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(72) Inventors:
• **Barton, Richard**
Birmingham, West Midlands B45 0JA (GB)
• **Karl, Christoph**
Birmingham, West Midlands B45 0JA (GB)

(74) Representative: **HGF Limited**
Cavendish House
39-41 Waterloo Street
Birmingham, West Midlands B2 5PP (GB)

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(71) Applicant: **Strip Tinning Limited**
West Midlands B45 0JA (GB)

(54) **CONNECTOR**

(57) A connector (1) for providing an electrical connection to a fragile substrate, the connector (1) comprises a first and a second mounting portion (2, 3) for engaging a fragile substrate and a connection portion (4) between the first and second mounting portions (2, 3) and for making an electrical connection to the connector (1), each mounting portion (2, 3) comprising a first surface (2a, 3a) for facing the fragile substrate in use, the connector (1) being formed from an alloy of iron having a coefficient of thermal expansion of from $10 \times 10^{-6} \text{ m/m}^\circ\text{C}$ to $16 \times 10^{-6} \text{ m/m}^\circ\text{C}$ and an electrical conductivity of greater than $4 \times 10^6 \text{ S/m}$.

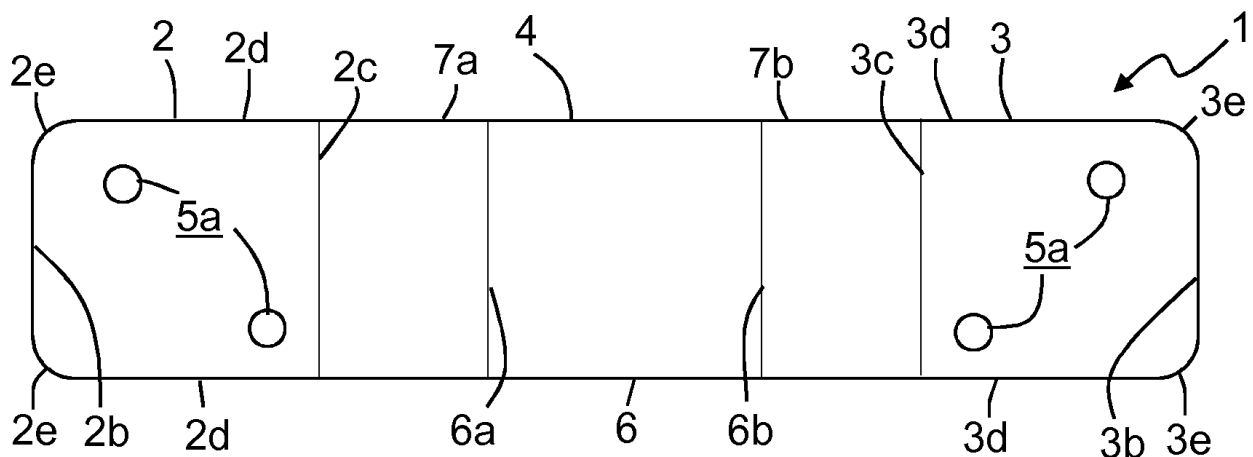
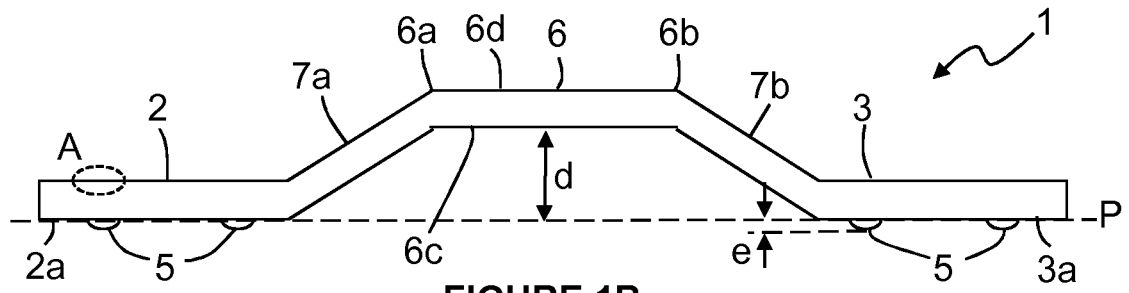


FIGURE 1A



Description

[0001] This invention relates generally to a connector. More specifically, although not exclusively, this invention relates to a connector for facilitating electrical connection between a source of electrical power and a site of use of electrical power.

[0002] In recent years it has become increasingly popular to provide electrical connections to fragile substrates, e.g. glass windshields. A busbar (for example a silver printed busbar) may be provided on the surface of a fragile substrate to provide an electrical pathway for the dispersal of electrical power. A connector may be soldered to the busbar in order to provide an electrical connection to a source of electrical power and/or to electrical components. To effect the connection, solder is brought into contact with the busbar and it is heated, melts and re-solidifies. As the melt-solidification process is undertaken it is necessary to ensure that the thermal and mechanical stresses exerted upon the fragile substrate do not cause damage.

[0003] Mechanical and thermal stresses may be generated in the fragile substrate due to differences in the coefficient of thermal expansion of one or both of the connector and solder and the fragile substrate. These stresses may result in damage to the fragile substrate, which may render the component unfit for purpose and it will therefore have to be replaced, resulting in considerable expense and waste of materials. It is also known to be possible for the mechanical and thermal stresses to result in failure of the connection between the connector and fragile substrate. Where the connection has failed, electrical connection to the electrical components may be interrupted or terminated.

[0004] Typically lead-based solders have been used to facilitate the solder connection between a fragile substrate such as glass (for example a windscreen) and a connector. Because lead-based solders are ductile the differences between the thermal expansion of the glass and the connector can be accommodated by the lead-based solder. However, in recent times there has been a move (or a desire to move) away from lead-based solder materials. Whilst non-lead-based (lead-free) solder materials are known and have been used it is understood that such materials are less ductile than the lead-based materials they are proposed to replace or have replaced. As such differences in the thermal expansion coefficients of the glass ($8 - 10 \times 10^{-6} \text{ m/m}^\circ\text{C}$) and the connector are exacerbated.

[0005] To seek to address this issue efforts have been made to find materials for the connector with thermal expansion coefficients which match that of the glass to which they are to be attached.

[0006] EP1942703 proposes a connector which uses titanium. However, in order to achieve adequate stability and processability it is proposed to use an excess of solder material which, in use can cause high mechanical stresses in the glass pane. US2015/0296615 discloses a two-part connector, a bridge part formed of copper and a connection part for contacting the glass substrate fabricated from a chrome-containing steel with a coefficient of thermal expansion which is similar to that of glass. Clearly the use of different materials requires complex manufacturing steps.

[0007] The operating conditions experienced by a motor vehicle (and the components thereof) are harsh. For example, the expected lifetime of a motor vehicle is long and a motor vehicle has to be capable of operating in diverse environments. As such, it is subject to large seasonal and daily variations in temperature, humidity, as well as exposure to pollutants, cleaning products, salt (for example as a result of road clearing during winter) and so forth. Accordingly, the components which are used in motor vehicles need to be able to withstand such environments and changing conditions across their lifespan, or at least in terms of the prevailing warranty. This means that the components which are used in motor vehicles are rigorously tested and have to be fit-for-purpose, especially where those components are not easily changed after installation. It is a requirement that the components do not become susceptible to failure when exposed to environmental agents and/or the chemicals which are prevalent (salt, cleaning fluids and so on).

[0008] It is an object of the invention to provide a connector which is capable of facilitating an electrical connection to a fragile substrate, e.g. a glass windshield. It is also an object of the invention to provide a connector which is capable of withstanding the harsh operating conditions experienced by a motor vehicle (and the components thereof).

[0009] Accordingly, a first aspect of the invention provides a connector for providing an electrical connection to a fragile substrate, the connector comprising a first and a second mounting portion for engaging a fragile substrate and a connection portion between the first and second mounting portions and for making an electrical connection to the connector, each mounting portion comprising a first surface for facing the fragile substrate in use and, preferably, at least a pair of lugs or spacers extending from the first surface to space the first surface from the fragile substrate in use, the connector being formed from an alloy of iron having a coefficient of thermal expansion of from $10 \times 10^{-6} \text{ m/m}^\circ\text{C}$ to $16 \times 10^{-6} \text{ m/m}^\circ\text{C}$ and an electrical conductivity of greater than $4 \times 10^6 \text{ S/m}$.

[0010] The use of iron alloys with a coefficient of thermal expansion (CTE) within the above-identified range and with an electrical conductivity in excess of the stated amount has, surprisingly, been found to be beneficial in terms of cost per connector (including materials, production and so on), and conductivity, whilst not having a CTE which can cause damage to a fragile substrate, such as glass, when applied thereto, especially when applied thereto with a lead-free solder material. In particular, the disparity between the CTE of the glass substrate and that of the connector (when within the above range) has been demonstrated to enable robust electrical connections between a fragile substrate (e.g. a glass windscreen) and the connector of the invention.

[0011] We prefer the material to have an electrical conductivity of less than $50 \times 10^6 \text{ S/m}$.

[0012] Preferably the connection portion provides a bridge between the first mounting portion and second mounting portion, the bridge preferably being spaced from the fragile substrate, in use.

[0013] Clearly, a connector which is fit for purpose (i.e. is suitable for use), which does not have a high failure rate, which is installable without causing damage, is readily processable and which is cheap to produce is desirable. We have found that the connector of the invention fulfils at least most, if not all, of these desiderata.

[0014] There may be provided plural lugs or spacers, e.g. two, which extend from the first surface. We have found this beneficial as the lugs or spacers minimise the contact between the connector and the fragile substrate, further mitigating the any effect which may be experienced by the different CTE of connector and fragile substrate. A solder preform may be provided in friction fit engagement with the mounting portion. Advantageously, the lugs or spacers may engage the solder preform. Frictional engagement between the mounting portion and the solder preform is beneficial because it means that a pre-determined amount of solder can be used, the location of the solder preform can be tightly controlled and the properties of the solder are known before installation and remain known once installed.

[0015] There is further provided, by a second aspect of the invention a connector for electrical connection to a fragile substrate, the connector comprising a first mounting portion for engaging a fragile substrate and a connection portion for making an electrical connection to the connector, the first mounting portion comprising a first surface for facing the fragile substrate in use and a solder preform in friction fit engagement with the first mounting portion.

[0016] Preferably, the connector may comprise one or more lugs or spacers extending from the first surface to space the first surface from the fragile substrate in use and the solder preform may be in friction fit relations with the one or more lugs or spacers extending from the first surface.

[0017] The first surface may have a surface area A and the solder preform may have a major surface with a surface area A_s and preferably $A > A_s$. By limiting the amount of solder compared to the surface area of the mounting portion we have found it possible to limit the flow of solder upon melting beyond the confines of the mounting portion, which we have found advantageous because of a reduction in damage than can occur to a fragile substrate when installing a connector. We have found that the volume of solder V_s should preferably and advantageously be no more than twice the volume defined between the fragile substrate and the facing surface of the mounting portion (V), and preferably less than 1.9, 1.8, 1.7, 1.6 or 1.5 times. In a preferred embodiment, $A > A_s$ and/or $V < V_s < 2V$, and more preferably $A > A_s$ and/or $1.1V < V_s < 1.6V$.

[0018] The first mounting portion may be connected to the connecting portion via a ramp portion. In such a fashion, and in use, the connection portion may be located further from the fragile substrate than is the mounting portion.

[0019] Free ends of the mounting portion are preferably radiused. We have found this to be beneficial because it appears to spread stress in the fragile substrate (as compared to right angled junctures), for example when the connector is secured thereto by heating, melting and re-solidifying a solder material.

[0020] The connector may further comprise a second or further mounting portion. The second or further mounting portion may be joined to the mounting portion by the connection portion. Preferably the connection portion provides a bridge between the first mounting portion and second or further mounting portion, the bridge preferably being spaced from the fragile substrate, in use.

[0021] A yet further aspect of the invention comprises a connector for electrical connection to a fragile substrate, the connector comprising a first mounting portion and a second mounting portion connected together by a connection portion for making an electrical connection to the connector, the first and second mounting portion each comprising a first surface for facing the fragile substrate in use and plural lugs or spacers extending from each first surface to space each first surface from the fragile substrate in use.

[0022] The mounting portions and connection portion may be provided on the same axis, the principal axis. Each mounting portion may comprise two lugs of spacers. A line drawn through the lugs or spacers on one of the mounting portions may extend at an obtuse angle to the principal axis, e.g. at an angle of about 135° .

[0023] The connection portion may comprise a pair of ramps, one of the ramps extending away from each of the first and second mounting portions to a central bridge. Each of the first and second mounting portions may be provided with a solder preform, preferably in friction fit with the lugs or spacers, for example to retain the solder preform in place. The free edges of the first and second mounting portions (being those edges distant from the respective ramps) are preferably radiused.

[0024] The connector may be fabricated from a substrate material and coated in a solderable material, for example, silver. The connector may be formed, at least principally, from steel, for example carbon steel. In a preferred embodiment we prefer a carbon steel with a relatively high conductivity, for example carbon steel designated as DC01, which typically has a maximum carbon content ($C_{\max}$) of 0.08% to 0.13%. Other carbon steels, such as CS1 (DC04) ($C_{\max}$ 0.03 - 0.06%) or CS3 (DC03) ($C_{\max}$ 0.04 - 0.08%) grades may also be used.

[0025] In a preferred embodiment the substrate is less than 5, 4, 3 or 2mm thick, for example less than 1 mm thick, and is provided with a top coat, preferably formed by a fine layer of silver. A flash coat may be provided between the top coat and the substrate. A flash coat may comprise a copper layer and/or a nickel layer. Where the top coat is a solderable layer, for example silver, it is most preferred to friction fit the solder layer to the mounting portion. If the solder

is installed on the mounting portion by heating and solidifying, it will tend to dissolve some of the silver from the top layer and thereby increase the proportion of silver within the solder, which will increase hardness and/or melting point. The substrate may be greater than 0.1 mm thick, preferably greater than 0.2mm thick. For example the substrate may be greater than 0.3, 0.4, 0.5, 0.6 or 0.7mm thick.

[0026] The solder preform is preferably lead-free. The solder preform may comprise one of more of silver, tin, bismuth, indium, copper. In one embodiment the solder may be formed from tin and silver. In another embodiment the solder preform may be formed of tin, silver and bismuth.

[0027] A further aspect of the invention provides a method of forming a connector, the method comprising the steps of providing a length of iron alloy with a coefficient of thermal expansion of from 10×10^{-6} m/m°C to 16×10^{-6} m/m°C and an electrical conductivity of greater than 4×10^6 S/m; forming the length of electrically conductive material into a connector comprising a first and second mounting portion and a connecting portion, where each mounting portion has a mounting surface defining a common plane and the connecting portion has a substrate facing surface which is spaced from the plane; and, preferably, providing one or more lugs or spacers on each mounting portion.

[0028] The method may further comprise step d) forming the length of electrically conductive material from a sheet of electrically conductive material. Preferably the electrically conductive material or the connector is provided with a flash coat and/or a top coat. The method may further comprise step e) providing a solder preform, and a step f) retaining the solder preform in position by a friction fit.

[0029] We have found that carbon steel is an eminently suitable material in terms of processability, performance, failure rate, low potential for damage to the underlying fragile substrate and cost. Indeed, we have found carbon steel DC01 to be a particularly suitable material for the connectors of the invention.

[0030] For the avoidance of doubt, any of the features described herein apply equally to any aspect of the invention.

[0031] Within the scope of this application it is expressly envisaged that the various aspects, embodiments, examples and alternatives set out in the preceding paragraphs, in the claims and/or in the following description and drawings, and in particular the individual features thereof, may be taken independently or in any combination. Features described in connection with one aspect or embodiment of the invention are applicable to all aspects or embodiments, unless such features are incompatible.

[0032] Embodiments of the invention will now be described by way of example only with reference to the accompanying drawings in which:

Figure 1A is a plan view of a connector according to a first embodiment of the invention;

Figure 1B is a side elevation of the connector of Figure 1A;

Figure 1C is a cross-sectional view of the region A from Figure 1 B;

Figure 2 is a perspective view of a solder preform according to the invention;

Figure 3 is a side view of a connector according to a further embodiment of the invention;

Figure 4A is a side view of the connector of Figure 3 located at a site of use;

Figure 4B is a side view of the connector of Figure 3 secured at a site of use;

Figure 5 is a plan view of a connector according to an embodiment of the invention;

Figures 6A and 6B is a stress model of a connector formed from a first prior art material;

Figures 7A and 7B is a stress model of a connector formed from a second prior art material; and

Figures 8A and 8B is a stress model of a connector formed in accordance with the invention.

[0033] Referring first to Figures 1A and 1B, there is shown a connector 1 having a first and second mounting portion 2, 3 connected by a bridging portion 4. The bridging portion 4 comprises a pair of ramp portions 4a and a connection portion 4b.

[0034] In a most preferred embodiment, the connector 1 is integrally formed from a single sheet of substrate material S, which may be steel, for example carbon steel or another iron alloy having a coefficient of thermal expansion of from 10×10^{-6} m/m°C to 16×10^{-6} m/m°C and an electrical conductivity of greater than 4×10^6 S/m. The CTE of carbon steel is about 11.7×10^{-6} m/m°C and the electrical conductivity of some carbon steels is 5.9×10^6 S/m.

[0035] The sheet may be thin, for example less than 2 mm thick, say less than 1 mm thick and in some embodiments is about 0.8 mm thick. The connector 1 may be 24 mm long by 4 mm wide in plan. The outer surface of the substrate material S may be coated with a flash coat F and/or a top coat T. In an embodiment, the flash coat F may comprise a fine layer (e.g. 0.1 to $10\mu\text{m}$ thick, for example less than $5\mu\text{m}$ thick and preferably about $2\mu\text{m}$ thick) of copper Cu, to which is coated a fine layer of nickel Ni, and/or the top coat T may comprise a fine (e.g. 0.1 to $10\mu\text{m}$ thick, for example less than $5\mu\text{m}$ thick and may be about $2\mu\text{m}$ thick) layer of silver Ag, as is shown in Figure 1C. In cases where a steel such as DC03, DC04 or DC01 is used the above flash coat and top coat combination may be used.

[0036] In an embodiment, the copper layer Cu provides a surface to which the nickel layer Ni more readily bonds (with respect to a steel surface). The nickel layer Ni provides enhanced protection from corrosion. The silver layer Ag, on the outer surface, enhances the solderability of the connector 1 whilst providing further resistance to corrosion.

[0037] The use of steel is advantageous because of its cost and strength. The use of a flash coat F and/or top coat T allows for the properties of the substrate material S to be modified so as to be fit for purpose.

[0038] We prefer to use a carbon steel which has a higher conductivity. We have found the higher conductivity carbon steels to be advantageous not only due to the higher conductivity but because we have found those materials easier to form and stamp and, surprisingly, that the lugs or spacers are formed easily and accurately.

[0039] The mounting portions 2, 3 each comprise a substantially flat substrate facing surface 2a, 3a and are generally rectangular in plan, each having a free end 2b, 3b, a connected end 2c, 3c and two sides 2d, 3d. The corners 2e, 3e at the juncture of the free end 2b, 3b and respective sides 2d, 3d are radiused (in plan), which may be to a radius of less than 1.0mm, say 0.5 mm. The substrate facing surfaces 2a, 3a of the mounting portions 2, 3 are positioned and aligned such that together they may define a plane P. Each substrate facing surface 2a, 3a defines a first surface area. The mounting portion 2, 3 may be 6 mm long from free end 2b, 3b to connected end 2c, 3c and may be 4 mm wide from side to side 2d, 3d.

[0040] Extending from the substantially flat substrate facing surface 2a, 3a are two lugs 5 which may be generally circular in plan and are each spaced from the sides 2d, 3d and from the ends 2b, 2c, 3b, 3c. The centre of each lug 5 may be located 1.0 mm inboard of an adjacent edge 2d, 3d and/or 1.5 mm inboard of an adjacent end 2b; 3b; 2c; 3c. Preferably the centre of a lug 5 is located about 20-40% along the length of the mounting portion 2, 3 from an adjacent end, 2b, 2c, 3b, 3c most preferably 20-30% (e.g. 25%) along the length of the mounting portion 2, 3 as measured from an adjacent end 2b; 2c; 3b; 3c. The lugs 5 may extend from the substantially flat substrate facing surface 2a, 3a by a distance e of between 0.05 mm and 0.15 mm. The lugs 5 are preferably integrally formed with the mounting portions 2, 3 and may be formed by pressing operation acting against the surface obverse to the substrate facing surface 2a, 3a.

[0041] We have found that four lugs 5 (two on each mounting portion 2,3) provides a stable platform when positioned on a surface and that an inwardly (or outwardly) flaring arrangement (as shown) is both particularly stable and affords the connector 1 a degree of directionality. The handedness or directionality is beneficial because in use a connector wire is connected by soldering to the connection portion 4b and having the lugs flaring inwardly ensures that the broadest platform at least helps to resist any rotational moment applied by the connector wire. Moreover, the use of two lugs is capable of providing a good frictional engagement with a solder preform and/or is readily fabricated.

[0042] The bridging portion 4 comprises a connection portion 4b or connection member 6 which is substantially rectangular in plan and is joined to the connected end 2c of the first mounting portion 2 by a first connecting arm 7a, as a ramp portion 4a, extending from the first end 6a of the connection member 6. A second connecting arm 7b, as a ramp portion 4a, extends from the second end 6b of the connection member 6 and joins the connection member 6 to the connected end 3c of the second mounting portion 3. The joining locations between the first and second connecting arms 7a, 7b and the connection member 6 and the mounting portions 2, 3 may be radiused, where the radius may in each location be about 0.5 mm. The bridging portion 4 may be 12 mm long in plan whilst the connection member 6 may be 6 mm long in plan, with both preferably being 4 mm wide.

[0043] As is best shown in Figure 1B, the connection member 6 has a substantially flat substrate facing surface 6c which is parallel to the plane P of the substrate facing surfaces 2a, 3a of the mounting portions 2, 3, but is spaced therefrom by a distance d which may be 1 mm. A connection surface 6d is defined obverse to the substrate facing surface 6c of the connection member 6.

[0044] Referring now to Figures 2, there is shown a solder preform 8 having a generally rectangular shape in plan and formed from a lead-free solder material (e.g. Sn3Ag). The solder preform 8 has a first major surface 8a defining a solder surface area A_s , which is configured to be less than the first surface area of the mounting portions 2, 3. The solder preform 8 may have a length of 5 mm and a width of 3.5 mm in plan and, say, a thickness of 0.2 mm.

[0045] Referring now to Figure 3 there is shown a connector 10 according to a second embodiment of the invention, the connector 10 comprising a connector 1 as shown in Figures 1A and 1B and solder preforms 8 as shown in Figure 2. The solder preforms 8 are retained in position on the mounting portions 2, 3 of the connector 1 by pushing a major surface 8a of the solder preforms 8 against the lugs 5 of the mounting portions 2, 3 (or vice versa). The relatively soft material of the solder preforms 8 deforms against the lugs 5 until the major surface 8a of the solder preforms 8 are adjacent the substrate facing surface 2a, 3a of the mounting portions 2, 3. The solder preforms 8 are, at least temporarily, held in place via friction against the lugs 5. The solder preforms 8 are positioned so that their peripheral edges are preferably inboard of the free end 2b, 3b, connecting end 2c, 3c and sides 2d, 3d of the mounting portions 2, 3.

[0046] In use, the connector 10 is presented against a fragile substrate FS, e.g. a glass substrate (see Figure 4A). Heat is transmitted to the solder preforms 8 causing them to melt and flow between the fragile substrate FS and the substrate facing surface 2a, 3a of the mounting portions 2, 3. Heat is then removed from the solder material 8a causing it to solidify and hence secure the connector 10 to the fragile substrate FS (as shown in Figure 4B). Advantageously, a bead of solder BS may form adjacent the connected end 2c, 3c of the mounting portions 2, 3, where the bead of solder BS enhances the pull-off strength of the attachment of the connector 10 to the fragile substrate FS.

[0047] It is beneficial that the solder material 8' does not extend beyond the free end 2b, 3b, and sides 2d, 3d of the mounting portions 2, 3. This is achieved through a combination of: carefully selecting the volume of solder material 8'

in the solder preform 8 relative to the first surface area of the substrate facing surface 2a, 3a of the mounting portions 2, 3; capillary forces acting upon the molten solder material 8'; and the distance e by which the lugs 5 extend, which provide a minimum clearance distance between the fragile substrate FS and the substrate facing surface 2a, 3a of the mounting portions 2, 3.

[0048] Advantageously, the "bridge" design of the connector 10 results in reduced localised temperatures being generated in an attached fragile substrate FS during the soldering of the connecting surface 6d of the connection member 6 to the fragile substrate FS. In such a way damage to the fragile substrate FS is beneficially reduced.

[0049] When secured to the fragile substrate FS the substrate facing surface 6c of the connection member 6 is spaced from said fragile substrate FS (as shown in Figure 4B). Therefore, application of heat to the connection member 6 will not be directly conducted through the thickness of the connection member 6 and hence into the fragile substrate FS. Instead, a small portion of the heat will radiate from the connection member 6 whilst the remainder will conduct into the first and second mounting portions 2, 3 and thence into the fragile substrate FS. However, the combined surface area of contact between the mounting portions 2, 3 and the fragile substrate FS (via the solder material 8') is significantly larger than the surface area of the substrate facing surface 6c of the connection member 6. Therefore, heat is conducted to a decreased area of the fragile substrate FS than would be the case if the connection member 6 was directly attached to the fragile substrate FS. Consequently, the concentration of heat per unit area of the fragile substrate FS is relatively reduced and hence damage (e.g. generated by thermal and mechanical stresses), as the likelihood thereof is reduced.

[0050] The applicant has surprisingly found that, prior to attachment to a fragile surface, by retaining the solder preforms 8 in position on the mounting portions 2, 3 via friction against the lugs 5, rather than by melting and then solidifying, a more effective connection (*i.e.* a connection which is more electrically and/or mechanically robust) to the fragile substrate FS is provided.

[0051] Moreover, the lugs 5 distance the connector 10 from the fragile substrate FS. This is beneficial because the connector 10 typically will have a higher coefficient of thermal expansion (CTE) than the fragile substrate FS and the spacing afforded by the lugs 5 reduces stress in the fragile substrate upon thermal cycling when heating and cooling the solder material 8 to secure the connector 10.

[0052] Stresses are caused in the fragile substrate by attachment of and/or to connectors due to a difference between the thermal coefficient of expansion of the fragile substrate and the components of the connector. Connectors are attached to the fragile substrate via the application of heat, causing the solder thereon to melt and then solidify, thereby effecting attachment. However, the heat also causes the fragile substrate and connector to both expand. The connector, due to the relatively higher coefficient of expansion of its components, expands by a greater extent than does the fragile substrate. When the connector and fragile substrate subsequently cool the connector is restrained from retracting to its natural size due to the binding action of the solder. The connector thence generates stresses in the fragile substrate. The magnitude of these stresses is related to the extent of expansion of the connector and of the fragile substrate, where the extent of expansion is dependent upon the temperature to which the components are raised.

[0053] Advantageously, the corners of the bridging member are radiused. The value of the radius may be selected based upon the length and/or width of the connector. The applicant has found that by radiusing the corners, stresses generated in an attached fragile substrate are relatively reduced with respect to connectors with sharp corners. Without wishing to be bound by any theory it is believed that relatively sharp corners act as stress concentrators with respect to attached fragile substrate. Therefore, by radiusing the corners these stress concentrators are at least partially mitigated and hence stress generated in the fragile substrate is reduced.

[0054] In order to make a robust connection (*i.e.* a mechanically and/or electrically robust connection) it is necessary to ensure that the materials are fit-for-purpose and there is sufficient material for the connector 10 to operate. When connecting to a fragile substrate FS such a glass (and, in particular, a silvered glass surface) it is necessary to ensure that damage does not occur. Clearly, a more robust connection is likely to be provided using more solder and/or over a greater facing surface area.

[0055] We have found that an optimal balance between the operability of the connector 10 and the robustness of the connection to a fragile substrate FS is effected when one or more of the following characteristics are employed:

- A substrate material (for example steel) of less than 1 mm thickness is used;
- Two lugs 5 are provided to space each mounting portion 2, 3 from the fragile substrate FS in use;
- The free edges of a mounting portion 2, 3 comprises radiused corners 2e;
- A fictionally engaged solder pre-form 8 is used;
- The surface area defined by a major surface of the solder pre-form 8 is less than the surface area of a substrate-facing surface of the mounting portion;
- The volume of the solder preform is less than twice, preferably less than 1.5 times than a volume under the mounting surface between the connector and the fragile substrate FS, in use;
- The connection member 6 is spaced away from the fragile surface, preferably more than 1 mm away, in use.

[0056] The connector 1 is preferably manufactured by press forming a substrate material to the required shape, coating the substrate with a flash coat and a top coat and stamp forming the lugs. Alternatively the lugs may be formed prior to coating, for example as part of the press forming operation or shortly thereafter. It is also possible to form the connector 1 from a sheet of material which is provided with a protective coating, form individual connectors 1 from the sheet and then treat and newly exposed surfaces.

[0057] A solder preform 8 is then engaged with the lug 5 bearing surface of the mounting portions 2,3 to effect a frictional engagement.

[0058] In use, the connector 10 is located at a site of use, which is typically a silvered portion of a fragile substrate FS (the silver acting as a busbar) and heat is conducted to the solder 8 whilst an engaging force may be applied to the connector 10 to ensure an intimate relation with the fragile substrate FS. Once the heat is reduced, and the solder 8' has solidified, the connector 10 is secured to the fragile substrate FS. To facilitate an electrical connection to the connecting portion 6, prior to securing the connector 10 to the fragile substrate FS (and preferably prior to engaging the solder perform 8 with the mounting portions 2, 3) a lead, copper braid or other conducting member L and so on is preferably secured to the bridge portion 6 by solder Ls (or other securing means such as adhesive).

[0059] In order to check that connectors 1 according to the invention could be secured to a fragile substrate a series of tests was conducted, as explained in the following, nonlimiting Example:

Example 1

[0060] A series of 32 connectors 1 was fabricated, in accordance with the above description and as shown in Figures 1A and 1B. The connector was made from an iron alloy having a coefficient of thermal expansion of about 12×10^{-6} m/m°C and an electrical conductivity of about 10×10^6 S/m. The connectors 1 were provided with a solder preform 8 comprising Sn3.5Ag ($T_M - 221^\circ\text{C}$) solder. The connectors were secured to a double silver layer of automotive glass using either blown hot air (an indirect method) or resistive heating (a direct method).

[0061] The results were as follows:

Number of Connectors	Heating Method	Results
12	Blown Air	No Crack
12	Resistive	No Crack

[0062] The results demonstrate that the connector 1 of the invention are secureable to a fragile substrate FS without cracking or otherwise damaging the fragile substrate FS. The results are positive irrespective of the method used to melt the solder 8 and to secure the connector 1 to the fragile substrate FS and thus show that a connector 1 fabricated from an iron alloy having the CTE within the range specified can be used to provide an effective connector on a fragile substrate.

[0063] Referring now to Figure 5 (integers similar or identical to those of the first embodiment are identified by a preceding '2'), there is shown a connector 21 according to another embodiment of the invention, having a 'T-piece' configuration in plan. The connector 20 comprises a platform 29 extending from one side of the connection member 26. The platform 29 preferably extends from the connection member 26 such that a substrate facing surface (not shown) of the platform 29 is also spaced from the substrate facing surface (not shown) of the mounting portions 22, 23 (and hence spaced from a substantially flat region of a fragile substrate to which the connector 21 may subsequently be attached).

[0064] Referring now to Figures 6A/B, 7A/B, and 8A/B, in each set of figures there is shown respectively upper and lower views of a mounting portion 2 provided with a pair of lugs 5 and provided with an identical solder preform within a computerised stress model. In each case, the stress is shown 560s after solder re-flow. It will be appreciated that the connector formed from a material with a coefficient of thermal expansion and conductivity within the ranges stated above (Figures 8A/B) demonstrated significantly less stress than that shown in Figures 6A/B (copper) or Figures 7A/B (stainless steel ss04). In each case the peak stress level is found to be in the area of the lugs 5. However, whilst the peak stress in Figures 8A/B is concentrated in the lugs 5, this peak stress is less than or equal to the stress formed in the mounting portion of the other figures (Figures 6A/B and 7A/B). These results clearly demonstrate the effectiveness of the lugs 5 in reducing stress and the benefit of having a material with a CTE of less than 16×10^{-6} m/m°C.

[0065] It will be appreciated by those skilled in the art that several variations to the aforementioned embodiments are envisaged without departing from the scope of the invention. For example, although the solder preform 8 is shown as having a generally rectangular shape in plan this need not be the case and the solder preform 8 may have any other suitable shape, for example square, hexagonal, circular, oval, and the like. Where the solder preform 8 has a non-rectangular shape in plan it will be appreciated that the mounting portions 2, 3 may also be non-rectangular in plan and may have a similar shape to that of the solder preform 8. Additionally or alternatively, the solder preform may not be

formed from Sn3Ag solder material but may instead be formed from any suitable solder material, for example a lead-based solder material or a different lead-free solder material. Moreover, whilst it is convenient to secure the solder preform 8 to the connector 10 by way of a friction fit, it is also possible to secure the solder preform 8 by way of adhesive or other securing means.

[0066] It will also be appreciated by those skilled in the art that any number of combinations of the aforementioned features and/or those shown in the appended drawings provide clear advantages over the prior art and are therefore within the scope of the invention described herein.

Claims

1. A connector (1) for providing an electrical connection to a fragile substrate, the connector (1) comprising a first and a second mounting portion (2, 3) for engaging a fragile substrate and a connection portion (4) between the first and second mounting portions (2, 3) and for making an electrical connection to the connector (1), each mounting portion (2, 3) comprising a first surface (2a, 3a) for facing the fragile substrate in use, the connector (1) being formed from an alloy of iron having a coefficient of thermal expansion of from $10 \times 10^{-6} \text{ m/m}^\circ\text{C}$ to $16 \times 10^{-6} \text{ m/m}^\circ\text{C}$ and an electrical conductivity of greater than $4 \times 10^6 \text{ S/m}$.
2. A connector (1) according to Claim 1, wherein the mounting portion (2, 3) is connected to the connecting portion via a ramp portion (7a, 7b).
3. A connector (1) according to Claim 1 or 2, wherein each mounting portion has a distal end (2b, 3b) and side portion (2d, 3b) and wherein the junctures between the distal end (2b, 3b) and side portions (2d, 3d) are radiused (2e, 3e).
4. A connector (1) according to any of Claims 1, 2 or 3, wherein the connection portion (4) provides a bridge portion between the mounting portions (2a, 3a), the bridge portion being spaced from the fragile substrate, in use.
5. A connector (1) according to any preceding Claim wherein, in use the connection portion (4) is located further from the fragile substrate than is the mounting portion (2, 3).
6. A connector (1) according to any preceding Claim, fabricated principally from steel, preferably carbon steel.
7. A connector (1) according to any preceding Claim, comprising a substrate material (S) coated with a relatively higher electrically conductive material (F).
8. A connector (1) according to any preceding Claim, comprising a substrate material (S) formed from said iron alloy and provided with a top coat (T) of a solderable material, for example silver.
9. A connector (1) according to any preceding Claim, wherein plural lugs or spacers (5a), e.g. two, extend from the first surface (2a, 3a).
10. A connector (1) according to any preceding Claim, further comprising a solder preform (8) in frictional engagement with the mounting portion (2, 3).
11. A connector (1) according to Claim 10, wherein the first surface (2a, 3a) has a surface area A and the solder preform (8) has a major surface with a surface area A_s and wherein $A > A_s$.
12. A connector (1) according to any one of Claims 10 or 11, wherein the solder preform (8) is formed from a lead-free solder.
13. A method of forming a connector, the method comprising the steps of:
 - a) providing a length of iron alloy with a coefficient of thermal expansion of from $10 \times 10^{-6} \text{ m/m}^\circ\text{C}$ to $16 \times 10^{-6} \text{ m/m}^\circ\text{C}$ and an electrical conductivity of greater than $4 \times 10^6 \text{ S/m}$;
 - b) forming the length of electrically conductive material into a connector comprising a first and second mounting portion and a connecting portion, where each mounting portion has a mounting surface defining a common plane and the connecting portion has a substrate facing surface which is spaced from the plane; and
 - c) preferably, providing one or more lugs or spacers on each mounting portion.

EP 3 240 360 A1

14. A method according to Claim 13, comprising coating the iron alloy with a flash coat and/or a top coat and providing as the top coat, a solderable material, for example silver.
- 5 15. A method according to Claim 13 or 14, further comprising providing a solder preform, and retaining the solder preform in position by frictionally engaging the solder preform with each mounting portion.

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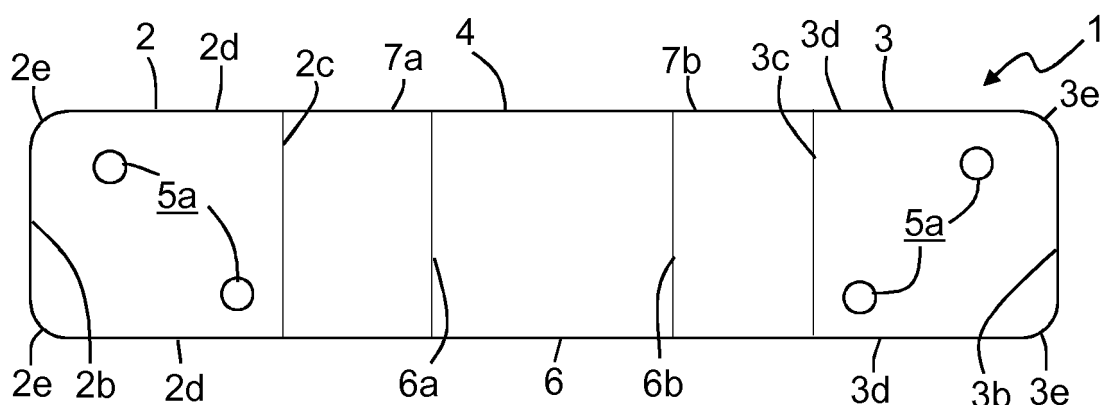


FIGURE 1A

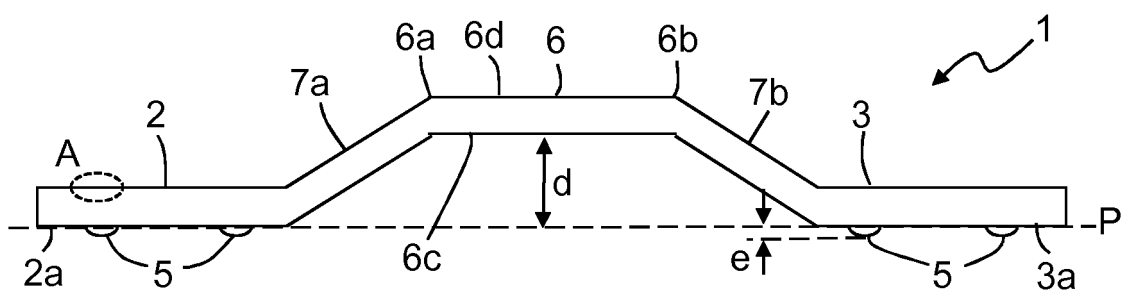


FIGURE 1B

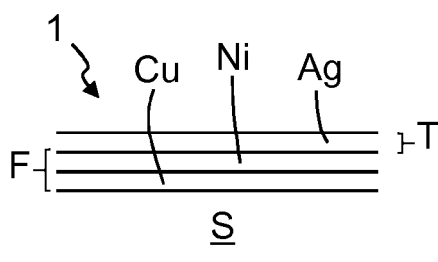


FIGURE 1C

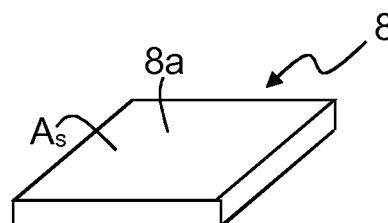


FIGURE 2

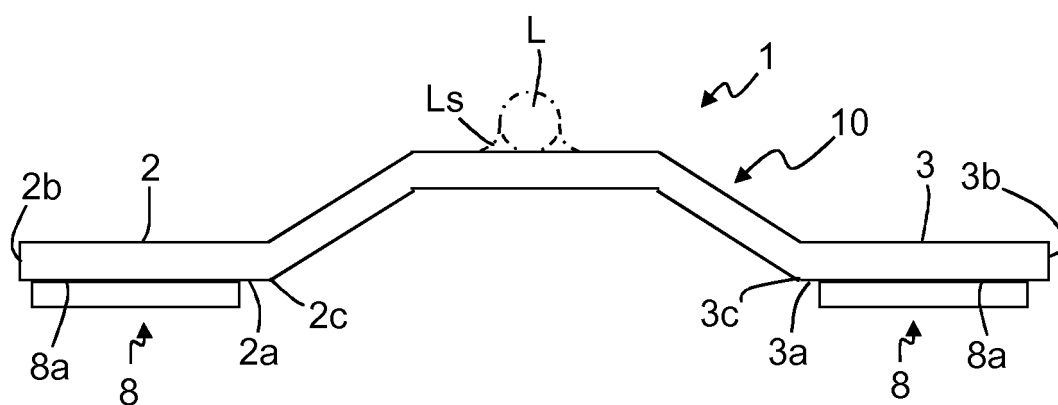
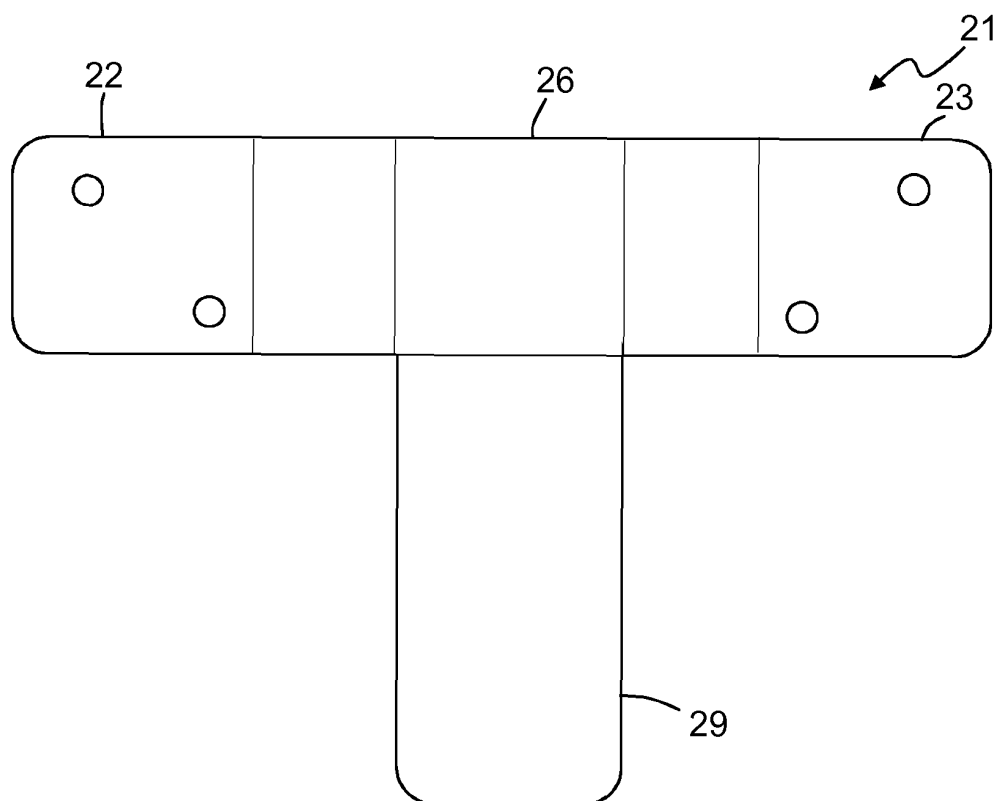
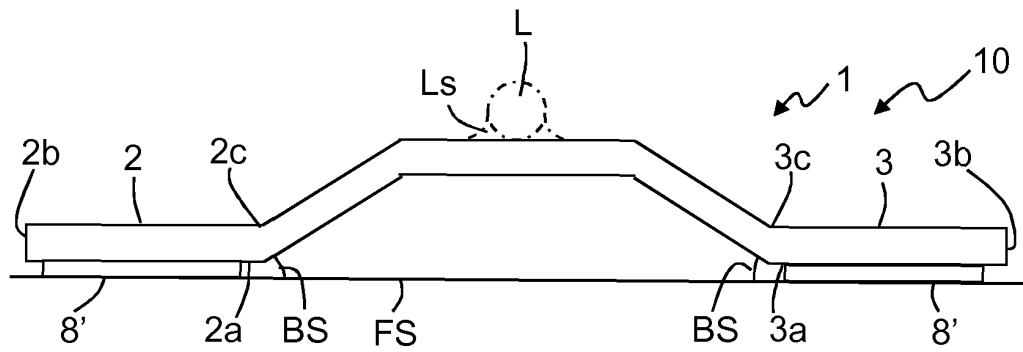
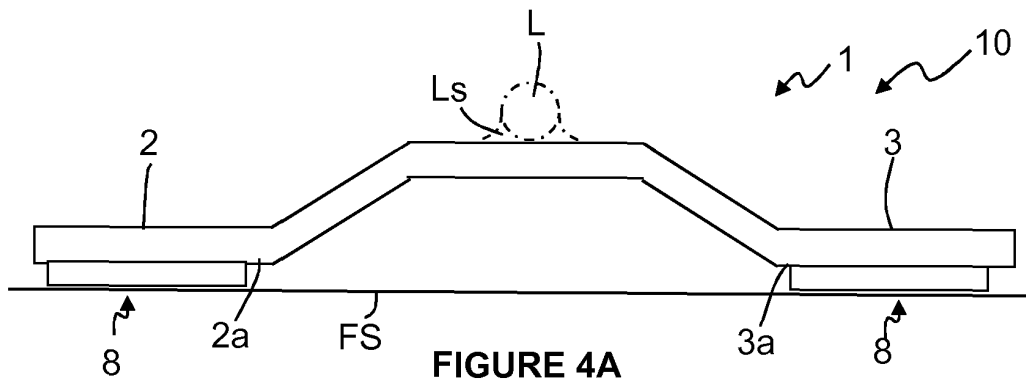


FIGURE 3



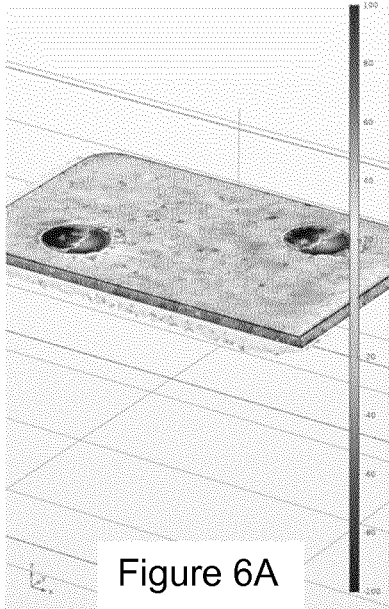


Figure 6A

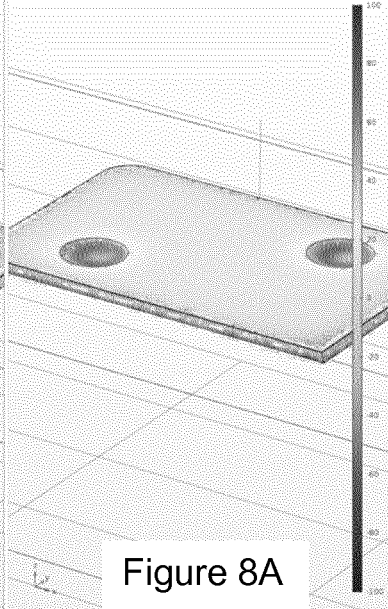


Figure 8A

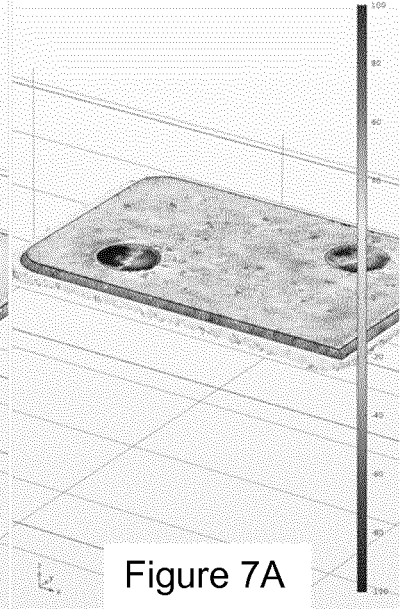


Figure 7A

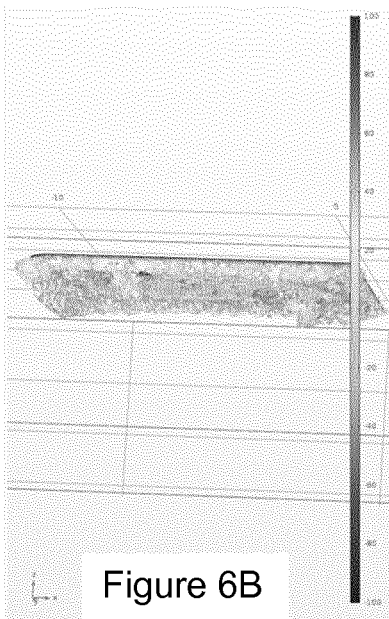


Figure 6B

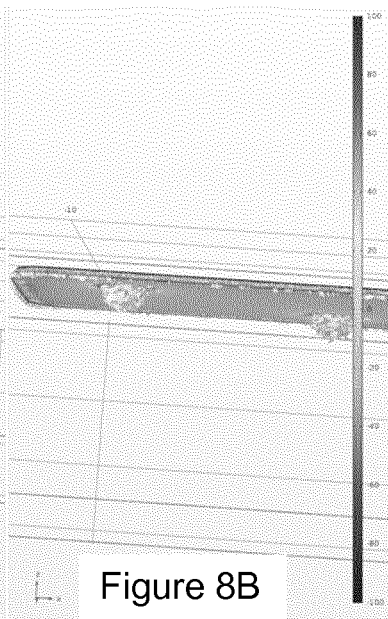


Figure 8B

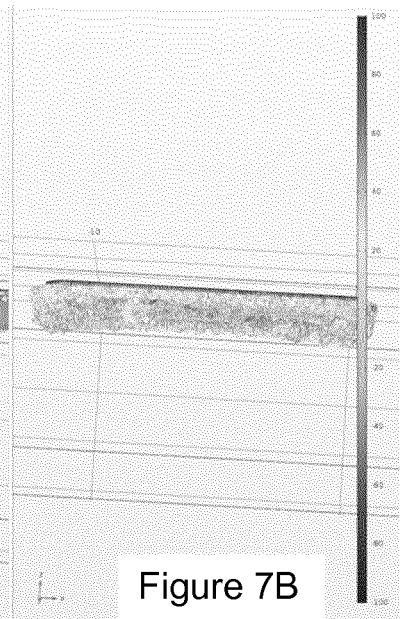
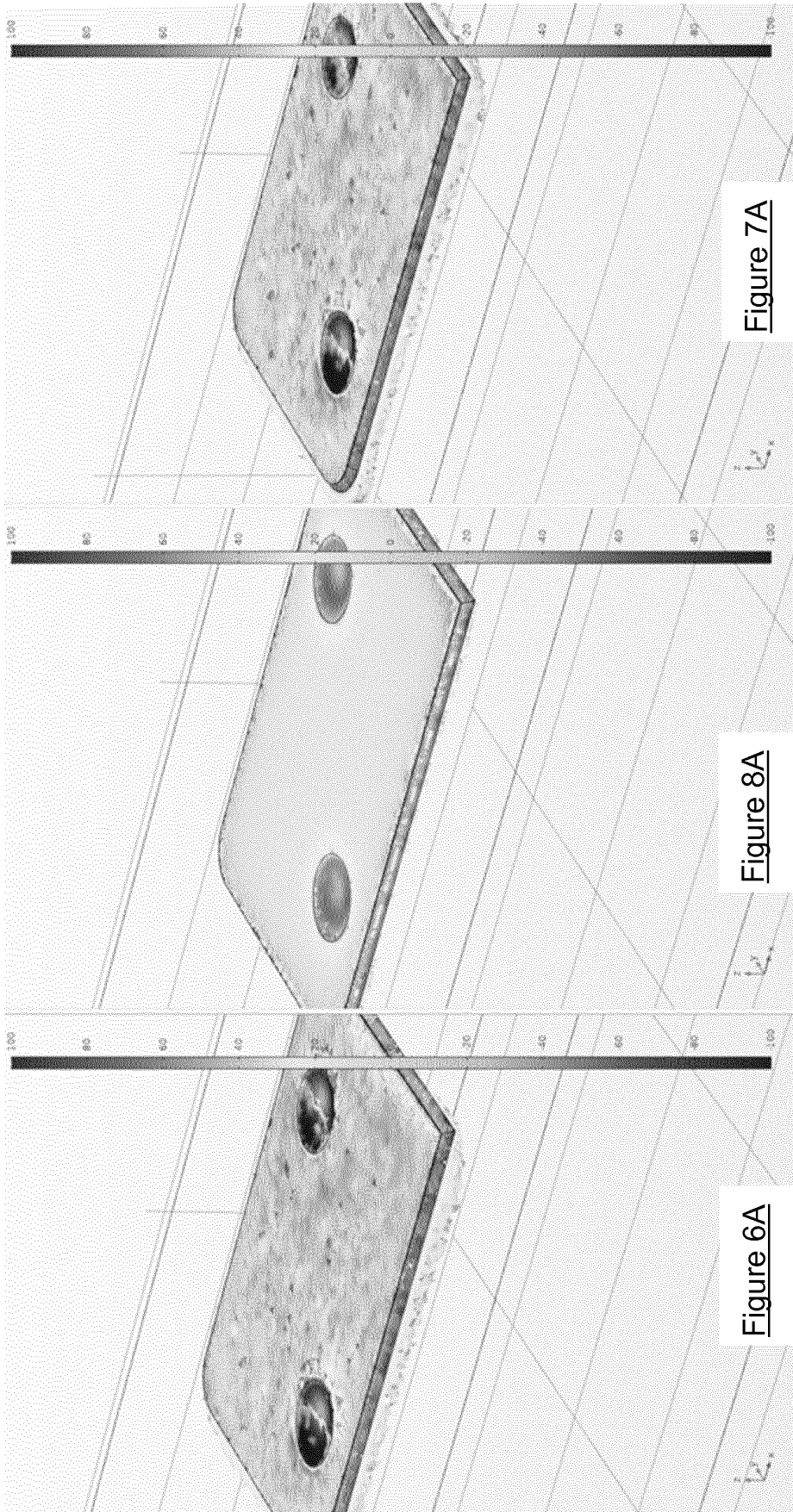


Figure 7B



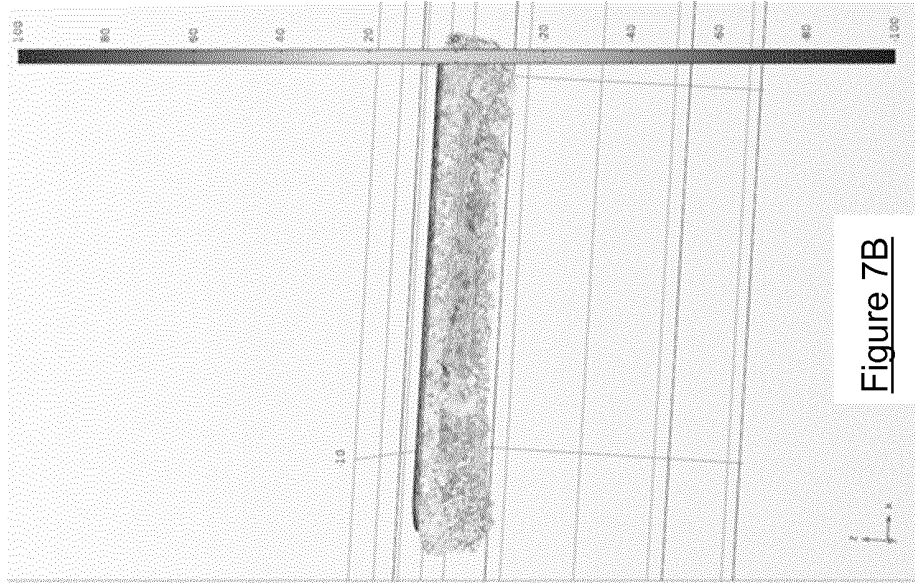


Figure 7B

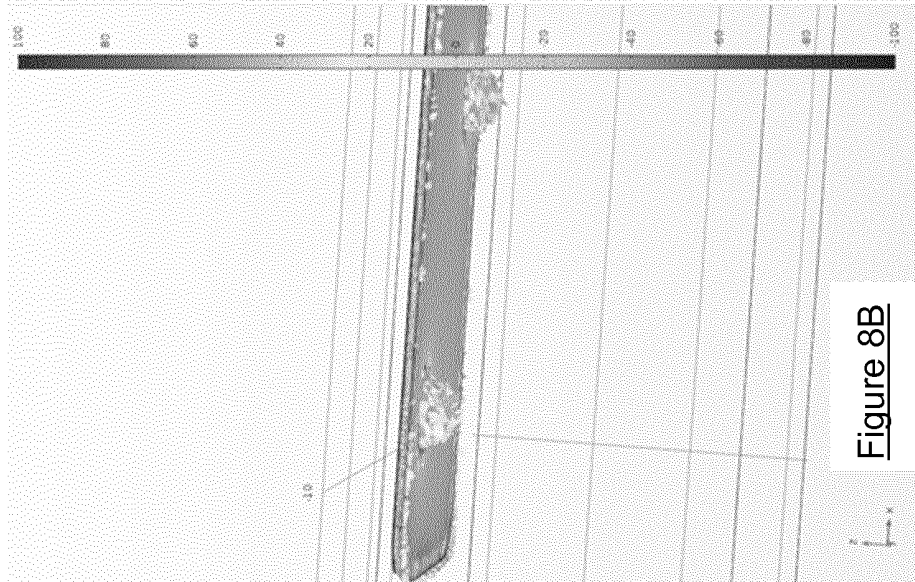


Figure 8B

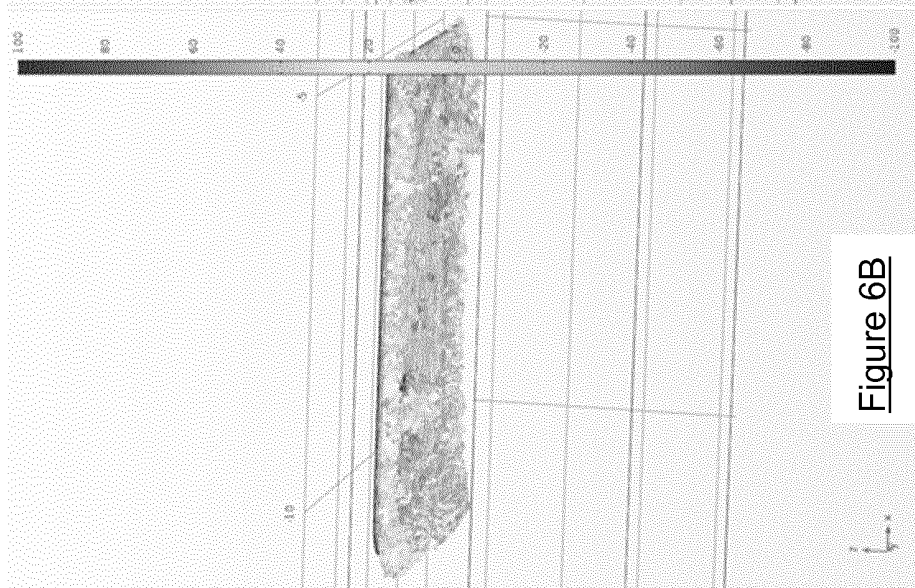


Figure 6B



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Application Number
EP 17 16 8859

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Place of search Munich		Date of completion of the search 11 September 2017	Examiner Gea Haupt, Martin
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