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(54) Title: DEVICE AND METHOD FOR ULTRASONIC WELDING

(57) Abstract: The present invention provides an ultrasonic welding device (1) for welding a first workpiece (2) onto a second workpiece (3) comprising an ultrasonic welding tool (4) with a sonotrode (5) for contacting the first workpiece (2), a confinement structure (6, 20) attached or attachable to the ultrasonic welding tool (4), whereby the confinement structure (6, 20) is arranged and attached or attachable to the ultrasonic welding tool (4) to surround a welding region (8) where the first workpiece (2) is welded onto the second workpiece (3). The present invention also provides a method for ultrasonic welding a first workpiece (2) to a second workpiece (3), comprising welding the first workpiece (2) to the second workpiece (3) using the above ultrasonic welding device (1).

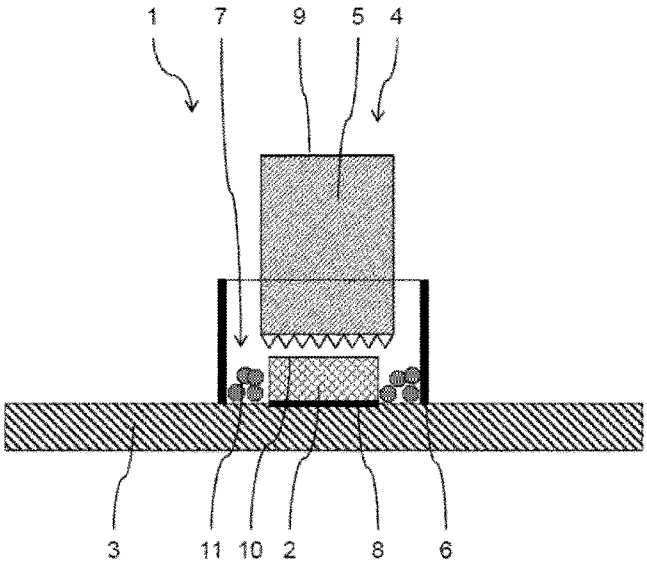

FIG. 1

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Description

Device and method for ultrasonic welding

Technical Field

[0001] The present invention relates to the area of ultrasonic welding. In particular, the present invention relates to the area of ultrasonic welding of components in power electronic modules.

Background Art

[0002] Ultrasonic welding is used in general for joining two workpieces, which comprise a contact surface for contacting the respective other workpiece. At least the contact surface is made of plastics, metal or any other material suitable for ultrasonic welding. The welding tool for performing the ultrasonic welding process comprises a sonotrode, which is brought into contact with one of the workpieces, i.e. a first workpiece. The sonotrode introduces ultrasonic vibration into the first workpiece, so that the contact surface of the first workpiece is moved with high frequency over the contact surface of the other workpiece, i.e. a second workpiece, and heat is generated in a welding region at the contact surfaces of the two workpieces creating an ultrasonic welding joint.

[0003] Ultrasonic welding is for example used in state-of-the-art power semiconductor modules. Electrical components such as electrical terminals, bonding wires or others are ultrasonic welded onto metallizations of substrates, which are commonly ceramic substrates. Accordingly, e.g. the electrical terminal is the first workpiece, and the substrate is the second workpiece.

[0004] Power semiconductor modules are used in high power applications to switch high voltages and currents and comprise multiple power semiconductors. Since each single semiconductor has a maximum voltage and current, the power semiconductors are frequently combined in parallel and/or in series within the power semiconductor modules to enable the

use in high power applications. To facilitate the manufacturing of such modules they commonly comprise multiple substrates, on which the power semiconductors are mounted. The substrates are provided with contacts for emitter, collector and base, so that the substrates can easily be connected within the power semiconductor modules.

[0005] The substrates are typically mounted on a common base plate, which can be part of a housing of the power semiconductor module or which can be held within a housing of the power semiconductor module. In nowadays power semiconductor modules, typically four or six substrates are combined, each provided with four to six power semiconductors comprising power transistors like insulated gate bipolar transistors (IGBT) or reverse conducting insulated gate bipolar transistors (RC-IGBT), power diodes, or other power semiconductors suitable for high power applications. For example, a substrate can comprise four IGBTs and two power diodes. The substrates are electrically connected to terminals, which provide a connection of the metallizations within the module. E.g. the electric terminals can be connected to electric contacts of the power module.

[0006] For ultrasonic welding an electrical terminal onto a metallization, the electrical terminal is placed onto the metallization of the substrate and ultrasonic welded onto the metallization with the welding tool. The sonotrode of the welding tool is brought into contact with the electrical terminal, so that ultrasonic vibrations are introduced into it. The ultrasonic energy locally heats the material of the electrical terminal and/or the metallization at its contact surface creating an ultrasonic welding joint.

[0007] During the ultrasonic welding process, particles can be torn off the workpieces and be ejected out of the welding region. These particles consist of the material of the first and/or the second workpiece and can originate from the welding region as well as from a contact region between the first workpiece and the sonotrode. When ultrasonic welding of electrical terminals to substrates, the area of deposition can have a radius of up to several centimeters around the welding region. Furthermore, when the welding process is finished, the welding tool frequently cleans itself

using ultrasonic vibrations, which results in more particles being ejected from and/or dropped off the welding tool. These particles can be deposited on the workpieces or other parts, where they can cause different problems, as explained further below. Therefore, depositing of particles out of the welding region during the ultrasonic welding process has to be avoided.

[0008] If particles are deposited on or close to mechanically moving parts or bearings they can cause damages and increase wear-out. Also for other reason it can be required that particles are not present, e.g. for reasons of hygienic, clean-room environment, health impact of particles on operating personnel etc.

[0009] In particular, particles can become critical when welding electrical terminals on substrates. Particles deposited onto semiconductors, substrates, or any place within the power semiconductor module, can act as sources for partial discharge and electrical insulation breakdown during operation at high voltages, if they are not completely removed. If an electrical voltage is applied during the operation of the power semiconductor module, a particle can lead to an electrical shortcut, an insulation breakdown or partial discharge, especially when a particle is located in an unfavorable position, e.g. where an electrical field is present during the operation of the power semiconductor module. Especially in power semiconductors modules dealing with blocking voltages up to 6.5 kV, this can cause problems.

[0010] Different methods and apparatus are known in the art to remove particles after ultrasonic welding. However, it is very difficult to remove all particles by cleaning processes since particles may be hot and bury themselves by burning into present materials. In particular, hot particles may burn into organic materials such as polyimide. Small particles may stick to surfaces by electrostatic forces. Other particles might not be accessible for a cleaning process if they are located underneath other structures, in corners, or other places where they cannot reliably be removed.

US 5,115,961 discloses in Fig. 1 and Fig. 2 also an ultrasonic welding device for welding a first workpiece onto a second workpiece comprising an ultrasonic welding tool with a sonotrode for contacting the first workpiece.

Disclosure of Invention

[0011] It is an object of the present invention to provide an ultrasonic welding device and an ultrasonic welding method using the ultrasonic welding device, which allow ultrasonic welding of two workpieces with high reliability and with reduced depositing of particles out of the welding region during the ultrasonic welding process. In particular, it is an object of the present invention to provide an ultrasonic welding device and an ultrasonic welding method using the ultrasonic welding device for welding electrical components, e.g. electric terminals of semiconductor modules, onto substrates, which allow welding electrical components onto substrates for use in high power applications with high reliability and with reduced depositing of particles out of the welding region during the ultrasonic welding process.

[0012] This object is achieved by the independent claims. Advantageous embodiments are given in the dependent claims.

[0013] In particular, the present invention provides an ultrasonic welding device for welding a first workpiece onto a second workpiece comprising an ultrasonic welding tool with a sonotrode for contacting the first workpiece, a confinement structure attached or attachable to the ultrasonic welding tool, whereby the confinement structure is arranged and attached or attachable to the ultrasonic welding tool to surround a welding region, in particular where the first workpiece is welded onto the second workpiece.

[0014] The present invention also provides a method for ultrasonic welding a first workpiece to a second workpiece, comprising welding the first workpiece to the second workpiece using the ultrasonic welding device.

[0015] Since the creation of particles during the ultrasonic welding process cannot be reliably avoided, the basic idea of the invention is to control

and/or minimize the deposition of particles on the workpieces or other components to which belong the workpieces. The use of the confinement structure around the welding region can trap particles as soon as they are ejected from the welding region. Regions out of the confinement structure are shielded from the particles. Especially hot and fast particles can be trapped by the confinement structure, since fast particles usually have a shallow ejection angle compared to contact surfaces of the workpieces. Accordingly, problems usually caused by these particles are reduced or overcome. By attaching the confinement structure to the ultrasonic welding tool, the welding process can be efficiently performed, since the workpieces do not have to be prepared. The confinement structure can be brought in place at the time the two workpieces are welded together. The confinement structure may be provided to fully surround the welding region, e.g. in cases where the welding region is located in a central area of the contact surface of the second workpiece, or the confinement structure may be provided to merely surround the welding region partially, e.g. when the welding region is located in a corner of the contact surface of the second workpiece and only the contact surface of this second workpiece has to be protected from depositing particles thereon.

[0016] Preferably, the confinement structure is arranged to surround also a contact region where the sonotrode contacts the first workpiece, so that also particles originating from this area can be trapped. Further preferred, the confinement structure is uncoupled from the ultrasonic welding tool, in particular from the sonotrode, so that ultrasonic vibrations are not introduced into the confinement structure and/or the oscillation of the ultrasonic welding tool is not affected by the confinement structure. Hence, the confinement structure can reliably trap the particles without danger of damaging the workpieces. The confinement structure can comprise any suitable material, e.g. metal, plastic, silicone, paper, cardboard, or other organic material. The confinement structure can have any suitable cross section, e.g. a rectangular, cylindrical, conical, or funnel-shaped cross section.

[0017] The ultrasonic welding device can be used for welding a single first workpiece onto the second workpiece, or multiple first workpieces simultaneously onto the second workpiece. Accordingly, the welding tool can have a single sonotrode for contacting multiple first workpieces, or multiple sonotrodes for individually contacting the first workpieces. Further preferred, the ultrasonic welding device can have a single confinement structure to commonly surround the welding regions where the first workpieces are welded onto the second workpiece, or multiple confinement structures to individually surround the welding regions.

[0018] According to a modified embodiment of the invention the confinement structure is moveable in an axial direction longitudinal and relative to the ultrasonic welding tool, in particular in axial direction from the first workpiece to the second workpiece. This direction refers typically to a direction vertical to the contact surface of the two workpieces. Therefore, the placement of the sonotrode for contacting the first workpiece can be separated from the placement of the confinement structure to surround the welding region.

[0019] According to a modified embodiment of the invention the confinement structure is moveable to form a surface contact with the second workpiece. Since the welding region is on top of the second workpiece, the surface contact of the confinement structure can reliably trap particles originating from this region.

[0020] According to a modified embodiment of the invention the confinement structure is provided to surround the first workpiece with a gap of less than 5 mm, preferably about 0.5 mm. In general, it is desired to make an area surrounded by the confinement structure as small as possible, so that a possible area of impurities due to particles torn off during the welding process is as small as possible. Nevertheless, a gap facilitates the placement of the confinement structure. In particular when ultrasonic welding electrical components onto substrates, it is preferred to keep the gap small to enable welding of electrical components close by to other components on the substrate.

[0021] According to a modified embodiment of the invention the confinement structure comprises a tubular body. The tubular body can have any suitable shape. The tubular body can be easily provided, e.g. by cutting from a tube. With its closed structure, it can prevent particles from leaving the region inside the confinement structure. Preferably, the tubular body is provided to extend along the sonotrode and surrounding the sonotrode.

[0022] According to a modified embodiment of the invention the tubular body has a wall thickness of less than 1 mm, preferably less than 0.1 mm. A thin wall facilitates the positioning of the ultrasonic welding device and in particular the positioning of the confinement structure. In particular when ultrasonic welding electrical components onto substrates, it is preferred to keep the wall thickness small to enable welding of electrical components close by to other components on the substrate.

[0023] According to a modified embodiment of the invention the confinement structure comprises a curtain structure. The curtain can adapt to different shapes of the workpieces, so that the workpieces can be reliably surrounded by the confinement structure. Preferably, the curtain structure is made of a soft material, which further facilitates adaptation to the workpieces. Furthermore, damages of the workpieces can be avoided. Preferably, the curtain structure comprises individual curtain elements. Further preferred, the curtain elements overlap to reduce the risk of particles escaping from inside the confinement structure.

[0024] According to a modified embodiment of the invention the confinement structure comprises a brush structure. The brush structure can be easily provided and can reliably trap particles during the welding process. The brush structure comprises individual bristles, which together form the brush structure. Preferably, the bristles are arranged in multiple layers to reduce the risk of particles escaping from inside the confinement structure.

[0025] According to a modified embodiment of the invention bristles of the brush structure are made of a flexible material, in particular a flexible plastic or silicone. The flexible material can adapt to the shape of the workpieces to reliably trap particles within the confinement structure. The flexible material can adapt to height differences of the second workpiece. Furthermore, the

risk of damaging the workpieces or any other component in or around the welding region is reduced. For example, the risk of scratching the workpieces is reduced. In particular when ultrasonic welding electrical components onto substrates, the risk of deforming wire bonds already provided on the substrate, e.g. for connection of a metallization of the substrate to a contact pad of a semiconductor, is reduced.

[0026] According to a modified embodiment of the invention the confinement structure comprises an anti-static material. The antistatic material is preferably provided at an interior side of the confinement structure. Further preferred, the confinement structure is covered by the antistatic material. Still further preferred, the confinement structure is made of the antistatic material. The antistatic material reduces or avoids static charge of the workpieces, so that particles do not stick thereto. Therefore, the particles can easily be removed if deposited thereon.

[0027] According to a modified embodiment of the invention the confinement structure comprises a sticky material. The sticky material is preferably provided at an interior side of the confinement structure. Further preferred, the confinement structure is covered by the sticky material. Still further preferred, the confinement structure is made of the sticky material. Particles generated during the ultrasonic welding process can stick to the sticky material of the confinement structure and can be automatically removed after the ultrasonic welding process.

[0028] According to a modified embodiment of the invention the ultrasonic welding device comprises a pump for extracting air from an area surrounded by the confinement structure. The pump preferably applies a vacuum or an underpressure to the area surrounded by the confinement structure to remove particles torn off during the ultrasonic welding process. The pump can also be used for a cleaning process after finishing the ultrasonic welding process, either by suction or blowing away particles, in particular from the two workpieces.

[0029] According to a modified embodiment of the invention the method comprises the additional step of cleaning particles from the workpieces. Preferably, the cleaning step is performed in an area surrounded by the

confinement structure during the welding process, since particles are supposed to be trapped in this area. Alternatively, the cleaning step can be applied entirely to the workpieces. Cleaning can comprise cleaning using an air blast, an ultrasonic bath, a dish washer or others.

[0030] According to a modified embodiment of the invention the method comprises the additional step of cleaning the confinement structure. The confinement structure can be cleaned when attached to the welding tool. Preferably, the confinement structure is attachable to the welding tool and can be removed for cleaning purposes. Depending on the confinement structure, different steps can be applied for cleaning, including washing. Accordingly, the confinement structure can be cleaned in an ultrasonic bath, e.g. with ethanol or de-ionized water.

Brief Description of Drawings

[0031] These and other aspects of the invention will be apparent from and elucidated with reference to the embodiments described hereinafter.

[0032] In the drawings:

[0033] Fig. 1 shows a sectional view of a ultrasonic welding device according to a first embodiment and two workpieces,

[0034] Fig. 2 shows a frontal view of a ultrasonic welding device according to a second embodiment,

[0035] Fig. 3 shows a detailed bottom view of a sonotrode and a brush structure of the ultrasonic welding device according to the second embodiment, and

[0036] Fig. 4 shows a lateral view of a sonotrode and a confinement structure of an ultrasonic welding device according to a third embodiment.

Detailed Description of the Invention

[0037] Fig. 1 shows an ultrasonic welding device 1 for welding two workpieces 2, 3 together according to a first embodiment. The ultrasonic welding device 1 comprises in this embodiment an ultrasonic welding tool 4, from which

Fig. 1 only shows a sonotrode 5. The ultrasonic welding device 1 in this embodiment is used for welding an electrical terminal 2 as first workpiece onto a ceramic substrate 3 as second workpiece. In particular, the electrical terminal 2 is welded onto a metallization of the substrate 3.

[0038] The ultrasonic welding device 1 further comprises a confinement structure 6, which is attached to the sonotrode 5, as indicated in Fig. 1. The confinement structure 6 is provided in this embodiment as a tubular body made of a sticky and antistatic plastic. The tubular body 6 has a rectangular cross section in accordance with the shape of the electrical terminal 2. The tubular body 6 has a wall thickness of approximately 0.1 mm, and a gap 7 is provided between the confinement structure 6 and the electrical terminal 2 with a width of approximately 0.5 mm.

[0039] The ultrasonic welding device 1 further comprises a pump for extracting air from an area surrounded by the confinement structure 6. The pump is not shown in Fig. 1.

[0040] A method for ultrasonic welding the electrical terminal 2 onto the substrate 3 using the ultrasonic welding device 1 will now be described with reference to Fig. 1.

[0041] The electrical terminal 2 is located on the substrate 3. Contact surfaces of the two workpieces 2, 3 are contacted to each other to form a welding region 8. The ultrasonic welding device 1 is moved towards the electrical terminal 2 from the top, so that the sonotrode 5 contacts a top surface 9 of the electrical terminal 2. Since the confinement structure 6 is attached to the sonotrode 5, it is moved towards the substrate 3 to surround the welding region 8 and a contact region 10 where the sonotrode 5 contacts the electrical terminal 2.

[0042] During the ultrasonic welding process, the sonotrode 5 introduces ultrasonic vibrations into the electrical terminal 2, so that the electrical terminal 2 is moved with a high frequency on the substrate 3. Heat is generated in the welding region 8, so that a welding joint can be formed in the welding region 8.

[0043] Due to the ultrasonic vibrations, particles 11 are torn off the electrical terminal 2 and the substrate 3 from the contact region 10 and the welding

region 8. The particles 11 are trapped by the confinement structure 6 and can be partially removed during the welding process by the pump, which extracts air from the area surrounded by the confinement structure 6. Partially, the particles 11 stick to the confinement structure 6.

[0044] Subsequently, the ultrasonic welding device 1 is moved away from the electrical terminal 2. Particles 11 remaining on the workpieces 2, 3 are removed by a cleaning step, e.g. using an air blast, an ultrasonic bath or a dish washer.

[0045] After use, the confinement structure 6 is cleaned. Accordingly, the confinement structure 6 is removed from the sonotrode 5 and cleaned by a washing step. In this embodiment, washing step includes an ultrasonic bath, e.g. with ethanol or de-ionized water.

[0046] Figs. 2 and 3 refer to an ultrasonic welding device 1 according to a second embodiment. The ultrasonic welding device 1 is similar to the ultrasonic welding device 1 of the first embodiment, so that only differences between the ultrasonic welding devices 1 are explained. Also the welding method using the ultrasonic welding device 1 of the second embodiment can be performed as described with reference to the ultrasonic welding device 1 of the first embodiment.

[0047] The ultrasonic welding device 1 of the second embodiment comprises a confinement structure 20 with a brush structure 21 formed by individual bristles 22

[0048] The confinement structure 20 has a circular cross section in this embodiment. The bristles 22 in this embodiment are made of a flexible, sticky and antistatic silicone. The bristles 22 are arranged in two layers forming a closed brush structure 21 for trapping particles 11 therein.

[0049] In this embodiment, the confinement structure 20 is in a way not shown in the figures moveable in an axial direction from the electrical terminal 2 to the substrate 3 relative to the ultrasonic welding tool 4, in particular relative to the sonotrode 5, which is surrounded by the confinement structure 20. Thereby, the confinement structure 20 is moveable to form a surface contact with the substrate 3.

[0050] Fig. 4 shows an ultrasonic welding device 1 according to a third embodiment. The ultrasonic welding device 1 is similar to the ultrasonic welding device 1 of the second embodiment. It only differs from the ultrasonic welding device 1 of the second embodiment in the design of the sonotrode 5, which is provided as a bending oscillator in this embodiment.

[0051] While the invention has been illustrated and described in detail in the drawings and foregoing description, such illustration and description are to be considered illustrative or exemplary and not restrictive; the invention is not limited to the disclosed embodiments. Other variations to be disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims. In the claims, the word “comprising” does not exclude other elements or steps, and the indefinite article “a” or “an” does not exclude a plurality. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage. Any reference signs in the claims should not be construed as limiting scope.

Reference signs list

1	ultrasonic welding device
2	first workpiece, electrical terminal
3	second workpiece, substrate
4	ultrasonic welding tool
5	sonotrode
6	confinement structure, tubular body
7	gap
8	welding region
9	top surface
10	contact region
11	particle
20	confinement structure
21	brush structure

22 bristle

Claims

1. Ultrasonic welding device (1) for welding a first workpiece (2) onto a second workpiece (3) comprising
an ultrasonic welding tool (4) with a sonotrode (5) for contacting the first workpiece (2),
a confinement structure (6, 20) attached or attachable to the ultrasonic welding tool (4), whereby
the confinement structure (6, 20) is arranged and attached or attachable to the ultrasonic welding tool (4) to surround a welding region (8).

2. Ultrasonic welding device (1) according to claim 1,
whereby
the confinement structure (6, 20) is moveable in an axial direction longitudinal and relative to the ultrasonic welding tool (4).

3. Ultrasonic welding device (1) according to claim 2,
whereby
the confinement structure (6, 20) is moveable to form a surface contact with the second workpiece (3).

4. Ultrasonic welding device (1) according to any preceding claim,
whereby
the confinement structure (6, 20) is provided to surround the first workpiece (2) with a gap of less than 5 mm, preferably about 0.5 mm.

5. Ultrasonic welding device (1) according to any preceding claim,
whereby
the confinement structure (6) comprises a tubular body.

6. Ultrasonic welding device (1) according to preceding claim 5,
whereby

the tubular body (6) has a wall thickness of less than 1 mm, preferably less than 0.1 mm.

7. Ultrasonic welding device (1) according to any preceding claim,
whereby
the confinement structure (6, 20) comprises a curtain structure.

8. Ultrasonic welding device (1) according to any preceding claim,
whereby
the confinement structure (20) comprises a brush structure (21).

9. Ultrasonic welding device (1) according to preceding claim 8,
whereby
bristles (22) of the brush structure (21) are made of a flexible material, in particular a flexible plastic or silicone.

10. Ultrasonic welding device (1) according to any preceding claim,
whereby
the confinement structure (6, 20) comprises an anti-static material.

11. Ultrasonic welding device (1) according to any preceding claim,
whereby
the confinement structure (6, 20) comprises a sticky material.

12. Ultrasonic welding device (1) according to any preceding claim,
comprising a pump for extracting air from an area surrounded by the confinement structure (6, 20).

13. Method for ultrasonic welding a first workpiece (2) to a second workpiece (3), comprising
welding the first workpiece (2) to the second workpiece (3) using the ultrasonic welding device (1) according to any of preceding claims 1 to 12.

14. Method according to claim 13,

comprising the additional step of cleaning particles (11) from the workpieces (2, 3).

15. Method according to any of preceding claims 13 or 14,

comprising the additional step of cleaning the confinement structure (6, 20).

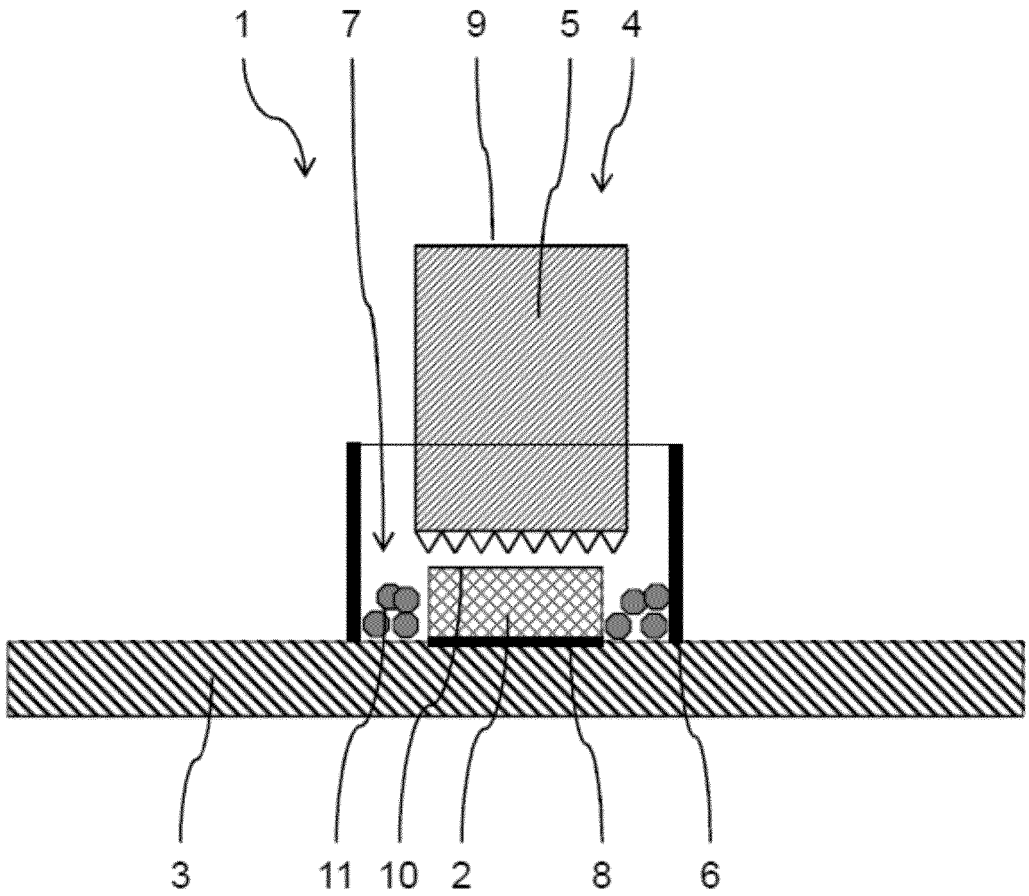

FIG. 1

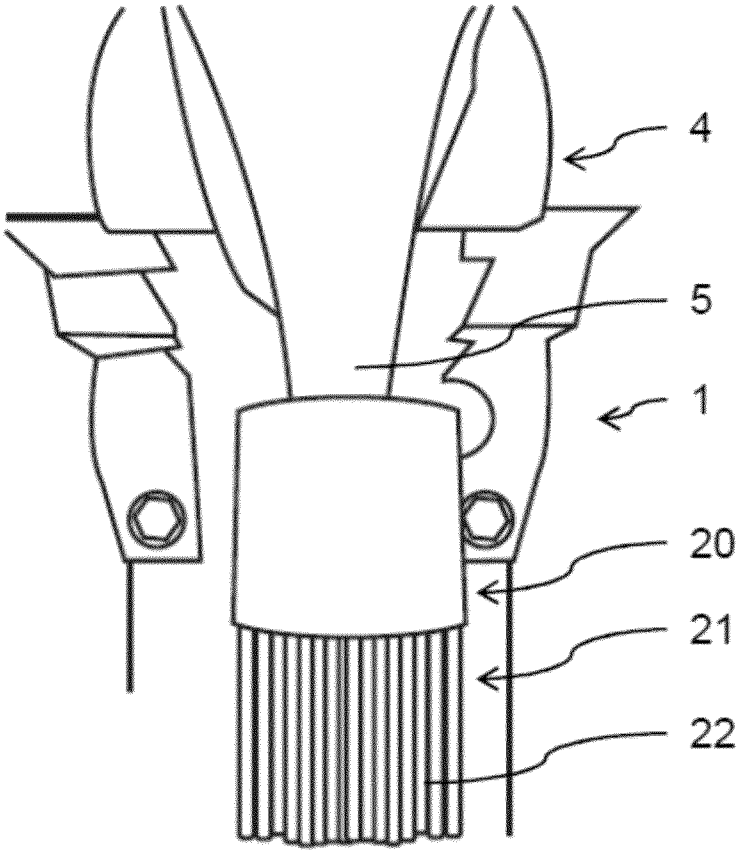

FIG. 2

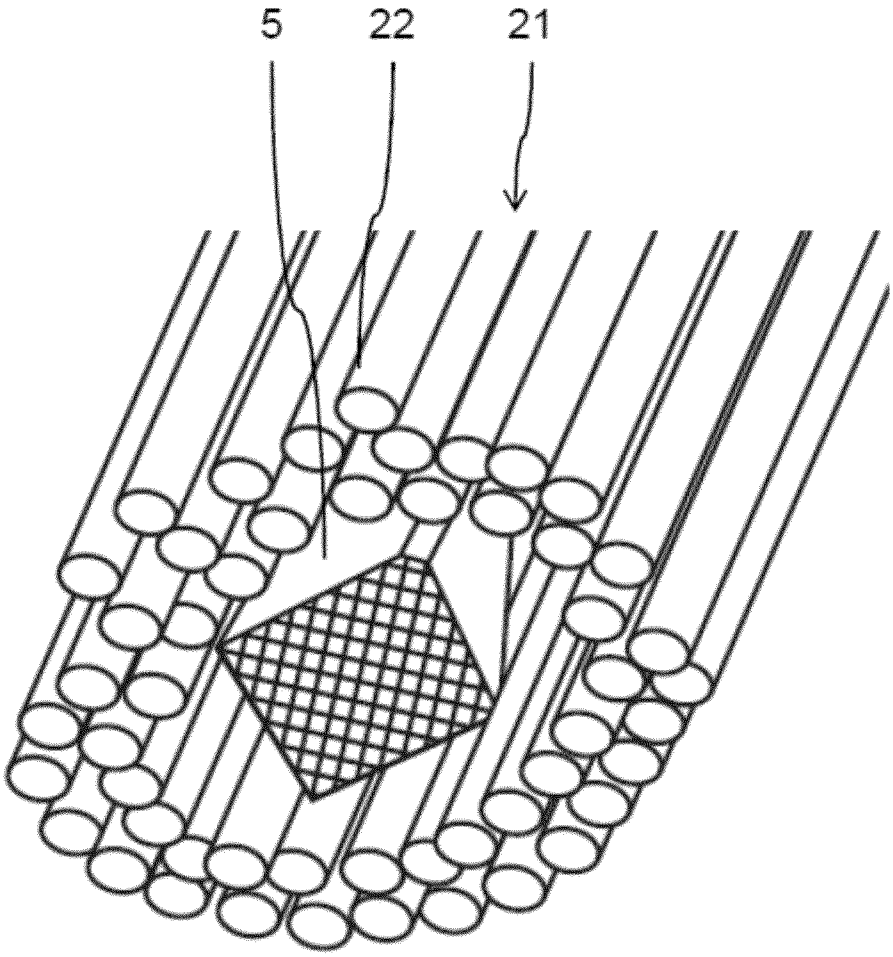

FIG. 3

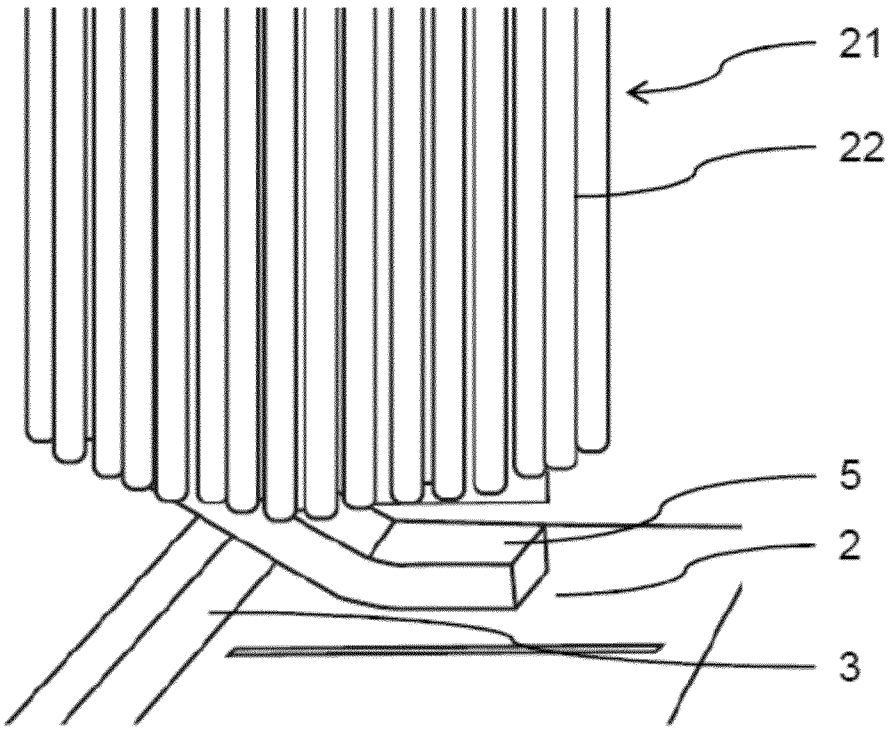

FIG. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2013/060355

A. CLASSIFICATION OF SUBJECT MATTER
INV. B23K20/10 B23K37/06
ADD.

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)
B23K

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5 115 961 A (NAKAJIMA SABURO [JP]) 26 May 1992 (1992-05-26) column 1, line 58 - column 2, line 9; figure 1	1-15
Y	JP 9 136177 A (FUJI ELECTRIC CO LTD) 27 May 1997 (1997-05-27) abstract; figures 1-3	1-15
A	CN 201 632 760 U (TIANJIN LISHEN BATTERY) 17 November 2010 (2010-11-17) abstract	1

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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Date of the actual completion of the international search	Date of mailing of the international search report
9 August 2013	20/08/2013

Name and mailing address of the ISA/	Authorized officer
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2013/060355

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5115961 A	26-05-1992	DE 4126904 A1	20-02-1992
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