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# CRACK-RESISTANT COMPOUND WITH CEMENT FILLER FOR INTEGRATED CIRCUIT PACKAGING APPLICATIONS

## FIELD OF THE INVENTION

The present invention relates to semiconductor device packaging and more particularly to compounds with active fillers used for package molding, die attachment, integrated circuit encapsulation, solder joint underfill and other applications in semiconductor manufacturing.

## BACKGROUND OF THE INVENTION

Current trends in semiconductor device packaging are demanding larger die sizes and thinner device packages in many applications. Unfortunately, the problem of cracking in device packages such as plastic surface mounts worsens as die size is increased and package thickness is reduced. A type of package cracking which often occurs during a solder reflow operation is referred to as "pop-corn" cracking and is generally attributed to the high internal pressure generated during evaporation of moisture previously absorbed by the package.

FIGS. 1A-1D illustrate pop-corn cracking in a surface mount packaged semiconductor device 10. The surface mount package of device 10 includes a package body 12 which in this example is formed from a resin molding compound. The package body 12 encapsulates a semiconductor integrated circuit 14 bonded by a die-attach adhesive to a die pad 16. The package body 12 also supports leads 18, 20 which are part of a leadframe and allow electrical connection of the integrated

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circuit 10 to external circuitry.

FIG. 1A illustrates moisture absorption by the package body 12. The moisture is shown by arrows 22 and may be diffused into the package body 12 from an ambient or controlled environment while the device 10 is being stored between manufacturing operations.

FIGS. 1B-1D show a possible mechanism of pop-corn cracking during a solder reflow operation. The solder reflow operation is carried out at a temperature in the range between about 220 °C to 260 °C such that solder used in prior manufacturing steps will reflow. The reflow improves the strength and conductivity of any solder connections within the device 10. FIG. 1B shows that heating device 10 during the solder reflow operation to a temperature of 220 °C or more creates a high water vapor pressure in the pores of package body 12 at the interfaces with die attach pad 16 as well as in the bulk resin molding compound material. The interfaces tend to be weaker than the bulk material due to factors such as poor adhesion, high pore densities and interfacial stress resulting from mismatch in the coefficient of thermal expansion (CTE) of the resin package body 12 and the die attach pad 16. The interface between the die-attach pad 16 and package body 12 is generally one of the weakest interfaces in the device 10. FIG. 1B indicates that peeling can occur at the interface 24 between die-attach pad 16 and package body 12 during the solder reflow operation.

FIG. 1C shows that the evaporation of absorbed moisture in combination with the peeling shown in FIG. 1B leads to a doming effect in region 26. A crack 28



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begins to form in package body 12 at an interface with die-attach pad 16. FIG. 1D shows that the combination of high pressure steam exerted by vaporizing moisture and the accompanying thermal stresses become greater than the package body 12 can withstand, and the crack 28 then extends to an outer surface of the package to thereby vent the steam. It is apparent from FIGS. 1A-1D that moisture absorption by a plastic surface mount package can cause package failure, and that the relatively weak interface between the encapsulant and die-attach pad is often the point at which the failure originates.

One possible technique for overcoming the above-described problems of moisture-induced package cracking is known as dry packing. The dry packing technique involves first baking the device 10 to remove moisture and then maintaining device 10 in a controlled environment to prevent subsequent absorption of moisture. For example, the device 10 may be placed in a sealed bag or other container for storage between manufacturing operations. The sealed bag prevents moisture absorption by package body 12 such that subsequent reflow operations performed on device 10 will be less likely to induce package cracking. Although the dry packing technique alleviates the cracking problem to some extent, it also suffers from a number of drawbacks. For example, the baking and packing operations unduly extend manufacturing time and increase manufacturing costs. The need to obtain and/or dispose of the sealing containers may create other problems. In addition, device packages will generally need to be re-baked and re-sealed if the container seal is broken for any reason.



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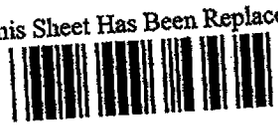


Another approach to solving the package cracking problem has been to attempt to improve the reflow temperature strength, adhesion strength and moisture absorption of the plastic molding compound which forms the package. This effort has resulted in a molding compound which includes a low glass transition temperature (Tg) material, biphenyl epoxy, with a high percentage by weight of silica as a filler. The low Tg biphenyl epoxy compound is described in greater detail in, for example, N. Mogi and H. Yasoda, "Development of High-Reliability Epoxy Molding Compound for Surface Mount Devices," 42nd ECTC, 1992, pp. 1023-1029; H. Fujita and N. Mogi, "High-Reliability Epoxy Molding Compound for Surface Mount Devices," 43rd ECTC, 1993, pp. 735-741; A.S. Shen et al., "A Study of the Interactions of Molding Compound and Die Attach Adhesive, with Regard to Package Cracking," 44th ECTC, 1994, pp. 115-120; and G.L. Lewis et al., "Role of Materials Evaluation in VLSI Plastic Packages in Improving Reflow Soldering Performance," 44th ECTC, 1994, pp. 177-185; all of which are incorporated by reference herein.

Although the low Tg biphenyl epoxy with silica filler provides reduced moisture absorption properties and therefore improvement over other known molding compounds, it does not exhibit sufficient reflow temperature strength, adhesion strength and thermal match to adequately overcome the package cracking problem. Other prior art molding compounds exhibit similar problems. These other prior art compounds include general molding compounds, such as Cresol-novolac epoxy molding compounds, and are described in greater detail in, for example, T. Nashioka et al., "Special Properties of Molding Compounds for Surface Mounting Devices," 40th



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ECTC, 1990, pp. 625-631; S. Kim, "The Role of Plastic Package Adhesion in IC Performance," 41st ECTC, 1991, pp. 750-758; S. Ito et al, "Molding Compound for Thin Surface Mount Packages and Large Chip Semiconductor Devices," 41st ECTC, 1991, pp. 190-197; and G.L. Tan and T.B. Lim, "Pop-corn Package Cracking: Critical Review and New Finding," IPFA '95, pp. 170-176; all of which are incorporated by reference herein.

As is apparent from the above, a need exists for a crack-resistant compound for use in semiconductor package molding, die-pad adhesion and other applications and which provides high reflow temperature strength, strong adhesion to and good thermal match with an integrated circuit die, die-attach pad and/or leadframe, as well as low moisture absorption.

## SUMMARY OF THE INVENTION

The present invention provides a crack-resistant compound suitable for use in semiconductor packaging applications such as package molding or integrated circuit die attachment. The compound utilizes anhydrous cement as a full or partial substitute for fillers such as silica, silicone, alumina and others currently utilized in conventional molding compounds. The weight ratio of cement in the filler may be on the order of from about 1% to up to 100% of the filler by weight. The compound exhibits the desirable properties of high strength at reflow temperatures, strong adhesion and thermal match to an integrated circuit die, die-attach pad and leadframe, and reduced moisture absorption. As such, the compound substantially reduce the



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incidence of "pop-corn" cracking in plastic surface mounts and other types of semiconductor device packages. The compound may be utilized to form a package body for a packaged semiconductor device and/or as an adhesive for attaching an integrated circuit die to an attach pad or other substrate in a semiconductor device package. The compound may also be utilized in other semiconductor packaging applications including, for example, underfill for solder joint protection.

In accordance with one embodiment of the invention, a semiconductor device is provided which includes a package body, an integrated circuit die, a die-attach pad, and a leadframe. The package body is formed from a molding compound which includes anhydrous cement as a filler. The cement may be Portland or non-Portland cement and as noted above may represent between 1% and 100% of the filler by weight. The molding compound may be biphenyl epoxy or other conventional molding or adhesive materials. The cement filler may be a replacement for conventional silica, silicon, alumina or other fillers used in prior art molding compounds.

In accordance with another embodiment of the invention, a semiconductor device is packaged using a compound which includes a conventional material such as biphenyl epoxy along with anhydrous cement as an active filler. The compound may be used to, for example, form a package body for the semiconductor device and/or to attach an integrated circuit die to a die-attach pad in the semiconductor device.

The compound of the present invention utilizes an anhydrous cement filler and therefore provides a number of advantages over prior art molding compounds and adhesives in semiconductor packaging applications. The high strength at reflow



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temperatures resists package cracking induced by high vaporization pressure of moisture during solder reflow operations. The low moisture absorption and diffusion reduce the risk of vaporization pressure formation at internal interfaces. The high adhesion strength to die, die-attach pad and leadframe eliminate the delamination of interfaces. A good thermal match with the die, die-attach pad and leadframe decrease interfacial stresses of the package to thereby prevent delamination and cracking. The cement filler is generally less expensive than conventional fillers such as silica, silicone or alumina, and therefore partial or complete substitution of a cement filler can significantly reduce the cost of a molding or adhesive compound.

These and other advantages and features of the present invention will become more apparent from the accompanying drawings and the following detailed description.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1A-1D illustrate exemplary "pop-corn" cracking in a surface mount plastic semiconductor device package.

FIGS. 2A-2D show four stages in the setting and hardening of Portland cement which may be used as an active filler in a package molding compound in accordance with the present invention.

FIG. 3 shows the relationship between compressive strength and amount of silica added to cement for mixes cured for 24 hrs. at 177 °C (curve A) and for 28 days at 21 °C (curve B).



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## DETAILED DESCRIPTION OF THE INVENTION

The present invention will be described below using an exemplary epoxy-based molding compound in which the silica, silicone and/or alumina filler conventionally utilized in accordance with prior art techniques is replaced with an anhydrous cement filler. The invention is illustrated using exemplary plastic surface mount packaging and die attachment applications. It should be understood, however, that the invention may be implemented using any of a number of other molding or adhesive compounds which are known in the art. These alternative molding or adhesive compounds include integrated circuit encapsulants such as glue-top and screen printing encapsulants, underfill materials, and die attach materials. Furthermore, the invention may be utilized in applications other than semiconductor packaging. These alternative applications include any other application in which encapsulation, adhesion and/or underfill by a moisture-resistant and crack-resistant compound is desirable, such as in general purpose encapsulation materials, paints or coatings.

The present invention recognizes that a molding compound resistant to the above-described "pop-corn" cracking problem should include the following desirable characteristics:

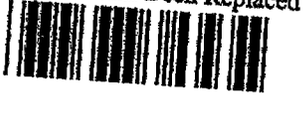
(a) high strength at reflow temperatures to resist package cracking induced by high vaporization pressure of moisture during solder reflow;

(b) low moisture absorption and diffusion to reduce the risk of vaporization pressure formation at internal interfaces;

(c) strong adhesion strength to an integrated circuit die, die-attach pad and/or



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leadframe to thereby eliminate interface delamination; and

(d) good thermal match with the integrated circuit die, die-attach pad and/or leadframe to thereby decrease interfacial stress and prevent delamination and cracking.

The above properties are provided in one embodiment of the invention by fully or partially replacing conventional silica, silicone or alumina fillers in prior art molding compounds with an anhydrous cement filler. The anhydrous cement may represent from about 1% to up to 100% of the filler by weight depending upon the application. For example, the cement filler may be utilized in the above-described biphenyl epoxy molding compound which generally includes between about 75% to 80% of silica filler by weight. A preferred cement weight percentage suitable for use in the filler of the biphenyl epoxy molding compound is about 10 to 80 percent. Of course, alternative amounts of cement by weight could also be used in the biphenyl epoxy molding compound. Cement may also be used as a complete or partial substitute filler in other conventional molding compounds such as Cresol-novolac epoxy molding compounds.

The term "anhydrous cement" as used herein should be understood to include both Portland cement and non-Portland cement. The term "non-Portland cement" refers to all types of cement other than Portland cement. Exemplary types of non-Portland cement suitable for use with the present invention include aluminous cements, slag cements and pozzolanic cements. Although cement has been used as an element in paints, it has not been heretofore utilized as a filler to provide the



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above-noted desirable properties in a molding or adhesive compound.

**TABLE 1. Composition of Portland Cement**

| | Grey Cement (%) | Grey Clinker (%) | White Clinker (%) | | Grey Cement (%) | Grey Clinker (%) | Grey Clinker (%) |
|---|---|---|---|---|---|---|---|
| $SiO_2$ | 18-24 | 21.7 | 23.8 | LSF[d] | 88-102 | 98.4 | 97.2 |
| $Al_2O_3$ | 4-8 | 5.3 | 5.0 | LCF[e] | - | 96.2 | 93.8 |
| $Fe_2O_3$ | 1.5-4.5 | 2.6 | 0.2 | S/R[f] | 1.5-4 | 2.7 | 4.6 |
| CaO | 62-67 | 67.7 | 70.8 | A/F[g] | 1-4 | 2.0 | 25 |
| MgO | 0.5-4.0 | 1.3 | 0.08 | $C_3S$% | - | 65.4 | 59.4 |
| $K_2O$ | 0.1-1.5 | 0.5 | 0.03 | $C_2S$% | - | 12.9 | 23.5 |
| $Na_2O$ | 0.1-1.0 | 0.2 | 0.03 | $C_3A$% | - | 9.6 | 12.9 |
| $SO_3$ | 2.0-3.0 | 0.7 | 0.06 | $C_4AF$% | - | 7.9 | 0.6 |
| LOI[a] | 3.0 | - | - | | | | |
| IR[b] | 1.5 | - | - | | | | |
| Free lime[c] | 0.5-1.5 | 1.5 | 2.5 | | | | |

(a) Loss on ignition ($CO_2$ + $H_2O$)
(b) Insoluble residue
(c) Also included in total CaO
(d) Lime saturation factor
(e) Lime combination factor
(f) $SiO_2/(Al_2O_3 + Fe_2O_3)$.
(g) $Al_2O_3/Fe_2O_3$.

TABLE 1 above shows exemplary compositions of conventional Portland cement and clinkers which may be used as a filler in a molding or adhesive compound in accordance with the invention. A clinker is a cement particle and is intended to be included within the term "anhydrous cement" as used herein. As can be seen from the table, Portland cement includes primarily $SiO_2$ and CaO which combine to produce calcium silicates $Ca_3SiO_5$ or $CA_2SiO_4$.

TABLE 2 below compares the properties of Young's modulus and coefficient of thermal



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expansion (CTE) for various filler materials, including silicone, silica and hydrated cement. It can be seen from the table that hydrated cement exhibits a Young's modulus of about 80 $kN/mm^2$ as compared to 71.7 for silica, and a CTE of about 1 ppm/°C as compared to 3.5 for silicone and 0.55 for silica.

**TABLE 2. Comparison of Young's Modulus and CTE for Various Filler Materials**

| Filler Material | Young's Modulus, $Kn/mm^2$ | CTE, ppm/°C |
|---|---|---|
| Silicone | ---- | 3.5 |
| Silica | 71.7 | 0.55 |
| Hydrated Cement | ~ 80 | ~ 1 |

The present invention utilizes anhydrous cement such as the Portland cement described in TABLE 1 as an active filler in a molding compound. The cement filler is distinct from the above-noted conventional silica, silicone or alumina fillers in a number of different respects. For example, the anhydrous cement can react with water to form new hydrated forms through the hydration reaction of cement as shown in equations [1] and [2] below.

$$2Ca_3SiO_5 + (6\text{-}8)H_2O = Ca_3Si_2O_7.(3\text{-}4).H_2O + 3Ca(OH)_2 \quad [1]$$

$$2Ca_2SiO_4 + (4\text{-}6)H_2O = Ca_3Si_2O_7.(3\text{-}4).H_2O + Ca(OH)_2 \quad [2]$$

The resulting hydration products of the cement filler are stable at solder reflow



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temperatures below about 300 °C and therefore absorbed moisture will not be vaporized out of a molding compound with a cement filler during a typical 220 °C to 260 °C solder reflow operation. This reduces the likelihood of pop-corn cracking during solder reflow. In contrast, conventional fillers such as silica, silicone and alumina are generally inert to the permeance of moisture. The anhydrous cement filler of the present invention thus plays a more active role than conventional fillers by actively reducing the influence of moisture in the molding compound.

FIGS. 2A-2D show simplified diagrammatic representations of an exemplary sequence of changes undergone by an anhydrous cement filler in the presence of moisture, as described in H.F.W. Taylor in The Chemistry of Cement, London & New York, Vol. 1, page 21, (1964). FIG. 2A shows dispersion of a number of unreacted cement grains in water. FIG. 2B shows the cement grains after a few minutes when hydration products have eaten into and grown out from the surface of each grain. FIG. 2C shows the result after a few hours when the coatings of different cement grains have begun to join together to form a continuous gel. This phenomenon is generally referred to as setting. FIG. 2D shows the filler after a few days when further development or hardening of the gel has occurred. The interlocking of the hydration product crystals formed on adjacent grains of the cement filler increases the mechanical strength of the molding compound.

FIG. 3 illustrates the compressive strength of hydrous cement after hardening as a function of the amount of silica added to the cement, as described in the above-cited reference by H.F.W. Taylor at p. 423. Curve A corresponds to a hydrous



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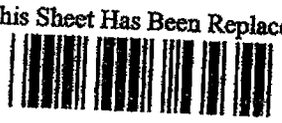
cement mix cured for 24 hrs. at 177 °C and curve B corresponds to a mix cured for 28 days at 21 °C. It can be seen from FIG. 3 that with either curing curve the amount of silica added to the mix beyond about 20% generally decreases the resulting compressive strength of the hardened mix. This is a general indication that cement in proper amounts can provide greater overall mix strength after curing than silica.

The present invention as applied to molding compounds used in semiconductor packaging provides a number of significant advantages. First, the cement filler significantly inhibits the permeance of moisture into a device package formed from the molding compound after partial hydration of the outer package surface. During the above-described hydration reactions, the hydration products formed on the individual cement grains extend and begin to join together such that a continuous gel is formed in the spaces between grains. During the final hardening stage the particles between the grains become increasingly densely packed, until the material can be regarded as a solid mass of particles in contact with each other as shown generally in FIG. 2D. The hydration reaction of the cement filler thus prevents or inhibits the permeance or ingress of moisture into the molding compound.

Second, the cement filler substantially eliminates the above-noted problem of pop-corn package cracking during solder reflow. At solder reflow temperatures below 300 °C, the moisture absorbed during the hydration of the cement filler will not be evaporated. That is, the hydration products of the cement filler in the molding compound are stable under typical solder reflow conditions. The pop-corn cracking problem as illustrated in FIGS. 1A-1D will therefore be alleviated.



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Third, the cement filler significantly increases the strength of the molding compound. Unlike currently used fillers, the grains of cement, after hydration, form a substantially continuous phase in the molding compound. The interlocking of the hydration product crystals formed on adjacent cement grains increases the mechanical strength of the molding compound.

Fourth, the cement filler increases the adhesion strength of the molding compound at internal interfaces with an integrated circuit die, die attach pad or leadframe. Unlike conventional fillers which have little or no adhesion capability, hydration products of cement exhibit good adhesion to the die, die-attach pad and leadframe and therefore decrease the likelihood of delamination at an interface.

Finally, the cement filler can reduce the cost of the molding compound. Commercial cement is generally much cheaper than silica, silicone, alumina or other fillers currently used in conventional molding compounds. A typical molding compound such as the above-described biphenyl epoxy molding compound can include on the order of 75% to 80% by weight of filler. The use of inexpensive cement as a full or partial substitute for the more expensive conventional fillers can therefore significantly reduce the materials cost in molding compound manufacture.

The present invention may also be applied to low moisture die-attach adhesive materials. The term "compound" as used herein should therefore be understood to include both molding compounds and adhesive compounds. Die-attach adhesives are commonly used to attach integrated circuit chips to die pads in plastic packages or to ceramic substrates in hermetic packages. Anhydrous cement can be used in



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accordance with the invention as an active filler in the conventional adhesives to thereby make the adhesives low moisture-sensitive. Low moisture polymer adhesives can significantly prevent delamination in an interfaces between a die and the die-attach pad/substrate. Low moisture polymer adhesives with cement filler in accordance with the invention can also eliminate moisture-induced corrosion package failures. An exemplary conventional polymer adhesive includes about 80 percent by weight of silver as a filler. In accordance with the invention, a cement filler may be completely or partially substituted for the conventional silver filler. In this example, a percentage by weight of about 5 to 50 percent of cement may be used in the filler, such that cement makes up about 4 to 40 percent by weight of the resulting adhesive compound. The advantages noted above with regard to molding compounds are thereby provided in adhesives. Further details of these and other adhesives are well-known in the art and are therefore not described in detail herein.

The above-described embodiments of the invention are intended to be illustrative only. Numerous alternative embodiments may be devised by those skilled in the art without departing from the scope of the following claims.



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**CLAIMS**

1. A semiconductor device package comprising:

a semiconductor die;

a die-attach pad; and

a package body substantially encapsulating the die and die-attach pad;

wherein the package body is formed from a molding compound with a filler including cement.

2. The device package of claim 1 wherein the filler comprises between about 1% and 100% of anhydrous cement by weight.

3. The device package of claim 1 wherein the molding compound further includes an epoxy.

4. The device package of claim 3 wherein the epoxy is biphenyl epoxy.

5. The device package of claim 1 wherein the compound is used to adhere the die to the die-attach pad.

6. The device package of claim 1 wherein the cement is anhydrous Portland cement.



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7. The device package of claim 1 wherein the cement is anhydrous non-Portland cement.

8. A method of packaging a semiconductor device including a semiconductor die, a die attach pad and a leadframe comprising the step of forming from a molding compound including a cement filler a package body substantially encapsulating the semiconductor die and die attach pad and at least a portion of the leadframe.

9. The method of claim 8 wherein the filler comprises between about 1% and 100% of anhydrous cement by weight.

10. The method of claim 8 wherein the molding compound further includes an epoxy.

11. The method of claim 10 wherein the epoxy is a biphenyl epoxy.

12. The method of claim 8 further including the step of attaching the die to the die attach pad using the compound.

13. The method of claim 8 wherein the cement is anhydrous Portland cement.

14. The method of claim 8 wherein the cement is anhydrous non-Portland cement.



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15. A compound for use in semiconductor device packaging applications, the compound including a filler comprising anhydrous cement.

16. The compound of claim 15 wherein the filler comprises between about 1% and 100% of anhydrous cement by weight.

17. The compound of claim 15 wherein the compound further includes an epoxy.

18. The compound of claim 17 wherein the epoxy is biphenyl epoxy.

19. The compound of claim 15 wherein the cement in the filler is anhydrous Portland cement.

20. The compound of claim 15 wherein the cement in the filler is anhydrous non-Portland cement.



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