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(54) **HEAT SPREADER BALL GRID ARRAY (HSBGA) DESIGN FOR LOW-K INTEGRATED CIRCUITS (IC)**

(75) Inventors: **Yian-Liang Kuo**, Hsinchu (TW); **Yung-Sheng Huang**, Hsin-Chu (TW); **Yu-Ting Lin**, Hsin-Chu (TW)

(73) Assignee: **Taiwan Semiconductor Manufacturing Co. Ltd.**, Shinchu (TW)

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H01L 23/10 (2006.01)

(52) **U.S. Cl.** **257/706**; 257/720; 257/790; 257/704; 257/738; 438/122; 174/52.4

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See application file for complete search history.

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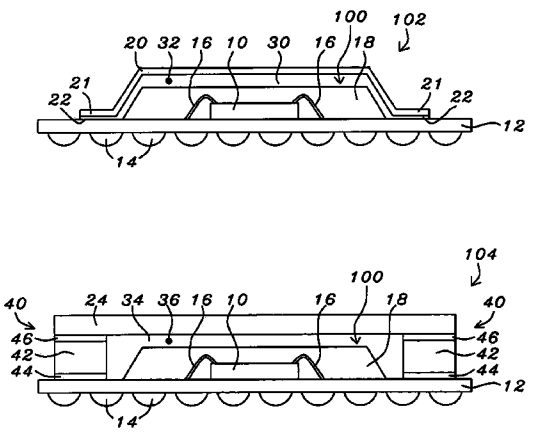
Primary Examiner—Kenneth Parker
Assistant Examiner—Chris C. Chu
(74) *Attorney, Agent, or Firm*—Thomas, Kayden, Horstemeyer & Risley

(57) **ABSTRACT**

A method of forming a heat spreader ball grid array package, and the resultant heat spreader ball grid array package, comprising the following steps. A semiconductor chip affixed to a ball grid substrate is provided. The semiconductor chip over the ball grid substrate is encased with a molding compound. A heat spreader is mounted over the ball grid substrate and spaced apart from the molding compound to form a gap. Thermal grease is placed into the gap, at least between the heat spreader and the molding compound, to form the heat spreader ball grid array package. It is also possible to place thermal grease over the molding compound and then mounting the heat spreader over the ball grid substrate.

30 Claims, 2 Drawing Sheets



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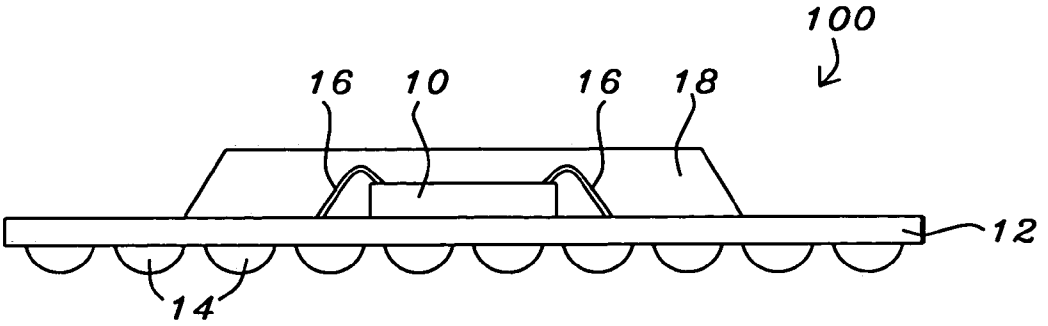

FIG. 1

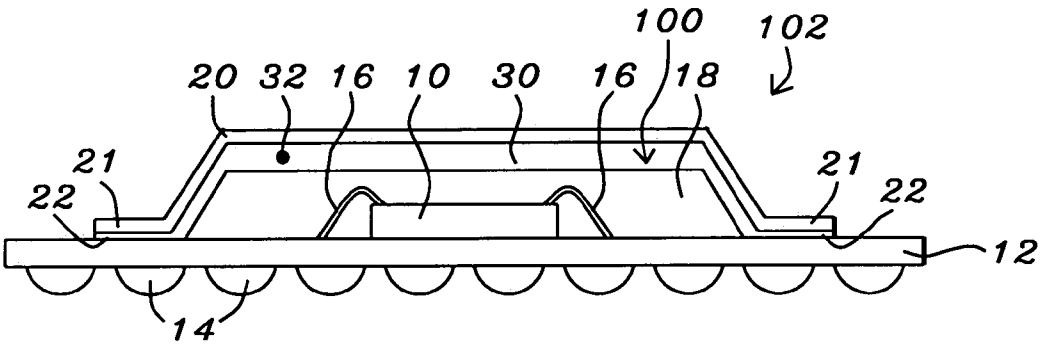

FIG. 2A

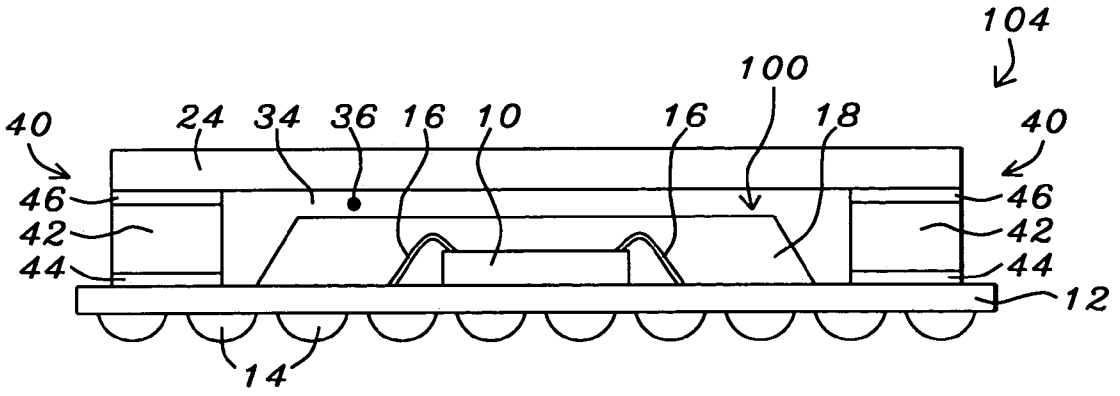

FIG. 2B

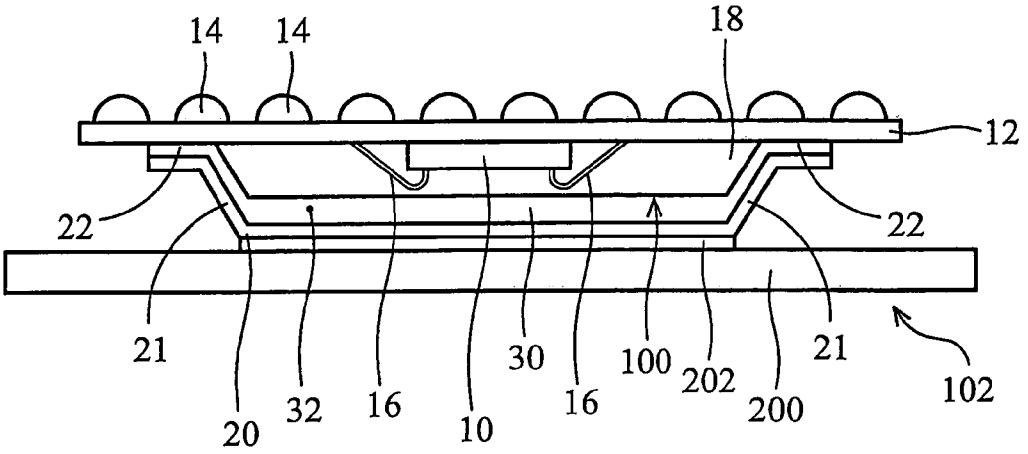
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FIG. 3A

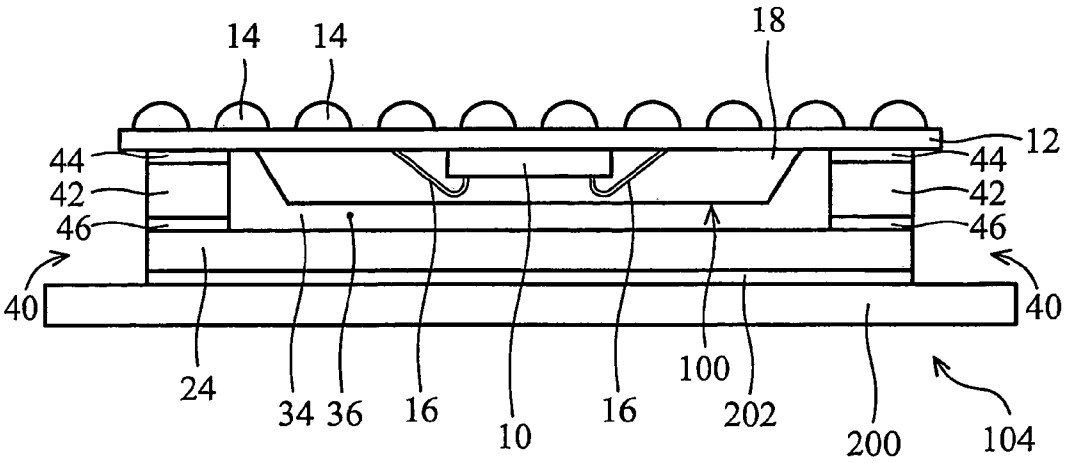
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FIG. 3B

HEAT SPREADER BALL GRID ARRAY (HSBGA) DESIGN FOR LOW-K INTEGRATED CIRCUITS (IC)

FIELD OF THE INVENTION

The present invention relates generally to semiconductor chip packaging and more specifically to ball grid array (BGA) packages.

BACKGROUND OF THE INVENTION

Because of their capacity of high input-output (IO) number and high speed, ball grid array (BGA) packages have become the main stream of package types for advanced integrated circuit (IC) products. Such advanced IC products produce lots of heat which require the use of heat spreaders to form heat spreader ball grid array (HSBGA) packages in order to dissipate the extra heat. However, such HSBGA packages have higher thermal stresses while TC/TS tests and low dielectric constant (k) (LK) materials show weak robustness with the HSBGA packages cracking or delaminating, thus failing qualification tests. LK (low-k) is a dielectric material having a dielectric constant of less than about 3.9, the dielectric constant of silicon oxide (SiO_2), that is used to insulate adjacent metal lines (interlayer dielectric (ILD) or intermetal dielectric (IMD)) in advanced micro devices. Low-k material reduces capacitive coupling ("cross-talk") between lines. LK dies are dies with LK IMD (intermetal dielectric) layers, i.e. their IMD layers use LK dielectric materials.

TC is Temperature Cycling and a TC test is conducted to determine the resistance of a part to extremes of high and low temperatures, and to alternate exposures to these extremes. TS is Thermal Shock and the purpose of TS testing is to determine the ability of sold state devices to withstand exposure to extreme changes in temperature by thermally stressing the device. Thermal shock effects include cracking and delamination of substrates or wafers, opening of terminal seals or case seams and changes in electrical characteristics. If more than 30 cycles are performed, the test is considered to be destructive.

Flip-chip packages are not a cost-effective alternative as they cost about 10 times that of HSBGA packages.

U.S. Pat. No. 5,977,633 to Suzuki et al. describes a semiconductor device with metal base substrate having hollows.

U.S. Pat. No. 5,223,741 to Bechtel et al. describes a package for an integrated circuit structure.

U.S. Pat. No. 5,585,671 to Nagesh et al. describes a low thermal resistance package for high power flip chip ICS.

U.S. Pat. No. 6,462,410 B1 to Novotny et al. describes an integrated circuit component temperature gradient reducer.

U.S. Pat. No. 4,748,495 to Kucharek describes a high density multi-chip interconnection and cooling package.

SUMMARY OF THE INVENTION

Accordingly, it is an object of one or more embodiments of the present invention to provide an improved heat spreader ball grid array (HSBGA) design and a method of fabricating the same.

Other objects will appear hereinafter.

It has now been discovered that the above and other objects of the present invention may be accomplished in the following manner. Specifically, a semiconductor chip affixed to a ball grid substrate is provided. The semiconductor chip

over the ball grid substrate is encased with a molding compound. A heat spreader is mounted over the ball grid substrate and spaced apart from the molding compound to form a gap. Thermal grease is placed into the gap, at least between the heat spreader and the molding compound, to form the heat spreader ball grid array package. It is also possible to place thermal grease over the molding compound and then mounting the heat spreader over the ball grid substrate. The invention also includes the heat spreader ball grid array package structure so formed.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be more clearly understood from the following description taken in conjunction with the accompanying drawings in which like reference numerals designate similar or corresponding elements, regions and portions and in which:

FIGS. **1**, **2**A, and **3**A schematically illustrate a first preferred embodiment of the present invention.

FIGS. **1**, **2**B, and **3**B schematically illustrate a second preferred embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Information Known to the Inventors—Not Prior Art

The following is known to the inventors and is not to be considered as prior art to the instant invention.

Flip-chips do not have a failure problem when a heat spreader is used and the inventors have determined that this is because thermal grease is used as a buffer between the chip and the heat spreader to release stress caused by the introduction of the heat spreader.

Structure Common to Both Preferred Embodiments of the Present Invention—FIG. **1**

FIG. **1** illustrates a ball grid array (BGA) chip **100** structure common to the first and second preferred embodiments of the present invention.

The ball grid array (BGA) chip **100** includes semiconductor chip **10** mounted onto a substrate **12** and is electrically connected to substrate **12** by, for example, lead wires **16**. Substrate **12** includes balls **14** mounted on its surface opposite the silicon semiconductor chip **10**.

Semiconductor chip **10** generally has a coefficient of thermal expansion (CTE) of about $3*10^{-6}$/K. Semiconductor chip/die **10** is preferably comprised of silicon (Si), germanium (Ge) or silicon germanium (SiGe) and is preferably silicon as will be used for purposes of illustration hereafter.

Semiconductor chip/die **10** generally has a coefficient of thermal expansion (CTE) of preferably from about $2.5*10^{-6}$/K to $3.5*10^{-6}$/K and more preferably about $2.8*10^{-6}$/K when comprised of silicon and from about $5.5*10^{-6}$/K to $6.5*10^{-6}$/K and more preferably about $6.1*10^{-6}$/K when comprised of germanium.

Balls **14** are preferably comprised of 63Sn37Pb (63% Sn+37% Pb— likely to be forbidden due to environmental protection), 96.5Sn3.5Ag (96.5% Sn+3.5% Ag— lead-free and expected to be used in the future due to environmental protection); 95.5Sn3.8Ag0.7Cu (95.5% Sn+3.8% Ag+0.7% Cu— lead-free) or 96.2Sn2.5Ag0.8Cu0.5Sb (96.2% Sn+2.5% Ag+0.8% Cu+0.5% Sb— lead-free) and are more preferably 63Sn37Pb for the present and 96.5Sn3.5Ag if 63Sn37Pb is banned.

Molding compound **18** encases silicon semiconductor chip **10** and lead wires **16**. Molding compound **18** is preferably an epoxy molding compound comprised of:

a) Epoxy resin: preferably from about 10 to 20 weight %; function—binder, increases moldability, cure speed, melt viscosity and resistance to voiding; generates minimal paddle shift and wire sweep; controls level on ionic concentration; typical agents—Cresol-Novolac epoxy (high temperature) DGEBA;

b) Curing agent: preferably from about 5 to 15 weight %; function—increases moldability, improves electrical properties, increases heat and humidity resistance; typical agents—amines, phenols and acid anhydrides;

c) Catalyst: very low concentration and preferably about 1 weight %; function—enhances rate of polymerization to decrease in-mold cure time; typical agents—amines, imidazoles, organophosphines, ureas, Lewis acids and their organic salts (preferred);

d) Coupling agent: very low concentration and preferably less than about 2 weight %; function—promotes interfacial adhesion between matrix polymer and inorganic filler; improves heat and humidity resistance; increases or decreases viscosity of molding compound; typical agents—silancs, titanates, aluminum chelates and zircoaluminates;

e) Filler: preferably from about 50 to 75 weight %; function—provides lower TCE, increases thermal conductivity, improves electrical and mechanical properties, reduces resin bleed at parting line, reduces shrinkage; typical agents—ground fused silica (widely used), alumina;

f) Flame retardant: preferably from about 2 to 5 weight %; function—retards flammability; typical agents—brominated epoxies, antimony trioxide;

g) Mold-release agent: trace amounts; function—aids in release of package from mold; minimizes moisture ingress and corrosion; typical agents—silicones, hydrocarbon waxes, inorganic salts of organic acids;

h) Coloring agent: preferably about 5 weight %; function—reduces photonic activity, provides device visibility, aesthetics; typical agents—carbon black; and

i) Stress-relief additive: preferably about 1 weight %; function—inhibits crack propagation, reduces crack initiation, lowers thermomechanical shrinkage; typical agents—silicones, acrylontrile-butadiene rubbers, polybutyl acrylate.

Molding compound **18** has a coefficient of thermal expansion (CTE) of preferably from about $5*10^{-6}$/K to $12*10^{-6}$/K or $15*10^{-6}$/k and more preferably about $7*10^{-6}$/K.

Formation of the First Preferred HSBGA Package **102** in Accordance with the Present Invention—FIG. **2**A

FIG. **2**A illustrates the formation of the heat spreader ball grid array (HSBGA) package **102** in accordance with the first preferred embodiment of the present invention.

Heat spreader **20** is placed over and above BGA chip **100** leaving a resultant gap **30** between the molding compound **18** that encases the semiconductor chip **10** and the heat spreader **20**. Heat spreader resembles an inverted square pie tin with an enlarged surrounding lip **21** which lip **21** is affixed to substrate **12** as by epoxy adhesive **22** as shown in FIG. **2**A.

Heat spreader **20** is preferably comprised of copper (Cu), aluminum (Al), chromium (Cr) plated on Cu, Cr plated on Al, nickel (Ni) plated on Cu, Ni plated on Al, stainless steel or other like materials and is more preferably Cu. The coefficient of thermal expansion (CTE) of the heat spreader **26** is preferably from about $10*10^{-6}$/K to $25*10^{-6}$/K depending upon the materials and is more preferably about $17*10^{-6}$/K for copper (Cu).

Further processing may then proceed. For example, heat spreader **20** may then be mounted onto a PCB substrate or stiffener **200** using an adhesive **202**, as shown in **3**A.

In an important aspect of the present invention, thermal grease **32** is inserted into the gap **30** between the heat spreader **20** and the molding compound **18** to fill gap **30**. Although the thermal grease **32** does not have to completely fill gap **30**, the more completely the thermal grease does fill gap **30**, the better the performance. It is preferably that a portion of gap **30** remains once the thermal grease **32** is inserted to allow for the thermal grease **32** to expand to release stress.

It is also noted that it is possible to place the thermal grease over the molding compound **18** and then mounting the heat spreader **24**.

Thermal grease **32** (also called thermal interface materials) is preferably a grease (silicon rubber) containing heat-conducting particles such as zinc oxide, aluminum oxide, aluminum nitride, boron nitride or ceramic fillers or other materials which have the properties of heat conduction.

The thermal grease **32** is thermally conductive and serves as a thermally conductive interface between the heat spreader **20** having a CTE of about $17*10^{-6}$/K, for example, and the molding compound **18** having a CTE of about $7*10^{-6}$/K, for example. This greatly reduces the thermal stress otherwise inherent and has been found to reduce cracking and delamination by up to from about 50 to 90% (depending upon the types of thermal grease **32** used and the selected thermal grease's filling process) in the first embodiment heat spreader ball grid array (HSBGA) package **102**. HSFCBGA (heat spreader flip chip ball grid array) has better heat-releasing properties than FCBGA but doesn't suffer higher stress which could damage LK dies. At present, PBGA could be used to assemble LK dies but HSBGA could not. However, HSBGA is required due to cost concern and heat-release.

Formation of the Second Preferred HSBGA Package **104** in Accordance with the Present Invention—FIG. **2**B

FIG. **2**B illustrates the formation of the heat spreader ball grid array (HSBGA) package **104** in accordance with the second preferred embodiment of the present invention.

Surrounding pillar **40** is formed around, and spaced apart from, ball grid array chip **100** (pillar **40** looks like a square ring). Pillar **40** comprises a stiffener portion **42** affixed to the substrate **12** as by epoxy adhesive **44**. Stiffener portion **42** is preferably comprised of copper (Cu) (mainly) and aluminum (Al), chromium (Cr) plated on Cu, chromium plated on Al, nickel (Ni) plated on Cu, nickel plated on Al or other materials such as stainless steel and is more preferable copper (Cu).

Heat spreader **24** is affixed upon the upper end of pillar **40** as by epoxy adhesive **46** so that heat spreader **24** is over and above BGA chip **100** leaving a resultant gap **34** between the molding compound **18** that encases the semiconductor chip **10** and: (1) the pillar **40**; and (2) the heat spreader **24**.

Heat spreader **24** is preferably comprised of copper (Cu), aluminum (Al), chromium (Cr) plated on Cu, Cr plated on Al, nickel (Ni) plated on Cu, or Ni plated on Al and is more preferably Cu. The coefficient of thermal expansion (CTE) of the heat spreader **26** is preferably from about $10*10^{-6}$/K to $25*10^{-6}$/K depending upon the materials and is more preferably about $17*10^{-6}$/K for copper (Cu).

Further processing may then proceed. For example, heat spreader **24** may then be mounted onto a PCB substrate or stiffener **200** using an adhesive **202**, as shown in **3**B.

In an important aspect of the present invention, thermal grease **36** is inserted into the gap **34** at least between the heat spreader **24** and the molding compound **18**. It is preferable that a portion of gap **34** remains once the thermal grease **36** is inserted to allow for the thermal grease **36** to expand to release stress.

It is also noted that it is possible to place the thermal grease over the molding compound **18** and then mounting the heat spreader **24**.

Thermal grease **36** (also called thermal interface materials) is preferably a grease (silicon rubber) containing heat-conducting particles such as zinc oxide, aluminum oxide, aluminum nitride, boron nitride or ceramic fillers or other materials which have the properties of heat conduction.

The thermal grease **36** is thermally conductive and serves as a thermally conductive interface between the heat spreader **24** having a CTE of about $17*10^{-6}$/K, for example, and the molding compound **18** having a CTE of about $7*10^{-6}$/K, for example. This greatly reduces the thermal stress otherwise inherent and has been found to reduce cracking and delamination by up to from about 50 to 90% (depending upon the types of thermal grease **36** used and the selected thermal grease's filling process) in the second embodiment heat spreader ball grid array (HSBGA) package **104**.

In both the first and second preferred HSBGA packages **102**, **104** the thermal grease **32**, **36** acts as a buffer to release the stress from the respective heat spreaders **20**, **24** and transmits heat from the molding compound **18** to the heat spreaders **20**, **24** so as to remove the heat from the silicon semiconductor chip **10**/molding compound **18**. The thermal grease **32**, **36** must have high thermal conductivity, high viscosity and high elasticity.

Advantages of the Present Invention

The advantages of one or more embodiments of the present invention include:

1. its possible to apply HSBGA package types on LK dies;
2.lower stress impact on LK dies;
3.high thermally conductive performance;
4.lower cost of assembly than the use of present HSBGA processes;
5.the process and tools used to attach the heat spreader is the same as HSFCBGA (flip chip with heat spreader);
6.the process and tools for BGA is the same as general PBGA;
7. easier assembly process than the one of the present HSBGA processes; and
8. low requirement of the property of molding compound.

While particular embodiments of the present invention have been illustrated and described, it is not intended to limit the invention, except as defined by the following claims.

We claim:

1. A heat spreader ball grid array package, comprising:

a ball grid substrate;

a semiconductor chip affixed to the ball grid substrate;

a single molding compound without interfaces, encasing the semiconductor chip over the ball grid substrate;

a heat spreader mounted over the ball grid substrate and spaced apart from the molding compound to form a gap; and

thermal grease within the gap at least between the heat spreader and the molding compound, wherein the thermal grease comprises silicon rubber containing heat-conducting particles, the heat spreader has a shape of an inverted square pie tin having an elongated surrounding lip mounted over the ball grid substrate and the heat spreader has a surface exposed to a surrounding ambient, not contacting the mounding compound and the thermal grease.

2. The structure of claim **1**, wherein the semiconductor chip is a silicon chip, a germanium semiconductor chip or a silicon germanium semiconductor chip.

3. The structure of claim **1**, wherein the molding compound is selected from the group consisting of epoxy resin and a curing agent; and the heat spreader is selected from the group consisting of copper, aluminum, chromium plated on copper, chromium plated on aluminum, nickel plated on copper and nickel plated on aluminum.

4. The structure of claim **1**, wherein the molding compound is comprised of epoxy resin; and the heat spreader is comprised of copper.

5. The structure of claim **1**, wherein the silicon rubber containing heat-conducting particles are selected from the group consisting of zinc oxide, aluminum oxide, aluminum nitride, boron nitride or ceramic fillers which have the properties of heat conduction.

6. The structure of claim **1**, wherein the molding compound is selected from the group consisting of epoxy resin, curing agent, a catalyst and a coupling agent.

7. The structure of claim **1**, wherein the molding compound has coefficient of thermal expansion of from about $5*10^{-6}$/K to $15*10^{-6}$/K; and the heat spreader has a coefficient of thermal expansion of from about $10*10^{-6}$/K to $25*10^{-6}$/K.

8. The structure of claim **1**, wherein the molding compound has coefficient of thermal expansion of about $7*10^{-6}$/K; and the heat spreader has a coefficient of thermal expansion of $17*10^{-6}$/K.

9. The structure of claim **1**, wherein the semiconductor chip is a silicon chip and has a coefficient of thermal expansion of from about $2.5*10^{-6}$/K to $3.5*10^{-6}$/K.

10. The structure of claim **1**, wherein the heat spreader being mounted onto the ball grid substrate at the elongated surrounding lip using epoxy adhesive.

11. The structure of claim **1**, wherein the thermal grease nearly fills the gap.

12. The structure of claim **1**, further including a pillar formed onto the ball grid substrate outboard of the semiconductor chip and the molding compound; wherein the heat spreader is mounted to the pillar.

13. The structure of claim **1**, further including a pillar formed onto the ball grid substrate outboard of the semiconductor chip and the molding compound; the pillar including a stiffer portion; wherein the heat spreader is mounted to the pillar.

14. The structure of claim **1**, further including a pillar formed onto the ball grid substrate outboard of the semiconductor chip and the molding compound; the pillar including a copper stiffener portion; wherein the heat spreader is mounted to the pillar.

15. The structure of claim **1**, wherein the heat spreader comprises a tilted sidewall connected with the elongated surrounding lip.

16. A heat spreader ball grid array package, comprising:

a ball grid substrate;

a semiconductor chip affixed to the ball grid substrate;

a single molding compound without interfaces, encasing the semiconductor chip over the ball grid substrate;

thermal grease over the molding compound, wherein the thermal grease comprises silicon rubber containing heat-conducting particles;

a heat spreader mounted over the ball grid substrate, the molding compound and the thermal grease; and

a PCB substrate or a stiffener mounted to the heat spreader, wherein the heat spreader has a shape of an inverted square pie tin having an elongated surrounding lip mounted over the ball grid substrate, and the heat spreader has a sidewall surface exposed to a surrounding ambient, not contacting the mounding compound and the thermal grease.

17. The structure of claim **16**, wherein the semiconductor chip is a silicon chip, a germanium semiconductor chip or a silicon germanium semiconductor chip.

18. The structure of claim **16**, wherein the molding compound is selected from the group consisting of epoxy resin and a curing agent; and the heat spreader is selected from the group consisting of copper, aluminum, chromium plated on copper, chromium plated on aluminum, nickel plated on copper and nickel plated on aluminum.

19. The structure of claim **16**, wherein the molding compound is comprised of epoxy resin; and the heat spreader is comprised of copper.

20. The structure of claim **16**, wherein the silicon rubber containing heat-conducting particles are selected from the group consisting of zinc oxide, aluminum oxide, aluminum nitride, boron nitride or ceramic fillers which have the properties of heat conduction.

21. The structure of claim **16**, wherein the molding compound is selected from the group consisting of epoxy resin, curing agent, a catalyst and a coupling agent.

22. The structure of claim **16**, wherein the molding compound has coefficient of thermal expansion of from about $5*10^{-6}$/K to $15*10^{-6}$/K; and the heat spreader has a coefficient of thermal expansion of from about $10*10^{-6}$/K to $25*10^{-6}$/K.

23. The structure of claim **16**, wherein the molding compound has coefficient of thermal expansion of about $7*10^{-6}$/K; and the heat spreader has a coefficient of thermal expansion of $17*10^{-6}$/K.

24. The structure of claim **16**, wherein the semiconductor chip is a silicon chip and has a coefficient of thermal expansion of from about $2.5*10^{-6}$/K to $3.5*10^{-6}$/K.

25. The structure of claim **16**, wherein the heat spreader being amounted onto the ball grid substrate at the elongated surrounding lip using epoxy adhesive.

26. The structure of claim **16**, wherein the thermal grease nearly fills the gap.

27. The structure of claim **16**, further including a pillar formed onto the ball grid substrate outboard of the semiconductor chip and the molding compound; wherein the heat spreader is mounted to the pillar.

28. The structure of claim **16**, further including a pillar formed onto the ball grid substrate outboard of the semiconductor chip and the molding compound; the pillar including a stiffener portion; wherein the heat spreader is mounted to the pillar.

29. The structure of claim **16**, further including a pillar formed onto the ball grid substrate outboard of the semiconductor chip and the molding compound; the pillar including a copper stiffener portion; wherein the heat spreader is mounted to the pillar.

30. The structure of claim **16**, wherein the sidewall surface is a tilted sidewall surface connected with the elongated surrounding lip.

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