

SPECIFICATION

Semiconductor device

- 5 The present invention relates to a semiconductor device, and, more specifically, to a semiconductor device having a semiconductor element sealed within it which may be, for example, a memory circuit. 5

In general, semiconductor elements are sealed by a sealing member such as a ceramic material, a glass or a plastics material (resin). Of such sealing members (hereinafter referred to as packages), packages made of ceramic material contain uranium and thorium in amounts of several ppm. As mentioned, for example, in 16th Annual Proceedings of 1978 International Reliability Physics Symposium, April 18-20, 1978, San Diego, U.S.A., however, these impurities emit alpha-particles causing the memory circuit to operate erroneously. Thus the reliability of the semiconductor elements may be decreased greatly. 10

- 15 Uranium and thorium release energy over a range of 4 to 9 MeV when they decay naturally. The energy distribution of alpha-particles emitted from the package, however, ranges from 0 to 9 MeV, since alpha-particles generated in the package interact with molecules of the material before they are emitted from its surface. 15

The alpha-particles which are incident on a silicon pellet excite electrons as they penetrate the pellet whilst gradually losing energy. Therefore, the range of the alpha-particles in the silicon is in inverse proportion to the density of the silicon and is directly proportional to the initial energy of the alpha particle. In silicon, alpha-particles excite electrons to transfer an energy of 3.6 eV. A typical 5 MeV alpha particle has a range of 25 μ m in silicon. The electrons excited in silicon give rise to the generation of holes, so that electron-hole pairs are generated along the path of the alpha-particles. If the energy of the alpha-particles is 5 MeV, the number of excited electrons Ne is given by, 20

$$Ne \approx 5 \text{ MeV} / 3.6 \text{ eV} = 1.4 \times 10^6$$

- 30 This is equivalent to an electric charge of 0.22 picocoulombs. The electrons then diffuse along the concentration gradient, and recombine with holes to annihilate the pairs. However, when the electric charge is supplemented by electrical biasing, and this biasing is significant when compared with the electric charge under boundary conditions in a pellet, the device operates erroneously. Such erroneous operation takes place without deterioration of the physical properties of the semiconductor element, and is hence often called a soft error. 35

In order to prevent such soft errors, the package material should be purified to a high concentration so that it does not contain either uranium or thorium. Usually, however, the package material is made of a composite material consisting of several raw materials, and may contain impurities introduced by the various manufacturing steps. Therefore, it is difficult to make the whole package which does not contain uranium or thorium. Even if a suitable material were obtained, the package will not be suitable for practical commercial application because of its high cost of manufacture. 40

According to the present invention there is provided a semiconductor device comprising a support substrate and a cap extending over a surface portion of the support substrate, the cap and the support substrate defining an enclosure for a semiconductor element, the semiconductor element being located on the surface portion of the support substrate over which the cap extends, there being a shielding member for shielding the semiconductor element from alpha-particles radiated from the cap the shielding member being located within the enclosure on a surface portion of the cap opposing the surface portion of the support substrate carrying the semiconductor element, at least a part of the shielding member lying adjacent but spaced from an active region of the semiconductor element. 45

The active region is where carriers (electrons and/or holes) generated in the semiconductor element by an external voltage are actively excited, so that the element operates as an active element (such as a transistor or a diode) or as a passive element (such as a capacitor or a resistor). 50

Embodiments of the present invention will now be described in detail by way of example, with reference to the accompanying drawings, wherein:

Figures 1 to 9 are cross-sectional views illustrating a plurality of semiconductor devices embodying the present invention;

Figure 10 is a diagram to illustrate the operation of the present invention; 60

Figure 11 is a cross-sectional view of a memory cell;

Figure 12 is a diagram of an equivalent circuit of the memory cell illustrated in Fig. 11;

Figure 13 is a plan view of a second memory cell;

Figure 14 is a diagram of an equivalent circuit of the second memory cell illustrated in Fig. 13; and 65

Figure 15 is a diagram of a memory cell circuit of a bipolar RAM (Random Access Memory).

Fig. 1 shows a semiconductor device in which a support substrate 1 and a cap 10 forming a package of a semiconductor element (referred to hereinafter as a pellet) are made of a high alumina ceramic (Al_2O_3 content of 90% by weight or more).

5 The support substrate 1 has a recess 3 in its centre, and the pellet 2 is attached via a gold layer (Au layer) 5 onto a bottom portion 4 of the recess 3. Leads 8, extending externally of the device are attached to the surfaces of projections 6 of the support substrate 1, the leads 8 being made of a Ni(42%) - Fe(58%) alloy or a Ni(29%) - Co(17%) - Fe(54%) alloy and being attached via a glass with a low melting-temperature ($\text{PbO}-\text{B}_2\text{O}_3$ type) which melts to a sufficient degree at a temperature of 400° to 500°C . Aluminium is coated onto the upper surface of the inner tips of the leads 8 by means of a metal vapourization or a cladding method. An aluminium wire 9 is bonded to bonding pads (not shown) of the pellet 2 and to the inner tips of the leads 8, such that the leads 8 are electrically connected to the bonding pads of the pellet 2.

10 The device has a cap 10 having a highly purified substrate 11 forming a shielding member attached to a recessed bottom surface by a suitable adhesive 5'. The highly purified substrate 11 may be of single-crystal silicon Si having a thickness of 50 to $150\text{ }\mu\text{m}$ purified to a degree in the range of 99.999% (one part in a hundred thousand) to 99.99999999 (one part in a ten thousand million). The substrate material should be purified to a degree comparable with that of the silicon pellet 2 which incorporates a transistor or other semiconductor element. The thickness of the substrate 11 may be varied slightly depending upon the number and energy of the alpha-particles emitted from the cap 10, but is preferably greater than $50\text{ }\mu\text{m}$. The layer 5' used to adhere the substrate 11 onto the cap 10 is usually gold. Thus, the silicon substrate 11 is adhered onto the recessed bottom surface of the cap 10 by a eutectic of silicon and gold. An SiO_2 film (not shown) is coated onto the surface of the substrate 11 facing the pellet 2 such that a short-circuit will not occur if a plurality of aluminium wires 9 contact its surface. The glass 7 is adhered to the surfaces of the projections of the cap 10. The cap 10 and the support substrate 1 are adhered together by the glass 7 to seal completely the pellet 2.

The substrate 11 may be made of any material if it can be purified to a condition in which it does not contain alpha sources. Metals and insulating material may provide suitable results.

30 For example, a highly purified aluminium plate of which the surface is anodically oxidized to a thickness of about $5\text{ }\mu\text{m}$ may be thermally stuck onto the recessed bottom surface of the cap 10 using glass as the adhesive agent 5'. Here, the anodic oxidation is not necessary, provided the aluminium wires 9 are spaced from the aluminium substrate 11. The aluminium plate should have a purity of about 99.999% (one part in a hundred thousand) and a thickness of 0.05 mm to 0.5 mm. As an alternative to an aluminium substrate, an oxygen free copper substrate may be employed.

In the device of Fig. 1, in which the substrate 11 is provided only on the recessed bottom surface of the cap 10 facing the upper surface of the pellet 2, the pellet 2 is shielded from the alpha-particles emitted from the cap 10 by the substrate 11. In addition, since alpha-particles are only radiated by the highly purified substrate 11 to a very small amount, soft error can be prevented to a sufficient degree.

40 In a pellet 2 having a plurality of Metal-Insulator-Semiconductor (MIS) type transistors on its surface alpha-particles generated below the pellet surfaces (upper surface) do not affect the active regions, such as channel regions or information storage regions, formed on the surface of the MIS transistors, and can be neglected. This is because the range of the alpha-particles in the pellet 2 is about 25 to $50\text{ }\mu\text{m}$. Therefore, even if alpha-particles generated from the support substrate have passed into the interior of the pellet from its lower surface, they do not reach the channel regions or the information storage regions at the surface of the pellet 2, which usually has a thickness of $150\text{ }\mu\text{m}$ to $500\text{ }\mu\text{m}$.

50 Thus the problems caused by alpha-particle sources are due to materials above the pellet surface. Such materials include the end surfaces of the leads 8, end surfaces of cap glass 7, side surfaces in the recessed portion of the cap 10, and the bottom surface of the recessed portion of the cap. Of these, the last has the greatest area with respect to the surface of the pellet 2, and alpha-particles emanating from this surface are the major cause of soft error.

55 However, the number of alpha-particles emitted differs depending upon the materials. Table 1 shows examples of these values.

TABLE

5	Source of radiation	Major material	Product	Number of alpha-particles radiated (number/cm ² .hr.)	5
10					10
	Support substrate and cap	High alumina ceramic (Al ₂ O ₃ content is 90% by weight or greater)	A	0.51	
			B	0.20	
15	Low softening glass	PbO-B ₂ O ₃ type	C	4.00	15
		(PbO content is greater than 60% by weight)	D	20.0	
20			E	3.2	20
			F	2.0	
25	Lead	Ni(29%)-Co(17%)-Fe(54% alloy)	G	0.20	25
		Ni(42%)-Fe(58%) alloy	H	0.20	
30		Epoxy resin (Acid anhydride cure)	I	0.20	30
		Ceramics surface of a laminated ceramics package	J	1.20	
35	Sealing member and sealing portion	(Al ₂ O ₃ content is greater than 90% by weight)	K	0.05	35
40		Ceramics surface and tungsten metallized Surface of a laminated ceramics package	L	2.00	40
45		(Al ₂ O ₃ content is greater than 90% by weight, and W content is greater than 90% by weight)			45

As will be obvious from Table 1, the number of alpha-particles radiated greatly differs depending upon the material product. For a semiconductor device consisting of a cap 10 made of material B which radiates alpha-particles at a minimal level (0.20/cm².hr) and a cap glass 7 made of material F (2.0/cm².hr), the total number of alpha-particles which affect the pellet surface when the relative effect based upon areas is taken into consideration, is given by

$$0.20 \times (0.90 \text{ to } 0.99) + 2.0 \times (0.1 \text{ to } 0.01) = 0.38 \text{ to } 0.218/\text{cm}^2.\text{hr.}$$

Here, the end surfaces of the leads 8 which affect the pellet surfaces have very small areas, radiate alpha-particles in numbers as small as 0.20/cm².hr as shown in Table 1, and can therefore be disregarded. If the leads 8 are at positions lower than the upper surface of the pellet 2, the alpha-particles radiated from the end surfaces of the leads 8 can be completely ignored. If the substrate 11 containing virtually no alpha-sources is provided in the recessed portion of the cap 10, the total number of alpha-particles incident on the pellet 2 is given by the second term on the left side only of the above equation, i.e. 0.2 to 0.02/cm².hr. Therefore, the number of alpha-particles are reduced to one-half to one-tenth of the number if the material 11 is not provided.

Fig. 2 shows a semiconductor device having a support substrate 1 and a cap 10 which are made of a high alumina ceramic in the same way as in the device of Fig. 1. In this and the remaining figures, the same reference numerals are used to denote the same features as in Fig. 1. In this embodiment, a highly purified material 12, which gelatinizes or solidifies from a liquid state upon after treatment such as curing, is adhered onto the recessed bottom surface of the cap 10, instead of the highly purified material in the form of a substrate 11 shown in Fig. 1. The material 12 may be, for example, silicone rubber, polyimide resin or polyimide isoindole quinazoline dione resin. When such a material is used, effects similar to those of the device of Fig. 1 can be obtained, and the manufacturing procedure can be simplified.

The use of a substrate 11 (Fig. 1), or the material 12 (Fig. 2) can reduce the effect of the alpha-particles on the pellet surface to one-half to one-tenth. Further reduction of this effect can be achieved in a semiconductor device as shown in Fig. 3.

In Fig. 3, the highly purified substrate 11 is brought close to the effective surfaces or active regions of the pellet 2, so that the solid angle of incidence of alpha particles from the side surfaces of the recess in the cap 10 is minimized. The active regions of the pellet 2 are located inwardly of the electrode terminals, the inner portion of the cap 10 facing to the electrodes having a projection 13 to which the substrate 11 is stuck. The device is sealed in a conventional manner. The aluminium wires 9 are thus located at positions away from the projection 13 and are not crushed by the projection 13. The active regions of the sealed pellet 2 are directly opposite the substrate 11 with only a small clearance. Therefore, the angle at alpha particles can pass is much reduced.

With this construction, the area of sources of alpha particles which affect the pellet surface is reduced by about $1/5$ to $1/20$. Further, satisfactory results may be obtained using a substrate 11 smaller than that of Fig. 1 and the device can be manufactured inexpensively.

Fig. 4 shows a semiconductor device in which a projection 14 formed in the substrate 11 is located as close as possible to the active region of the pellet 2. If silicon substrate is used as the substrate 11, it is difficult to machine the projection. A suitable substrate 11 is obtained by drawing highly purified aluminium, to form a projection, and highly purified insulating material is coated on the surfaces of the substrate 11 opposite the pellet 2 in order to prevent the wires 9 from being short-circuited. The substrate 11 may alternatively be made of a highly purified insulating substrate e.g. quartz or a high alumina ceramic.

In the device of Fig. 4, the portions of the substrate 11 other than the projection 14 are also made of highly purified material, and thereby stop alpha-particles from surfaces of the cap 10 around the projection 13 (Fig. 3) as is possible problem with the semiconductor device of Fig. 3.

Consequently, the numbers of alpha-particles that affect the pellet surfaces is reduced to $1/5$ to $1/50$.

Moreover, the aluminium substrate 11 which has a thickness less than 0.1 mm, mitigates stress by its plastic deformation, even when it is brought into contact with the pellet 2. Hence, the gap between the aluminium substrate 11 and the pellet 2 can be in the range 0 to 5 μm . In such a case, it is expected that the number of alpha-particles can be reduced to $1/10$ to $1/1000$. An aluminium substrate 11 40 μm thick is sufficient to act as a shield to alpha-particles.

Fig. 5 shows a semiconductor device with a laminated ceramic package construction obtained by laminating a plurality of green ceramic (unsintered) sheets after they have been metallized with tungsten or molybdenum, and sintering them to form a unitary structure. The surface of an exposed metallized layer 15 is plated with nickel and gold. The pellet 2 is fastened to the recessed bottom surface of the support substrate 1. Electrode terminals (not shown) of the pellet 2 are connected via aluminium wires 9 to the metallized layer 15 which is exposed at the projections 16 of the support substrate 1. The periphery of a cap 17 made of a Ni(29%)–Co(17%)–Fe(54%) alloy is fastened to an uppermost metallized layer 15' via a thin ring-like plate 18. Thus, the cap 17 is mounted on the support substrate 1 by a ring welding method to completely seal the pellet 2. The leads 8 are attached to the layer 15 which is metallized onto the bottom surface of the support substrate 1. The silicon substrate 11 may be attached to the inner surface of the cap 17 via a gold layer 5' in the manner shown in Fig. 1. Alpha-particles radiated from the cap 17 are blocked by the silicon substrate 11 and prevented from reaching the active regions of the pellet 2. As is clear from Fig. 5, the substrate 11 which protrudes beyond a sealing surface 19 of the cap 17, serves to facilitate the positioning of the cap 17 with respect to the substrate 1 during the mounting of the cap 17.

Fig. 6 shows a semiconductor device with a laminated ceramic package construction similar to that of Fig. 5 and employing a highly purified material 12 similarly to that of Fig. 2 which is attached to the inner surface of the cap 17.

Fig. 7 shows a semiconductor device of a laminated ceramic package construction has a projection 19 formed on the cap 17 projecting towards the active region of the pellet 2, as in Figs. 3 and 4. Also, the highly purified material 12, like that of Fig. 2, is adhered onto the inner

surface of the cap 17.

The alpha-particles which effect the effective surface of the pellet 2 can be reduced if a cap 10 as shown in Fig. 8 having recesses side surfaces covered with a highly purified material is used or a cap 10 which is made wholly of a highly purified material (not shown) is used.

- 5 Furthermore, greater reduction of alpha particles effects can be obtained if the semiconductor device is constructed as shown in Fig. 9 using the cap 10 of Fig. 8 and a support substrate 1 not having a recessed surface for attaching the pellet 2. Here, the upper surface of the pellet 2 is above the lower edge of the cap 10 which includes a layer 11 of a highly purified material. This material 11 covers the upper surface of the pellet over the entire solid angle that alpha-
10 particles are incident on the element 2 so that the number of alpha particles reaching the element 2 is reduced to within the range $1/1000$ to $1/(1 \times 10^6)$ though it varies depending upon the amount of alpha-particles radiated from the highly purified material 11.

The incident solid angle is the angle θ illustrated in Fig. 10. A shallow incident solid angle means that the angle θ is small, and a deep incident solid angle means that the angle θ is large.

- 15 In Fig. 10 there is shown the path 30 of an incident alpha-particle, and a protective coating 31 formed on the surface of the pellet 2, consisting, for example, of an SiO_2 film. As is clear from Fig. 10 the number of incident alpha-particles which affect the effective surface of the pellet can be reduced by adjusting the thickness of the protective coating 31 of the pellet 2, or by controlling the thickness or area of the highly purified material 11 which shields the pellet 2
20 from alpha-particles.

In the semiconductor devices illustrated above, pieces of a highly purified substance are located so as to prevent the alpha-particles from reaching the semiconductor element.

- The invention can easily be applied to multichip packages other than those of Examples 14 and 15, for instance pellets which form a dynamic RAM (random access memory) or a static
25 RAM consisting of a plurality of insulated gate field effect transistors (IGFETS) which operate with signals of such low values that they may easily be disturbed by alpha-particles.

Figs. 11 to 15 illustrate typical semiconductor devices and their circuits, to which the invention can be applied.

- Fig. 11 illustrates a memory cell construction in a pellet forming such a dynamic RAM. A p-type silicon substrate 30' has a thick SiO_2 coating 31'. A thin SiO_2 film 31A is formed in an opening of the SiO_2 film 31'. Also shown is an N^+ -type diffusion region 32, a first low-resistance polycrystalline silicon layer 33, an insulating coating 34 made of a phosphorus silicate glass formed between the layers, a second low-resistance polycrystalline silicon layer 35,
30 and a passivation coating 36 of a phosphorus silicate glass.

- 35 The second polycrystalline silicon layer 35 formed on the SiO_2 coating 31A serves as a word line W shown in Fig. 12 and as a gate electrode of an N-channel Metal-oxide-semiconductor (MOS) type transistor Q. The N^+ -type diffusion region 32 serves as a digit wire DG shown in Fig. 12. A surface 30A of the substrate corresponding to the drain region of the transistor Q forms a capacitor C for storing information shown in Fig. 12, together with a portion of the first
40 polycrystalline silicon layer 33 which is formed on the surface 30A via the SiO_2 coating 31A. The polycrystalline silicon layer 33 is further connected to a potential supply V shown in Fig. 12. The wiring of information in the form of stored charge, into the capacitor C or the reading of information from the capacitor C is controlled by the switching of the transistor Q.

- A plurality of memory cells thus formed may be provided in semiconductor chips to form a
45 RAM. The density of integration increases with the increase in the memory capacity of the RAM, and cell size decreases. Therefore, with a MOS-type dynamic RAM having a memory capacity of greater than 16 K bits, the capacitance of the capacitor C is very small, and the stored information is easily destroyed by electron-hole pairs formed by alpha-particles incident upon the surface 30A of the substrate 30 giving rise to a soft error.

- 50 Such soft errors can be prevented if the present invention is applied to a dynamic RAM.

- Fig. 13 shows a memory cell in a pellet which forms a static RAM. Regions 41 to 45 surrounded by broken lines are diffusion regions formed in the semiconductor substrate 40. A power supply line VL and a word line WL composed of a polycrystalline silicon layer are formed on the insulation layer which in turn is formed on the surface of the semiconductor substrate
55 40. Shown in Fig. 14 are N-channel MOS transistor Q_1 to Q_4 and load resistors R_1 and R_2 formed by increasing the resistance of portions of the power supply line VL. Bit lines b and $\bar{b}$ and an earth line G are composed of an aluminium layer, and are formed on the insulation layer on the surface of the semiconductor substrate 40 so as to cross the power supply line VL and the word line WL.

- 60 Even in a static RAM, the irradiation of the point A or point B in Fig. 14 by alpha particles causes the operation state (ON or OFF) of the transistors Q_1 and Q_2 to be reversed. However, such a soft error can also be prevented effectively by construction of the device in accordance with the present invention.

- Fig. 15 illustrates a memory cell circuit of a bipolar RAM of the emitter coupled logic (ECL) type to which the present invention can be applied. The memory cell shown in Fig. 23 forms a
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flip-flop relying upon multi-emitter transistors Q_1 and Q_2 and resistors R_1 and R_2 . Also, shown are a potential supply V_{CC} , an address line AD , and data lines D and $\bar{D}$ respectively. Even in a bipolar RAM relying upon the above memory cell construction and having a large capacity and high degree of integration, the electron-hole pairs formed by alpha-particle irradiation cause the state of the flip-flop to be reversed, resulting in the occurrence of a soft error.

Such a soft error can also be effectively prevented by construction of the device in accordance with the present invention.

CLAIMS

1. A semiconductor device comprising a support substrate and a cap extending over a surface portion of the support substrate defining an enclosure for a semiconductor element, the semiconductor element being located on the surface portion of the support substrate over which the cap extends, there being a shielding member for shielding the semiconductor element from alpha-particles radiated from the cap the shielding member being located within the enclosure on a surface portion of the cap opposing the surface portion of the support substrate carrying the semiconductor element, at least a part of the shielding member lying adjacent but spaced from an active region of the semiconductor element.
2. A semiconductor device according to claim 1 wherein a part of the shielding member projects closer to the support substrate than an other part or other parts of the shielding member.
3. A semiconductor device according to claim 1 or claim 2 wherein the shielding member is a highly purified material which gelatinizes or solidifies from a liquid state to form the sealing member.
4. A semiconductor device according to claim 3 wherein the highly purified material includes at least one of silicon rubber, polyimide resin or polyimide isoindolequinazolinedione resin.
5. A semiconductor device according to claim 1 wherein the shielding member comprises a plate of highly purified aluminium.
6. A semiconductor device according to claim 5 wherein the aluminium has a purity of at least 99.999%.
7. A semiconductor device according to any one of the preceding claims, wherein transistors for constituting a memory circuit are formed in the semiconductor element.
8. A semiconductor device substantially as herein described with reference to and as illustrated in any one of Figs. 1 to 10 of the accompanying drawings.



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- 15 on a surface portion of the cap opposing the surface portion of the support substrate carrying the semiconductor element, at least a part of the shielding member lying adjacent but spaced from an active region of the semiconductor element.
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