

METHOD FOR MAKING ELECTRICAL CONTACT
TO SEMICONDUCTOR DEVICES

This invention relates generally to
5 semiconductor devices and particularly to a method of
making electrical contacts to semiconductor devices by low
temperature bonding.

Many types of semiconductor devices require
10 electrical contacts and, accordingly, methods of making
electrical contacts, that are both physically and
electrically reliable, to semiconductor devices are
extremely important in modern technology. In fact, the
making of reliable electrical contacts to such devices is
15 often a critical semiconductor device fabrication step
and, consequently, numerous methods have been developed
for making such contacts. The semiconductor device must
be appropriately contacted by a method that permits the
desired connection to an external power source to be made
20 without adversely altering device or materials
characteristics.

One method that has been developed for making
contacts is commonly referred to by those skilled in the
art as thermocompression bonding. This method was
25 developed for external lead attachment to the electrical
terminals of semiconductor devices. The method is
presently implemented by pushing a metal lead wire into
firm physical contact with the desired metallized surface
using a heated tool. The forces that are applied are
30 typically high enough to produce appreciable plastic
deformation of the lead wire. See, for example, "9th
Annual Proceedings," Reliability Physics, 1971, pp. 175-
186, English et al.

Another method that has been developed is referred to by those skilled in the art as ultrasonic bonding. As this method is typically implemented in present practice, an ultrasonic generator provides high frequency electrical power which is delivered to a transducer. The transducer changes the electrical power into mechanical vibrations which are ultimately coupled to a bonding tool and the metal lead wire which transmits the energy to the bond interface during the bonding process.

See, for example, Semiconductor Measurement Technology: Microelectronic Ultrasonic Bonding, George G. Harman, Editor, National Bureau of Standards, January, 1974, pp. 23-79.

Another bonding method, which is described in U. S. Patent 4,005,523 issued on February 1, 1977 to Samson Khaim Milshtein, achieves bonding with low mechanical stress. The method was developed for gold wire bonding and produces localized high temperatures in the contacted material.

Consideration of the above briefly described processes leads one skilled in the art to the conclusion that while they are perfectly adequate for making many electrical bonds to semiconductor devices, they unfortunately suffer several drawbacks which may significantly and adversely effect device performance for several reasons. For example, during thermocompression bonding, the material is typically heated to an elevated temperature which may be as high as 350 to 400 degrees C. A temperature as high as 200 degrees C may be utilized in ultrasonic bonding methods. The mechanical stresses that are applied to the semiconductor device during the bonding process can generate unwanted defects in the semiconductor material which can result in, for example, catastrophic failures during device operation. As there is no way to accommodate the different thermal expansion coefficients of the contact materials and the semiconductor materials, defects may be generated in these methods. The defects

generated by the lack of matching of thermal expansion coefficients may result in catastrophic failures during device operations when thermal cycling occurs. It should also be noted that the effects of heating and mechanical damage may be deleterious to both device performance and longevity.

According to the present invention there is provided a method of making an electrical contact to a semiconductor device, said method comprising forming on an end portion of a wire, being used in making said electrical contact, a solid enlarged end portion configuration, adding a contact material to said enlarged end portion on the wire positioned by a guide; keeping said contact material at a temperature near its melting point; and touching said contact material to a desired contact point, said touching resulting in heating a localized area around said contact point and in coupling of said enlarged end point configuration and of said contact material so as to form an electrical connection.

We have found that electrical contacts may be made to semiconductor devices comprising semiconductor materials or metallized bonding pads on semiconductor materials by heating the end of a wire which is, for example, attached to a wire bond tip or another type of guide; adding a contact material to the end of said wire; and touching said end of said wire to the desired contact point. The wire comprises an electrically conducting material. The contact material is typically a metal. In one preferred embodiment, a ball comprising the wire material is formed and the contact metal is added to the ball. The ball is advantageously formed by subjecting the wire to a burst from a torch such as a hydrogen flame. The contact metal may have a single constituent or it may be an alloy. In the latter case, additional metals may also be added to the end of the wire to form an alloy, i.e., the metals may be separately contacted. The alloy is typically an appropriate metal alloy having characteristics, such as a low melting point and optimum metallurgical characteristics, consistent with the requirements of device operation, such as operating temperature, etc. The wire need not be heated initially as long as the contact



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metal is maintained at a temperature near its melting temperature after it is added to the end of the wire. When the ball or wire end contacts the surface, it does so under its own weight and forms a bond with the surface. The molten alloy heats a localized portion of the substrate; the ball then cools and the alloy solidifies to form a bond. The metals, forming the alloy, may be selected to optimize device electrical properties, mechanical

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strength, and thermal expansion characteristics. When the wire bond tip is pulled away from the bond, either the tail of the wire is utilized to form a second electrical contact or the tail is left for other types of electrical connections. The method of this invention
5 is advantageously employed in fabricating bonds to damage sensitive Group III-V semiconductor devices such as light-emitting diodes, lasers, and photodetectors.

For a better understanding of the invention, reference is made to the accompanying drawing, in which:-

10 FIG. 1 is a sectional view of the wire bond apparatus after the wire has been heated to form a ball;
and

FIG. 2 is a sectional view of a bond made according to our invention.

15 For reasons of clarity, the elements of the device are not drawn to scale.

Our invention is expeditiously implemented with a conventional wire bonder, and one embodiment, as well as several variations, will be discussed. Other variations will be readily apparent to those
20 skilled in the art. Such wire bonders are well known to those skilled in the art and need not be described in detail. The wire, which is attached to, or carried by, a heated guide, and comprises gold, aluminum, or another suitable material, is heated to a temperature slightly above the melting point of the contact metal. The wire is
25 then extended from the guide tip and subjected to means which form a ball comprising the wire metal at the end of the wire. Typical means comprise a burst from the small torch, such as a hydrogen flame, which is present in typical wire bonding apparatus. The ball is supported by the wire, and the ball is held away from the guide tip.

30 The ball is now contacted to an appropriate contact metal, which may have a single constituent or be an alloy. The contact metal may be in solid or liquid

form. The metal or metal alloy is picked up by the metal ball and either softens or alloys with the ball metal. The contact metal is typically a metal alloy, i.e., it comprises at least two metals, which have characteristics consistent with the requirements of device operation. The structure is depicted in FIG. 1 and comprises guide assembly 1, wire 3, ball 5, and alloy region 7.

10 The guide assembly carries the wire and alloyed ball to the desired contact point, if it is not already at that point, where the ball is lowered onto the contact site on the semiconductor device. The resulting structure is depicted in FIG. 2 with the hatched region 9 indicating
15 a bonding pad or semiconductor device. It should be noted that the ball contacts the surface under its own weight and thus subjects the contacted structure to negligible heating and minimal mechanical stress. The contact or bond is typically formed by the alloy metal which is on
20 the small ball, and as the temperature is low, the amount of heat transmitted to the device surface during the bonding operation is small. The alloy solidifies in a short time, e.g., 1 to 2 seconds. Consequently, the device surface region is subjected only to a small thermal
25 perturbation and, in essence, the bonding is a low stress process. This is advantageous because it minimizes diffusion of the contact materials and impurities in the device within the region of contact and thus does not alter the local materials properties. This was
30 demonstrated on InP-Schottky barrier diode structures which are extremely sensitive to contact formation induced damage.

 The bond dimensions are limited primarily by the size of the wire and the ball formed by the flame. The
35 smallest bond dimension easily obtainable appears to be the wire diameter. The relevant parameters which control the size of the ball are the diameter of the wire and the

length of the wire exposed to the flame, i.e., the amount of material melted.

In practice, the actual contact area is somewhat smaller than the ball diameter. A maximum ball diameter of approximately 6 to 8 wire diameters can be formed. The diameter of the wire which is heated is not critical and wires of essentially any size may be utilized provided that they are consistent with the requirements of the device structure, the guide structure and flame capabilities. In other words, the desired site of the bond is one of the parameters which determines the appropriate wire size. For example, contact pads and devices having dimensions of approximately 60 to 80 μ m may be readily contacted with the method. Smaller contacts may be made if desired. Furthermore, if still larger contact areas or flat contact surfaces are desired, the ball may be deformed by mechanical means. The deformation may be performed by pressing the ball to a suitable nonbonding surface with the wire guide tip. This step may be executed either prior to, or after, contacting the metal alloy material.

The positioning of the metal ball for bonding is easily controlled by the guide apparatus and is thus limited by the mechanical accuracy of the guide and the operator and/or machine capabilities. Of course, this step can be automated. It will be appreciated by those skilled in the art that the limitation regarding operator capabilities is similar to that present in the operation of the standard wire bonding apparatus rather than a limitation unique to our method. The actual position of the bond can in practice be controlled to a fraction of a ball diameter.

Reproducibility of the contact characteristics is limited by the consistency with which the desired length of wire is exposed to the flame, that is, the ball size; the quantity of alloy metal picked up by the ball; and precision of the alloyed ball placement. In practice,

the length of exposed wire may be precisely controlled and the ball dimensions may be similarly controlled. The quantity of the alloy metal picked up may be accurately controlled by the use of metal preforms or a molten metal or metal alloy bath.

5 Contacts may be formed on a variety of surfaces. For example, the contacts may be formed on either bare semiconductor or metallized surfaces. Compound semiconductors selected from the group consisting of Group III-V or Group IV, or Group II-VI
10 compound semiconductors may be contacted by our method. The quality of the electrical and physical characteristics of the contacts
15 fabricated by our method is predicated on the interaction of the alloyed metal and the contacted material. Appropriate alloy systems which exist for various semiconductors and contact metals are well known to those skilled in the art and there is therefore essentially
20 no limitation on the materials which can be bonded. In practice, alloys can be selected which have characteristics, for example, thermal expansion coefficients, that are similar to those of the contacted surface. The ability to utilize various alloy systems enables thermal expansion coefficients to be matched between the
25 contact alloy and the material contacted, e.g., semiconductor or semiconductor metallization, while the alloy composition is also selected to minimize bonding temperature thus again minimizing stresses in the device structure.

 The bond strength depends on the quality of the
25 semiconductor/alloy or metal/alloy interaction. It has been found that mechanical strength of bonds made by our method are sufficient to permit lifting by a force of greater than 7 grams utilizing gold wires 25 μ m in diameter and greater than 12 grams utilizing gold wires 50 μ m in diameter.

30 Bond failure was observed to occur by two primary mechanisms: first, by the wire parting either at the junction of the wire and ball or in the main part of

the wire, i.e., ductile fracture; and second, by the contact ball material parting from the alloy which is bonded to the surface region. Adhesion is influenced by the chemical-mechanical interaction of the contact alloy and the contact material. Bond formation may be further enhanced by utilizing fluxes in the contacting process. The flux may be solid, liquid, or gas. The flux may be used in an intermediate step between the contact alloy pickup and contact formation and/or between heating the wire and contact alloy pickup.

It will be readily appreciated that many materials may be used with our method. Any metal materials which are bonded presently by thermocompression or ultrasonic bonding techniques may be bonded with our technique.

CLAIMS

1. A method of making an electrical contact to a semiconductor device, said method comprising forming on an end portion of a wire, being used in making said electrical contact, a solid enlarged end portion configuration, adding a contact material to said enlarged end portion on the wire positioned by a guide; keeping said contact material at a temperature near its melting point; and touching said contact material to a desired contact point, said touching resulting in heating a localized area around said contact point and in coupling of said enlarged end point configuration and of said contact material so as to form an electrical connection.
2. A method as recited in claim 1, wherein said contact material comprises a contact metal.
3. A method as recited in claim 2, wherein said contact metal comprises at least two metals.
4. A method as recited in claim 2 further comprising the step of adding a flux to the end of said wire.
5. A method as recited in claim 4, wherein said contact point comprises a metallization layer.
6. A method as recited in claim 5, wherein said contact point further comprises a semiconductor material under said metallization layer.
7. A method as recited in claim 6, wherein said semiconductor is selected from Group IV and Group III-V and Group II-VI compound semiconductors.
8. A method as recited in claim 1, wherein the solid end portion is a ball comprising said wire metal.
9. A method as recited in claim 1 or 8, wherein said forming is by heating to a temperature sufficient to melt said wire.
10. A method as recited in claim 9, wherein said heating is by exposing to a torch.
11. A method as recited in claim 8, further comprising the step of adding a flux to the end of said wire.
12. A method as recited in claim 11, wherein said contact



point comprises a metallization layer.

13. A method as recited in claim 12, wherein said contact point further comprises a semiconductor material under said metallization layer.

5 14. A method as recited in claim 13, wherein said semiconductor is selected from Group IV and Group III-V and Group II-VI compound semiconductors.

15. A method as recited in claim 11, wherein said contact point comprises a semiconductor.

10 16. A method as recited in claim 15, wherein said semiconductor is selected from Group IV and Group III-V and Group II-VI compound semiconductors.

17. A method as recited in claim 4, wherein said contact point comprises a semiconductor.

15 18. A method as recited in claim 17, wherein said semiconductor is selected from Group IV and Group III-V and Group II-VI compound semiconductors.

19. A method as recited in claim 2 wherein said adding a contact metal step involves contacting the end portion with a molten bath.

20 20. A method as recited in claim 4, wherein said adding a contact metal step involves contacting the end portion with a molten bath.

21. A method of making an electrical contact substantially as
25 hereinbefore described with reference to the accompanying drawings.

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