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D E C I S I O N
of 9 September 1998

Case Number: T 0340/95 - 3.4.1

Application Number: 89202085.0

Publication Number: 0348018

IPC: H01L 23/49

Language of the proceedings: EN

Title of invention:
Resin encapsulated semiconductor device and method of manufacture thereof

Applicant:
Hitachi, Ltd.

Opponent:
-

Headword:
Resin encapsulated semiconductor Device/HITACHI LTD.

Relevant legal provisions:
EPC Art. 56

Keyword:
"Inventive step - main request (denied);
"Auxiliary request (yes)"

Decisions cited:
-

Catchword:
-

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Beschwerdekammern | Boards of Appeal | Chambres de recours

Case Number: T 0340/95 - 3.4.1

D E C I S I O N
of the Technical Board of Appeal 3.4.1
of 9 September 1998

Appellant: Hitachi, Ltd.
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Decision under appeal: **Decision of the Examining Division of the European Patent Office posted 26 October 1994 refusing European patent application No. 89 202 085.0 pursuant to Article 97(1) EPC.**

Composition of the Board:

Chairman: G. Davies
Members: R. K. Shukla
G. Assi

Summary of Facts and Submissions

I. European patent application No. 89 202 085.0 was refused by a decision of the examining division, dated 26 October 1994, on the grounds that the application according to a main request and an auxiliary request filed at the oral proceedings on 6 July 1994, did not comply with the requirement of inventive step according to Articles 52(1) and 56 EPC. The following prior art documents were relied upon in the above decision:

D1: Patent Abstracts of Japan, vol. 6, No. 72 (E-105) [950], 7 May 1982; & JP-A-57 012 531; and

D2: EP-A-0 043 692.

II. The applicants lodged an appeal on 22 November 1994, paid the appeal fee on 23 November 1994 and filed the statement of the grounds of appeal on 3 March 1995. The applicants requested, as a main request and an auxiliary request, respectively, the grant of a patent on the basis of the main request and the auxiliary request submitted during the oral proceedings on 6 July 1994, and oral proceedings before the Board in the event that the main request was not granted. Moreover, the applicants requested that the appeal fee be refunded as the decision under appeal was not fully reasoned, and thereby constituted a serious procedural violation.

III. In a communication annexed to the invitation to attend oral proceedings, the Board cited the following documents D4 and D6 as evidence of common general knowledge in the art, and document D5 (which was cited as document D3 in the proceedings before the examining division):

D4: Manufacturing Engineering and Technology; S. Kalpakjian; Addison-Wesley Publication Co.; page 65;

D5: GB-A-205 5508; and

D6: Fundamentals of Engineering Materials; P. Thornton and V. Colangelo; Prentice-Hall, Inc; pages 470 to 472 and 162 to 163.

In the above communication, the Board expressed its provisional views that the semiconductor device according to claim 1 of the applicants' main request did not appear to involve an inventive step, and that the decision under appeal contained sufficient reasons for the refusal of the application, so that the request for the refund of the appeal fee was not justified.

IV. In response, the applicants filed on 28 August 1998 a main request (this being the main request before the examining division)and several auxiliary requests, and submitted the following documents D7 and D8 to assist in the interpretation of document D4, and an English translation of the opening paragraphs of D1 (i.e. JP-A-57 012 531):

D1': English translation of opening paragraphs of D1 (i.e. JP-A-57 012 531);

D7: Ductile Fracture and Ductility; B. Dodd and Y. Bai; Academic Press, 1987; Section 2.1.5- Measures of ductility; and

D8: An Introduction to Metallurgy; A. Cottrell; Edward Arnold (Publishers) Ltd.; 1982; pages 386 and 387.

V. Oral proceedings were held on 8 and 9 September 1998 before the Board, and on 9 September 1998 the applicants requested the grant of a patent on the basis of the following documents:

Main request:

Claims 1 to 5 filed on 28 August 1998 with the description to be adapted, and the figures as originally filed.

Auxiliary request:

Claims 1 to 4 and pages 1 to 3, 3a and 4 to 11 of the description filed in the oral proceedings on 9 September 1998, and the figures as originally filed.

The request for the refund of the appeal fee due to the alleged procedural violation was withdrawn by the applicants.

VI. The only independent claims 1, respectively, of the main request and the auxiliary request have the following wording:

Main request

Claim 1

"A resin encapsulated semiconductor device having at least one semiconductor element (3) which has at least one electrical connection to a lead frame by means of a wire (1) which has been solid-state bonded at one end to said semiconductor element and at the other end to the lead frame, said element and wire being

encapsulated hermetically with a resin (12), characterised in that said wire (1) is made of Cu and is in the annealed state having a maximum elongation at room temperature of not more than 60%."

Auxiliary request

Claim 1

"A method of manufacturing a resin encapsulated semiconductor device having at least one semiconductor element (3), the method including the steps of:
solid state bonding one end of a wire (1) to a semiconductor element (3) and the other end to a lead frame; and
encapsulating said element and wire hermetically with a resin (12),
characterized in that said wire (1) is made of Cu and, before said bonding step, is fully annealed at a temperature higher than the recrystallization temperature of the metal material, subsequently having a maximum elongation at room temperature of not more than 60%, and in that said wire (1) is bonded to said semiconductor element by ball-bonding and to said lead frame by wedge-bonding, the ball for the ball-bonding being formed on the wire after the annealing of the wire, the ball prior to the ball-bonding being round in shape, symmetrical with respect to the axis of the wire and having substantially no local constriction at its tip adjacent to the ball."

VII. The applicants' submissions in support of the inventive step can be summarised as follows:

(i) **Main request**

The process disclosed in document D1' is specifically directed to the use of aluminium wire which is annealed below the temperature of 400°C after bonding. Annealing is stated to improve elongation of the wire by a factor of two. However, there is no hint at a specific upper limit of 60% elongation of aluminium wire. Moreover, document D1' is not concerned with the problem of bondability, since the annealing of the wire is carried out after bonding. The disclosure in document D2 makes it clear that conventionally aluminium and gold have been used in integrated circuits, and not copper or steel, since the technical problems in the use of copper or steel in mass production of integrated circuits had not been solved. Moreover, there is a clear teaching in document D1' that heating of aluminium wire after bonding should be below 400°C, since otherwise the semiconductor device would be liable to damage. At a temperature below 400°C, copper would not anneal satisfactorily, so that the skilled person would not consider using the method disclosed in document D1' for a copper wire. Furthermore, although in document D4 the elongation value for a copper sample (50 mm long) is disclosed to be the same as that for a similar sample of aluminium, the elongation value in claim 1 in suit is for a fine copper wire in a semiconductor device. As can be seen from the elongation equation 2.14 in document D7, the elongation value at fracture depends upon the dimensions of the wire. Accordingly, it cannot be concluded from the elongation value for copper in

document D4 that a fine copper wire in an annealed state necessarily has an elongation of less than 60%. The inventors have found that in the use of a pre-annealed copper wire, the elongation of the wire in the annealed state has to be no more than 60% to obtain optimum results in terms of resistance to breakage and bondability.

(ii) **Auxiliary request**

According to the method as claimed in claim 1 in suit, the copper wire is fully annealed at a temperature higher than the recrystallisation temperature of copper; after annealing, a round and symmetrical ball is formed at the tip of the wire, there being no constriction in the wire adjacent to the ball, and subsequently, the wire is bonded to a semiconductor element by ball-bonding. There is no suggestion in either D1' or D2 of a product in the form of a wire having a round ball at the tip thereof, the wire having been annealed at a temperature higher than the recrystallisation temperature of the metal material. The essential concept of document D1' is annealing after bonding, which is useful for resistance to stress during encapsulation, and is unrelated to bonding properties. The method of bonding is irrelevant in this document, so that the document is not concerned with the problems of a uniform ball formation and constriction of the wire adjacent to the ball in a ball bonding method, addressed by the present invention. Document D2 makes no mention of pre-annealing, and implies that the ball and the metal wire have a different hardness prior to bonding. It is hindsight to suggest that a skilled person would be prompted to anneal a wire, prior to ball bonding from the teaching of these two documents.

Reasons for the Decision

1. The appeal is admissible.

2. *Main request*

The only issue under consideration in respect of claim 1 is that of inventive step.

2.1 Document D1' discloses the use of a fine (25 µm diameter), hard aluminium wire as an interconnecting lead wire which is ultrasonically bonded to a semiconductor element of a semiconductor device. After the bonding of the wire and prior to resin encapsulation, the device is heated at a temperature above the recrystallisation temperature of aluminium (but not exceeding 400°C), so as to reduce the hardness of the wire, whereby the risk of the breakage of the wire during the resin encapsulation is reduced. The elongation value of the aluminium wire after annealing is not disclosed in document D1'.

Thus, the semiconductor device according to claim 1 is distinguished from the semiconductor device according to document D1' in that

(i) the wire is made of copper;

(ii) it has an elongation of not more than 60 % at room temperature in its annealed state; and

(iii) it is connected between a semiconductor element and a lead frame.

Having regard to the above distinguishing features, the objective problem addressed by the present invention can be seen in providing a semiconductor device employing an interconnection lead wire of a material other than the conventional wire materials such as aluminium and gold, wherein good connection by solid state bonding is formed between the wire on the one hand and the semiconductor element or the external leads on the other hand, and wherein the risk of the breakage of the wire is reduced.

2.2 The use of lead frames in a packaged semiconductor device is well known in the art (see e.g. D5: GB-A-2 055 508), so that the feature (iii) would have been obvious to a skilled person.

2.3 In the consideration of the inventive step, the essential question is, therefore, whether a skilled person concerned with the above problem would consider as obvious the use of a copper wire having the elongation value as set out in feature (ii) above, in the process described in document D1'.

In connection with document D2, it was submitted by the applicants that, (i) it follows from the disclosure in this document that aluminium and gold are conventional metals for lead wires in integrated circuit devices, and (ii) that, where the document refers to extending the method of ball bonding to metals such as copper and steel wires, it is for use outside the electronic field (see the paragraph bridging pages 1 and 2). Although the Board agrees with the above submissions, aluminium and copper are known to be excellent conductors of electricity and can be regarded as equivalents in so far as their electrical conductivity is concerned. Also, as can be see from document D6 (see pages 470 and 472), copper is well known for its corrosion resistance properties, and ease of formability, and it is also

known that work-hardening can increase the tensile strength of copper considerably and annealing can be used to make copper soft and ductile. In the process of document D1', the aluminium wire in the as-drawn state (i.e. prior to annealing) is hard and is softened by annealing at a temperature higher than the recrystallisation temperature of aluminium. Thus, it is evident that copper has the mechanical and metallurgical properties required of a metal wire in the process of document D1'.

As stated above, there is no suggestion in document D1' that, maximum elongation of the wire in the annealed state should be 60%. In the invention as disclosed in the application in suit, however, this maximum value of elongation has no particular significance in the sense that below this value, there is no unexpected improvement in the bondability of the wire or the risk of its breakage. As was submitted by the applicants, the upper limit for elongation ensures that the wire in the annealed state has the optimum hardness to resist forces encountered in resin encapsulation and to provide good bondability. In the Board's view, since it is known that annealing significantly changes the hardness of copper, it would be evident to a skilled person to control annealing, so that the wire does not become excessively soft and retains sufficient stiffness to withstand the forces encountered during resin encapsulation. In the Board's view, therefore, the skilled person would arrive at a maximum elongation of no more than 60% by routine experiments.

It was submitted by the applicants (see paragraphs 16 to 19 of the statement of the grounds of the appeal) that, the high annealing temperature of between 400°C

to 600°C required for copper would damage the semiconductor device, and as a result a skilled person would not consider the use of a copper wire in the process of document D1'.

In this connection, although document D1 teaches to anneal the entire IC device so as to soften the aluminium wire prior to resin encapsulation, it also mentions an alternative method known in the art for avoiding the breakage of the wire, i.e of using soft aluminium which is able to absorb external force. In the Board's view, in the context of the disclosure in D1', this implies that it was known in the art to use **pre-annealed** aluminium wire, whereby the entire device would not need to be annealed. Although, the use of pre-annealed wire is not recommended in document D1', this is only when ultrasonic energy is to be used for bonding. As the invention as claimed is not restricted to ultrasonic bonding, and may employ other type of solid state bonding, e.g. thermocompression bonding, the skilled person in the circumstance of the present case, had the option of annealing the wire prior to bonding. Thus, the requirement of annealing copper at a temperature higher than 400°C would not have deterred the skilled person from using copper in the process of document D1'.

Moreover, even if the skilled person considered annealing the entire device prior to resin encapsulation following the teaching of document D1', it is evident from the application in suit (see column 4, lines 21 to 33) that the temperature range of 400°C to 600°C for copper is a **preferred** temperature range, and that the preferred annealing temperature is in fact higher than the recrystallisation temperature. Thus, it follows that copper can be annealed at a temperature below 400°C and still above its recrystallisation temperature. The annealing period at

the lower temperature would indeed be longer in comparison to that required at a higher annealing temperature. However, it is the temperature, and not the annealing period, which is crucial in the consideration whether or not the device is likely to be damaged by the annealing. Moreover, as can be seen from document D6, the recrystallisation temperature of a plastically deformed metal (or alloy) is known to depend, *inter alia*, upon the degree of plastic deformation, the recrystallisation temperature being lower when a metal is highly deformed than when the metal is lightly deformed. In case of a fine copper wire which is normally highly deformed by the drawing operations, the skilled person would expect its recrystallisation temperature to be lower than 400°C.

In view of the above, the use of a copper wire having the elongation value as specified in the claim would be regarded as obvious by the skilled person.

2.4 For the foregoing reasons, in the Board's judgement, the subject-matter of claim 1 of the main request does not involve an inventive step within the meaning of Article 56 EPC.

3. *Auxiliary request*

3.1 Amendments

Claim 1 is based on claims 6, 7 and 10 as originally filed and additionally contains the following features:

(a) the ball for the ball-bonding process is formed after the wire has been annealed; and

(b) prior to the bonding, the ball is round in shape, symmetrical with respect to the axis of the wire and has substantially no constriction at its tip adjacent to the ball.

The features in paragraph (a) are disclosed on page 10, lines 1 and 2 of the application as filed and also the features in paragraph (b) are derivable from page 7, fourth paragraph and page 11, lines 3 and 4 of the application as filed. The amendments thus comply with the requirements of Article 123(2) EPC.

3.2 Inventive step

The method of manufacturing a resin encapsulated semiconductor device according to claim 1 is distinguished from the method according to document D1' essentially in that,

(i) a copper wire is fully annealed at a temperature higher than the recrystallisation temperature of copper, and subsequently a ball is formed at the tip of the wire; and

(ii) prior to ball-bonding, the ball is round in shape, is symmetrical with respect to the axis of the wire and has substantially no local constriction at its tip adjacent to the ball.

As discussed in the application in suit, annealing of the wire at a temperature above the recrystallisation temperature of copper softens the wire throughout, whereby when the ball is formed at the tip of the annealed wire, the wire has substantially no local constriction at its tip adjacent to the ball, and the latter is formed symmetrically with respect to the axis of the wire. Thus, the problem of short-circuiting due to an asymmetric ball projecting from a bonding pad is

avoided. Also, since the wire is free of local constriction adjacent to the ball, the risk of breakage of the wire at the constriction during the ball bonding is reduced, and the wire forms a smooth loop without any sharp bend when connected between a semiconductor element and a lead frame (see pages 1 to 3 of the application as filed).

The objective problem underlying the present invention can therefore be regarded as providing a method of manufacturing a resin encapsulated device, which method provides a reliable wire connection by ball bonding, and with which there is a low risk of breakage of the wire (see page 3, last full paragraph, of the application as filed).

As mentioned in paragraph 2.3 above, in connection with the disclosure in document D1', it is implicit from this document that it was known in the art to use annealed aluminium wire prior to its bonding for avoiding the breakage of the wire during resin encapsulation. However, the type of bonding, i.e. the ball bonding or wedge bonding, is not relevant for the teaching of this document, and consequently, there is no mention of the prior art problem of the formation of a constriction in the wire adjacent to a ball.

Document D2 concerns the formation of a ball on a metal wire for bonding in an IC device (see pages 1 and 2), but does not mention the problem of breakage of the wire nor discuss advantages of annealing the wire prior to formation of the ball.

In view of the above, the Board agrees with the applicants that documents D1' and D2 do not suggest annealing of the wire with a view to avoiding formation of a constriction in the wire adjacent to the ball in

the ball bonding method, and thereby reduce the risk of the breakage of the wire, or to enabling the wire to form a smooth loop without a sharp bend adjacent to the ball.

For the foregoing reasons, in the Board's judgement, the subject-matter of claim 1 involves an inventive step within the meaning of Article 56 EPC.

3.3 Claims 2 to 4 are dependent on claim 1, and also therefore comply with the requirement of inventive step.

Order

For these reasons it is decided that:

1. The decision under appeal is set aside.

2. The case is remitted to the first instance with the order to grant a patent on the basis of the auxiliary request presented during the oral proceedings.

The Registrar: The Chairman:

M. Beer G. Davies