Title: ULTRASONIC BONDING OF ELECTRICAL DEVICES

Abstract: A method for bonding an electronic device (1) to a substrate (6) without raising the ambient temperature of the environment is provided by forming a raised metallization layer (5) on a bond pad (4) of the electronic device (1), placing the bond pad (4) of the electronic device opposite a contact pad metallization (7) of the substrate (6) creating an interface between the electronic device (1) and the substrate (6), applying a compressive force normal to the interface between the electronic device (1) and the substrate (6), and applying ultrasonic energy to the electronic device whereby a diffusion joint is formed between the bond pad (4) of the electronic device (1) and the contact pad metallization (7) of the substrate.
SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

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ULTRASONIC BONDING OF ELECTRICAL DEVICES

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BACKGROUND OF THE INVENTION

Field of the Invention
[01] This invention relates to electrically and mechanically bonding an electronic device to conducting bond pads of a flexible or rigid substrate using ultrasonic energy to create a diffusion joint.

Description of Related Art
[02] In the manufacture of highly integrated electronic circuit assemblies, electronic devices, e.g., semiconductor devices, are generally mounted directly onto a substrate, for example, a circuit board. Currently, wire bonding and flip-chip die bonding are two most commonly used technologies. A third, less prolific technique is ultrasonic bonding.

[03] When a wire bonding process is used, a semiconductor chip or other electronic device is mounted face up onto the substrate (e.g., circuit board) by either soldering or using an adhesive. The bond pads of the semiconductor chip are then electrically connected to the wiring of the substrate using thin gold or aluminum wires, which are thermosonically or ultrasonically welded to the bond pads and the contact pads on the substrate. An additional coating of the semiconductor chip, the wires, and the contact pads with a resin to protect the sensitive wires and chip surface is usually required.

[04] In the case of a flip-chip process, the semiconductor chip or other electronic device is mounted face down onto the substrate. Standard technologies for connecting the bond pads of the chip to the wiring on the substrate are soldering or applying anisotropic conductive adhesives. Often a metallic bump is built up onto the bond pads of the semiconductor chip. When employing a soldering technology, this bump acts as a diffusion barrier and enables wetting of the solder to an opposing contact pad. Flip-chip technologies using adhesives require the bump as a stand-off between the chip surface and the substrate surface as well as to enable the electrical connection with the contact pad. Curing of the adhesive is primarily performed at an elevated temperature for a certain period of time.
To create an ultrasonic bond according to the prior art, the bond pads of the electronic device the contact pads of the substrate, each generally gold coated (e.g., by electroplating or stud bumping), are placed in alignment with one another to form an interface. A heating source is used to increase the substrate to an elevated temperatures between 150 °C and 200 °C in order for a bond to be formed. A compressive force is then applied to the back side of the electronic device in a direction generally normal to the interface. Ultrasonic energy is then activated while the compressive force is held and the substrate is heated. The ultrasonic energy is thereby transmitted across the semiconductor device to the substrate in the form of vibration and a diffusion bond is formed.

These technologies do have shortcomings, however. For example, both the wire bonding and flip-chip processes are time consuming—welding wires and building bumps—and can be relatively expensive—gold wires and conductive adhesives are costly. Ultrasonic bonding can be time consuming and poses its own potential problems. With conventional gold-to-gold thermosonic flip-chip bonding, due to relatively high temperatures required (>150 °C) by the process, many types of electronic devices may not be able to bear the high temperatures. Further, the selection of the substrate materials is limited to extremely high grade, high cost materials to withstand the high temperatures. Such high grade substrates are not favored for use in, for example, mass quantity, and in some cases disposable, mobile electronics products, especially with paper or polypropylene substrates desired for smart inlays. Also, when working with soft substrates such as paper or polypropylene, the conventional understanding is that such substrates must be stiffened in order to create a solid ultrasonic bond. Such stiffening is usually achieved by applying a hard metal undercoat, for example, nickel or chrome, underneath the softer copper or aluminum traces forming the contact pads on the soft substrate.

**SUMMARY OF THE INVENTION**

One embodiment of the present invention provides a method for bonding an electronic device to a substrate without raising the ambient temperature of the environment by forming a raised metallization layer on a bond pad of the electronic device; placing the bond pad of the electronic device opposite a contact pad metallization of the substrate creating an interface between the electronic device and the substrate; applying a compressive force normal to the interface between the electronic device and the substrate; and applying ultrasonic energy to the electronic device whereby a diffusion joint is formed between the bond pad of the electronic device and the contact pad of the substrate.
In another embodiment of the present invention, a method is provided for ultrasonically bonding an electronic device without raising the ambient temperature of the environment to a substrate by forming a raised metallization layer on a bond pad of the electronic device; placing the bond pad of the electronic device opposite a contact pad metallization of the substrate creating an interface between the electronic device and the substrate; applying an adhesive to the interface between the electronic device and the substrate; applying ultrasonic energy to the electronic device, whereby a diffusion joint is formed between the bond pad of the electronic device and the contact pad of the substrate; wherein the adhesive is at least partially cured by the ultrasonic energy.

Additionally, other embodiments of the present invention may include methods by which the raised metallization layer is harder than the contact pad metallization, or vice versa, and the metallization layer is at least partially embedded in the contact pad metallization, or vice versa. Other embodiments of the present invention may also include devices configured to implement the metallization described herein as well as products manufactured using such processes.

BRIEF DESCRIPTION OF THE DRAWINGS

Figures 1-4 depict a conventional flip-chip bonding process using prior art soldering technology.

Figure 5 depicts an ultrasonic flip-chip bond between an electronic device and a substrate.

Figure 6 depicts an ultrasonic horn assembly for creating an ultrasonic bond between an electronic device and a substrate according to the present invention.

Figure 7 depicts a ultrasonic flip-chip bond between an electronic device and a substrate.

DETAILED DESCRIPTION OF THE INVENTION

The various embodiments of the present invention relate to a method of joining an electronic device (e.g., an integrated circuit (IC) chip, a light emitting diode (LED), a surface acoustic wave (SAW) filter, a multi-chip module (MCM), or other device) to a flexible or rigid substrate with conducting contact pads. Desirably, such joining forms an electrical and/or mechanical connection between the device and the substrate. Using ultrasonic energy, the bond pads of the electronic device may be bonded to the substrate metallization (i.e., contact pads) creating a diffusion joint with excellent performance and reliability. This invention also relates to devices, for example, RFID devices (e.g., smart cards and smart...
labels/inlays), LED dice assembled to different carriers (for example, headers, ceramic substrates, and lead frames), and other electronic devices, including devices that may require a high density of components on the substrate (for example, mobile phones, electronic organizers, and laptop computers), manufactured with this new ultrasonic bonding method using suitable production machinery.

At least one embodiment of the present invention builds upon flip-chip mounting methodologies to mount a device to a substrate using ultrasonic energy to form a metallurgical joint between elevated or raised bond pads of the device and the substrate metallization. The bond pads on the device (for example, a semiconductor) may be raised, for example, by printing a nickel-based viscous paste or ink, by evaporative or sputter deposition of nickel, or by the electroless or galvanic deposition of nickel with or without a layer of gold (Au) (i.e., immersion gold) overcoat for oxidation prevention. Other metallic materials may also be used to form the elevated bond pads if such metals can be ultrasonically welded to the substrate metallization. Using ultrasonic energy, the nickel (Ni) layer with an immersion gold coating (Ni/Au) on the bond pads may be welded to various substrate metallizations, for example, aluminum (Al), copper (Cu), silver (Ag), or gold, or alloys combining these and other metals like silicon (Si) and lead (Pb), for example, aluminum-silicon (AlSi), aluminum-copper (AlCu), aluminum-silicon-copper (AlSiCu), and silver-lead (AgPd). Within this specification, the term “substrate metallization” is used to indicate both pure metals like Al, Cu, Ag, and Au and alloys composed of a combination of these pure metals and others (e.g., AlSi, AlCu, AlSiCu, and AgPd).

Another embodiment of the present invention provides a high-speed, ultrasonic manufacturing process for flip-chip die bonding that minimizes the thermal stress during the assembly. It has been determined that the costly technologies of solder bumping and/or expensive conductive adhesives are not necessary because, by using the methodologies of the present invention, it is possible to weld a raised bond pad metallization directly onto a contact pad substrate metallization. By choosing the right materials on the chip bond pads and substrate contact pads it is possible to join both metals using ultrasonic vibration in the horizontal axis without any additional heating source to increase the temperature.

The ultrasonic energy may be applied with a flat sonotrode, with or without a hole for vacuum fixture of the die. The ultrasonic energy may also be applied, for example, using a tool shaped in the form of tweezers. It is to be appreciated that other tools may also be used to apply the ultrasonic energy. It is to be appreciated that destruction or damage to the chip may be prevented and/or minimized by applying a self-resonance frequency.
There are no special requirements for what metal surfaces may be used for the raised chip bond pads and the substrate metallization for the contact pads in the present invention. The metallization layer on one bonding surface, either the bond pads on the chip or the contact pads on the substrate, may be more deformable than the metallization layer on the other bonding surface to enhance the metallurgical junction. The metal surfaces are then joined together forming a metallurgical interface using ultrasonic energy and a compressive force at room temperature or slightly increased temperature. In one embodiment of the present invention, raised Ni/Au bond pads formed by electroless deposition on the base bond pads of an electronic device are ultrasonically welded to softer substrate metallizations, for example, Al, Cu, Au, and Ag, or to alloys like AlSi, AlCu, AlSiCu, AgPd. In another embodiment, softer materials may be present in the bond pads versus the substrate.

Additionally an adhesive may be applied to the die attach area of the electronic device and optionally onto the contact areas of the substrate before the chip attachment. This adhesive additionally fixes the electronic device on the substrate and protects the active surface of the electronic device against environmental influences like oxidation or corrosion. This adhesive may be cured by light, ultraviolet (UV) radiation, increased temperature, or by the ultrasonic energy. It is also possible to merely initiate the curing of the adhesive by these methods and then allow the adhesive to cure autocatalytically at room temperature. When curing is initiated by ultrasonic energy during the bonding process, the curing can be further cured by additional exposure to, for example, light, ultraviolet (UV) radiation, or increased temperature.

Figure 1 shows a schematic cross section view of an IC chip (1). The IC chip (1) may be, for example, a mono-crystalline semiconductor, typically of Si, for example, an RFID chip. The bond pads (2) may be made out of many different materials depending on the manufacturing process of the semiconductor, for example: Al, AlSi, AlCu, AlSiCu, Cr:CrCu:Cu, Ti:Cu, Ti:Ni-V, Ti:W, Ti:W:Au, Ni:Au, and other materials, with a thickness usually less than 1 μm. A passivation layer (3) isolates the IC chip surface and may be composed of silicon nitride or silicon oxide. An additional organic protection layer (e.g., a polyimide) may be applied to the surface of the IC chip and may have a thickness up to several microns.

Figure 2 shows the IC chip (1) with metallic raised bond pads (4) formed, for example, by the electroless plating of Ni/Au. A typical thickness of the nickel layer is in the rage of 10μm to 25μm with optionally an immersion gold layer to protect the nickel against oxidation and corrosion. The thickness of the gold layer is in the order of a fraction of a
micron. The optimal thickness of the nickel layer is influenced by the passivation layer (3) and type of substrate metallization.

[22] Figure 3 shows a cross section of the IC chip (1) with the bond pad metallization (4) and solder bumps (5). Reflowing the solder bumps to join the bond pads of the IC chip to the substrate contact pads is one commonly used technology for the flip-chip assembly of electronic devices.

[23] Figure 4 shows the IC chip (1) assembled onto a substrate (6) using solder bump flip-chip technology. The solder bump (5) is reflowed and forms a metallurgical phase at the interface between the under-bump metallization (UBM) (bond pads) (4) and the metallization of the substrate (7).

[24] In comparison, Figure 5 shows an example of an assembled electronic component manufactured in accordance with one embodiment of the present invention. In Figure 5, an electronic device (1) with metallized bond pads (4) is connected to the substrate metallization (7) of the substrate (6) by a diffusion joint (9). According to the present invention, conventional ultrasonic systems, with an appropriate selected ultrasonic frequency, bonding time, bond force, and contact materials, may be used to form a metallic diffusion joint between the bond pads (4) of the chip and the substrate metallization (7).

[25] In one exemplary experiment, a flexible polyester foil substrate (6) with a thickness of 38µm and an aluminum contact pad structure (7) of 30 µm thickness is mechanically and electrically connected to an IC chip via two bond pads (2), which are covered with a Ni/Au layer (4) of a thickness between 5µm to 25µm above the passivation layer (3) of the IC chip. Using a flat sonotrode operating at 60 kHz, a diffusion joint between the nickel and the aluminum is created within less than 500 ms. As an alternative, before the IC chip attachment, an adhesive (8) may be applied to the substrate (6) and contact pads (7) and cured by UV radiation after creation of the ultrasonic bond to provide additional mechanical bonding strength.

[26] In a first embodiment of this invention, bonding an electronic device to a substrate consists of two steps. The first step involves raising the bond pads of the electronic device above any passivation layer by treating the electronic device (either as a single object or as part of another larger object, e.g., an individual IC chip on an undiced wafer) with an electroless metal or other galvanic deposition method, by printing a layer of metal-based paste, or by sputter or evaporative deposition of a metal. Through this process, the bond pads on the electronic device may be coated with a layer of metal, preferably nickel. The thickness of the nickel layer on the bond pad is application dependent and may vary from less
than 1 micron to up to over 100 microns depending upon the level the bond pad needs to be raised. A layer of gold overcoat may be further cast over nickel surface by immersion plating or other plating methods. This step is similar to an under-bump metallization process. However, the height of the raised nickel may be much greater than a standard UMB if it is needed in the particular case.

[27] The second step involves bonding the electronic device ultrasonically to a substrate. The electronic device, for example, if it is an IC chip on a wafer, may have to be diced before performing the second step. An apparatus for use in ultrasonic bonding according to the present invention may be easily modified from a conventional ultrasonic flip-chip die bonder. A schematic drawing of such an apparatus is shown in Figure 6. Typically such an apparatus consists of partial or full combination of: a vacuum system, which is employed to pick up and place dies; an ultrasonic horn; an ultrasonic oscillator, which controls the magnitude and frequency of the vibration of the ultrasonic horn; a substrate holder; and a fixed stage (an “anvil”).

[28] Unlike conventional gold-to gold-thermosonic welding, the raised nickel bond pad of the present invention may be directly bonded to a substrate metallization such as aluminum, copper, silver, or gold to form a reliable metallic joint at ambient room temperatures or slightly higher than ambient room temperatures, for example, up to 100° C. Further, heating the substrate is not required in the present inventive process.

[29] The general ultrasonic bonding process of the present invention consists of the following five substeps. First, the electronic device is either manually or automatically picked up by vacuum. Second, the contact surfaces of the first component (i.e., the bond pads of the electronic device) and the second component (i.e., the contact pads of the substrate) are placed in alignment with one another to form an interface. Third, a compressive force is applied through an ultrasonic horn to the back side of the electronic device in a direction generally normal to the interface such that at least a portion of the elevated nickel bond pad is in close contact with the substrate metallization before the ultrasound is activated. The magnitude of compressive force is dependent on the area of the interface between the contact surfaces and the properties of the components. Fourth, the ultrasonic energy is activated while the compressive force is held so that the ultrasonic energy is transmitted across the semiconductor device to the substrate in the form of vibration. The vibration normally is parallel to the interface of the components being joined. A diffusion bond is thereby created. For easier control, the compressive force may be held constant throughout the ultrasonic process. Theoretically, the vibration frequency of the chip and the
horn is the same, but the vibration amplitude of the ultrasonic horn (sonotrode) may be larger than that of the chip. Fifth, the compressive force is released and the ultrasonic energy is deactivated.

[30] The process of the present invention differs from the conventional thermosonic gold-to-gold flip chip bonding in many ways. First, the process utilizes electrolessly plated nickel as a medium to form metallic joint, instead of gold. The advantage is that not only is nickel a much less expensive metal than gold, but unlike gold, nickel may be bonded with various metals under room temperature conditions. Even though the raised nickel bond pads of the present invention may be coated with a layer of gold, this layer is generally extremely thin, on the order of a fraction of a micron in thickness. Upon application of the ultrasonic energy, this immersion gold layer is quickly displaced to allow for bonding with the nickel. Because the inventive process occurs at ambient temperatures, many additional advantages are realized. For example, low temperature bonding may minimize the thermal stress on the electronic device that otherwise often presents in the high temperature thermosonic gold bonding.

[31] The present invention is also better suited for flip-chip die bonding than conventional thermosonic bonding, especially for bonding IC chips on substrates to manufacture high volume, low cost commodity products, such as RFID devices. As noted, with conventional gold-to-gold thermosonic flip-chip bonding, due to relatively high temperatures required (generally greater than 150° C) by the process, many types of IC chips may not be able to bear the high temperatures. Further, the selection of the substrate materials is limited to extremely high grade, high cost materials to withstand the high temperatures. Such high grade substrates are not favored for use in, for example, mass quantity, and in some cases disposable, mobile electronics products, especially with paper or polypropylene substrates desired for smart inlays. In contrast, the metallic nickel joint formed using ultrasonic energy at room temperature according to the present invention is especially suitable for mass quantity, low cost, commodity products requiring the attachment of an IC chip to a substrate. Some of these low cost products, for example, RFIDs, LEDs, and SAWs, are very common today and even more are likely to emerge in the near future.

[32] In a second embodiment of the present invention, an adhesive, preferably a nonconductive adhesive, may be used in conjunction with the ultrasonic system. The adhesive may be dispensed at the interface between the bond pads on the electronic device and the substrate metallization before the step of ultrasonically bonding the components as described with respect to the first embodiment. The adhesive may also be dispensed on either
the surface of the electronic device or the substrate before being mated together. Application of the adhesive is not limited to the bond pad areas and it may be applied to the entire interface between the electronic device and the substrate. The adhesive, once cured, protects the chip surface against moisture and other environmental influences, and also enhances the mechanical bond between the components beyond the ultrasonic metallic joint. Further the adhesive may be light, UV radiation, heat, or ultrasonic energy curable.

[33] Ultrasonic curable adhesive may be particularly suitable for use in conjunction with ultrasonic bonding system of the present invention. Select adhesives, for example, UV Acryl PS (manufactured by MS Duroplast, Schierling, Germany) and Delo Katiobond 4578 (manufactured by Delo, Schollkrippen, Germany), when dispensed between an electronic device and a substrate, may form gel under the power of ultrasonic energy. When the ultrasonic system is activated, significant friction and resultant localized heat may be created between the stationary substrate and the vibrating electronic device, which moves at the same frequency and similar magnitude as the sonotrode. The friction and resultant generated heat may cure, or at least partially cure, the selected adhesives to transform the adhesive to a gel state. The gel, together with the metallic joint formed between the nickel on the electronic device bond pads and the substrate metallization, creates a reliable bond for the component assembly. Although, in some cases, the adhesive is only partially cured by ultrasonic energy, it may be subsequently cured by any other means (e.g., light or UV radiation) or the adhesive may simply cure autocatalytically after the component device is moved off-line from the assembly process.

[34] A significant advantage of the present inventive process is that it is much faster than any conventional adhesive die bonding methods using anisotropic adhesives. In a conventional anisotropic adhesive bonding process, the adhesive has to be cured under external compressive forces. The cure time, depending on the selection of the type of adhesive, varies from seconds to hours. In the present process, ultrasonic energy is typically activated for a fraction of a second. A metallic joint is formed in an extremely short time and adhesive may be cured, partially or fully, during the period of application of the ultrasonic energy. The actual length of the ultrasonic operating time may vary and is a function of operating temperature, the physical characteristics of the metals to be joined, and the magnitude of the compressive force. Once the metallic joint is formed and the adhesive is cured, or at least partially cured, the external compressive force is no longer required. The components can be moved away from the bonding machine. The adhesive can thereafter be further fully cured because the metallic diffusion joint holds the surfaces of the electronic
device and substrate close together. Further, if ultrasonic curable adhesive is used, the subsequent curing step for the adhesive may not be needed.

In current practice, soft metals, for example, aluminum, copper, silver, and gold, are often used as substrate metallization for contact pads. Also, in many cases, soft materials are used as substrate base materials, for example, flame retardant 4 (FR4 – epoxied fiberglass printed circuit boards); polypropylene, polyethylene (PET), polyester, and other polymer materials; and paper. In conventional ultrasonic flip-chip bonding technology, it has been found that it is extremely difficult to bond semiconductor chips onto soft metallizations, especially soft or ductile metallizations on soft or flexible substrates like FR4, PET, or similar low cost materials. This is primarily because the soft metallization, the soft substrate material, or the combination, may cause unwanted movement of the substrate metallization of the contact pads or slippage between the bond pads of the electronic device and the contact pads on the substrate during ultrasonic vibration and damping of the ultrasonic energy.

In a third embodiment of the invention, the raised bond pad may be pushed into the soft or ductile metallization on substrate. As indicated, the raised bond pads may be formed by electroless deposition of nickel, a very strong and hard metal, to a significant height above the passivation around the bond pad. In the third substep of the ultrasonic bonding process previously discussed with respect to the first embodiment, a compressive force is applied through an ultrasonic horn to the back side of the electronic device in a direction generally normal to the interface of the electronic device and the substrate. In this manner, at least a portion of the elevated nickel surface formed on the bond pad is in tight contact with the substrate metallization before activation of the ultrasonic energy. However, when the substrate metallization or the substrate is a soft material (e.g., aluminium or PET, respectively), the elevated nickel bond pads (4) can be pressed into the aluminium contact pad (7), as shown in Figure 7. In this embodiment, both the contact pad (7) and the soft substrate (6) deform about the raised nickel of the bond pad (4). Since the elevated nickel bond pads are actually at least partially embedded in the soft substrate metallization of the contact pads, slippage at the metallic interface or energy damping due to the softness of the substrate metallization may be reduced and a reliable ultrasonic joint may be formed. No stiffening of the contact pad with an underlayer of a hard metal is required. As a result, a very reliable ultrasonic metallic bond is formed between the electronic device and the opposing soft substrate through the deformation of the substrate during the present process.
[37] In some cases, depositing Ni or Ni/Au bumps onto semiconductor chip contact pads made out of special materials may not be applicable. For example, a SAW filter may be built upon a material that is incompatible with nickel plating baths. Therefore it may be more beneficial to deposit the Ni or Ni/Au on the substrate (ceramic) side, instead of on the semiconductor chips. Therefore, in a fourth embodiment, Ni or Ni/Au bumps may be deposited on the substrate contact pads, onto which the semiconductor chip, for example a SAW filter, may be bonded. On the bond pads of the semiconductor chip, the metallization may be a thick layer of aluminum, copper, silver or gold. The ultrasonic bonding method of the present invention previously described can still be used to facilitate the metallic diffusion bond. Further, the adhesives, including those that may be activated or cured by light, UV radiation, thermal, or ultrasonic energy may be applied in the same manner as described above.

[38] In summary, the present process differs clearly from conventional ultrasonic bonding in several ways. In conventional flip-chip die attach technologies employing ultrasonic energy, gold-to-gold thermosonic bonding is the dominant methodology. High temperatures (between 150 to 200 °C) provided by an additional heat source is always required. The high temperature mandates strict requirements for selections of substrates and electronic device materials and may cause thermal stress in the assembly of products. The present invention utilizing raised nickel or nickel/gold bond pads requires no additional heat source as the ultrasonic bonding can be achieved under room temperature. The present invention also differs clearly from convention ultrasonic flip chip bonding through its contemporaneous use of adhesives, in particular an ultrasonic energy curable adhesive. In addition, the present invention is unique and distinct in its application on soft substrates by pushing raised bond pads into soft substrate before the application of ultrasonic energy.
CLAIMS

1. A method for bonding an electronic device to a substrate without raising the ambient temperature of the environment comprising:
   forming a raised metallization layer on a bond pad of the electronic device;
   placing the bond pad of the electronic device opposite a contact pad metallization of the substrate creating an interface between the electronic device and the substrate;
   applying a compressive force normal to the interface between the electronic device and the substrate; and
   applying ultrasonic energy to the electronic device whereby a diffusion joint is formed between the bond pad of the electronic device and the contact pad of the substrate.

2. A method for ultrasonically bonding an electronic device to a substrate comprising:
   forming a raised metallization layer on a bond pad of the electronic device;
   placing the bond pad of the electronic device opposite a contact pad metallization of the substrate creating an interface between the electronic device and the substrate;
   applying an adhesive to the interface between the electronic device and the substrate;
   applying ultrasonic energy to the electronic device whereby a diffusion joint is formed between the bond pad of the electronic device and the contact pad of the substrate; and
   wherein the adhesive is at least partially cured by the ultrasonic energy.

3. A method for ultrasonically bonding an electronic device to a substrate comprising:
   forming a raised metallization layer on a bond pad of the electronic device;
   placing the bond pad of the electronic device opposite a contact pad metallization of the substrate creating an interface between the electronic device and the substrate;
   applying a compressive force normal to the interface between the electronic device and the substrate, wherein the raised metallization layer of the bond pad is harder than the contact pad metallization and the raised metallization layer is at least partially embedded in the contact pad metallization; and
   applying ultrasonic energy to the electronic device whereby a diffusion joint is formed between the bond pad of the electronic device and the contact pad of the substrate;
   wherein the steps of the method are performed without raising the ambient temperature of the environment.
4. The method of claim 1, 2, or 3 wherein the raised metallization layer is a layer of nickel.

5. The method of claim 4 wherein the raised nickel metallization is further covered by a layer of gold.

6. The method of claim 1, 2, or 3 wherein the raised metallization layer extends above a passivation layer on a surface of the electronic device.

7. The method of claim 1 or 3 wherein the step of applying the compressive force at least partially embeds the raised metallization layer into the contact pad metallization.

8. The method of claim 1 or 3 further comprising:
   applying an adhesive to the interface between the electronic device and the substrate;
   and
   curing the adhesive.

9. The method of claim 8 wherein the adhesive is at least partially curable by ultrasonic energy and wherein the step of curing is initiated by the step of applying ultrasonic energy.

10. The method of claim 2 wherein the adhesive is fully cured by the step of applying ultrasonic energy.

11. The method of claim 9 wherein the adhesive is fully cured by the step of applying ultrasonic energy.

12. The method of claim 2 further comprising completing the step of curing of the adhesive by further activating the curing process.

13. The method of claim 9 further comprising completing the step of curing of the adhesive by further activating the curing process.

14. The method of claim 2 further comprising completing the step of curing of the adhesive by allowing the adhesive to cure autocatalytically.

15. The method of claim 9 further comprising completing the step of curing of the adhesive by allowing the adhesive to cure autocatalytically.
16. The method of claim 1, 2, or 3 wherein the contact pad metallization of the substrate comprises a metal or metal alloy selected from the group consisting of: nickel, aluminum, copper, gold, aluminum-silicon, aluminum-copper, aluminum-silicon-copper, and silver-lead.

17. The method of claim 1, 2, or 3 wherein the substrate comprises a material selected from the group comprising: polyethylene, flame retardant 4, polypropylene, polyester, and paper.

18. The method of claim 2 wherein the contact pad metallization deforms around the raised metallization layer during the step of applying a compressive force.

19. The method of claim 2 wherein the substrate deforms under the raised metallization layer during the step of applying a compressive force.

20. A method of ultrasonically bonding a first electrical component to a second electrical component comprising:
   forming a raised metallization layer on a first electric contact surface of the first component;
   placing the first electric contact surface of the first electrical component in alignment with a second electric contact surface of the second electrical component creating an interface between the first electrical component and the second electrical component;
   applying a compressive force normal to the interface between the first electrical component and the second electrical component; and
   applying ultrasonic energy to the interface whereby a diffusion joint is formed between the first electric contact surface of the first electrical component and the second electric contact surface of the second electrical component;
   wherein the steps of the method are performed without raising the ambient temperature of the environment.
FIG. 1

FIG. 2
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : B23K 1/06
US CL : 228/1.1, 110.1, 175, 245, 254; 156/73.1, 580.1

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 228/1.1, 110.1, 175, 245, 254; 156/73.1, 580.1

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic database consulted during the international search (name of database and, where practicable, search terms used)

Please See Continuation Sheet

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category *</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
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<tr>
<td>X</td>
<td>US 6,193,136 B1 (HIGASHI et al) 27 February 2001, (abstract; Figures; column 2, lines 34-62; column 4, lines 26-33; column 5, lines 40-60; and the claims).</td>
<td>1-3, 20</td>
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<td>4-19</td>
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* Further documents are listed in the continuation of Box C.  

\( ^* \) Special categories of cited documents:

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\( ^& \) document member of the same patent family

Date of the actual completion of the international search

24 March 2004 (24.03.2004)

Date of mailing of the international search report

21 APR 2004

Name and mailing address of the ISA/US

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Form PCT/ISA/210 (second sheet) (July 1998)
Continuation of B. FIELDS SEARCHED Item 3:

EAST:
ultrasonic, bond, adhesive, bump, penetrate