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(54) **Title:** POWER SEMICONDUCTOR HAVING A SHUNT RESISTOR

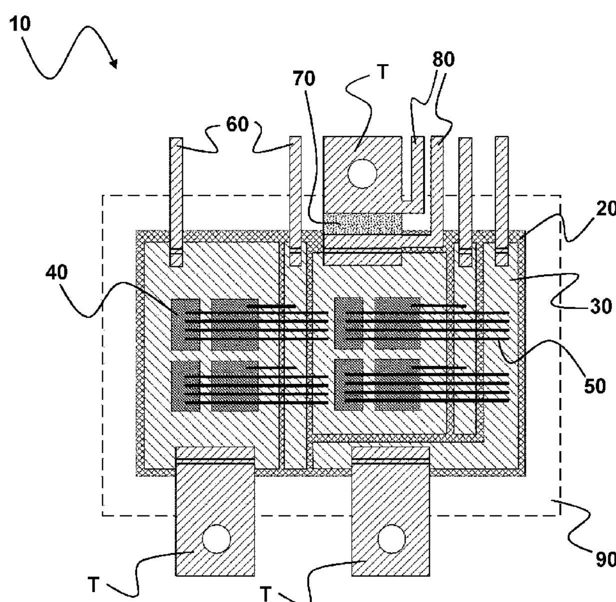

FIG. 2

(57) **Abstract:** Power semiconductor module having an external electrical connection and a shunt resistor, characterized in that the shunt resistor is integrated into the external electrical connection.

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[Continued on next page]

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Power semiconductor having a shunt resistor

5 The invention relates to a power semiconductor module having a shunt resistor.

Sensor components are increasingly being integrated in modern power semiconductor modules. For simple current measurement, use is made of so-called shunt resistors (constant-resistance elements) which are mounted on connection zones provided
10 specifically for them on the ceramic power substrate (DCB) by means of soldering. Typically, the actual resistance element of the shunt is produced from Manganin® (CuMn12Ni), and the connections are produced from copper.

To be able to compensate for a certain difference in linear expansion between the ceramic
15 power substrate and the shunt, shunts are usually provided with a U-shaped expansion loop and soldered onto the connection zones.

The disadvantage of this design is that the space requirement on the power substrate is approximately of the order of magnitude of a power semiconductor chip. The additional
20 space requirement of such a solution may thus be about 20 % of the active useful area of the substrate.

The arrangement in the power semiconductor module furthermore has the disadvantage that a good thermal linking to the power substrate also transmits the heat thereof to the
25 resistance element and the latter thus experiences all thermal load changes.

Therefore, it is an object of the present invention to provide a power semiconductor module having a shunt resistor integrated in the semiconductor module more compactly.

30 To overcome the disadvantages of the state of the art, the invention provides a power semiconductor module having the features of claim 1. The dependent claims represent advantageous embodiments of the invention.

The invention proposes integrating the shunt into the external connections, e.g. lead frames in the case of molded modules, terminals in the case of framed modules or the busbar system in the case of encapsulated power modules. Thus, no additional space for the shunt
5 is required on the power substrate (DCB). Particularly, it is unimportant whether the shunt is situated in a region of the external connections within or outside the housing.

According to the invention, one connection of the shunt is connected to the lead frame, terminal or to the busbar system and the second connection of the shunt is mounted on the
10 power substrate, or connected to a further lead frame section. In this case, this particular mounting location occupies the same space as would otherwise be occupied by the mounting location of the lead frame, the wire bonds to the terminals or the busbar system. Thus, this integrated version of a shunt is space-neutral and therefore very cost-effective.

15 One particular configuration variant relates to molded power modules in which a lead frame is usually applied to the DCB by means of soldering. After the assembly has been encapsulated by molding, the lead frame is stamped and, if appropriate, bent to shape (so-called “trim & form step”). According to the invention, a power connection path of the lead frame is now designed such that the actual resistance element of the shunt becomes an
20 integral part of the power connection path of the lead frame. It is possible to utilise the material from which the lead frame is normally made to function as the resistance element of the shunt. However, the choice of lead frame material is normally dictated by electrical resistance and hardness characteristics, and it thus may not have the low temperature coefficient of resistance or long-term stability characteristics that are required for a good
25 quality shunt resistance element. It is often an advantage to use a different material for the resistance element of the shunt. For this purpose, the main connection of the shunt is cohesively connected to the copper of the lead frame, e.g. by welding, particularly laser welding, electron beam welding or the like, silver sintering or soldering.

30 The second main connection of the shunt is then either linked simultaneously with the other lead frame connection directly to the power substrate, e.g. by means of soldering or silver

sintering, or, in a manner contacted with a further section of the lead frame linked via the latter to the power substrate.

In the case of lead frame connections, features known as “downsets” are widely used, i.e. a stepped connection arrangement which ensures a sufficient insulation distance between the elements leading away from the power substrate and, for example, the cooling devices positioned below the power substrate.

The arrangement of the actual resistance element of the shunt in the vertical region of the downset is very advantageous for the integration of the shunts into the lead frame. One major advantage is that by placing the resistance element of the shunt in the vertical section of the downset, no horizontal area is needed for the resistance element. An alternative might be to place the resistance element on the circuit substrate of the power module, but this would take up valuable space and will cause the power module to be larger than needed. Another alternative may be to place the resistance element in the horizontal section of the lead frame; this has the disadvantage that the lead frame has to be large enough to accommodate the resistance element, thus taking up horizontal space. The arrangement of the resistance element of the shunt in the vertical region of the downset can be implemented either after the embossing of the downset or before the embossing of the downset.

Preferably for the correct electrical measurement function, a lead frame connection that carries e.g. the summation current of the power module is chosen.

Crucial for the electrical measurement function of the shunt are the sense connections, that is to say the auxiliary connections of a “four-conductor system”, comprising a first conductor where the current to be measured flows into the shunt, a second conductor where the current to be measured flows out of the shunt, and two auxiliary connections placed at either end of the resistance element of the shunt. This distribution of conductors enables a tapping of the voltage appearing across the resistance element. Said sense connections can also be integrated into the lead frame in this way. On the side of the power substrate, these

small auxiliary connections can be linked simultaneously with the main connections, e.g. by soldering or silver sintering.

A second configuration variant relates to the arrangement of the shunt in a load terminal of a bondable frame of conventional power modules. In this case, a part of the terminal is formed by the integrated shunt. The connection of the terminal to the power substrate can then be performed as usual by means of many wire bonds routed parallel. A wire bond then takes up the current path of the auxiliary connection of the shunt. It is likewise conceivable to mount the integrated shunt to the power substrate by means of ultrasonic welding or laser welding.

A third configuration variant relates to busbar systems, such as are typically used in the case of power modules having very high current-carrying capacities (600 A to 1800 A). These load busbars are suitable for the integration of shunts in just the same way as lead frames. The mounting of the busbar system to the power substrate and the simultaneous mounting of the main connection and the auxiliary connection of the shunt are then carried out e.g. by means of ultrasonic welding or laser welding or silver sintering.

Hence, the invention provides a power semiconductor module having an external electrical connection and a shunt resistor, wherein the shunt resistor is integrated into the external electrical connection.

Particularly, the power semiconductor module is designed such that the electrical connection comprises a first section and a second section made of an electrically conductive first material and a shunt resistor section connecting the first and second sections made of an electrically conductive second material. The first section of the electrically conductive first material, the shunt resistor section and the second section of the electrically conductive first material are positioned in a sequential manner, one after the other.

In a preferred embodiment the shunt resistor section occupies the full cross sectional area of the electrical connection in the shunt resistor section. This ensures that all of the current

being measured flows through the electrically conductive second material and thus enables the most accurate and stable measurement of the current to be made.

According to a preferred embodiment the first section and/or the second section is connected to the shunt resistor by means of a form-fit connection. The form-fit connection is preferably a dovetail joint.

As mentioned above the external electrical connection is part of a lead frame, designed as a terminal or designed as a bus bar.

In a further embodiment, the external electrical connection may be part of a lead frame which comprises a downset where the shunt resistor is placed in a vertical region of the downset. By this is meant that the shunt resistor is placed where the lead frame turns from a horizontal section to a vertical section in order to change height from the external connection to the level of the circuit substrate. As described above, this is very advantageous for the reduction of horizontal space used by the shunt resistor in the power module.

As mentioned above, the power module may be a molded power module that is a module formed by inserting the completed power module circuitry into a mold tool and forming a hard encapsulation over the power module circuitry and part of the external electrical connections. Such an encapsulation protects the circuitry from mechanical and chemical disturbances.

In a yet further embodiment the shunt resistor may be completely encapsulated in the mold compound. Such an embodiment ensures that the shunt resistor is protected from mechanical damage, mechanical shocks and chemical disturbances such as corrosion. This protection ensures that the shunt resistor maintains its electrical characteristics for longer, enhancing the lifetime and stability of its ability to measure current.

In a yet further embodiment the external connection may protrude from the surface of the mold compound. Such a protrusion may enhance the ability to make connections to the external connection in order to conduct high currents in or out of the power module. The protrusion may comprise a hole suitable for connecting a bolt, or it may in turn be fitted with some another form of connector such as a captive nut, or be machined to have an internal thread.

According to a further embodiment, the shunt resistor comprises at least one of Manganin® (CuMn12Ni), Constantan® or Isotan® (Alloy of 55 % copper, 44 % nickel and 1 % manganese) and Isabellin® (Alloy of 84 % copper, 13 % manganese and 3 % aluminium).

Still further, a first sense wire and a second sense wire are provided, wherein the first sense wire is electrically coupled with the first section and the second sense wire is electrically coupled with the second section each adjacent to the shunt resistor section.

To provide for a good signal to noise ratio, the sense wires are both located on same side of the external electrical connection with respect to its longitudinal axis.

Finally, in the case of providing a lead frame having the integrated shunt resistor, a method for producing such a power semiconductor module is provided wherein the shunt resistor is integrated into the external electrical connection of the lead frame before or after embossing downsets as part of the lead frame. The shunt resistor is preferably placed in a vertical region of the downset.

The invention is described in more detail with respect to a preferred embodiment shown in the accompanying figures, wherein

Fig. 1 shows a top view of a first preferred embodiment according to the invention;

Fig. 2 shows a top view of a second preferred embodiment according to the invention;

Fig. 3 shows a top view of a third preferred embodiment according to the invention;

Fig. 4 shows a perspective view of a fourth preferred embodiment according to the invention;

Fig. 5 shows a fifth preferred embodiment of an electrical connection including a shunt resistor;

Fig. 6 shows a cross-section of a molded power semiconductor module having a shunt resistor arranged in the downset region of a lead frame portion;

Fig. 7 shows selected parts of a module comprising a busbar according to the present invention;

Fig 8 shows a top view of a further preferred embodiment;

Fig. 9 shows steps in the preferred method for producing a power semiconductor module where the shunt resistor is integrated into the external electrical connection;

Fig. 10 shows steps in an alternative method for producing a power semiconductor module where the shunt resistor is integrated into the external electrical connection; and

Fig. 11 shows an alternative method of forming the shunt resistor integrated into the external connection of the lead frame.

Fig. 1 depicts the general structure of a first preferred embodiment according to the invention in a top view. Particularly, Fig. 1 shows a power semiconductor module 10 having an electronic circuit built on the upper copper layer 30 of a DBC substrate 20 and comprising

electronic components 40 including power switching semiconductors with interconnections using wire bonds 50. The module typically is encapsulated in a mold compound 90 which is indicated by the dashed line. The external connections are made by a lead frame 60 and one component of this, i.e. one of the module's external power connectors T, contains a shunt
5 resistor 70 with two sense connections 80 from either side of the shunt area.

The embodiment shown in Fig. 2 basically shares the same features as the embodiment of Fig. 1, but with the two sense connections 80 configured on the same side of the external connector T. Compared to the embodiment of Fig. 1, the design shown in Fig. 2 is a preferred
10 embodiment, since because the sense connections 80 are closer together, there is a reduced risk of inductive coupling.

Fig. 3 shows an embodiment basically the same as in Fig. 1, but where the shunt 70 comprises a particular area in one of the lead frame connectors T but without the section
15 comprising a different material. Although this is easier and cheaper to manufacture, the result is not as stable or accurate as using a second material specifically chosen for its resistance properties. The lower area of the figure illustrates the two embodiments of the lead frame portion with (Fig. 3B), and without (FIG. 3C), the separate material used in the shunt area 70.
20

Fig. 4 illustrates the utilisation of a “dovetail joint” form-fit connection for the shunt 70 in an external portion of the external connector T.

Fig. 5 shows an alternative embodiment of sensing connections 80. Here pressed pins 80 are
25 inserted into holes in the external electrical connection T. One advantage of these is that they are easy to place centrally in the connector, and so the measured voltages less affected by edge effects.

Fig. 6 is a cross-section through the edge of a module comprising a DBC substrate 110 on
30 which are placed components (not shown), the DBC substrate 110 being mounted on a baseplate 100. Also shown here is a lead frame 60 which forms the external electrical

connection T. This lead frame has a downset 65 and the actual resistance element 70 of the shunt is placed in the vertical region of the downset 65. The module 10 is completed by encapsulating it in a mold compound 90.

5 Fig. 7 shows selected parts of a module comprising a busbar 120. Here are three separate substrates 20 are mounted on a baseplate 100. On top of each substrate 20 is a conducting circuit layer 30 and electronic components 40 such as semiconductors. A load busbar 120 is illustrated with a connection to each of the substrates 30 and an external connection T. The shunt area 70 is shown adjacent to the external connection T and to sensing connections 80 10 are shown connected to either side of the shunt area 70.

Fig. 8 depicts an embodiment similar to that shown in Fig. 2, but where the sensing connections 80 of the shunt 70 are made using wire bonds 50.

15 Fig. 9 depicts the various steps in the preferred method for producing a power semiconductor module where the shunt resistor is integrated into the external electrical connection of the lead frame before embossing the downsets which form part of the lead frame. In Fig. 9A the component parts of the lead frame are supplied. These comprise a section for forming the main section of the lead frame 60, made from an electrically 20 conductive first material, and a section to form the shunt resistor 70, made of an electrically conducting second material. The main section of the lead frame 60 is shown in two parts. In Fig. 9B these parts have been connected to form a single object. This connecting process can be made e.g. by means of soldering, silver sintering, brazing, welding or by means of a form-fit connection such as a dovetail joint as described above. After the parts have been 25 connected, they can then be embossed to form the downset 65 as shown in Fig. 9C. In Fig. 9D the completed lead frame is mounted on the DBC substrate 110 which is mounted on the baseplate 100. Fig. 9E shows the final power module 10 after the encapsulation in the mold material 90. Note that the lead frame 60 protrudes from the molded body 90 of the module 10.

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Fig. 10 depicts the various steps in an alternative method for producing a power semiconductor module where the shunt resistor is integrated into the external electrical connection of the lead frame. Here the mounting of the shunt resistor takes place after the embossing process for forming the downsets which form part of the lead frame. In Fig. 10A the component parts of the lead frame are supplied. These comprise a section for forming form the main section of the lead frame 60, made from an electrically conductive first material, and a section to form the shunt resistor 70, made of an electrically conducting second material. The main section of the lead frame 60 is shown in two parts. In Fig. 10B the two parts of the main section of the lead frame 60 have been embossed to form the ends of the downset. In Fig. 10C these parts have been connected to form a single object. This connecting process can be made e.g. by means of soldering, silver sintering, brazing, welding or by means of a form-fit connection such as a dovetail joint as described above. In Fig. 10D the completed lead frame is mounted on the DBC substrate 110 which is mounted on the baseplate 100. Fig. 10E shows the final power module 10 after the encapsulation in the mold material 90.

Fig. 11 illustrates an alternative method of forming the shunt resistor integrated into the external connection of the lead frame. Fig. 11A shows the supplied parts; a section for forming form the main section of the lead frame 60, made from an electrically conductive first material, and a section to form the shunt resistor 70, made of an electrically conducting second material. In Fig. 11B these parts have been connected to form a single object. This connecting process can be made e.g. by means of soldering, silver sintering, brazing, welding or by means of a form-fit connection such as a dovetail joint as described above. In the current embodiment this connection has been made by soldering, and the solder areas are shown by 71. The electrically conducting second material which forms the shunt resistor 70 has been orientated so that it is vertical, and therefore forms the downset of the lead frame. In Fig. 11C the completed lead frame is mounted on the DBC substrate 110 which is mounted on the baseplate 100. Fig. 11D shows the final power module 10 after the encapsulation in the mold material 90.

CLAIMS

5 1. Power semiconductor module having an external electrical connection and a shunt resistor,
characterized in that
the shunt resistor is integrated into the external electrical connection.

10 2. Power semiconductor module according to claim 1, characterized in that the electrical connection comprises a first section and a second section made of an electrically conductive first material and a shunt resistor section connecting the first and second sections made of an electrically conductive second material.

15 3. Power semiconductor according to claim 2, characterized in that the shunt resistor section occupies the full cross sectional area of the electrical connection in the shunt resistor section.

4. Power semiconductor module according to claims 2 or 3, characterized in that the
20 first section and/or the second section is connected to the shunt resistor by means of a form-fit connection.

5. Power semiconductor module according to claim 4, characterized in that the form-fit connection is a dovetail joint.

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6. Power semiconductor module according to one of the preceding claims, characterized in that the external electrical connection is part of a lead frame.

7. Power semiconductor according to one of the preceding claims, characterized in that
30 the external electrical connection is designed as a terminal.

8. Power semiconductor according to one of the claims 6 or 7, characterized in that the lead frame comprises a downset and that the shunt resistor is placed in a vertical region of the downset.

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9. Power semiconductor according to one of the preceding claims, characterized in that the power module is a molded power module

10. Power semiconductor according to claim 9, characterized that the shunt resistor is completely encapsulated in the mold compound.

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11. Power semiconductor according to claim 9 or 10, characterized in that the external connection protrudes from the surface of the mold compound.

12. Power semiconductor according to one of the claims 1 to 5, characterized in that the

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external electrical connection is designed as a bus bar.

13. Power semiconductor module according to one of the preceding claims, characterized in that the shunt resistor comprises at least one of CuMn12Ni, an Alloy of 55 % copper, 44 % nickel and 1 % manganese and an Alloy of 84 % copper, 13 %

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manganese and 3 % aluminium.

14. Power semiconductor module according to one of claims 2 to 13, characterized by a first sense wire and a second sense wire, wherein the first sense wire is electrically coupled with the first section and the second sense wire is electrically coupled with

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the second section each adjacent to the shunt resistor section.

15. Power semiconductor module according to claim 14, characterized in that the sense wires are both located on same side of the external electrical connection with respect to its longitudinal axis.

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16. Method for producing a power semiconductor module according to claim 6 characterized by integrating the shunt resistor into the external electrical connection of the lead frame before embossing downsets as part of the lead frame.

5 17. Method for producing a power semiconductor module according to claim 6 characterized by integrating the shunt resistor into the external electrical connection of the lead frame after embossing downsets as part of the lead frame.

18. Method according to claim 16 or 17, characterized in that the shunt resistor is placed
10 in a vertical region of the downset.

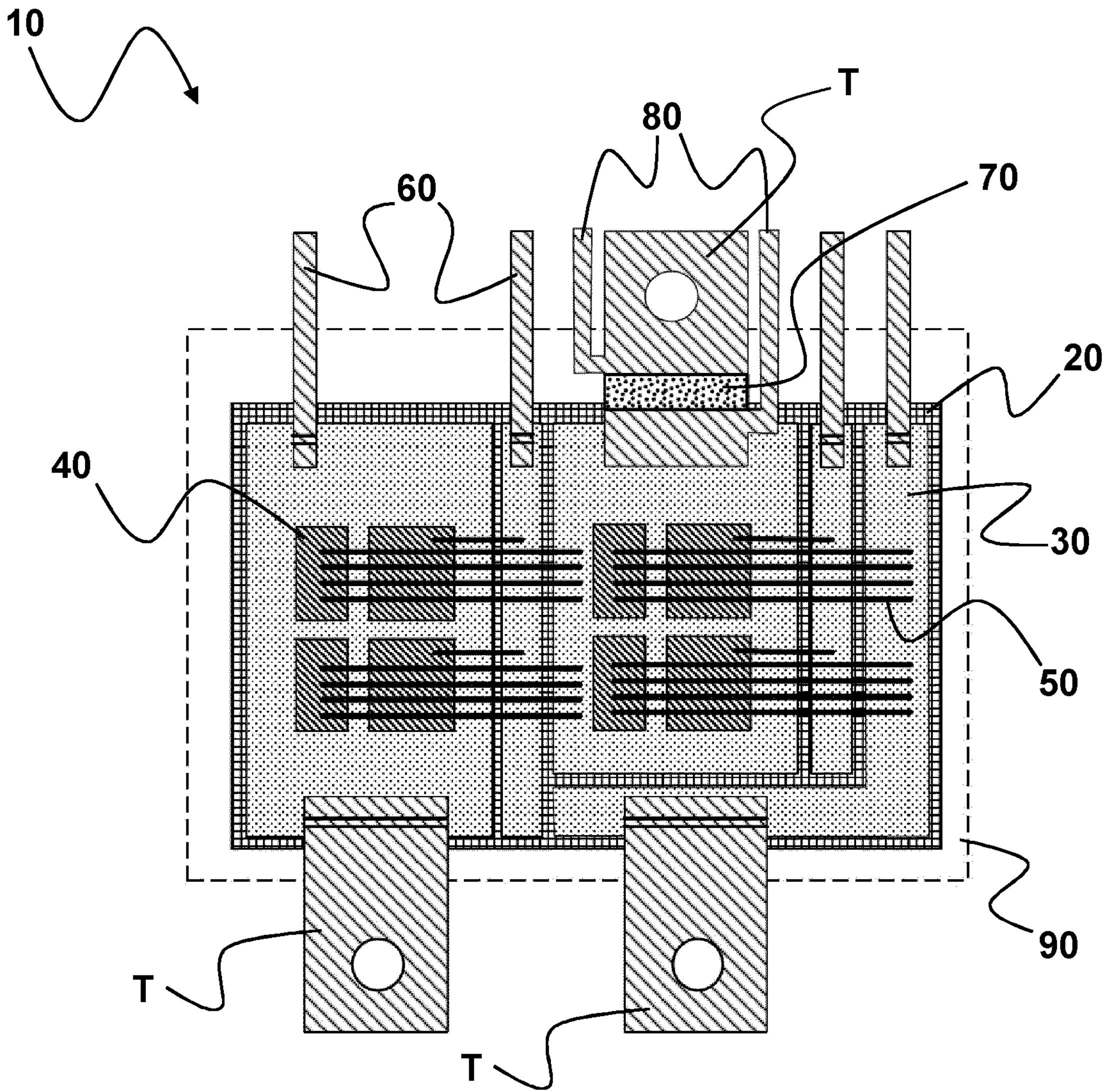

FIG. 1

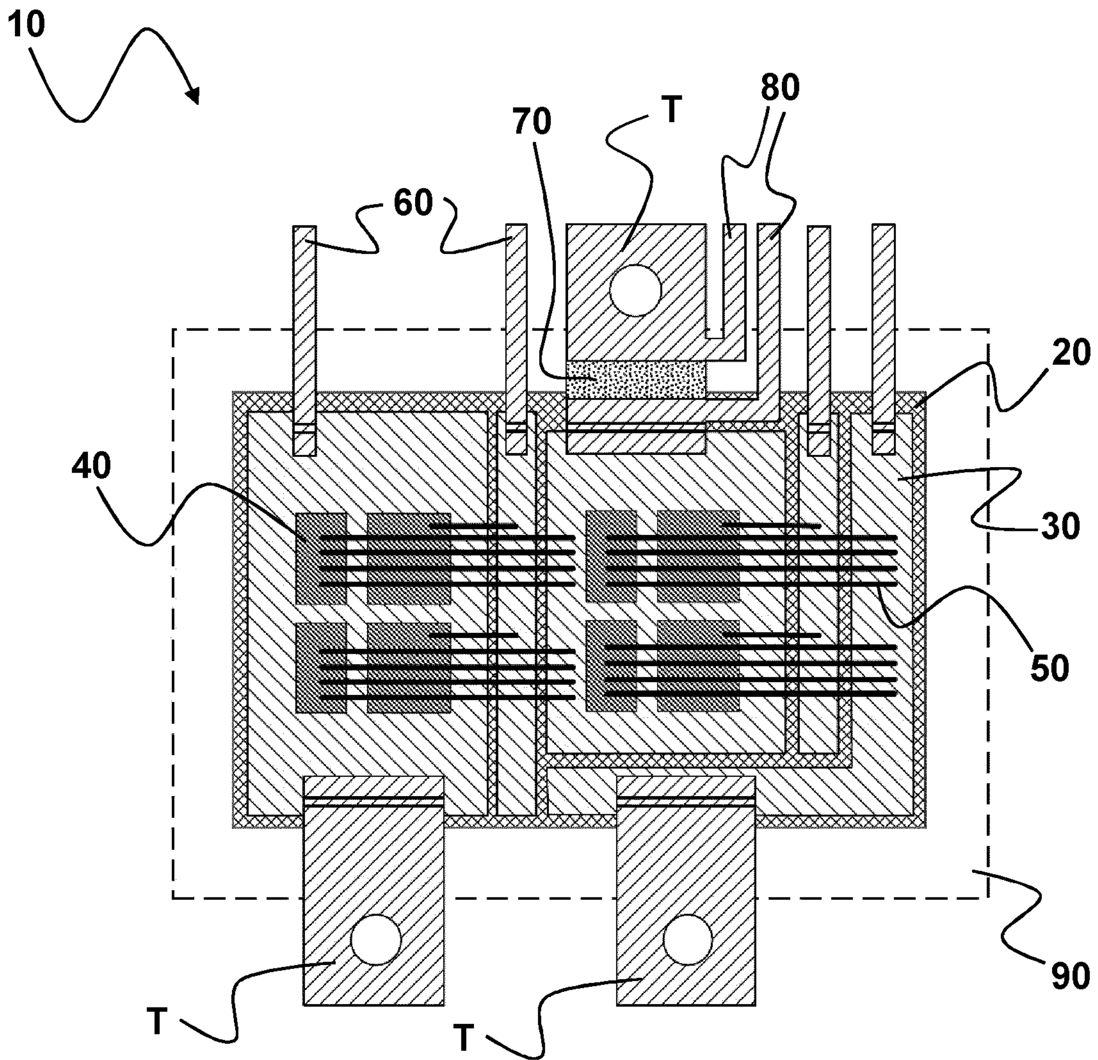

FIG. 2

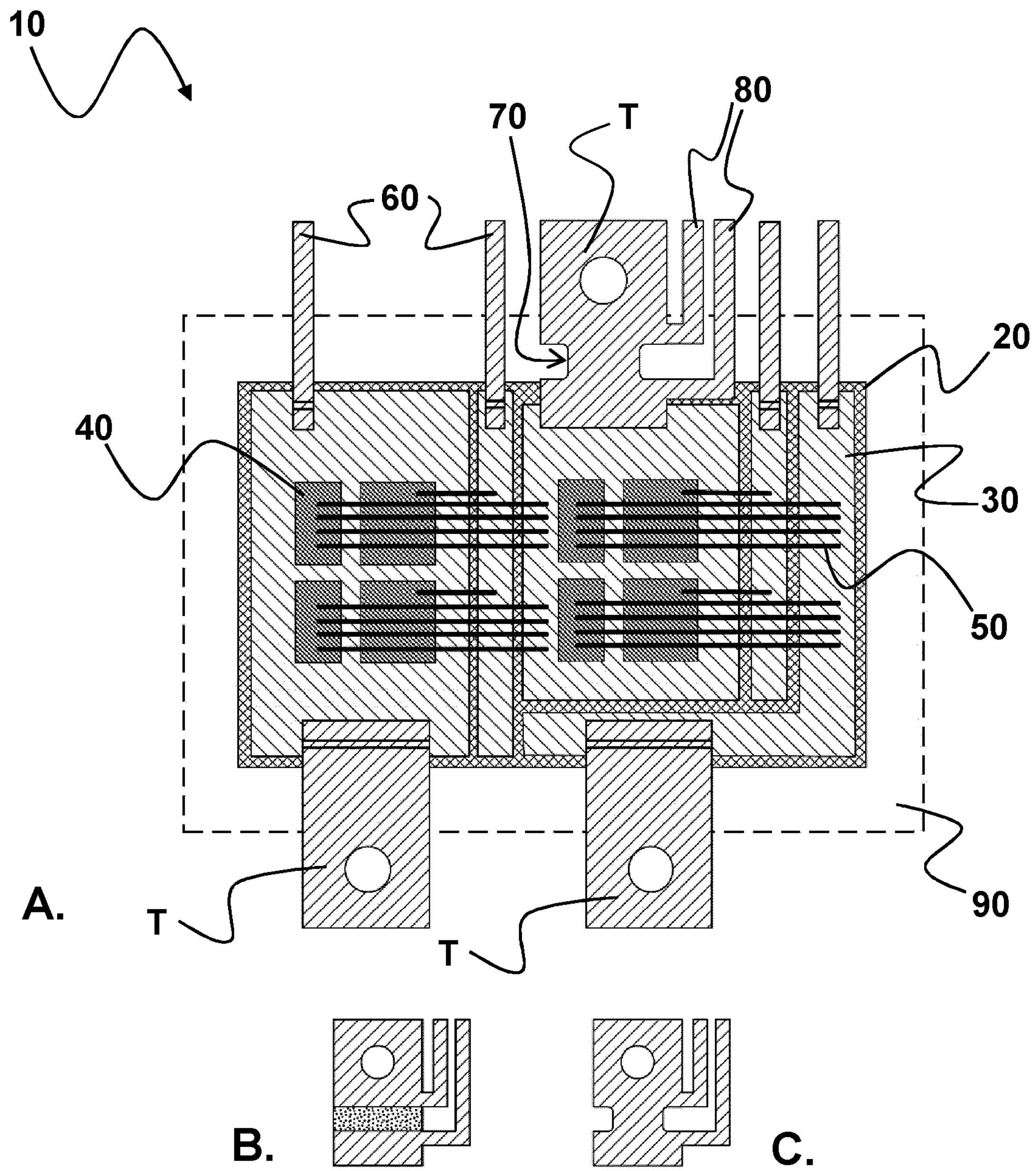

FIG. 3

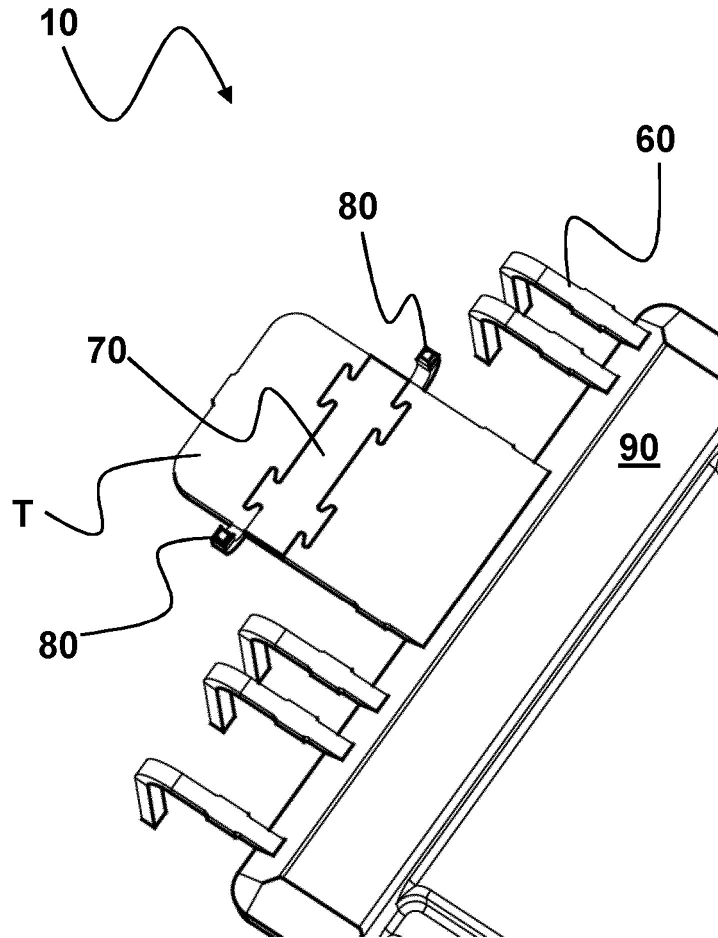

FIG. 4

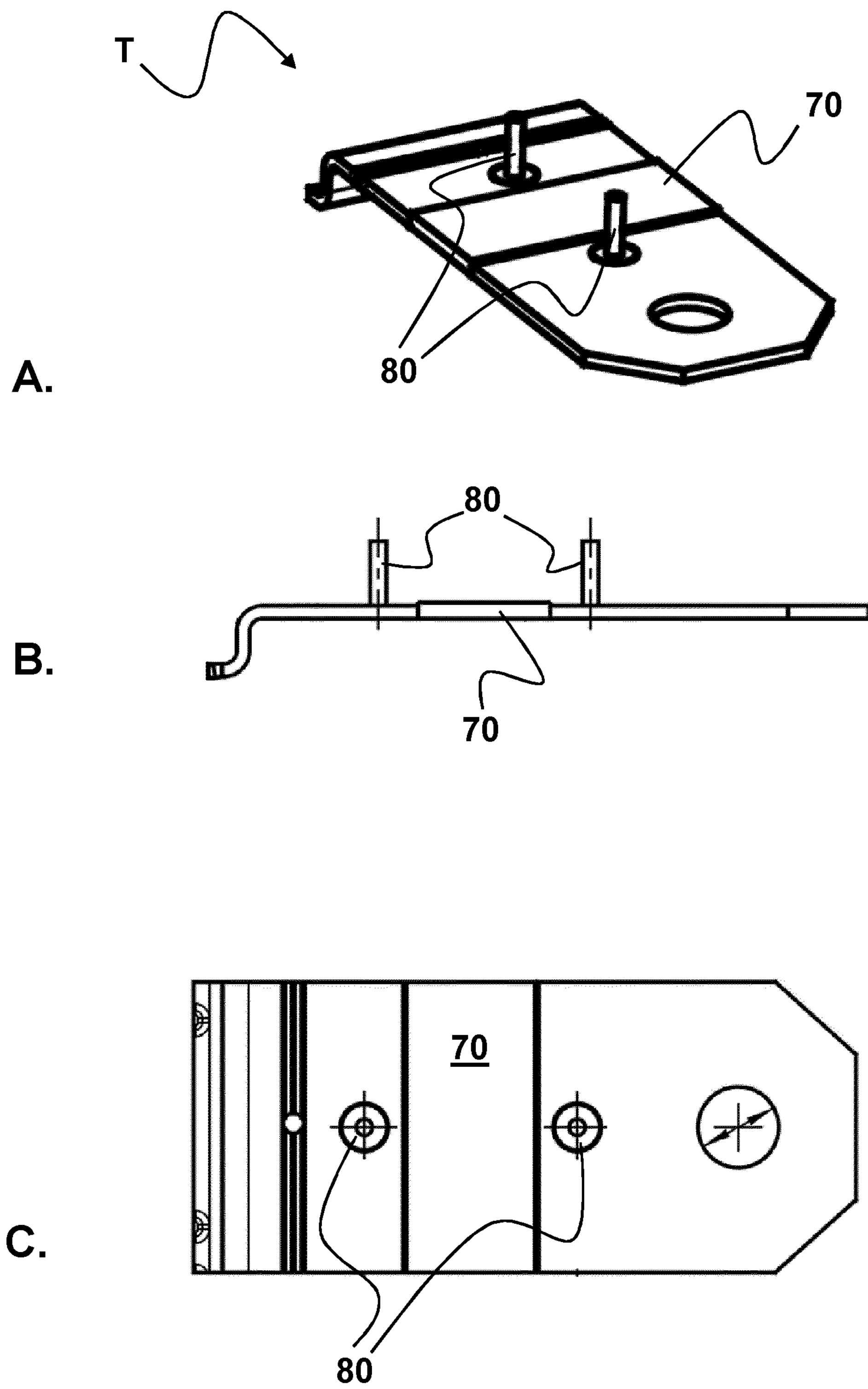

FIG. 5

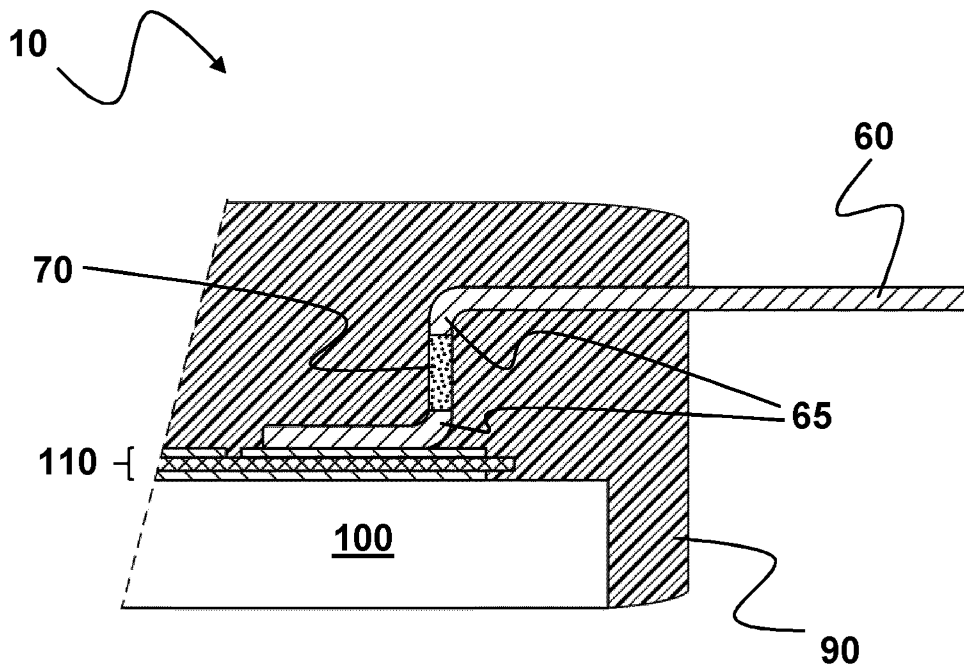

FIG. 6

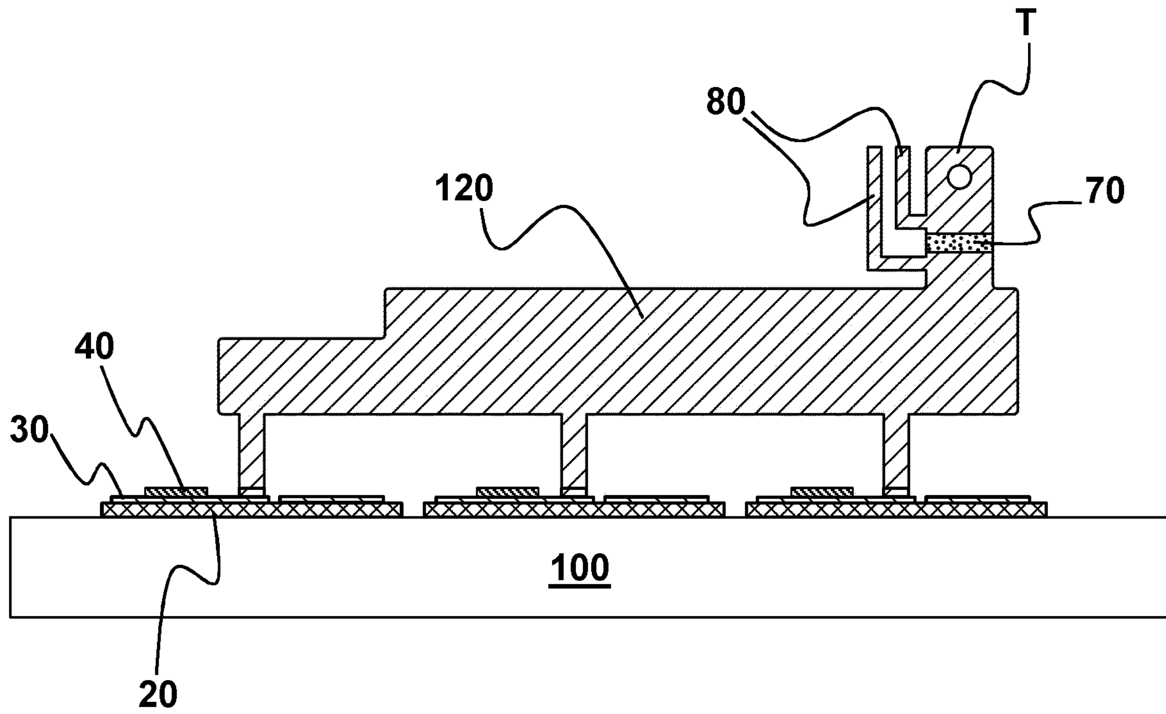

FIG. 7

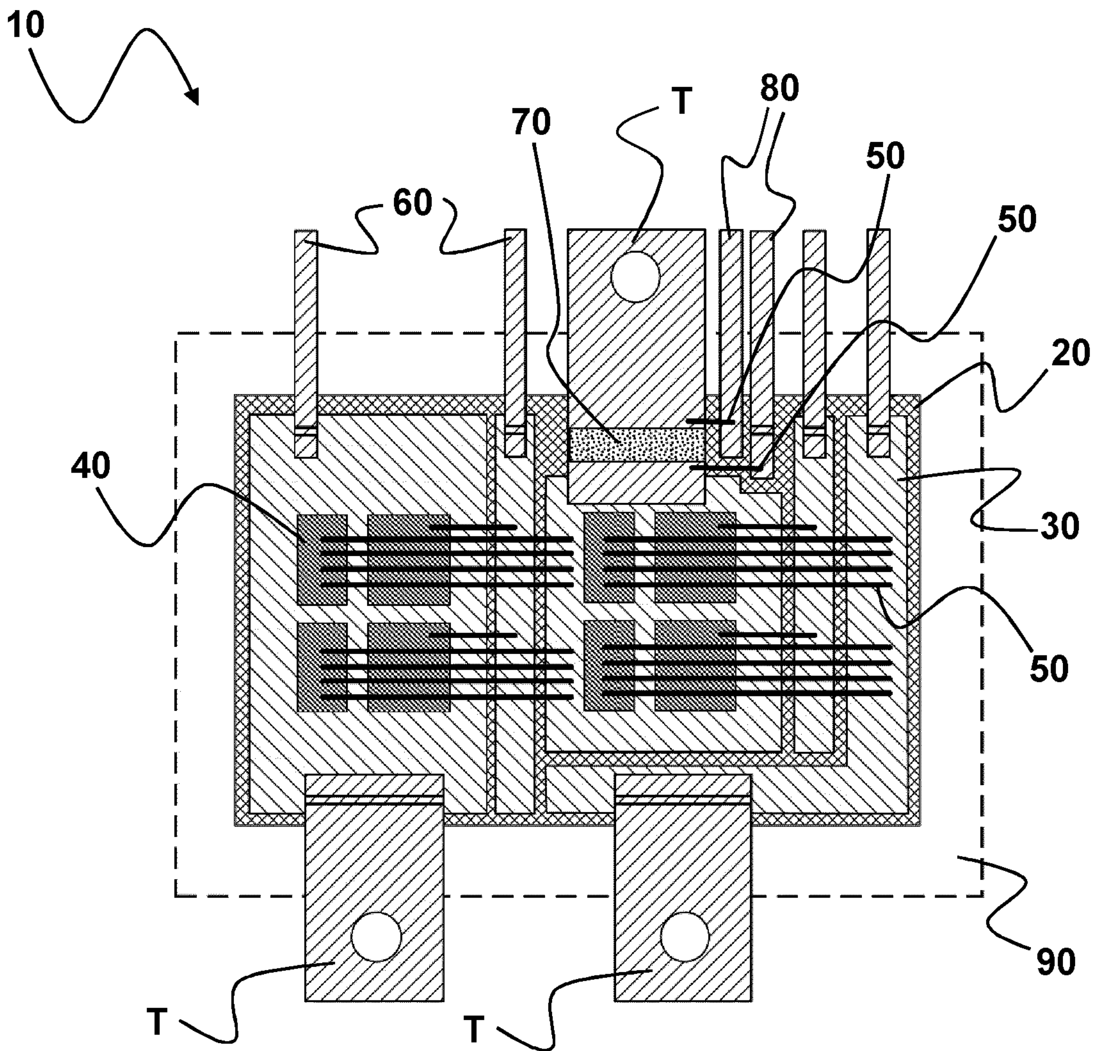

FIG. 8

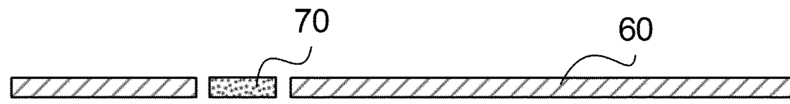

FIG. 9A

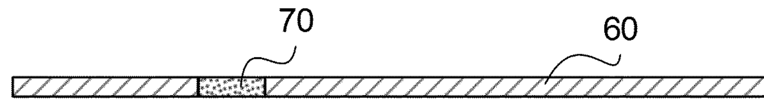

FIG. 9B

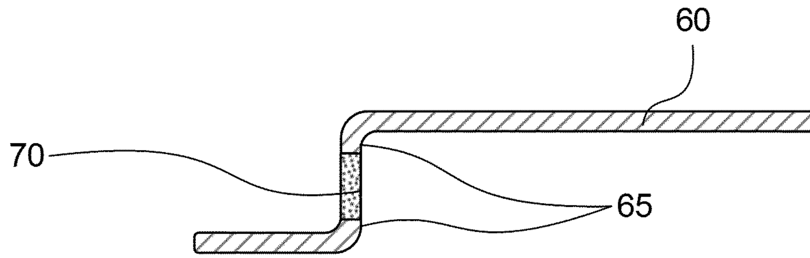

FIG. 9C

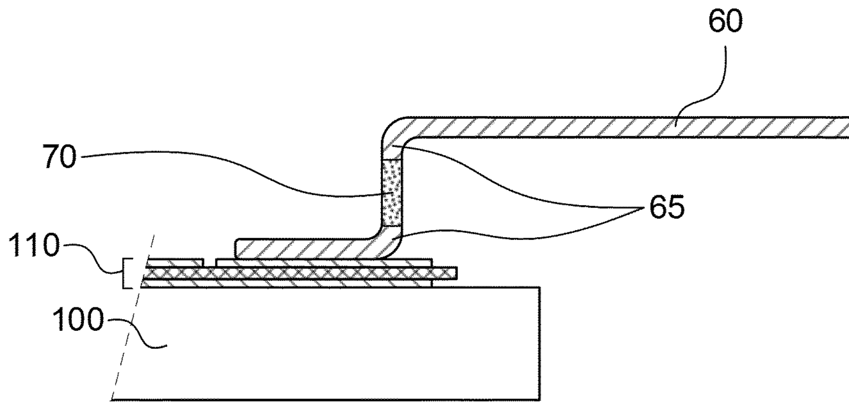

FIG. 9D

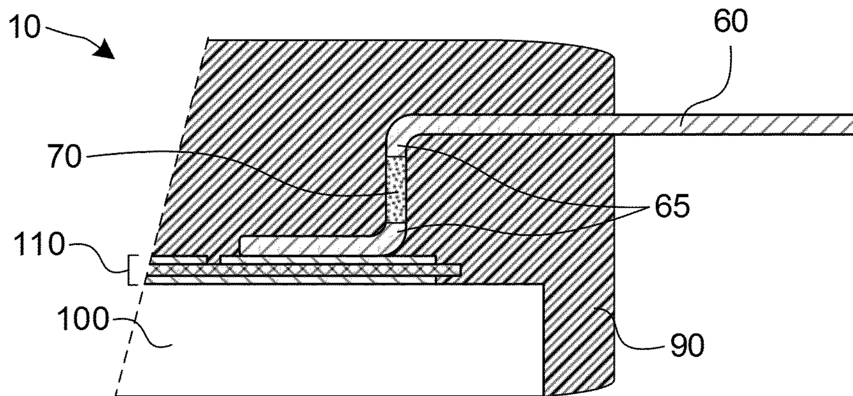

FIG. 9E

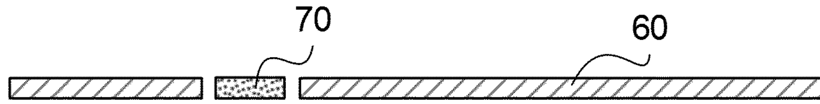

FIG. 10A

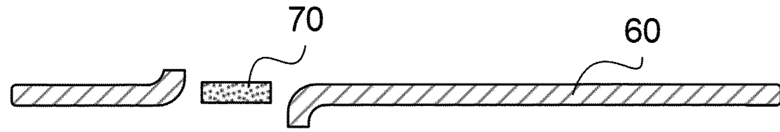

FIG. 10B

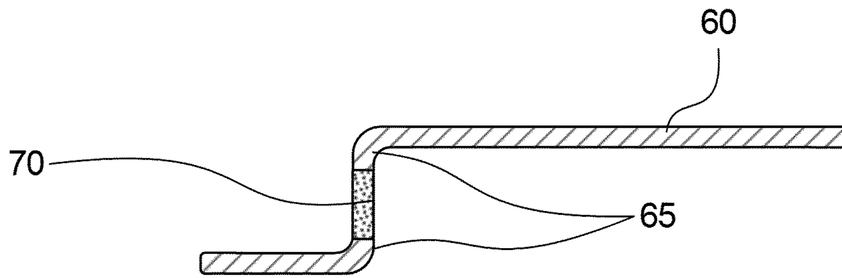

FIG. 10C

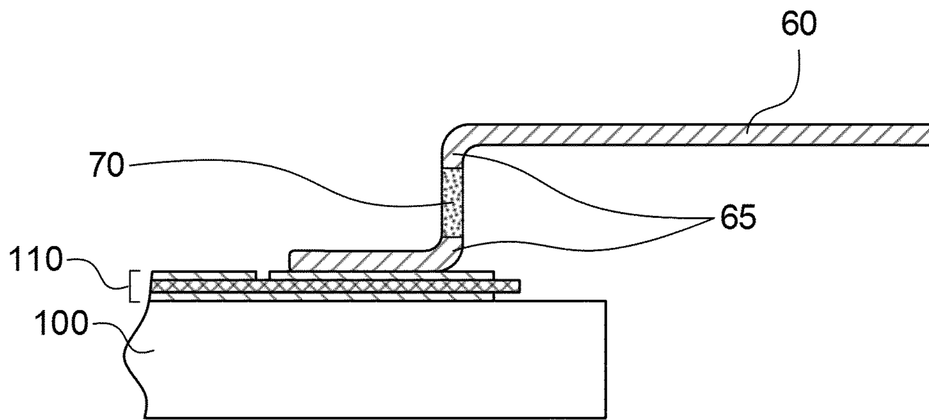

FIG. 10D

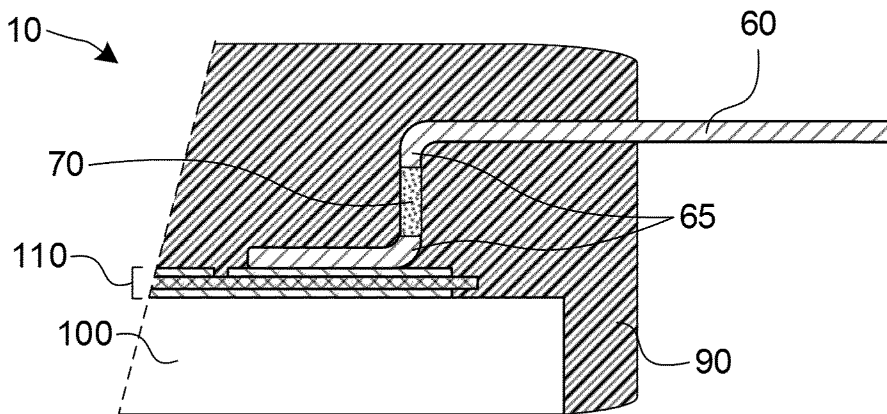

FIG. 10E

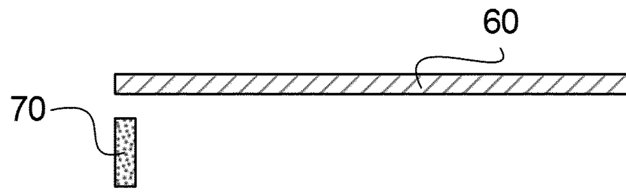

FIG. 11A

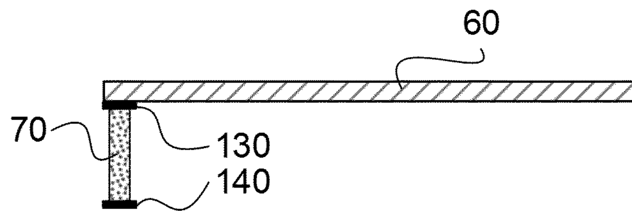

FIG. 11B

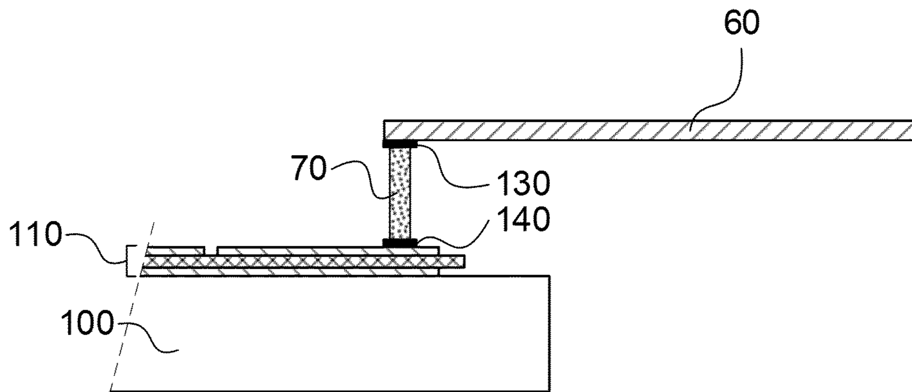

FIG. 11C

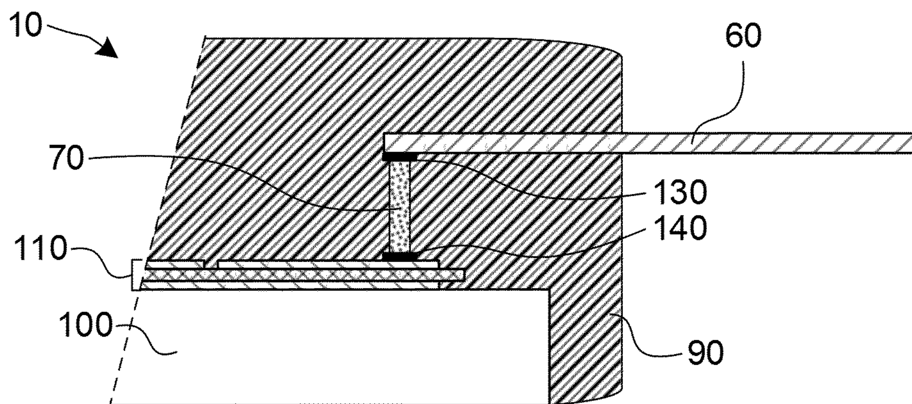

FIG. 11D

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/072252

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01L23/498 H01L23/495 H01L23/64 H01L25/07 H01L25/18
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)
H01L

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.
X Y	US 2014/035605 A1 (KURZ THORSTEN [DE] ET AL) 6 February 2014 (2014-02-06) paragraphs [0025] - [0038]; figures 1,3	1-4,7, 9-15 5,6,8, 16-18
Y	CN 203 339 155 U (SHUEN DER INDUSTRY JIANGSU CO LTD) 11 December 2013 (2013-12-11) abstract; figures 1-3	5
Y	WO 2016/125674 A1 (MURATA MANUFACTURING CO [JP]) 11 August 2016 (2016-08-11) paragraphs [0093] - [0095]; figures 15A,15B	6,8, 16-18

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

☒ See patent family annex.

* Special categories of cited documents :

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
12 October 2018	24/10/2018

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/EP2018/072252

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2014035605 A1	06-02-2014	CN 103545285 A	29-01-2014
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		JP WO2016125674 A1	12-10-2017
		WO 2016125674 A1	11-08-2016