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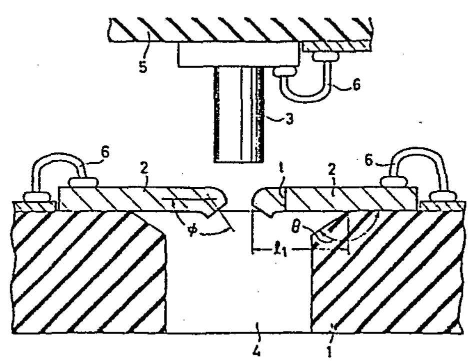
(54) **Connector using a shape memory alloy member.**

(57) A connecter has thin sheets (2) of shape memory alloy on a surface of a substrate (1), positioned such that the sheets (2) project over a hole in the substrate. A pin (3) is inserted into the hole with the temperature being such that the sheets (2) are easily deformed. A suitable change of temperature causes the sheets (2) to attempt to return to their original shape, thereby establishing a good electrical connection between the sheets (2) and the pin (3). Another change of temperature causes the sheets (2) to stop trying to return to their original shape, making it easy to remove the pin (3). This arrangement makes possible a reliable connector which may easily be made small.

FIG. 1a



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CONNECTER

The present invention relates to a connecter suitable for transmitting electric signals between electronic circuit devices.

A connecter using a shape memory alloy is disclosed in e.g. Japanese Patent Laid-Open No.16056/1973 entitled "Low Temperature Physical Connection Method and Device". This connecter establishes electric connection by making use of the recovery of shape of a shape memory alloy resulting from a martensitic reverse transformation due to a temperature rise. The shape memory alloy returns to its initial state by making use of the softness of the martensite phase generated by a temperature drop and by the restoring force of a spring. The connecter utilizes a one-way shape memory effect resulting in a large deformation and combines a shape memory alloy with a spring so as to cause effective two-way deformation. The prior art device is satisfactory if the size of the connecter is large. However, when a large number of connecters must be provided at a high density, each connecter must be as small as possible. Reduction in size of the prior art connector is limited because it is necessary that a spring be provided in addition to the shape memory alloy. This results in the problem that the device cannot be miniaturized because the spring must have a certain level of mechanical strength.

The present invention seeks to provide a connecter in which the problem of the prior art connecter discussed above is resolved by making possible the omission of the spring. It does this by providing a connecter with a connection terminal in the form of a thin sheet of shape memory alloy on a substrate. The connection terminal is adapted to receive a pin, thereby establishing an electrical connection.

In this way the forces necessary to achieve connection and disconnection may be made small relative to those necessary in the prior art connecter. Furthermore the present invention permits the connecter itself to be made small relative to the prior art connecter, making it particularly suitable for use where a compact connecter is required such as in an electronic computer.

Embodiments of the invention will now be described in detail, by way of example, with reference to the accompanying drawings, in which :

Fig. 1a is a partial sectional view showing a first embodiment of the present invention,

Fig. 1b is a plan view showing the planar shape of one of the connecting terminals of the embodiment shown in Fig. 1a,

Figs. 2a to 2d are sectional views for explaining the operation of the present invention, Figs. 3a to 3c are schematic views for explaining the relationship between the projection length, width and thickness of a connecting terminal, and

Figs. 4a and 4b respectively show other embodiments of the present invention.

First the properties of a shape memory alloy will be explained briefly, though they are described in detail by Kazuhiro Ohtsuka, in "Plasticity and Machining", Vol. 22, No. 246 (1981), p. 645-653.

The term "shape memory alloy" is used for those alloys such as Ti-Ni, Ag-Cd and Cu-Al-Ni, which exhibit a memory effect. When such alloys are deformed in a low temperature phase generated by thermoelastic martensite transformation (martensite phase, hereinafter referred to as the "M phase") and then the phase returns to the parent phase, the alloys return to the shape they had before they underwent deformation. This shape recovery occurs only once per deformation, and after the phase returns to the parent phase, deformation does not occur by mere change of temperature unless machining is again applied.

This is a summary of the behaviour of a shape memory alloy resulting from a martensite transformation, but the following properties are also observed. When a force is applied to the alloy to cause its deformation within a temperature range where the M phase is stable, strain increases in accordance with stress but when the stress reaches a certain stress value, the strain thereafter increases without a corresponding increase in the stress. This phenomenon is analogous to the yield of an ordinary material and is referred to as "pseudoelastic behaviour". This behaviour can be distinguished from ordinary plastic deformation because the alloy assumes its original shape if this stress is released within a certain strain range. The "yield strength" of pseudoelastic behaviour is considerably less than the yield strength of plastic deformation of structural materials, so that large deformation can be obtained in the M phase by relatively small stresses and the material appears to be soft.

For example, if a tensile test is carried out on a Ti-Ni alloy at a temperature slightly lower than the martensite transformation point, causing deformation of strain $\varepsilon = 4\%$, the stress is approximately 15 kg/mm². If the ratio of these figures is obtained and converted to the dimension of Young's modulus, the value is approximately 400 kg/mm². This value is considerably smaller than the Young's modulus E = 12,000 kg/mm² of a Be-Cu alloy when acting as a spring material. On the other hand, the stress occurring at the time of reverse transformation from the M phase to the parent phase may be as great as 60 to 70 kg/mm².

Suppose that the parent phase has a shape denoted by A, for example, which shape is memorized at high temperatures and the material is then deformed to another shape denoted by B, for example, within the temperature range corresponding to the parent phase. Then the material does not return to its original shape memorized in the parent phase, that is, A, but remains in shape B even if the material is held in shape B whilst the temperature is reduced to a temperature range corresponding to the M phase and then the material is released.

The connecter shown in Figs. 1a and 1b is formed by utilizing the properties of a shape memory alloy as described above. First, a one-way shape memory alloy such as Ag-Cd (44 ~ 49 at% Cd), Au-Cd (46.5 ~ 50 at % Cd), Cu-Al-Ni (14 ~ 14.5wt% Al, 3 ~ 4.5 wt% Ni), Cu-Au-Zn (23 ~ 28 at% Au, 45 ~ 47 at% Zn), Cu-Sn (~ 15 at% Sn), Cu-Zn (38.5 ~ 41.5 wt% Zn), Cu-Zn-X (X = Si, Sn, Al, Ga, 1 ~ 5 at% X), Ni-Al (36 ~ 38 at% Al), Ti-Ni (49 ~ 51 at% Ni), Fe-Pt (~ 25 at% Pt) or Fe-Pd (~ 30 at% Pd) produced by ordinary plastic working is repeatedly cold-worked and annealed to form a thin sheet. Separately, a metal film (not shown) is formed by sputter vapor deposition at a predetermined position on a heat-resistant oxidation-resistant flat insulator substrate 1 consisting of e.g. SiO_2, or Al_2O_3. The thin sheet of shape memory alloy is then spot-welded onto the metal film. It is also possible to deposit the shape memory alloy film directly on the substrate by vapour deposition. The alloy film 2 thus formed is etched to a desired pattern, with a cross-sectional shape of the parent phase as shown in Fig. 1a, thereby forming a socket 4 of the connecter. Fig. 1b shows a plan view of the socket 4 shown in Fig. 1a. Also shown in Fig. 1, are a pin 3 of a plug to be inserted into the socket, a fitting plate 5 and wire bonding 6 which connects the connecter to circuit wiring (not shown).

The operation of this connecter will now be explained with reference to Figs. 2a to 2d. The treatment described above is carried out at a temperature higher than the lower temperature limit of reverse transformation Af to form a socket having a construction as shown in Fig. 2a. Then the temperature is reduced to a point lower than the lower temperature limit of martensite transformation Mf but the thin sheet 2 maintains the shape shown in Fig. 2a. Next, as shown in Fig. 2b, the pin 3 of a plug (portions other than the pin are omitted for simplicity) is inserted into the hole of the socket 4 at a temperature substantially equal to the upper temperature limit of martensite transformation Ms or a temperature close to the upper limit of the temperature range, at which the M phase is stable, and which is lower than the former point. Then, the thin sheet 2 of shape memory alloy forming the socket 4 is pushed by the pin 3 and undergoes deformation as shown in Fig. 2b. However, the inserting force of the pin 3 in this instance is approximately 4 g, i.e. is not very large.

Next, the temperature is raised to a point higher than the lower temperature limit of reverse transformation Af and the thin sheet 2 attempts to return to its original shape shown in Fig. 2a and a strong contact force (40 g/pin) therefore acts between the thin sheet 2 and the pin 3 as shown in Fig. 2c. However, since movement of the thin sheet 2 is prevented by the pin 3, there is no substantial deformation of the thin sheet 2. If an electric device using this connecter is operated under this state, electric connection can be maintained with high reliability.

Next, the temperature of the connecter is reduced to a point lower than the lower temperature limit of martensite transformation Mf and the pin 3 is removed from the socket 4, as shown in Fig. 2d the connecter being maintained at that temperature. The pin 3 may be removed from the socket 4 using only an extremely small force for the following reason. If a martensite transformation is generated from the parent phase to the M phase when the pin 3 is in the socket 4 as described above, there is little spring-back of the thin sheet 2 even if the pin 3 is removed, so that the shape of the thin sheet 2 remains substantially the same as the shape when the pin 3 is first inserted into the socket 4. Thus, when the connecter is used again, a state corresponding to the state when the pin 3 was first removed (Fig. 2(d)) can be established both when the pin 3 is inserted and when it is removed. Thus the force necessary for inserting or removing the pin 3 a second or subsequent time may be extremely small.

An explanation of the principle of the connecter requiring small forces for insertion and removal in accordance with the present invention has been given. Examples of suitable dimensions for the various parts of the device will now be discussed. First, the size of the hole formed on the insulator substrate 1 is such that the minimum diameter or length of the hole should be at least equal to the diameter of the hole or its length in the longitudinal direction plus 20 μm. The taper angle θ (see Fig. 1(a)) of the hole is preferably $90° \leqslant \theta \leqslant 170°$. The thin sheet 2 is normally a rectangle or a quadrilateral. The number n of the thin sheets 2 is $2 \leqslant n \leqslant n_{max}$ (n_{max} is a division number obtained from consideration of the case where the maximum sheet width is equal to the thickness of the sheets used). The bending direction at the tip of the thin sheet 2 may be either downward or upward (i.e. in the direction of insertion of the pin 3 or in the opposite direction), and the bending angle ø (see Fig. 1(b)) is preferably between 90° and 180°. The length of the bent portion between zero and t where t is the thickness of the thin sheet 2.

Assume now that the thin sheet 2 has a cantilever shape such as shown in Figs. 3a to 3c and that its cross-sectional shape is constant. Then the force of F_1 of insertion of the pin 3 is given by the following equation :

$$F_1 = \frac{3VE_1 I}{\ell_1^3} \qquad \text{......(1)}$$

where V is the maximum deflection

E_1 is Young's modulus in the martensite phase of the shape memory alloy,

b is the width of the thin sheet 2

t is the thickness of the thin sheet 2

I is the moment of inertia of area ($I = \frac{1}{12} bt^3$) when the cross-sectional shape of the cantilever is rectangular and

ℓ_1 is the projection length of the connecting terminal.

On the other hand, when the pin 3 has been inserted and is heated to the temperature of the parent phase, the force F_c acts upon the pin 3 in the transverse direction and the magnitude of this force F_c is expressed by the following equation :

$$F_c = \frac{3E_2 I}{\ell_1^2} \qquad .....(2)$$

where E_2 is the Young's modulus in the parent phase of the shape memory alloy.

The ratio S between equation (2) and (1) is given by :

$$S = \frac{F_c}{F_I} = \frac{3E_2 I}{\ell_1^2} \times \frac{\ell_1^3}{3VE_1 I} = \frac{\ell_1 E_2}{VE_1} \qquad .....(3)$$

Thus the greater the ratio S, the smaller the force F_1 of insertion of the pin 3 and the greater the transverse force F_c (that is, the contact force). This means that a connecter having high performance may be achieved.

In equation (3), E_1 and E_2 are constants that are determined by the material used for the alloy. Hence, it is desirable that a material is selected for which the ratio E_2/E_1 is as large as possible.

Also the transformation temperatures of the alloy for the thin sheet 2 are selected to be :

$$T_1 - 50\ (°C) \leqslant Mf,\ Ms,\ Af,\ As \leqslant T_1 - 10\ (°C)$$

where T_1 is the lower limit of the operating temperature of the device;

Mf, Ms, and Af are as defined above; and

As is the upper temperature limit of the reverse transformation.

Thus the composition of the shape memory alloy is selected so that the transformation points Mf, Ms, Af, As are lower than the lower limit of the operating temperature of the device by between 10°C and 50°C.

In a connecter according to the present invention the thin sheet of shape memory alloy at the junction is preferably formed as a plate on the flat insulator substrate. This construction facilitates the application of techniques associated with photolithography and makes it possible to produce a large number of miniature sockets simultaneously.

It is preferable to form the thin sheet of the shape memory alloy on the upper surface (on the pin inserting side) of the insulator substrate than on its lower surface because higher strength is provided against peel forces acting upon the region of adhesion between the thin sheet and the insulator substrate when the pin is inserted.

If the tip of a thin sheet of shape memory alloy (hereinafter called a "connecting terminal"), by which the thin sheet contacts a pin is bent by bending work such as illustrated in Fig. 1(b) and by suitable selection of the various dimensions of the connecting terminal, the insertion and removal of the pin can be carried out smoothly.

Significant local deformation of the connecting terminal at the edge of the hole can be mitigated by fixing a part of the connecting terminal onto the upper surface of the insulator substrate with the rest disposed in such a manner as to project over the hole in the insulator substrate as illustrated in Fig. 1(b), by suitable selection of the various dimensions of the connecting terminal and by forming a taper at the edge of the hole in the proximity of the connecting terminal, as illustrated in Fig. 1(a).

Using a construction according to the present invention, a plurality of connecters 4 can be superposed and connected one to another using a pin 3 in common, as shown in Fig. 4(a). This is based upon the phenomenon that the connecting terminal becomes soft in the M phase, and upon its shape memory effect.

The number of connecting terminals 2 is preferably at least two, as shown in Fig. 1. To increase this number, however, the connecting terminals 2 may be disposed radially as shown in Fig. 4b or in a multi-stage arrangement as shown in Fig. 4a. When the number of connecting terminals increases, the reaction per connecting terminal against deformation decreases. If the centering of the pin 3 in the socket hole deviates for some reason, therefore, the resultant change of the force necessary for insertion or removal of the pin is small, thereby making the connection between the pin and the socket reliable.

Example 1

The first embodiment of the present invention will be explained in detail with reference to Fig. 1. This embodiment used two connecting terminals 2 consisting of a Ti-Ni alloy containing 50.5 at% Ni. An alloy sheet produced by ordinary plastic working was repeatedly subjected to cold rolling and annealing to form a thin sheet, and a hole having a length of 450 μm, a width of 200 μm and a taper angle of 146° was bored in advance in an alumina substrate 1 onto which a base metal had been evaporated. The thin sheet was spot-welded or was deposited by vapour deposition directly onto this substrate 1. The resulting Ti-Ni alloy film 2 was etched by photolithography to a shape such as shown in Fig. 1(b) and was then worked in the sectional shape shown in Fig. 1(a) and described above. It was then held at 500°C to 650°C for several hours to form a connecting terminal 2 having a planar shape and cross-sectional shape corresponding to those of the parent phase. The connecting terminal 2 had a rectangular shape having a length ℓ = 350μm, a width b = 100 μm and a thickness t = 50 μm and the projection length ℓ_1 of the connecting terminal 2 over the hole in the substrate 1 was 200 μm. The connecting terminal 2 was combined with a square prism-like pin 3 (Cu alloy) having a side of 100 μm.

The temperature of the Af, As, Mf and Ms points of the Ti-Ni alloy used in this embodiment were 13°C, 3°C, -10°C and -20°C, respectively and the temperature when the pin 3 is inserted and removed was from -30°C to -50°C. The operating temperature of the connecter was 20°C. Gold plating was applied to the pin 3 and to the connecting terminal 2 of the socket 4. When a large number of pin- and-socket pairs, each consisting of one pin 3 and one socket 4, are arranged on the same insulator substrate 1, the gap between the pins 3 is desirably 1,000 μm. After insertion and removal of the pin were repeated 100 times, the connecter operation was found to be satisfactory. The force necessary for inserting and pulling out the pin was 4 g/pin as described earlier.

<u>Example 2</u>

If the film thickness is reduced in Example 1 described above, working becomes difficult and the number of steps increases. Therefore, this second example involved simultaneous evaporation of Ti and Ni on an SiO_2 insulator substrate by electron beam vapour deposition in vacuum to form a 50 μm-thick Ti-Ni alloy film, from which the connecting terminal 2 described above was produced. The film was then uniformly treated at a temperature above 700°C. Gold plating was applied to the resulting Ti-Ni alloy film, and subsequent treatment was made for the insulator substrate. In other words, wet etching was carried out on the SiO_2 insulator substrate using an aqueous HF solution and dry etching was effected as a final step from the opposite side to the vacuum deposition surface, using CF_4 to bore a hole in the SiO_2 insulator substrate. Thereafter, the socket was produced in the same way as in Example 1. The insertion and removal test of the product in this example provided the same data as those of Example 1.

Example 3

A plurality of sockets 4, each having connecting terminals 2 disposed radially around the hole of an insulator substrate 1, were superposed and connected as shown in Fig. 4. In this example, the first insertion, heating, cooling and removal of the pin 3 were effected for each socket, and a pin jig having a diameter greater by 10% than the pin 3 used for a practical device was used. Since a considerably larger jig was used for the first insertion and removal, the increase of the stress load to the pin due to the lamination can be mitigated. This method showed that the force necessary for inserting and pulling out the pin 3 did not increase significantly even when a plurality of sockets were superposed.

As described above, the present invention may provide an electric connecter requiring a significantly reduced force for inserting and removal of a pin, as compared with the conventional spring type connecter. Moreover, since the present invention makes possible miniaturization of the connecter, a connecter having a large number of pin connections may be produced. Since the connecter is highly reliable, it is suitable for apparatus requiring particularly high reliability, such as computers and communication equipment.

CLAIMS:

1. A connecter having a connection terminal of a shape memory alloy; characterised in that:

the connecter includes an insulator substrate (1) having a hole therein; and in that the connection terminal comprises a thin sheet (2) of the shape memory alloy on the substrate, the terminal having a gap portion for insertion of a pin (3).

2. A connecter according to claim 1 wherein the tip of the thin sheet (2) is bent in the direction of insertion of the pin.

3. A connecter according to claim 1 or claim 2, wherein the connection terminal includes at least two thin sheets (2) of the shape memory alloy, the gap portion being between the ends of the two sheets.

4. A connecter according to claim 3, wherein the number n of thin sheets is:

$$2 \leqslant n \leqslant n_{max}$$

where n_{max} is a number determined by consideration of thin sheet each having a maximum width equal to their thickness.

5. A connecter according to any one of the preceding claims, wherein the hole has a tapering portion at the surface of the substrate (1).

6. A connecter according to any one of the preceding claims, wherein the connection terminal is located on the surface of the substrate towards which the pin is inserted.

7. A connecter according to any one of the preceding claims having a plurality of substrates (1) and a corresponding plurality of connection terminals (2), whereby the terminals are electrically connected one with another when the pin (3) is inserted.

8. A connecter according to any one of the preceding claims, wherein the thin sheet (2) is shaped by photolithography.

FIG. 1a

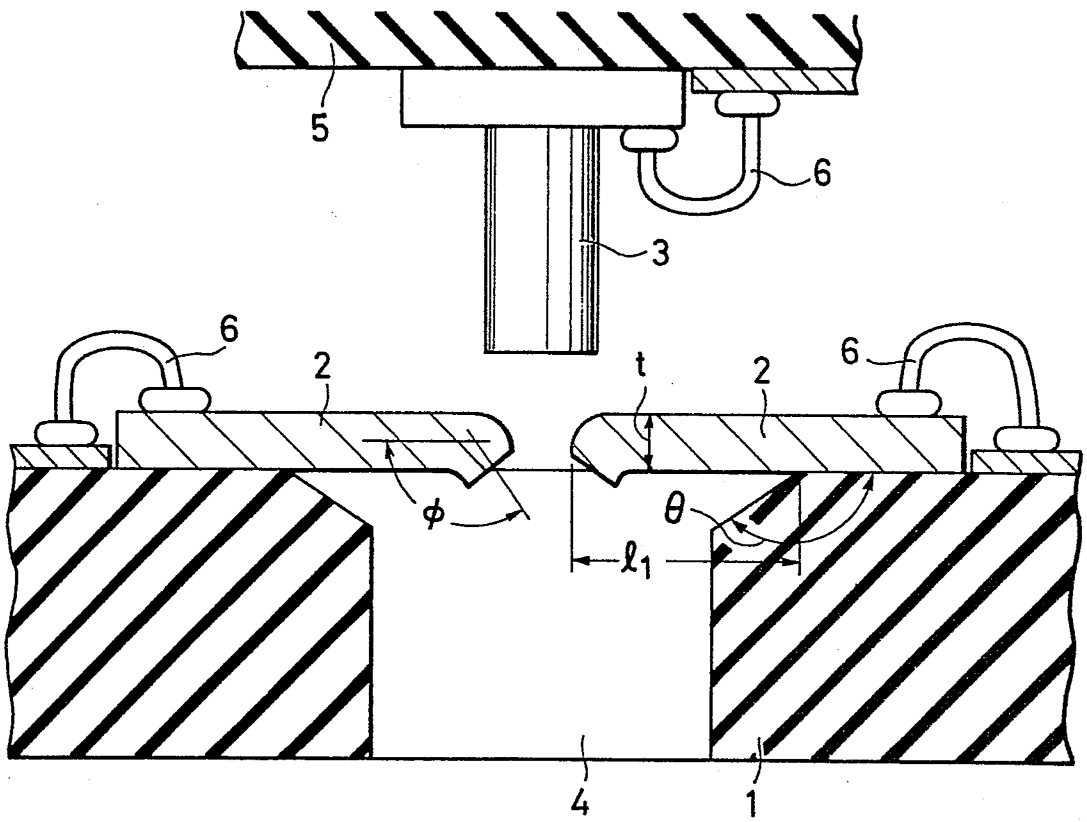

FIG. 1b

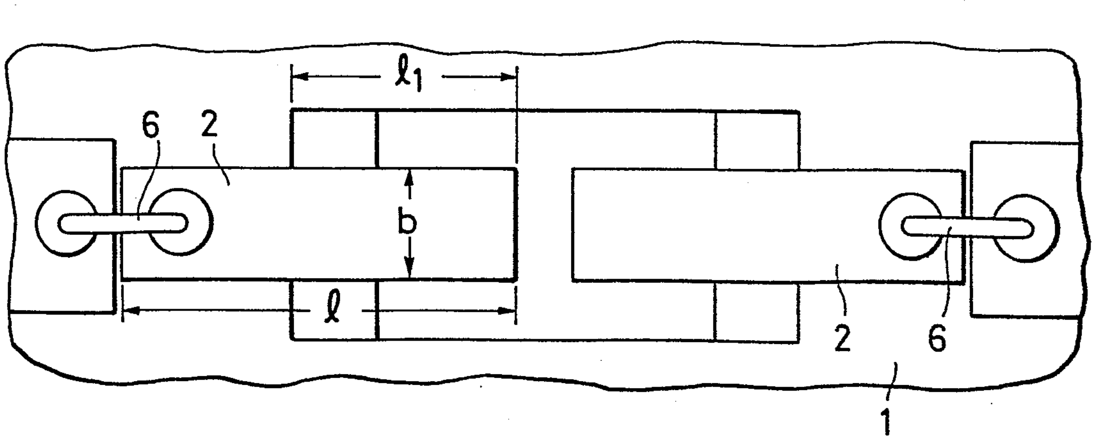

FIG. 2a

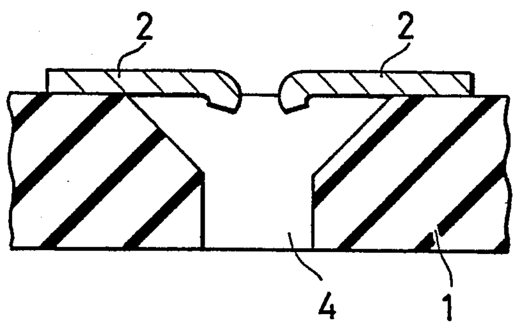

FIG. 2b

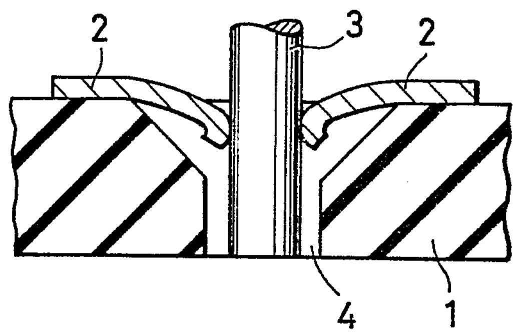

FIG. 2c

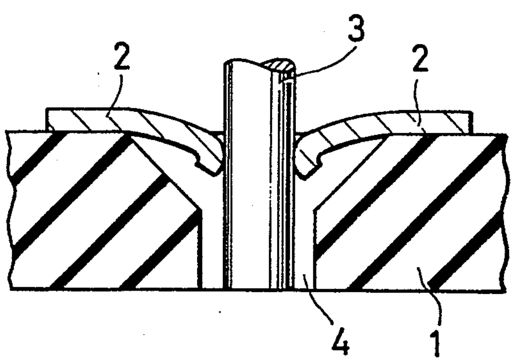

FIG. 2d

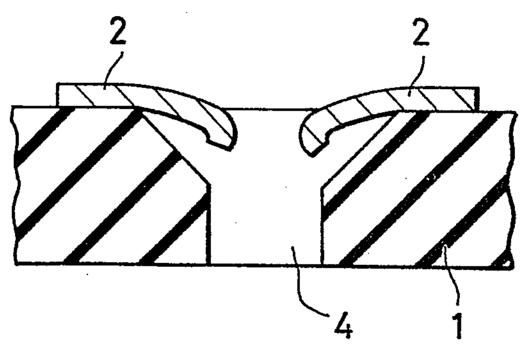

FIG. 3a

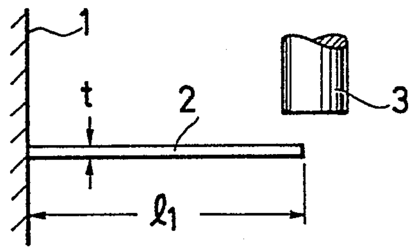

FIG. 3b

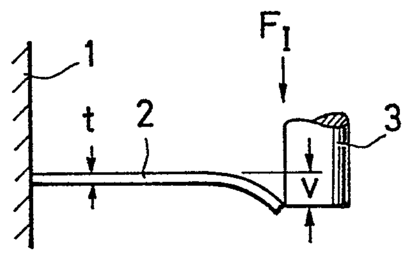

FIG. 3c

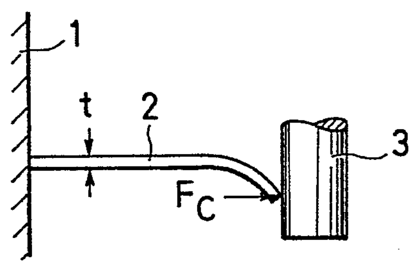

FIG. 4a

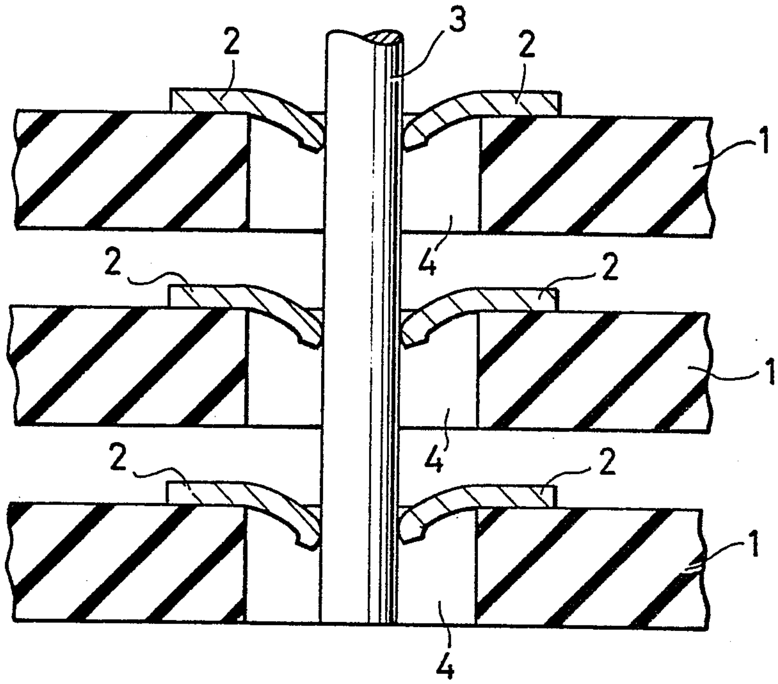

FIG. 4b