic material having thickness of at least 50 nanometers, and a second operation of depositing a getter material layer (24) having thickness not higher than 10 micrometers onto said intermediate layer; and that the getter material employed is an alloy containing zirconium and at least a second element chosen among molybdenum, niobium, tantalum and tungsten, wherein zirconium is present in percentages comprised between 70 and 97% by weight.

2. A process according to claim 1, wherein said second element is chosen between niobium and tantalum, and zirconium is present in said alloy in percentages comprised between 85 and 95% by weight.

3. A process according to claim 1, wherein said intermediate layer is made of silicon oxide or nitride and its formation is carried out by means of reaction of the silicon support part with oxygen or nitrogen.

4. A process according to claim 1, wherein said intermediate layer is made of silicon oxide or nitride and its formation is carried out by means of oxygen or nitrogen ion implantation into silicon.

5. A process according to claim 4, wherein the ion implantation is followed by thermal treatments of oxygen or nitrogen diffusion into silicon.

6. A process according to claim 1, wherein said intermediate layer is formed through cathodic deposition.

5 7. A process according to claim 6, wherein the cathodic deposition takes place in reactive conditions.

8. A process according to claim 6, wherein the cathodic deposition is carried out on a restricted area of the silicon support part (20), by placing onto said support part a mask (21) with an opening (22) that defines an area of said silicon support part where
10 the deposit will be formed.

9. A process according to claim 1, wherein said operation of deposition of the getter material layer (24) occurs by means of cathodic deposition.

10. A process according to claim 9, wherein said operation of deposition of the getter material layer (24) is carried out only onto the intermediate layer, by placing on
15 the silicon support part (20) a mask with an opening having a size lower or equal to that of the mask used in the formation of the intermediate layer, and so aligned to the silicon support part (20) that the getter material deposits on said intermediate layer only.

11. A process according to claim 10, wherein the forming operations of the intermediate and getter material layers occur by employing the same mask (21) with
20 constant alignment with respect to the silicon support part (20).

12. A process according to claim 1, wherein the thickness of the getter material layer is comprised between 0.1 and 10 μm .

13. A process according to claim 1, wherein the surfaces of said two support parts to be welded together are subject to cleaning and surface modification treatments
25 before welding.

14. A process according to claim 13, wherein said treatments are chosen among mechanical polishing, lapping or chemical washings.

15. A process according to claim 1, wherein said operation of welding said two support parts by direct bonding is carried out in the presence of a noble gas at sub-
30 atmospheric pressure.