METHOD FOR ELECTRICALLY CONNECTING A METAL ELEMENT TO A MULTI-LAYER COMPOSITE PRINTED CIRCUIT BOARD BY MEANS OF ULTRASONIC WELDING

FIELD OF THE INVENTION

The present invention relates to a method for electrically connecting a multilayer composite printed circuit board to a metal element by means of ultrasonic welding.

BACKGROUND OF THE INVENTION

For various applications, it may be necessary to electrically connect a multilayer composite printed circuit board to a metal element. In this case, the multilayer composite printed circuit board, which is sometimes also referred to as a PCB (printed circuit board), generally comprises a layer stack in which a plurality of thin metal layers are spaced apart from one another and electrically insulated from one another by thin insulator layers arranged between said layers. In this case, the metal layers may be configured in a structured manner in the form of one or more electrical conductor tracks. In this case, multilayer composite printed circuit boards make it possible, inter alia, to mechanically support one or more electrical components and in this case to electrically connect said components to other electrical components with the aid of their metal layers or conductor tracks. For this purpose, in each case one metal element, for example in the form of a wire, strip, platelet or the like, is applied locally to an external metal layer of the composite printed circuit board and is then mechanically and electrically connected thereto.

In order to electrically connect a metal layer or a conductor track, formed therewith, of the composite printed circuit board to a metal element, soldering techniques in which a fusible solder material is temporarily melted locally in order to make contact with both joining partners and, after the solidification of the solder material, to connect both electrically and mechanically to one another have generally been used hitherto.

In order to connect, in particular, very fine wires to metal pads of a composite printed circuit board, so-called bonding techniques are furthermore known in which one end of the fine wire is gripped with the aid of a tool and is applied to the metal pad and then high-frequency ultrasonic vibrations are coupled in by means of the tool in order to bond the wire end to the metal pad.

JP 2024-517878 A discloses an electrode assembly for a battery and a method of manufacturing the same.

CN 103779247 B discloses a method for soldering a power semiconductor module terminal to a substrate.

DE 11 2018 000 674 T5 discloses an ultrasonic bonding apparatus, an ultrasonic bonding inspection method and a method of manufacturing an ultrasonically bonded region.

CN 102969306 A discloses a power module and a method of manufacturing the same.

SUMMARY OF THE INVENTION AND ADVANTAGEOUS EMBODIMENTS

There may be a need for an alternative method for electrically connecting a multilayer composite printed circuit board to a metal element. In particular, there may be a need for a method in order to be able to fasten a metal element to a metal layer of a multilayer composite printed circuit board in a high-quality, reliable and/or stable manner over the long term. Furthermore, there may be a need for a method with the aid of which the multilayer composite printed circuit board may be connected to a metal element with little processing effort, low costs, low material expenditure and/or a relatively simply constructed apparatus.

Such a need may be met by the method according to the independent claim. Advantageous embodiments are defined in the dependent claims and the following description or are illustrated in the accompanying figures.

According to one aspect of the invention, a method for electrically connecting a metal element to a multilayer composite printed circuit board by means of ultrasonic welding is described. The composite printed circuit board comprises, in a connecting region, a first metal layer, at least one insulator layer supporting the first metal layer and at least one second metal layer which is spaced apart from the first metal layer by the insulator layer. The method comprises at least the following method steps, preferably in the stated order: (i) arranging the metal element adjacent to the first metal layer of the composite printed circuit board; (ii) applying an ultrasonic sonotrode with a sonotrode surface to a surface of the metal element opposite the composite printed circuit board; and (iii) bringing about ultrasonic vibrations at the sonotrode surface. The ultrasonic vibrations are brought about here with a frequency of less than 55 kHz, a power of more than 400 W and over a contact area between the sonotrode surface and the metal element of at least 2 mm^2. The ultrasonic sonotrode is displaced by a servo press provided in an ultrasonic welding unit and pressed against the metal component, the servo press being driven by a servomotor or by means of an electromagnetic actuator.

As an introduction, a basic concept for embodiments of the invention described herein is intended to be explained briefly, wherein this explanation is to be interpreted as merely roughly summarizing and not limiting the invention:

As already stated in the introduction, metal elements have hitherto typically been connected to a metal layer of a multilayer composite printed circuit board with the aid of soldering techniques or, in the case of very thin wires, with special bonding techniques. However, it has hitherto been assumed that multilayer composite printed circuit boards are mechanically sensitive on account of their structural properties, such as, in particular, the fact that many very thin metal and insulator layers adjoin one another therein and are mechanically connected to one another, and therefore, when metal elements are connected to the composite printed circuit board, excessive forces should not be exerted on the composite printed circuit board, since the integrity thereof could otherwise be damaged.

Overcoming this long-held prejudice, it has now been recognized that a multilayer composite printed circuit board with one of its metal layers may be welded to a metal element using ultrasonic welding techniques, provided that specific conditions are created or specific process parameters are adhered to in this case.

In particular, it has been recognized that, in the case where the ultrasonic vibrations used for ultrasonic welding are brought about with a sufficiently low frequency and at the same time with a sufficiently high power and over a sufficiently large contact area and are transmitted to the metal element to be connected, reliable welded connections of high quality may be produced between the metal element and the external metal layer of the composite printed circuit board and, in the process, damage to the composite printed circuit board may be avoided.

Possible configurations and advantages of embodiments of the ultrasonic welding method presented herein are described in more detail below.

Ultrasonic welding has been developed in order to connect welding material in the form of at least two joining partners to one another in a mechanically load-bearing manner. If the joining partners consist of electrically conductive material, in particular metal, a connection with good electrical conductivity is generally also intended to be created between the joining partners in this case.

Conventionally, the joining partners are accommodated in a welding space within an ultrasonic welding device. In this case, the welding space is delimited on one side by a surface of an anvil and on an opposite side by a surface of a sonotrode. During an ultrasonic welding process, the joining partners are clamped between the anvil and the sonotrode and the sonotrode is set into ultrasonic vibrations. The ultrasonic vibrations are transmitted via the sonotrode surface to at least one of the joining partners and, at a boundary surface between the joining partners, have the effect that the joining partners enter into a cohesive connection with one another. In this case, material of the joining partners is generally not heated above a

respective melting point. Instead, the cohesive connection develops, for example, on account of diffusion processes between the joining partners.

In order to weld two relatively solid metallic joining partners, such as, for example, two wires or a wire and a metal platelet, to one another by means of ultrasound and in this case to produce both a mechanical and an electrical connection between the joining partners, it is generally necessary to exert relatively strong forces on the joining partners and to provide relatively high ultrasonic powers at the sonotrode and to couple them via the sonotrode surface into at least one of the joining partners. For this purpose, the sonotrode is generally applied with its sonotrode surface directly to a surface of one of the metallic joining partners and is pressed with a sufficient pressure against the joining partner.

It has hitherto been assumed that ultrasonic welding techniques are not suitable for welding relatively large metal elements to multilayer composite printed circuit boards on account of mechanical loads, such as are supposedly necessarily exerted on the joining partners during an ultrasonic welding operation. This was based on the idea that composite printed circuit boards are mechanically sensitive on account of their multilayer structure and may not withstand the mechanical loads acting thereon during ultrasonic welding in a damage-free manner. This also appeared to be confirmed in the context of experiments in which, in an attempt to connect metal wires or metal platelets to connection pads of a composite printed circuit board by means of ultrasonic welding, partial regions of the connection pad were repeatedly detached from the composite printed circuit board or delaminations even occurred between the layers of the composite printed circuit board. It was therefore hitherto assumed that ultrasound-based techniques may not be used for welding relatively large metal elements to a composite printed circuit board, but at most, for example, for bonding very fine wires.

However, it has now been recognized in a surprising manner that even sensitive multilayer composite printed circuit boards may be connected to relatively large joining partners in the form of metal elements by means of ultrasonic welding,

provided that suitable conditions are created and process parameters are adhered to in this case, as is explained in detail further below.

As an introduction, properties of the joining partners, such as are intended to be welded to one another by means of the method described herein, are first described below.

The composite printed circuit board has a substantially two-dimensional, plate-like or disk-like geometry. In this case, it may have a length and a width of typically several centimeters, for example between 1 cm and 100 cm, preferably between 2 cm and 20 cm. A thickness is typically significantly smaller and may be, for example, less than 15 mm, typically between 0.5 mm and 10 mm, usually between 1 mm and 5 mm.

In this case, the composite printed circuit board is composed of a plurality of layers which are stacked one above the other and are mechanically connected to one another. The composite printed circuit board may be composed of at least three, preferably at least five, at least seven, at least 10 or even at least 20, but typically less than 100 or less than 50 layers.

In particular, the layers may be adhesively bonded, laminated or adhesively connected to one another in another manner. In particular, the layers may be cohesively connected to one another. Mutually adjacent layers may in this case consist of different materials. By way of example, a layer composed of metal may adjoin a layer composed of an insulator.

At least one of the layers, a plurality of the layers or all of the layers may have a layer thickness of at least 5 µm, at least 10 µm, at least 20 µm or at least 50 µm, but preferably less than 700 µm, less than 500 µm, less than 300 µm, less than 200 µm or less than 100 µm. In this case, a layer thickness may be homogeneous, i.e. identical along the entire layer, or may vary locally within the stated layer thickness limits.

The composite printed circuit board has at least two metal layers, preferably at least three, four, five, six or more metal layers. In this case, the metal layers may extend along the entire area of the composite printed circuit board. Alternatively, the metal layers may extend only along partial regions of the composite printed circuit board and in this case form, for example, conductor tracks, contact pads or similar structures.

In this case, a first metal layer may be arranged lying furthest to the outside in the composite printed circuit board. Further metal layers may run further in the interior of the composite printed circuit board and be surrounded on both sides by other layers. Possibly, in the case of a composite printed circuit board having a plurality of metal layers, one of the metal layers lying further to the inside may also serve as a first metal layer if it has been exposed locally in a partial region, for example by deep milling or the like, and thus acts in the partial region as a metal layer lying furthest to the outside.

The first metal layer may thus be mechanically and electrically contact-connected from the outside. The first metal layer may have, in particular, an outwardly exposed surface which may serve as a connecting region for the composite printed circuit board. The exposed surface may extend along the entire outwardly directed surface of the first metal layer or alternatively may be provided only in partial regions of the first metal layer, for example as locally contact-connectable contact pads. The exposed surface may be free of another layer which covers it.

Alternatively, the first metal layer may be covered by a very thin protective layer which may be penetrated without problems during the contact-connection of the first metal layer in order to produce an electrical contact to the first metal layer. The protective layer may protect, for example, the first metal layer from environmental influences, in particular from corrosion. The protective layer may have, for example, a very small thickness of less than 10 μm, less than 2 μm or even less than 0.2 μm.

In this case, the first and further metal layers may consist partially or completely of copper, aluminum, nickel, silver, gold and/or palladium or a mixture or alloy

thereof. For example, the first metal layer may consist of copper or aluminum as materials with very good electrical conductivity. If appropriate, the first metal layer may be covered with a thin protective layer of gold, palladium or similarly acting materials or of a material combination such as ENIG (Electroless Nickel Immersion Gold) or ENEPIG (Electroless Nickel Electroless Palladium Immersion Gold).

The composite printed circuit board furthermore has at least one, preferably a plurality of insulator layers. In particular, in each case at least one insulator layer may be interposed between two metal layers which are neighboring along the thickness direction of the composite printed circuit board, in order to space apart the two metal layers from one another, to electrically insulate them from one another and to mechanically connect them to one another. The insulator layers may have an identical, similar, larger or smaller layer thickness than the metal layers. In this case, a layer thickness of an insulator layer may be selected in an application-specific manner in such a way that reliable electrical insulation between the adjacent metal layers is ensured. For example, the layer thickness of the insulator layers may be between 20 μm and 3 mm and in many cases may be greater than 40 μm, greater than 80 μm or greater than 150 μm, but usually less than 2 mm, less than 1 mm or less than 0.5 mm.

The insulator layers of the composite printed circuit board may all consist of an identical material. Alternatively, the insulator layers may be formed with different materials. Various electrically insulating materials are suitable as materials. In particular, an insulator layer may consist of a polymer material. For example, an insulator layer may consist of epoxy, polyimide or similar materials. The insulator layer preferably consists of a non-ceramic material. The insulator layer itself may also be formed as a material composite. By way of example, the insulator layer may be produced as a prepreg layer. The insulator layer may thus serve as an electrically non-conductive carrier material onto which metal layers may then be laminated on one side or on both sides, for example as copper foils.

Furthermore, the insulator layer may be fiber-reinforced, for example in order to increase its mechanical strength. For this purpose, for example, a multiplicity of

fibers, for example glass fibers, carbon fibers, Kevlar fibers or the like, may be embedded in a polymer material serving as a matrix.

In particular, the insulator layer may consist of a dielectric. There are a whole series of different dielectrics which offer different insulation values depending on the requirements of a circuit application. Some of these dielectrics are polytetrafluoroethylene (Teflon), FR-4, FR-1, CEM-1 or CEM-3. Known prepreg materials which are used in the printed circuit board industry are FR-2 (phenolic cotton paper), FR-3 (cotton paper and epoxy), FR-4 (glass fabric and epoxy), FR-5 (glass fabric and epoxy), FR-6 (matte glass and polyester), G-10 (woven glass and epoxy), CEM-1 (cotton paper and epoxy), CEM-2 (cotton paper and epoxy), CEM-3 (glass nonwoven and epoxy), CEM-4 (woven glass and epoxy), CEM-5 (woven glass and polyester). Thermal expansion is an important aspect especially in ball grid array (BGA) and naked die technologies, and glass fiber offers the best dimensional stability.

Electrically conductive connection regions in the form of so-called vias may extend through one or more of the insulator layers. Such vias may, for example, connect conductor track regions of one of the metal layers to conductor track regions of an adjacent metal layer. The vias may have relatively small lateral dimensions, for example a diameter or a width of less than 5 mm, often less than 2 mm, less than 1 mm or less than 0.5 mm. The vias may further increase a mechanical sensitivity of the composite printed circuit board. A sensitivity to temperature fluctuations may also be increased by vias, since they may impede thermal expansion, for example under unfavorable conditions.

The metal element to be welded to the composite printed circuit board may be formed, for example, in the form of a wire, a strip, a platelet, a profile, a pin or the like.

The metal element may be configured to produce an electrical connection between the first metal layer of the composite printed circuit board, on the one hand, and, for example, an electrical component, a plug connector or the like. In this case, the electrical component, the plug connector or similar components may be arranged

in direct mechanical contact with the composite printed circuit board or may be provided remotely from the composite printed circuit board.

In this case, the metal element may have lateral dimensions which correspond approximately to the dimensions of the connecting region at which the metal element is to be welded to the first metal layer of the composite printed circuit board. Such lateral length and width dimensions are typically in the range from a few to several millimeters, for example, depending on the application, between 1 mm and 20 mm, typically between 2 mm and 10 mm. In this case, a thickness of the metal element is usually smaller than its lateral dimensions, i.e. the metal element usually has a flat structure such as, for example, in the case of a strip or a platelet or an elongate structure such as, for example, in the case of a wire. For example, the thickness of the metal element may be greater than 0.2 mm, greater than 0.3 mm or greater than 0.5 mm and may thus be significantly greater than in the case of the structures typically used during bonding. In this case, the thickness of the metal element is usually less than 5 mm or even less than 2 mm.

In a similar manner to the metal layers of the composite printed circuit board, the metal element may consist of one or more metals or mixtures or alloys thereof. In particular, metals with good electrical conductivity such as copper, aluminum, nickel, silver, gold, platinum, palladium, etc. may be used. In the context of the method described herein, materials which are not conventionally solderable may also be used for the metal element and/or the first metal layer of the composite printed circuit board. The material of the metal element may be identical to the material of the first metal layer of the composite printed circuit board. For example, both components may consist of copper or both components may consist of aluminum. However, it may also be possible to weld a metal element made of a different material from that of the first metal layer of the composite printed circuit board to this first metal layer. For example, an aluminum strip may be attached to a first metal layer made of copper.

In the context of the method described herein, the metal element is first attached adjacent to the first metal layer of the composite printed circuit board. As a result, the metal element preferably comes into direct mechanical contact with the first

metal layer, which is to be contact-connected from the outside in the connecting region of the composite printed circuit board, with a surface directed toward the composite printed circuit board. For this purpose, the composite printed circuit board may, for example, have been arranged beforehand in a welding space of an ultrasonic welding device and the metal element may then be gripped with a suitable tool and moved toward the composite printed circuit board. However, the composite printed circuit board and the metal element may also be introduced into the ultrasonic welding device in another manner or in another order.

An ultrasonic sonotrode is then applied to the metal element arranged in this way. In this case, a sonotrode surface contacts the surface of the metal element opposite the composite printed circuit board. The metal element is thus interposed between the sonotrode surface and the first metal layer of the composite printed circuit board and is preferably clamped between them.

In this configuration, ultrasonic vibrations are then brought about at the sonotrode surface. For this purpose, for example, an ultrasonic vibration generator may generate ultrasonic vibrations and these are then passed on to the sonotrode and transmitted via the sonotrode surface thereof to the joining partners, i.e. in particular to the metal element.

In order to be able to weld the metal element to the composite printed circuit board in a damage-free manner, suitable conditions must be created or process parameters must be kept within a narrow process window in this case.

In particular, the ultrasonic vibrations should be brought about with a frequency of less than 55 kHz, preferably less than 50 kHz, less than 45 kHz or less than 40 kHz. The frequency of the ultrasonic vibrations used herein for ultrasonic welding is thus significantly below the frequencies typically used for ultrasonic bonding of thin wires. The ultrasonic vibrations are in this case generated with at least 20 kHz, possibly with at least 25 kHz. It has been recognized that a use of ultrasonic vibrations with relatively low frequencies makes it possible to transmit larger amounts of energy during a predetermined welding time, i.e. to increase a power

transferred during ultrasonic welding, which is advantageous in particular in the ultrasonic welding method described herein.

In addition, the ultrasonic vibrations are brought about with a power of more than 400 W, possibly more than 450 W, more than 500 W or more than 600 W. It has been recognized that the ultrasonic vibrations should be brought about with a sufficiently high power in order to be able to ensure reliable welding of the joining partners. Accordingly, in the method described herein, a sufficiently powerful ultrasonic welding device and an ultrasonic sonotrode suitably configured for transmitting such powerful ultrasonic vibrations are preferably used. The powers used are in this case significantly higher than those which are typically used during ultrasonic bonding of thin wires. However, the powers generally remain below 10 kW, usually below 6 kW or below 3 kW or in certain cases below 1 kW. The power with which the ultrasonic vibrations are brought about is in this case understood to mean a power made available by the generator. The power is thus the electrical power output by the generator. This is typically detected during the output in the generator itself.

Furthermore, the ultrasonic vibrations are transmitted via a contact area between the sonotrode surface and the metal element and this contact area is dimensioned to be relatively large with at least 2 mm^2. In other words, the ultrasonic sonotrode is intended to bear with its sonotrode surface against the metal element over a large area. Accordingly, both the pressure exerted by the ultrasonic sonotrode on the metal element and the transmitted ultrasonic vibrations are transmitted along the large contact area to the metal element. As a result, a risk of damage to the composite printed circuit board in contact with the metal element may be reduced.

Depending on the type and intended use of the metal element to be welded, the contact area may also be significantly greater than 2 mm^2, for example at least 3 mm^2, at least 4 mm^2, at least 5 mm^2, at least 10 mm^2 or even at least 20 mm^2. However, the contact area should typically be less than 50 mm^2, usually less than 30 mm^2. The contact area may in this case have any desired shape, for example be square, rectangular, round or the like.

According to one embodiment, the ultrasonic vibrations may be brought about with an amplitude of more than 10 μm.

In other words, the amplitude with which the ultrasonic vibrations vibrate may be greater than 10 μm, preferably greater than 15 μm, greater than 20 μm, greater than 25 μm or even greater than 30 μm. It has been recognized that ultrasonic vibrations with amplitudes of this size may advantageously act when welding relatively large joining partners to a composite printed circuit board. Typically, however, the amplitude is less than 60 μm, preferably less than 50 μm or less than 40 μm.

The ultrasonic vibration amplitudes used for the method described herein are thus significantly greater than those which are typically used during ultrasonic bonding of thin wires.

In this context, the amplitude is to be understood to mean half of the distance covered overall during a vibration, that is to say the distance between a neutral position and a maximum deflected position, which is sometimes also referred to as the “lambda half” value, “λ/2” value or “lambda/2” value.

According to one embodiment, the arranging of the metal element adjacent to the first metal layer of the composite printed circuit board and the applying of the ultrasonic sonotrode to the surface of the metal element opposite the composite printed circuit board are to be effected separately from one another in terms of time.

In other words, in the context of the method proposed herein, the metal element is preferably first attached to the composite printed circuit board and the ultrasonic sonotrode is applied to the metal element only in a separate subsequent step. Thus, both joining partners are already accommodated in the ultrasonic welding device before the ultrasonic sonotrode is then brought up to the joining partners for welding the same. In order to attach the metal element to the composite printed circuit board, a tool independent of the ultrasonic sonotrode may be used in this case.

As a result, the ultrasonic welding described herein differs fundamentally from conventional ultrasonic bonding in which the thin wire to be joined is gripped and displaced by means of a gripping tool and the high-frequency ultrasonic vibrations are also coupled in with the aid of the same tool. A construction of the apparatuses used for connection in the ultrasonic welding method proposed herein thus differs fundamentally from that in conventional ultrasonic bonding. In particular, by separating the two steps of applying the metal element to the composite printed circuit board and of subsequently applying the ultrasonic sonotrode, each of these two steps may be optimized better or independently of the respective other step.

According to one embodiment, a power area density which is defined as the ratio between the power with which the ultrasonic vibrations are brought about and the contact area between the sonotrode surface and the metal element is less than 200 W/mm^2.

The power area density is preferably brought about with less than 150 W/mm^2 or even less than 100 W/mm^2, but usually more than 20 W/mm^2 or more than 50 W/mm^2. The power area density is defined here as the quotient of the ultrasonic vibration power applied by the sonotrode and the size of the contact area via which the ultrasonic vibrations are transmitted to the metal element.

It has been recognized that the ultrasonic vibration power introduced per contact area should, on the one hand, be sufficiently high to be able to bring about reliable welding of the joining partners, but, on the other hand, should remain below predetermined limits in order to avoid damage to the composite printed circuit board. An upper limit, which is specifically to be adhered to, for the power area density may in this case depend greatly on the respective application and in particular on the properties of the composite printed circuit board.

According to one embodiment, an energy which is transmitted overall to the metal element during a welding operation by means of the ultrasonic vibrations brought about should be less than 200 Ws.

In other words, energies of less than 200 Ws (1 Ws=1 watt*second=1 J=1 joule), preferably less than 150 Ws, preferably less than 100 Ws, preferably less than 80 Ws, less than 65 Ws or less than 50 Ws, but usually more than 3 Ws, more than 5 Ws, more than 10 Ws or more than 20 Ws should be used as far as possible overall for welding the metal element to the first metal layer of the composite printed circuit board.

In particular, according to one embodiment, an energy area density which is defined as the ratio between an energy which is transmitted overall to the metal element during a welding operation by means of the ultrasonic vibrations brought about and the contact area between the sonotrode surface and the metal element should be less than 5 Ws/mm^2.

The energy area density should preferably be less than 4 Ws/mm^2, less than 3 Ws/mm^2, less than 2 Ws/mm^2 or even less than 1 Ws/mm^2, but usually greater than 0.1 Ws/mm^2, greater than 0.5 Ws/mm^2 or even greater than 1 Ws/mm^2.

Furthermore, according to one embodiment, a force with which the sonotrode surface is pressed against the metal element during the bringing about of the ultrasonic vibrations may be at least 10 N and at most 300 N.

In other words, the sonotrode may be pushed with its sonotrode surface towards the joining partners during the ultrasonic welding process and in the process may be pressed with a force of at least 10 N (10 newtons), preferably at least 20 N, at least 30 N or at least 40 N, but at most 300 N, preferably at most 200 N, preferably at most 150 N, preferably at most 100 N, preferably at most 90 N, at most 80 N, at most 70 N or at most 60 N against the metal element.

In particular, according to one embodiment, a pressure with which the sonotrode surface is pressed against the metal element during the bringing about of the ultrasonic vibrations should be at least 1 N/mm^2 and at most 30 N/mm^2.

The pressure should preferably be greater than 1.5 N/mm^2, greater than 2 N/mm^2, greater than 3 N/mm^2 or greater than 4 N/mm^2, but less than 30 N/mm^2, less than

20 N/mm^2, less than 10 N/mm^2, less than 9 N/mm^2, less than 8 N/mm^2, less than 7 N/mm^2 or less than 6 N/mm^2.

It is assumed that metal elements may be attached to composite printed circuit boards by means of the method described herein in a particularly efficient, reliable and/or damage-free manner with the aid of the method described herein with the abovementioned process values or within the abovementioned process value ranges, as were stated for the frequency of the ultrasonic vibrations, the power of the ultrasonic vibrations, the contact area, the amplitude of the ultrasonic vibrations, the power area density, the energy transmitted overall, the energy area density, the pressing force and the pressure. The process parameters to be used specifically in an application in this case depend greatly on the specific case, in particular on properties such as geometry, a material, a construction, etc. of the joining partners to be connected, and must be determined in the individual case if appropriate by series of experiments, calculations, modelling, simulations or the like.

According to one embodiment, the ultrasonic sonotrode may be displaced and pressed against the metal element by means of a servo press provided in an ultrasonic welding device.

In other words, the ultrasonic welding device may displace the ultrasonic sonotrode in one direction towards the joining partners by means of the servo press and press against the metal element in the process. A servo press may in this case be understood to mean a displacement unit to be actuated electrically in a height direction, that is to say a lifting unit. The servo press may be driven, for example, by a servomotor or by means of an electromagnetic actuator (voice coil). In contrast to conventional ultrasonic welding devices in which the sonotrode is displaced and/or pressed against the joining partners by means of an actuator in the form of pneumatics, an ultrasonic welding device with a servo press may typically position the sonotrode more accurately, more quickly, more controlled and/or more gently on the welding material and then press against the latter. In particular, a servo press may control or regulate a setting-on speed, a setting-on depth and/or a setting-on pressure in a targeted and variable manner in order to realize, for example, a so-called “soft touch”. In this case, the servo press may if

appropriate use active force regulation. For this purpose, the servo press may have an electrically activatable and controllable actuator, for example in the form of a servomotor.

According to one embodiment, the ultrasonic sonotrode may be formed as a bending oscillator.

In the case of such an ultrasonic sonotrode formed as a bending oscillator, the ultrasonic vibrations are generated not orthogonally to a boundary surface between the joining partners to be welded but parallel or tangentially to this boundary surface. In comparison with other types of longitudinally vibrating ultrasonic sonotrodes, bending oscillators typically vibrate with greater amplitudes. In this case, bending oscillators may vibrate similarly to a whip because of their geometry. On account of the parallel vibration direction and/or the large vibration amplitudes, the ultrasonic vibrations are transmitted with less damaging forces and/or force directions and/or in a more efficient manner to the metal element and through the latter to the first metal layer of the composite printed circuit board. Furthermore, bending oscillators may make it possible to achieve components better and/or be constructed more simply than other types of longitudinally vibrating ultrasonic sonotrodes.

According to one embodiment, the composite printed circuit board may be supported on a surface opposite the metal element by means of an abutment element during the bringing about of the ultrasonic vibrations.

In other words, the joining partners, while they are subjected to force in a first direction by the sonotrode which is pressed with its sonotrode surface against the metal element, may be held in an opposite second direction by a component which is referred to herein as an abutment element. This abutment element may act in the same way as or similarly to an anvil, as is usually used in ultrasonic welding devices for welding two metallic joining partners. The abutment element may consist partially or completely of metal. Alternatively, the abutment element may consist partially or completely of a non-metallic material, in particular a plastics material. The abutment element may act directly on the composite printed circuit board. In particular, the abutment element may

support the composite printed circuit board by direct planar contact with the surface thereof directed away from the metal element (that is to say virtually from the rear or from below). A supporting area may in this case be approximately as large, equally large or even larger than the contact area at which the sonotrode surface is pressed against the joining partners. Accordingly, the abutment element may support the joining partners over a large area. By means of such large-area supporting, the forces acting on the joining partners and in particular on the composite printed circuit board may be distributed well and force peaks and/or bending moments may be minimized.

According to a more specific embodiment, the abutment element may be planar on a surface contacting the composite printed circuit board or may have a surface texture with texture projections which project toward the composite printed circuit board and are rounded in such a way that radii of curvature at ends of the texture projections directed toward the composite printed circuit board are greater than 20 μm.

In other words, the abutment element may be formed on the abutment element surface with which it contacts the composite printed circuit board or against which the composite printed circuit board is pressed during the ultrasonic welding process without a surface texture or at most with a surface texture without sharp-edged texture projections. The radii of curvature at the ends of the texture projections directed toward the composite printed circuit board may in particular be greater than 30 μm, greater than 50 μm, greater than 100 μm or even greater than 300 μm.

By means of the absence of a surface texture or at least sharp edges or burrs of such a texture, local mechanical stresses such as, for example, punctiform pressing in, scratching or the like on the rear side of the sensitive composite printed circuit board may be avoided.

In particular, it is considered to be advantageous if the abutment element surface has at most a surface texture with texture depths of less than 0.4 mm, preferably less than 0.3 mm or less than 0.2 mm. In particular, a use of an abutment with a planar surface or at most with a 0.3 corrugation, a 0.2 corrugation or an even finer corrugation on its abutment element surface is assumed to be advantageous. In

order to fix the printed circuit board, a lateral clamping of the latter may optionally be provided.

Such small texture depths make it possible, on the one hand, for the abutment element surface not to be able to press too deeply into the rear-side surface of the multilayer composite printed circuit board. On the other hand, such surface textures are nevertheless sufficient to be able to transmit the high-frequency ultrasonic vibrations from the sonotrode to the joining partners and, in the process, to be able to hold and support the composite printed circuit board reliably on its rear side.

According to an alternative more specific embodiment, the abutment element may be planar on a surface contacting the composite printed circuit board or may have a surface texture with texture projections which project toward the composite printed circuit board and are rounded in such a way that radii of curvature at ends of the texture projections directed toward the composite printed circuit board are greater than 20% of a layer thickness of an outermost layer of the composite printed circuit board which is directly contact-connected by the abutment element.

In other words, if the abutment element is provided with a surface texture, the latter may be of rounded design in such a way that it does not damage the composite printed circuit board and, in particular, an outermost layer which is arranged on the rear side thereof and comes into direct contact with the abutment element. For this purpose, the radii of curvature of the texture projections may be selected to be sufficiently large so that the texture projections are relatively blunt in relation to the layer thickness of this outermost layer, i.e. are rounded to a sufficiently great extent in order, for example, not to deform and/or scratch this layer. The stated radii of curvature may preferably be greater than 30%, greater than 40%, greater than 50%, greater than 75%, greater than 100% or even greater than 200% of the layer thickness of the outermost layer of the composite printed circuit board.

According to one embodiment, different ultrasonic welding conditions may be brought about in successive time phases during the bringing about of the ultrasonic vibrations.

In other words, the ultrasonic welding device used in the present case for welding the joining partners may be specifically configured not to always bring about the same ultrasonic welding conditions constantly during a welding operation, but rather to vary them over time. This is also referred to as so-called phase welding.

The ultrasonic welding conditions may in this case include, inter alia, a contact pressure, an ultrasonic frequency, an ultrasonic amplitude, an ultrasonic power, an ultrasonic welding energy, a welding height, a temporally variable welding height profile, etc. Various welding phases may in this case comprise durations of a few milliseconds up to a few seconds, i.e. for example last between 5 ms and 0.5 s.

For example, ultrasonic vibrations with a lower contact pressure may be brought about during a first time phase of, for example, 50 ms in order, for example, to free surfaces on the joining partners of dirt and/or an oxide layer. Subsequently, a higher contact pressure may be set during a second time phase of, for example, 200 ms in order to carry out the actual ultrasonic welding.

It is pointed out that possible features and advantages of various embodiments of the invention are described herein partially with reference to a method configured according to the invention and partially with reference to an ultrasonic welding device which may be used to carry out this method. Persons skilled in the art will recognize that the features described for individual embodiments may be suitably transferred in an analogous manner to other embodiments, may be adapted and/or may be exchanged in order to arrive at further embodiments of the invention and possibly synergy effects.

BRIEF DESCRIPTION OF THE DRAWINGS

Advantageous embodiments of the invention are explained further below with reference to the accompanying drawings, wherein neither the drawings nor the explanations are to be interpreted as limiting the invention in any way.

FIG. 1 illustrates an ultrasonic welding device during the carrying out of a method according to one embodiment of the present invention.

FIG. 2 shows an exploded view of an exemplary multilayer composite printed circuit board.

FIGS. 3-5 illustrate examples of metal elements which have been welded to a composite printed circuit board by means of the method according to the invention.

The figures are merely highly schematic and not true to scale. Identical reference signs denote identical or identically acting features in the various drawings.

DESCRIPTION OF ADVANTAGEOUS EMBODIMENTS

FIG. 1 shows an ultrasonic welding device 1, with the aid of which a multilayer composite printed circuit board 3 may be electrically connected to a metal element 5 in the form of a metal strip 6 by ultrasonic welding. FIG. 2 shows an example of such a multilayer composite printed circuit board 3 in an exploded view.

In the example illustrated, the multilayer composite printed circuit board 3 is composed of a multiplicity of thin layers 7 which are stacked one above the other and are connected to one another to form a firm composite. In this case, some of the layers 7 are metal layers 9, for example in the form of thin copper foils 11. Other of the layers 7 consist of an electrically non-conductive material such as, for example, fiber-reinforced epoxy resin and thus act as insulator layers 13. The insulator layers 13 may be formed, for example, as so-called prepregs 15.

A metal layer 9 lying furthest to the outside on a front side of the composite printed circuit board 3 is referred to as a first metal layer 17. A metal layer 9 lying furthest to the outside on a rear side of the composite printed circuit board 3 is referred to as a last metal layer 19. In the center of the composite printed circuit board 3 illustrated merely by way of example, there are two further metal layers 9

which, together with a relatively thick insulator layer 13 arranged in between, form a stable core structure 21 in the form of a copper composite laminate 23.

The metal element 5 may be, for example, a connecting plate which may be configured as part of a contacting system (not illustrated). The metal element 5 may consist, for example, of copper or aluminum and have a significantly greater thickness than the composite printed circuit board 3 or at least than the first metal layer 17 thereof.

In a connecting region 25 in which the composite printed circuit board 3 is to be connected to the metal element 5, the first metal layer 17 is freely contact-connectable from the outside. In this case, the connecting region 25 may extend along the entire front surface of the composite printed circuit board 3 or, for example as a contact pad, may cover only a partial region of the surface.

In order to mechanically and electrically connect the composite printed circuit board 3 at its connecting region 7 to the metal element 5, both components are intended to be welded to one another by means of ultrasonic welding with the aid of the ultrasonic welding device 1.

For this purpose, the ultrasonic welding device 1 has an ultrasonic sonotrode 27. The ultrasonic sonotrode 27 has a sonotrode surface 29 which, during the welding, is directed toward the connecting region 25 of the composite printed circuit board 3 and the metal element 5 already arranged there beforehand. This sonotrode surface 29 has a surface texture 39, for example in the form of a corrugation, in particular a cross corrugation.

During the ultrasonic welding process, the ultrasonic sonotrode 27, controlled by a controller 41 of the ultrasonic welding device 1, is applied and pressed with its sonotrode surface 29 along a contact area 30 to an opposite first surface 31 of the metal element 5 with the aid of an actuator system 43. Subsequently, ultrasonic vibrations are generated in the ultrasonic welding device 1 and passed on to the ultrasonic sonotrode 27 and ultimately transmitted via the sonotrode surface 29 thereof to the metal element 5. The metal element 5 contacts with a rear-side

second surface 33 a front-side first surface 35 of the first metal layer 17 of the composite printed circuit board 5 so that a cohesive connection of the two joining partners occurs on account of the coupled-in ultrasonic vibrations at this boundary surface.

In the process, the composite printed circuit board 3 is supported on a rear side by an abutment element 45. For this purpose, the composite printed circuit board 3 bears with a rear-side second surface 37 against a surface 47 of the abutment element 45 directed toward it, which surface is planar in the illustrated example. Alternatively, the surface 47 of the abutment element 45, similarly to the sonotrode surface 29, may have a texture which should, however, have as far as possible no sharp-edged structures but at most rounded texture projections.

The ultrasonic welding device 1 with its sonotrode 13 is formed as a bending oscillator 49. In the case of such a bending oscillator 49, ultrasonic vibrations are generated in such a way that the sonotrode surface 29 moves exclusively or at least predominantly in a bending vibration direction 51 which is parallel or tangential to the surface of the composite printed circuit board 3 to be welded in the connecting region 25 thereof.

The ultrasonic welding device 1 may be configured, in particular, as a servopress. In this case, the ultrasonic welding device 1 has a sensor system 53, the actuator system 43 and the controller 41 (indicated merely very schematically in the figure). With the aid of the sensor system 53, forces or pressures acting on the sonotrode surface 29 may be measured in this case. With the actuator system 43, inter alia, the ultrasonic sonotrode 27 may be displaced, in particular in a direction towards the composite printed circuit board 3. The controller 41 may control the actuator system 43 and take account of signals of the sensor system 53 in this case. In particular, with the aid of the controller 41, the ultrasonic sonotrode 27 may thus be displaced towards the composite printed circuit board 3 in such a way that a contact pressure between the sonotrode surface 29 and the composite printed circuit board 3 may be limited to a predefinable pressure or a predefinable force correlating therewith by targeted control or regulation of the actuator system 43.

Furthermore, the controller 41 and if appropriate the actuator system 43 and/or the sensor system 53 may be configured in such a way that different ultrasonic welding conditions may be brought about in successive time phases during the ultrasonic welding, for example in the form of temporally varying ultrasonic frequencies, ultrasonic amplitudes, contact pressures, ultrasonic powers or energies, welding heights, etc.

In this case, the ultrasonic welding device 1 and the manner in which it is operated are selected in such a way that the ultrasonic vibrations may be transmitted, on the one hand, as effectively as possible and, on the other hand, as gently as possible for the sensitive multilayer composite printed circuit board 3 to the metal element 5 and the adjacent composite printed circuit board 3 as joining partners and may ensure the desired welding there. For this purpose, as explained in detail further above, special conditions are created or process parameters are kept within predefined process windows.

Some or all of the stated properties of the ultrasonic welding device 1 or of the measures and/or conditions used during welding may contribute to the fact that, in the method described here, the composite printed circuit board 3 is not damaged in its connecting region 25 on account of the ultrasonic welding process.

In this case, the stated properties, measures and/or conditions may contribute in particular to the fact that the composite printed circuit board 3 is at most insignificantly loaded and/or deformed locally during the ultrasonic welding process. As a result, in particular superficial damage to the composite printed circuit board 3 and delaminations between the individual layers 7 of the composite printed circuit board 3 may be avoided.

Overall, with the method described herein and the ultrasonic welding device 1 which may be used for this, an electrical connection of a composite printed circuit board 3 to any desired metal element 5 may be significantly simplified, configured reliably and/or costs may be saved in this case.

FIGS. 3-5 illustrate examples of joining partners which have been welded successfully with the aid of the method presented herein.

In FIG. 3, an elongate metal strip 61 is welded to a connecting region 25 of a first metal layer 17 on a multilayer composite printed circuit board 3. In this case, a contact area or a welded area has dimensions of 3.5×3.5 mm^2. The sonotrode was pressed with 40 N. In this case, an energy of 45 Ws was transmitted during the welding operation.

In FIG. 4, a plurality of elongate pins 63 are welded in each case to associated connecting regions 25 of a first metal layer 17 of a composite printed circuit board 3. For this purpose, the pins 63 have, at their lower end, in each case an annular flange 65 which bears against the first metal layer 17 of the composite printed circuit board 3. In the example illustrated, a contact area between this flange 65 and the first metal layer 17 is 3.5×3.5 mm^2. The sonotrode was pressed with 50 N and in this case an energy of less than 10 Ws was introduced.

In FIG. 5, two relatively thick wires 69 coming from an electrical component 67 were welded in each case to connecting regions 25 in the form of contact pads 71 of a first metal layer 17 of a composite printed circuit board 3. In this case, a contact area is again 3.5×3.5 mm^2. The sonotrode was pressed with 50 N and in this case an energy of 10 Ws was introduced.

Finally, it should be pointed out that terms such as “having”, “comprising”, etc. do not exclude any other elements or steps and terms such as “a” or “an” do not exclude a multiplicity. Furthermore, it should be pointed out that features or steps which have been described with reference to one of the above exemplary embodiments may also be used in combination with other features or steps of other exemplary embodiments described above. Reference signs in the claims should not be regarded as a restriction.

Claims

1. Method for electrically connecting a metal element (5) to a multilayer composite printed circuit board (3) by means of ultrasonic welding,
wherein the composite printed circuit board (3) has, in a connecting region (25), a first metal layer (17), at least one insulator layer (13) supporting the first metal layer (17) and at least one second metal layer (9) which is spaced apart from the first metal layer (17) by the insulator layer (13),
wherein the method comprises:
arranging the metal element (5) adjacent to the first metal layer (17) of the composite printed circuit board (3),
applying an ultrasonic sonotrode (27) with a sonotrode surface (29) to a surface (31) of the metal element (5) opposite the composite printed circuit board (3),
bringing about ultrasonic vibrations at the sonotrode surface (29),
wherein the ultrasonic vibrations are brought about with a frequency of less than 55 kHz, a power of more than 400 W and over a contact area (30) between the sonotrode surface (29) and the metal element (5) of at least 2 mm^2,
wherein the ultrasonic sonotrode (27) is displaced and pressed against the metal element (5) by means of a servo press (55) provided in an ultrasonic welding device (1), the servo press being driven by a servomotor or by means of an electromagnetic actuator.

2. Method according to claim 1,
wherein the ultrasonic vibrations are brought about with an amplitude of more than 10 µm.

3. Method according to one of the preceding claims,
wherein the arranging of the metal element (5) adjacent to the first metal layer (17) of the composite printed circuit board (3) and the applying of the ultrasonic sonotrode (27) to the surface (31) of the metal element (5) opposite the composite printed circuit board (3) are effected separately from one another in terms of time.

4. Method according to one of the preceding claims,
wherein a power area density which is defined as a ratio between the power with which the ultrasonic vibrations are brought about and the contact area (30) between the

sonotrode surface (29) and the metal element (5) is less than 200 W/mm^2.

5. Method according to one of the preceding claims,
wherein an energy which is transmitted overall to the metal element (5) during a welding operation by means of the ultrasonic vibrations brought about is less than 200 Ws.

6. Method according to one of the preceding claims,
wherein an energy area density which is defined as the ratio between an energy which is transmitted overall to the metal element (5) during a welding operation by means of the ultrasonic vibrations brought about and the contact area (30) between the sonotrode surface (29) and the metal element (5) is less than 5 Ws/mm^2.

7. Method according to one of the preceding claims,
wherein a force with which the sonotrode surface (29) is pressed against the metal element (5) during the bringing about of the ultrasonic vibrations is at least 10 N and at most 300 N.

8. Method according to one of the preceding claims,
wherein a pressure with which the sonotrode surface (29) is pressed against the metal element (5) during the bringing about of the ultrasonic vibrations is at least 1 N/mm^2 and at most 10 N/mm^2.

9. Method according to one of the preceding claims,
wherein the ultrasonic sonotrode (27) is formed as a bending oscillator (49).

10. Method according to one of the preceding claims,
wherein the composite printed circuit board (3) is supported on a surface (37) opposite the metal element (5) by means of an abutment element (45) during the bringing about of the ultrasonic vibrations.

11. Method according to claim 10,
wherein the abutment element (45) is planar on a surface (47) contacting the composite printed circuit board (3) or has a surface texture with texture projections which project

toward the composite printed circuit board (3) and are rounded in such a way that radii of curvature at ends of the texture projections directed toward the composite printed circuit board (3) are greater than 20 μm.

12. Method according to claim 10,
wherein the abutment element (45) is planar on a surface (47) contacting the composite printed circuit board (3) or has a surface texture with texture projections which project toward the composite printed circuit board (3) and are rounded in such a way that radii of curvature at ends of the texture projections directed toward the composite printed circuit board (3) are greater than 20% of a layer thickness of an outermost layer (19) of the composite printed circuit board (3) which is directly contact-connected by the abutment element (45).

13. Method according to one of the preceding claims,
wherein different ultrasonic welding conditions are brought about in successive time phases during the bringing about of the ultrasonic vibrations.

14. Method according to one of the preceding claims,
wherein the composite printed circuit board (3) is composed of at least five layers (7) stacked one above the other and mutually adjacent layers (7) consist of different materials, and/or
wherein the composite printed circuit board (3) has at least one layer (7) with a layer thickness of between 5 μm and 300 μm, and/or
wherein the first metal layer (17) of the composite printed circuit board (3) has a material selected from the group comprising copper, aluminum, silver, nickel, gold and palladium, and/or
wherein the insulator layer (13) of the composite printed circuit board (3) has a material selected from the group comprising epoxy, polyimide, polytetrafluoroethylene, FR-4, FR-1, CEM-1 or CEM-3, and/or
wherein the insulator layer (13) is fiber-reinforced.