A packaging method for MEMS devices, and MEMS packages produced using the method

Field of the invention

The present invention relates to processes for packaging MEMS devices, and MEMS packages produced using the method. The term "MEMS package" is used in this document to imply a package including at least one MEMS device.

Background of Invention

Microelectro-mechanical systems (MEMS) devices are known which convert physical phenomena, such as pressure, acceleration, sound, or light, into electrical signals. Each type of MEMS device interacts with the world in a different way, and demands custom or at least semi-custom packaging solutions. So called system-in-package techniques attempt to form an entire microsystem – which could include a microprocessor, communications components, actuators and sensors – within a single package. However, packaging of a MEMS device is totally different from packaging an integrated circuit. MEMS devices are categorically different from ICs despite sharing some fundamental processing technologies. Packaging is the biggest challenge for commercializing most MEMS devices.

A MEMS device might function perfectly well in the controlled environment in which it was created. However, the device can be a real viable product only after it has been packaged with proven performance in a package. For example, the packaging stress can distort the sensitivity and the performance of the MEMS devices. MEMS devices include delicate movable structures, which are easily damaged through fabrication and assembly processes. As

such, the assembly yield of a MEMS package is often a challenging target to meet.

The packaging requirements of MEMS devices are complex because the devices need to interact with the physical phenomenon and yet the devices need to be protected from the environment. As such, exotic package structures with specialized assembly techniques and unique packaging materials are employed for MEMS devices. Packaging is usually responsible for at least 60 percent of the cost of a MEMS device, and sometimes as much as 85 percent. Thus, it has been recognized that a low cost packaging solution with robust assembly is needed to promote the use of MEMS devices.

A variety of packages are known for packaging various MEMS products. Ref. [1] describes (for example with reference to its Fig. 3) various metal packages, such as TO8 (or round) headers, and butterfly and platform packages. Metal packages provide good heat dissipation capability and shielding of electrical radiation. The TO8 header is commonly fabricated from Kovar alloy to reduce the thermo-mismatch between the packaging material and the silicon etched devices.

Ref. [2] describes (for example with reference to its Fig. 3) ceramic or LTCC packages. These are low cost, high reliability, gastight and multi-layer packaging architectures. An example of a ceramic package is an IR bolometer which is produced at high processing temperature in a vacuum seal environment.

Ref. [3] compares (for example with reference to its Fig. 1) IC packages and MEMS pressure sensor packages. Plastic/lead frame packages are commonly employed in IC packaging and commonly classified as pre-molded

and post-molded packages. The difference between pre-molded and post-molded packages is that pre-molded packages comprise a package body including a hollow cavity into which the IC is placed and then covered with a sealing cap, whereas in post-molded packages the package body is molded over the assembly after the IC has been attached. Both these alternatives apply also to MEMS devices. For example, a post-molded package can be used for ICs or wafer capped accelerometers, while a pre-molded package can be used for a pressure sensor or microphone packaging. The plastic package offers a low cost packaging option. However, the required mold tooling is often expensive and time consuming, making it inflexible to meet fast changing needs from end-users' applications. Others key issues are that the plastic has very poor matching of thermal expansion with silicon and is also susceptible to moisture ingression.

Wafer level packaging (refs. [4,5]) is a niche method for MEMS packaging. It involves an extra fabrication process where a micromachined wafer is bonded to a second wafer which has appropriate cavities etched into it. Once bonded, the second wafer creates a protective silicon cap over the micro-machine structure. This method leaves the microstructure free to move within a vacuum or an inert gas atmosphere. The bond is hermetic and therefore prevents moisture contamination and hence failure of the microstructure.

US patent application No. 2002/0102004 A1 (ref. [6]) discloses a MEMS microphone package in which a MEMS transducer element, an IC die and other capacitor components are located on a first multi-layer FR4 PCB. A second multi-layer FR4 PCB is used as a cover. The two FR4 boards are spaced apart by a third FR4 board, which is cut to include a window which is placed around the components on the first PCB. Thus, the three PCBs cooperate to house and shield the transducer element, the IC die and other capacitor components. Compared with plastic/lead frame packages, such a

package enables a larger batch operation, requires minimal hard tooling and has better match of thermal expansion with end user's PCB. Nevertheless, the mixing of the transducer element, the IC die and other electronic components on the same FR4 PCB substrate still presents difficulties in operating a high yield assembly process. Nor is a multi-layer FR4 PCB a cheap packaging material.

Summary of the Invention

The present invention aims to provide a new and useful packaging method to produce a MEMS package incorporating a MEMS device and one or more other electronic circuits.

The invention further aims to provide MEMS packages produced using the method.

In general terms, the invention proposes that at least one MEMS device is mounted on a first flex substrate, and that one of more electronic components (typically, an application specific IC (ASIC) and one or more passive components) are mounted on a second substrate. The two substrates are then joined mechanically in parallel with a spacer element between them and connected electrically by electrical connecting elements. The substrates sandwich the spacer element, the electrical connecting elements, the MEMS device and the one or more electronic components between them.

Since the MEMS device and the set of one or more electronic components are located on different respective substrates, the process of mounting the MEMS device onto its substrate is performed separately from the process for mounting the electronic components onto their substrate. This has several advantages.

Firstly, this allows the respective mounting process on each of the substrates to be performed by people and equipment specialized in the respective field of assembly. This maximizes the yield, eases infrastructure constraints and allows standard processes for assembly before integrating together. This eases assembly, helps in rework and achieves good assembly yield.

Secondly, the set of electronic components can be mounted on the second substrate by techniques which do not take into account the delicate nature of MEMS devices. For example, soldering is commonly used as the interconnect method for forming IC packages. This is due to its high assembly yield, its ability to eliminate probe marks by re-flow, the fact that it allows reworking after assembly, its electrical stability, its ease of accurate placement with a self-alignment effect, and its reliability. However, this robust process is not suitable for packaging in the presence of a MEMS device due to its use of flux and its residues. Flux generates outgas that may induce structural stiction and affects the performance of the MEMS device. Its residue may either cripple the performance of the MEMS device, or deteriorate the assembly yield of MEMS devices.

Since, in the present invention, the set of electrical components can be mounted on the second substrate in the absence of the MEMS device, and the MEMS device does not subsequently have to be mounted on the second substrate, this problem is removed. This allows a standard SMT process to be used for mounting the ASIC and passive devices which reduces the cost significantly without affecting the MEMS device. A more delicate MEMS packaging technique can still be used for mounting the MEMS device on the first substrate before integrating the two substrates together. Thus, this eases assembly and rework, and improves the assembly yield significantly. Therefore, it lowers the MEMS packaging cost significantly.

As mentioned above, the MEMS device is mounted on a flex substrate, a term which is used here in a conventional sense to imply a flexible substrate principally composed of a body of flexible material, such as polyimide. The fact that the first substrate is a flex substrate has important advantages also.

Firstly, it means that the costs of producing the package are lower than, for example, in the package of ref. [6] described above. That is, in place of the three 4-layer FR4 boards of ref. [6], at least one is replaced by a flex layer.

Furthermore, the number of processes needed to produce the package is reduced, since, in comparison to an FR4 PCB, no patterning of the first substrate and no drilling of it need be performed.

Furthermore, since a flex layer is thinner than a FR4 board, the package height is reduced. A thickness as low as 1mm can be achieved.

Furthermore, the presence of the flex substrate with a low modulus makes the package more flexible. This may reduce the stress on the microphone and ease selection of die attach materials.

Indeed, it is possible for the second substrate also to be formed from a flex substrate, in which case these various advantages may be doubly applicable.

Note that the middle adhesive tape inside the first flex substrate has good adhesion to Cu foils. The adhesive tape may be given a second use: to project across an aperture in the first substrate and thus as an environmental protection layer. In this configuration it also reduces burrs produced at the aperture by processing of the flex substrate.

The two substrates may be spaced apart by a conductive spacer element having a window which, in the final package, surrounds the regions of the substrates carrying the MEMS device and the set of electrical components. This conductive body and the metal layers on the two substrates together

provide a Faraday cage with simplicity. Thus, this architecture offers a low cost packaging option in which the substrate includes a minimum number of layers, and yet which meets electrical shielding requirements.

Brief Description of The Figures

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

Fig. 1, which is composed of Figs. 1(a) to 1(d), shows how electronic components are mounted on a substrate in one step of a packaging method which is an embodiment of the invention;

Fig. 2, which is composed of Figs. 2(a) to 2(c), shows how a MEMS device is mounted on a flex substrate in another step of a packaging method which is a first embodiment of the invention;

Fig. 3 is a cross-sectional view showing how the substrates of Figs. 1 and 2 are joined to form a MEMS package which is an embodiment of the invention;

Fig. 4 is a cross-sectional view of a second embodiment of the invention;

Fig. 5 shows an assembly process for forming the first embodiment of the invention;

Fig. 6 shows a surface mount assembly application for the first embodiment of the invention;

Fig. 7 shows an economic layout of the substrate housing the electronics in batch processing for the first embodiment of the invention; and

Fig. 8, which is composed of Figs. 8(a) and 8(b), shows an individual substrate housing the electronics as well as the spacer element after substrate dicing.

Detailed Description of the embodiments

A first embodiment of the invention will now be described with reference to Figs. 1 to 3. For the sake of concreteness, this particular embodiment is illustrated with a MEMS microphone device. However, the invention is not limited in this respect, and many other applications of the invention exist, for packaging other types of MEMS device such as pressure sensor, accelerometers, gyroscope, and so on, or indeed MEMS devices which may be proposed in the future.

Referring firstly to Fig. 1, a structure is shown in which an ASIC 1 and passive components 3 (e.g. capacitors for RF noise filtering) are mounted on an FR4 printed circuit board 5. Fig. 1(b) shows a view of the board looking toward the mounted components. Fig. 1(a) is a cross-sectional view in the line A-A' in Fig. 1(b). Fig. 1(c) is a cross-sectional view in the line B-B' in Fig. 1(b). Fig. 1(d) shows the reverse side of the board from the view of Fig. 1(b).

The FR4 board 5 has copper layers 9, 11 on its two major faces, and three vias, plated and plugged as inter layer interconnects. The vias labelled Vcc and Vout in Fig. 1(d) connect signals Vcc and Vout to respective circuitry paths on the upper surface of the board 5, also labelled Vcc and Vout. The another via 13 connects the Gnd signal on layer 9 to layer 11. The vias are connected on the lower surface of the board 5 to LGA pads 7 (plated with Ni/Au, that is nickel, gold or an alloy of the two) through the routing trace. These pads 7 are later connected to an external printed circuit board (as described below) for communication of the signals Gnd, Vcc and Vout.

Layer 11 carries a peripheral layer 15 of thin plated Ni/Au. This layer allows a ring-like spacer 17 to be soldered onto this plated layer 15. The spacer can be either a metal frame, a solder preform or a metal plated plastic frame.

Alternatively, such a conductive spacer can be joined with a conductive adhesive. The layers 9, 11 and the spacer 17 are all interconnected together through the via 13, and in use are connected to a large Cu plate which acts as a sink to shield the package against EMI interference.

The layer 11 of the FR4 board 5 includes two pads 19, 21 for signal inputs. As explained later, these pads will be used in the electrical interconnection to the flex assembly (shown in Fig. 3). The connection can be achieved through the use of solder preform (i.e. bodies preformed of solder) or a large solder ball 23, which will subsequently be connected by conductive adhesive or soldering to corresponding pads on the flex substrate.

A conventional SMT process is used to mount the capacitors 3. As the ASIC die 1 includes a few I/O ports at a relatively large pitch, standard flip chip process can be used to mount the ASIC chip 1 with the active surface facing down (i.e. towards the board 5), and with its electrical contacts contacting corresponding electrical contacts on the substrate. This assembly technique is commonly known as the flip chip technique. This approach minimizes the real estate of the FR4 board 5 consumed, and thus minimizes the packaging size and hence saves on material cost. A solder mask layer is commonly applied over the Cu surface to protect and isolate the Cu plane and circuitry. For simplicity in drawing, the solder mask 25 is only shown on backside of the FR4 substrate in Fig 1 .

Turning to Fig. 2, a flex assembly is shown including a flex substrate 31 formed of polymide. This flex substrate 31 has a much lower modulus (typically 5 GPa) than the FR4 PCB (typically 25 GPa), and so offers stress relaxation and minimizes the interaction of packaging stress or environmental induced stress with a MEMS device 33 mounted on it. The flex substrate 31 includes an opening 35 (normally a circular or square shaped opening) that

allows external fluid, acoustic energy or pressure to interact with the MEMS device 33.

A tape adhesive layer 37 on the flex substrate 31 extends across the opening 35, and also adheres a Cu layer 39 to the substrate 31. Thus, the adhesive layer 37 has a dual use: as a constructional component and for environmental protection if the need arises. The structure in Fig 2 can be fabricated by mechanically punching the hole 35 through the polymide 31 before laminating the Cu 39. Alternative a laser ablation process can be used to remove the polymide of the hole 35 leaving the adhesive layer 37 intact. The flex base core 31 eases the fabrication of the opening 35 and removes any possible residue, fiber or Cu burr affecting the performance of the MEMS device 33.

Alternatively, this adhesive layer 37 can be removed to provide more sensitivity of the MEMS device 33 to the source of the physical phenomenon the MEMS device 33 is measuring. This can be achieved by mechanically punching the opening 35 through both the substrate 31 and the adhesive layer 37. Alternatively, the adhesive layer 37 can be omitted completely, so that the Cu layer 39 is formed directly on the flex substrate 31 (so called "adhesiveless flex substrate"), and then chemical etch or laser ablation can be used to produce the opening 35 in the substrate 31.

Optionally, a protective soldermask layer 44 is formed over much of the Cu layer 39.

The MEMS device 33 is then attached to the flex substrate 31 with a non-conductive adhesive 41. A low modulus adhesive would be preferred for stress relaxation such as a silicone base adhesive. The MEMS device 33 is then wire-bonded by wires 42 to two Ni/Au plated pads 47 and 49 formed on

the two isolated Cu bases as shown in Fig 2. These pads 47, 49 have positions corresponding to the signal pads 19, 21 on the FR4 board 5.

Fig. 3 shows show the flex assembly of Fig. 2 connected to the FR4 assembly of Fig. 1. The pads 19, 47 and the pads 49, 21 carry signals IN and BIAS respectively. The ring-like spacer 17 is connected to the periphery of the flex substrate 31 using a solder or conductive adhesive 51. Thus, the GND pad is also connected through the conductive spacer to the periphery of the flex substrate 31. The Cu layers 9, 11, the conductive spacer 17 and the Cu layer 39 together form a Faraday cage for EMI shielding. The combination is shown in place over a layer 25 which can be a solder mask of the kind typically formed over circuitry.

The main advantage of this architecture is the isolation of the MEMS assembly from the SMT process used to form the structure of Fig. 1. This thus allows each to be fabricated separately using specialist equipment and personnel.

The package structure also offers further miniaturization feasibility. This is because its thickness in the z-axis (i.e. the up-down direction in Fig. 3) is reduced by the use of the flex substrate 31 which typically has a substrate thickness of 0.1mm or smaller.

Turning to Fig. 4, the second embodiment of the invention is shown. This is generally similar to the first embodiment (and the same reference numerals are used to designate some corresponding items), but has the difference that the MEMS device 33 includes electrical contact pads 51 on its surface which faces away from the flex substrate 31. These pads 51 are connected via solder balls 53 (or other conductive elements) to a conductive path formed on the FR4 substrate 5. This makes the wires 42, and the electrical contacts 47

and 49 shown in Fig. 1 and the conductive element 23 shown in Fig. 2 unnecessary. Such a packaging approach will help to reduce the packaging size accordingly.

Figs. 5 illustrates the process of assembling a MEMS package according the 1st embodiment of the invention by attaching a flex assembly similar to that shown in Fig. 2 to an assembly similar to that shown in Fig. 1. Again, corresponding elements are given the same reference numerals. The spacer element 17 can be a leadframe which in this case may be Cu, Alloy 42, of thickness 0.5mm and having Ag plating. Alternatively, the spacer element 17 may be a solder preform or a metal plated plastic frame. Its outer surface 55 may have a layer of Ni/Au surface which allows using Pb free solder for more environment friendly and better reliability. Such a conductive spacer can be surface mounted to the FR4 substrate which is pre-printed with solder. As mentioned before in relation to Figs. 1 to 3, the connecting element 23 may be preformed solder, or solderable conductive material. Alternatively, the conductive spacer 17 and the connecting element 23 may be attached to the flex substrate before mounting the MEMS device 33.

Fig. 5 shows the attachment of the flex assembly to the other assembly. This attachment may be made by soldering or using a conductive adhesive.

Fig. 6 shows how, once the MEMS package is completed, it can be then surface mounted onto a printed circuit board 59 in a system product.

To further minimize the cost for the FR4 board, a number of vias on the FR4 board can be shared. This is illustrated in Fig 7, which shows an assembly which is a variant of that of Fig. 1 and which is used to form a further embodiment of the invention. Again, items of this embodiment corresponding to items of previous embodiments are given the same reference numerals.

The vias 61 are shared with between units 5a, 5b, and then isolated during singulation. After dicing, each unit has four quarter vias.

In contrast to Fig.1, this requires PCB layout modification. Fig. 8(a) shows an assembly after the singulation. As shown in Fig. 8(a), the soldermask layer 25 in this case is patterned differently on the frontside for electrical isolation. Furthermore, the spacer element 17 is also designed differently, as shown in Fig 8(b). The spacer element can be assembled onto the FR4 assembly in the same way as depicted in the other embodiments. The conducting layers on the flex substrate, the spacer and the FR4 will be grounded for EMI shielding.

Although only a few embodiments of the invention have been described here in detail, many variations are possible within the scope of the invention as will be clear to a skilled reader. For example, although the embodiments have only a single MEMS device, the invention is not limited in this respect, and conveniently two or more MEMS devices may be mounted on the flex substrate 31.

References

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Claims

1. A MEMS package comprising:

at least one MEMS device located on a first flex substrate, and

one of more electronic components located on a second substrate,

the two substrates being electrically connected and joined mechanically in parallel, sandwiching between them at least one electrical connecting element, a conductive spacer element, the at least one MEMS device and the one or more electronic components.

2. A package according to claim 1 in which the conductive spacer element has a window surrounding the MEMS device and the one or more electronic components, the conductive spacer element and conductive layers on the two substrates together providing EMI shielding of the MEMS device and the one or more electronic components.

3. A package according to claim 1 or claim 2 in which one or more electrical contacts of the MEMS device are wire bonded to the flex substrate, the one or more electrical connecting elements being provided to provide electrical conduction paths between electrical contacts on the flex substrate in electrical contact with the wire bonds and corresponding contacts provided on the second substrate.

4. A package according to claim 1 or claim 2 in which the MEMS device comprises one or more electrical contacts facing away from the flex substrate, the one or more electrical connecting elements being provided between the one or more electrical contacts and corresponding contacts provided on the second substrate.

5. A package according to any preceding claim in which the conductive spacer element is composed of metal.

6. A package according to claim 5 in which the conductive spacer element is formed of Cu and plated with nickel and gold

7. A package according to any of claims 1 to 4 in which the conductive spacer element is a plastic frame plated with nickel and gold.

8. A package according to claim 3 in which the electrical connecting elements are solder performs, solderable adhesive or large solder balls.

9. A package according to any preceding claim in which the second substrate is a FR4 printed circuit board or a flex substrate comprising an insulating laminar body and conductive layers on one or both of its major surfaces.

10. A package according to any preceding claim in which the flex substrate includes an aperture permitting interaction between the MEMS element and the environment outside the package.

11. A package according to claim 10 further comprising an adhesive tape layer carried on the flex substrate and extending across the aperture.

12. A method of forming a MEMS package comprising:

mounting at least one MEMS device on a first flex substrate,

mounting one or more electronic components on a second substrate,

connecting the two substrates in parallel by joining the substrates to a conductive spacer element, the substrates sandwiching between them the MEMS device, the conductive spacer element and the one or more electronic components.

13. A method according to claim 12 in which the conductive spacer element has a window surrounding the MEMS device and the one or more electronic components, the conductive spacer element and conductive layers on the substrates together providing EMI shielding of the MEMS device and the one or more components.

14. A method according to claim 12 in which the conductive spacer element is first connected to the second substrate, and subsequently connected to the first flex substrate.

15. A method according to claim 12 in which the conductive spacer element is first connected to the first flex substrate, and subsequently connected to the second substrate.

16. A method according to claim 12, claim 13, claim 14 or claim 15 in which:

said step of mounting the MEMS device on the flex substrate includes forming wire bonds between one or more electrical contacts of the MEMS device and corresponding contacts on the flex substrate, and

said step of connecting the substrates includes providing one or more conductive interconnecting elements which form electrical conduction paths between the electrical contacts on the flex substrate in electrical contact with the wire bonds, and corresponding contacts provided on the second substrate.

17. A method according to claim 12 in which the MEMS device comprises one or more electrical contacts facing away from the flex substrate, said step of connecting the two substrates including providing conductive paths between the one or more electrical contacts on the MEMS devices and corresponding contacts provided on the second substrate.

18. A method according to claim 17 in which the conductive paths are provided by solder balls.

19. A method according to any of claims 12 to 18 in which the second substrate comprises an insulating laminar body and conductive layers provided on one or both of its major surfaces.

20. A method according to any of claims 12 to 19 further including forming an aperture in the flex substrate.

21. A method according to claim 20 further including providing an adhesive tape on the flexible substrate, the aperture and adhesive tape being positioned such that the adhesive tape extends over the aperture.

22. A method according to any of claims 12 to 21 in which the first and second substrates are connected at a time when at least the second substrate is a portion of a body comprising multiple second substrates, the method further including a step, following connection of the first and second substrates, of singulating the body to form the individual package.

23. A method according to claim 22 in which, prior to the singulation step, the second substrate is electrically connected to other second substrates contained within the body by vias, and during the singulation step the vias are divided leaving respective via portions on each of the second substrates.