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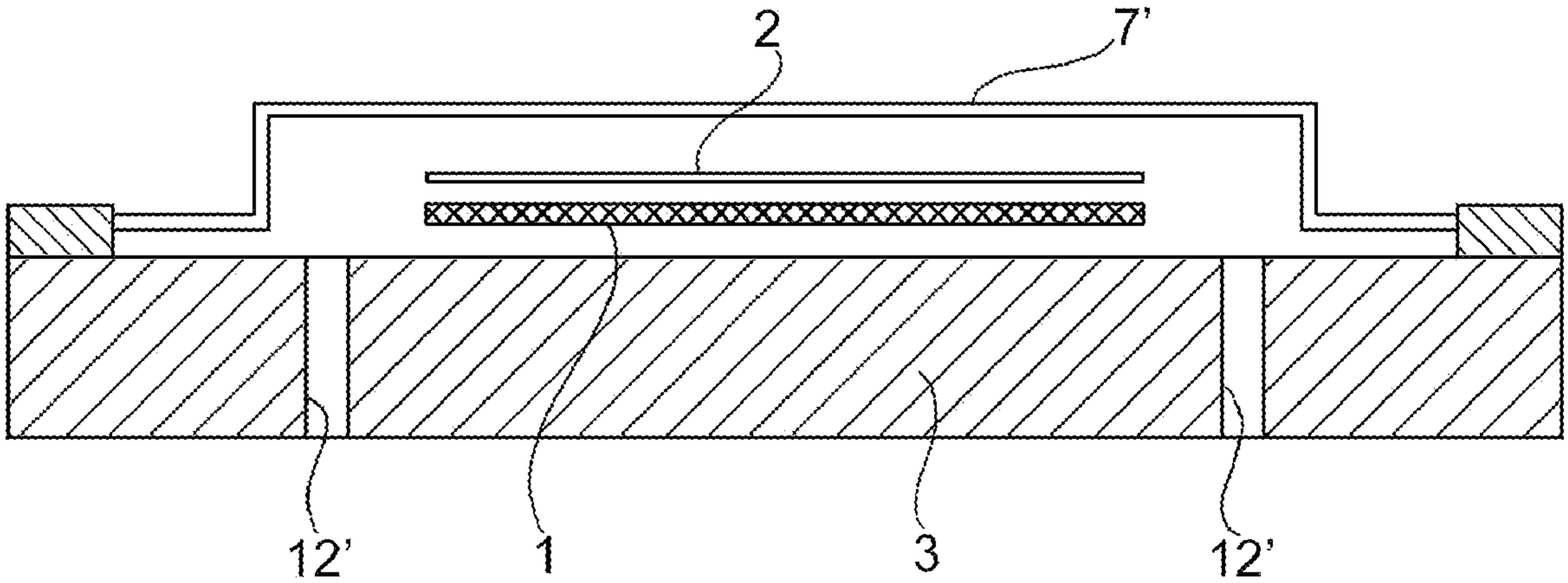
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(54) Title: A METHOD OF MANUFACTURING A CURVED ELEMENT MADE OF COMPOSITE MATERIAL



(57) Abrégé/Abstract:
A method of manufacturing a curved element made of composite material comprises the following steps: a) preparing at least one dry, flat reinforcing layer (1) with curved fibres, b) combining a resin film (2) with the dry, flat reinforcing layer, and applying heat and pressure in controlled manner so as to bring about the infusion of the resin into the reinforcing layer and to obtain at least one layer of pre-infused material (Y), c) preparing at least one prepreg layer (31, 32) with straight fibres impregnated with resin compatible with the resin of the pre-infused material, d) superimposing the layer of pre-infused material and the prepreg layer on one another so as to obtain a layered structure (1''), and e) subjecting the layered structure, arranged on a shaped support tool (30), to a polymerization cycle so as to obtain the curved element.

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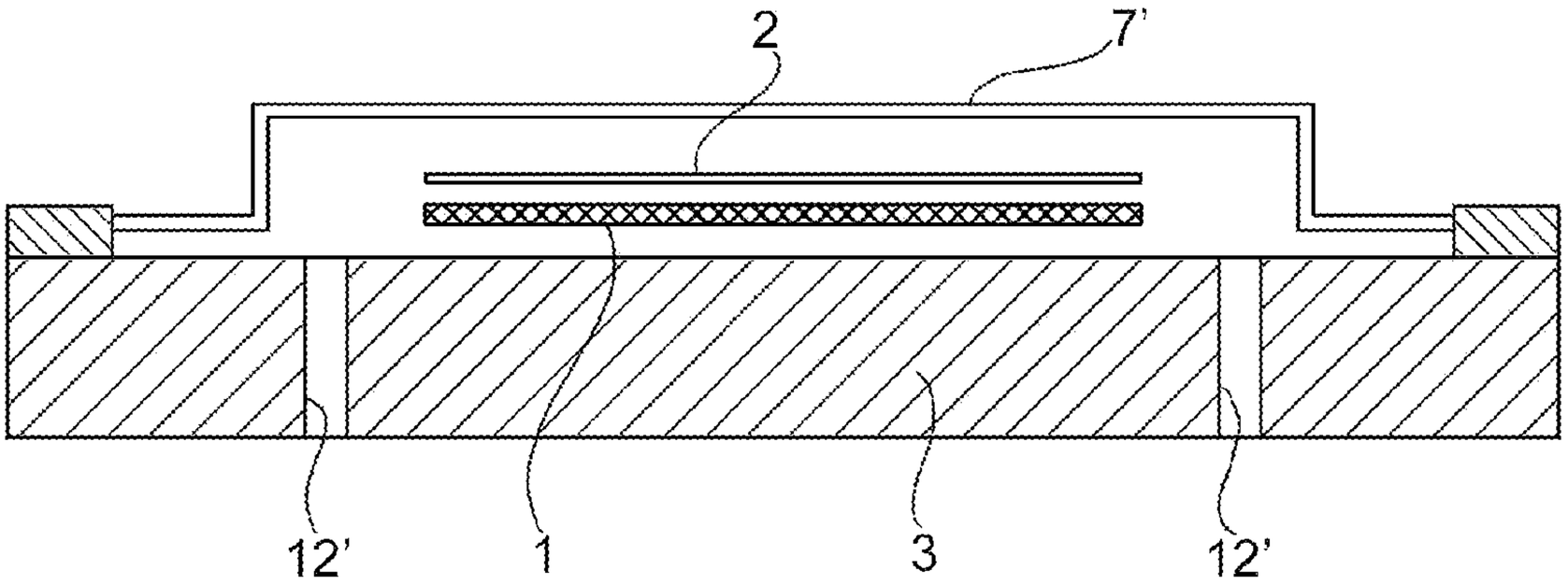
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[Continued on next page]

(54) Title: A METHOD OF MANUFACTURING A CURVED ELEMENT MADE OF COMPOSITE MATERIAL

FIG.3



(57) Abstract: A method of manufacturing a curved element made of composite material comprises the following steps: a) preparing at least one dry, flat reinforcing layer (1) with curved fibres, b) combining a resin film (2) with the dry, flat reinforcing layer, and applying heat and pressure in controlled manner so as to bring about the infusion of the resin into the reinforcing layer and to obtain at least one layer of pre-infused material (Y), c) preparing at least one prepreg layer (31, 32) with straight fibres impregnated with resin compatible with the resin of the pre-infused material, d) superimposing the layer of pre-infused material and the prepreg layer on one another so as to obtain a layered structure (1"), and e) subjecting the layered structure, arranged on a shaped support tool (30), to a polymerization cycle so as to obtain the curved element.

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A method of manufacturing a curved element made of composite material

The present invention relates to a method of manufacturing a curved element made of composite material.

As is known, some important curved structural elements, such as fuselage frames for example, can advantageously be made of composite material to improve their stiffness and reduce weight. These elements often require the carbon, fibreglass or other reinforcing fibres to have the same curved orientation as the structural element to improve its structural efficiency and reduce its weight.

This requirement cannot be satisfied with the use of conventional prepreg composite materials. In fact these are produced from groups of straight fibres, unidirectional fabrics, or strips which are impregnated with resin film in a continuous process. Owing to its continuous nature, the conventional pre-impregnation process is not suitable for the impregnation of reinforcing layers with fibres that are not straight.

Various methods have been developed to overcome the limitations imposed by pre-impregnation and to produce curved structural components but they have some disadvantages.

In particular, processes which partially solve the problem have been developed; these processes enable reinforcing layers with curved fibres, such as flat, curved, braided layers and spiral fabric layers to be assembled. However, these flat elements must be formed into the geometrical shape of the component to be produced (for example, C-sectioned frames or L-sectioned shear ties), prior to the infusion of resin. The shaping of these fabrics presents considerable difficulties since the non-impregnated fibres easily stray from the original orientation so as to be arranged in unpredictable ways inconsistent with the design. To overcome this problem, a technology based on a special weaving technique known as "overbraiding" has been developed. In this technique, the reinforcing fibre is woven, by means of special machines, onto a temporary support mandrel having the same curved shape as the component to be produced and having a cross-section such that the section of

the component to be obtained can be produced therefrom simply by longitudinal cutting.

However, this innovative technology also has some important limitations. In fact:

- it is not possible to orient the reinforcing fibres in all directions, as would be desirable to improve structural performance, but only within a more restricted range, normally within the range of from about +70° to -70° relative to the longitudinal axis of the element to be produced; it is therefore not possible to insert fibres arranged at 90° (relative to the longitudinal axis of the element), which are typical of the lay-up of composite structural components;

- the delicacy of the preforms requires them to be supported by the auxiliary weaving mandrels from the time when they are woven until the time of use, creating problems with regard to costs and to transport and storage logistics; a corresponding number of expensive support mandrels is also required;

- the cross-sections that can be produced by the overbraiding process are limited to those that can be obtained from a closed C-section; other cross-sections are obtained with difficulties that are accompanied by quality problems, that is: fibre orientation not to design, wrinkles, etc.,

- the sections that can be produced by the overbraiding process are limited to a uniform thickness and cannot have variations relative to the transverse axis of the element,

- the process for the infusion of the reinforcing preform with resin is particularly complex and limits the types of resin that can be used.

The object of the present invention is therefore to provide a method of manufacturing a curved element which overcomes the above-mentioned disadvantages of the prior art.

This object is achieved, according to the invention, by a method of manufacturing a curved element of composite material having the characteristics defined in Claim 1.

The method according to the invention is based on the pre-infusion of flat elements having fibres arranged in a curved orientation and in their use in combination with conventional prepreg layers, provided that they have compatible resin. This enables curved components to be produced with curved fibre orientation without problems of fibre deformation during

forming and overcomes the limitations of the overbraiding technique with respect to fibre angles, thickness variations, and logistics.

Preferred embodiments of the invention are defined in the dependent claims.

Some preferred but non-limiting embodiments of the invention will now be described with reference to the appended drawings, in which:

- Figure 1 is a plan view of an example of a preform for the production of a curved element,

- Figure 2 is a schematic view showing, in section, a vacuum bag for the pre-infusion of the preform of Figure 1 according to a first embodiment of a pre-infusion stage of the method according to the invention,

- Figure 3 is a schematic view showing, in section, a membrane device for the pre-infusion of the preform of Figure 1 according to a variant of the first embodiment of the pre-infusion stage of the method according to the invention,

- Figure 4 is a schematic view showing, in section, a vacuum bag for the pre-infusion of a plurality of preforms according to a variant of the first embodiment of the pre-infusion stage of the method according to the invention,

- Figures 5 and 6 are a schematic side view and a schematic plan view, respectively, of apparatus for the pre-infusion of a plurality of preforms according to a second embodiment of the pre-infusion stage of the method according to the invention,

- Figure 7 is a plan view of an example of a layered structure obtained from the preform of Figure 1, and

- Figure 8 is a section through the layered structure of Figure 7, arranged on a support tool.

Figure 1 shows, by way of example, a dry preform 1 as the starting material for the production of a curved element by the method according to the invention, arranged on a base platform 3. The preform 1 has substantially the shape of a flat strip and is arranged so as to be curved in the plane of the strip, that is, in the plane defined by the support surface of the platform 3. This curved arrangement is shown in the drawing by a curved principal axis S.

The dry preform 1 is constituted by a layer of reinforcing fibres in which a first predefined percentage A1 of the fibres have a curved orientation, that is, substantially parallel to the axis S, a second predefined percentage A2 of the fibres have a straight arrangement with an orientation inclined at between 0 and +70 degrees to the axis S, and a third predefined percentage A3 of the fibres have a straight arrangement with an orientation inclined at between 0 and -70 degrees to the axis S. The orientations of these three fibre percentages are shown, by way of indication, by respective arrows A1, A2 and A3 in Figure 1. This arrangement is achieved by a conventional braiding technique. The braiding of the fibres of the three different fractions with different arrangements enables a firm fabric to be obtained in which the fibres do not move because they are braided. The percentage for each orientation is selected on the basis of the load requirements but with constraints resulting from the need to stabilize the orientations of the fibres by means of the braiding. A flat reinforcing layer is thus obtained. Instead of the braiding technique, the reinforcing layer may also be prepared by other conventional techniques such as tow placement and spiral weaving techniques which may be selected according to the structural characteristics to be obtained in the finished curved element. The geometrical characteristics (radius of curvature, width in a radial direction, circumferential length) and the physical characteristics (type of reinforcing fibre, weight per unit area of the fibres) are selected according to the structural characteristics of the finished curved element. The curved fibres of the reinforcing layer 1 thus have predefined orientations relative to the axis S which are established at the stage of the production of the reinforcing layer 1 and are dependent on the desired characteristics of the finished element.

According to the invention, the dry, flat reinforcing layer 1 thus obtained is combined with a resin film, indicated 2 in Figures 2 to 6. Controlled temperature and pressure are then applied to bring about the infusion, i.e. the penetration of the resin into the reinforcing layer and to obtain a layer of pre-infused material, indicated 1' in Figures 5 to 8.

According to a first embodiment, this pre-infusion stage takes place discontinuously in a vacuum bag in which the pressure necessary for the infusion is exerted by the vacuum bag in which a vacuum is produced.

This discontinuous pre-infusion requires the resin film to be cut beforehand to a geometrical shape similar to that of the reinforcing layer 1 to be pre-infused, with care being taken that the overall weight of the resin is in the correct proportion relative to the overall weight of the layer to be pre-infused.

Once the layer of reinforcing fibre 1 and the layer/s of resin 2 have been combined on the base platform 3, a vacuum bag is prepared for the pre-infusion process. The vacuum bag can be put into effect in many ways, some of which are listed below.

A first method, which is now described with reference to Figure 2, provides for a layer of release film 5, for example a non-perforated, fluorinated ethylene-propylene film (FEP), a layer of breather fabric 6, and a layer of nylon film 7, sealed onto the base platform by the peripheral positioning of sealing tape 8, to be positioned, in order, over the assembly of reinforcing fibres 1 and resin film 2. The release film 5 is fixed, by means of an adhesive tape 9, to a peripheral ventilation system comprising a strip of breather fabric 10 and a peripheral material 11 for rendering the pressure within the vacuum bag homogeneous. Suitable valves 12 are positioned on the nylon film for the application of the vacuum which is produced by means of a pump or other suitable mechanism.

A second method of putting the vacuum bag into effect, which is now described with reference to Figure 3, may be to use a silicone rubber membrane 7' which can be sealed onto the base platform 3 by means of gaskets and which, again, must have holes 12' for the application of the vacuum by means of a pump or other suitable device.

A third method, which is now described with reference to Figure 4, provides for a plurality of reinforcing layers 1 combined with respective resin films 2 and release films 11 to be arranged on top of one another in piles 13 under the same vacuum bag 7", prepared on the base platform 3. The release film 11 is interposed between each pair of layers comprising a reinforcing layer 1 and a resin film 2 and the pair arranged above it to prevent undesired adhesion between them. A plurality of layers of pre-infused material can thus be produced simultaneously.

Once the vacuum bag 7, 7', 7" has been prepared, a pre-infusion cycle is performed by the programmed application of heat and vacuum. In particular, the process provides for the vacuum to be applied at the moment at which the rise in temperature has brought the resin 2 to a fairly low viscosity so that it can penetrate into the dry fabric 1 under the effect of the vacuum, bringing about the pre-infusion thereof. However, the temperature must not exceed a limit value corresponding to the activation of the polymerization reaction of the resin. The combined vacuum and temperature cycle may alternatively be performed with the use of:

- an oven (schematically indicated 15 in Figure 4) which is provided with vacuum taps and in which the assembly can be positioned,

- a heated table provided with a vacuum pump; this system is particularly suitable in conjunction with the use of the membrane vacuum bag since the overall time required for the pre-infusion process is minimized.

According to a second embodiment, the pre-infusion stage takes place semi-continuously.

The semi-continuous pre-infusion process, which is now described with reference to Figures 5 and 6, enables several reinforcing layers to be covered with a resin film of a width suitable to cover the reinforcing layers continuously.

This process provides for a series of dry reinforcements 1 to be positioned on a conveyor belt 20; the reinforcements are pre-infused by means of one or more continuous resin films 2 which are heated to the required temperature beforehand by means of heaters 21 and are caused to penetrate into each reinforcement 1 with the aid of compression rollers 22.

The process provides for the use of several continuous rolls of resin film 23, the unwinding of the resin film 2, the positioning of the film 2 on the reinforcements 1, the heating of the film 2, the pre-infusion of the film, the consolidation of the film in the reinforcement by passage through cooling rollers 24, and the separation of the infused preforms 1' by cutting of the excess resin film with cutting devices 25. The arrows A in Figures 5 and 6 indicate the direction of movement of the conveyor belt 20.

The method according to the invention then provides for the preparation of one or more prepreg layers, indicated 31 and 32 in Figures 7 and 8, which are formed by straight fibres impregnated with resin compatible with the resin of the pre-infused material, for use mainly to introduce angular orientations greater than 70 degrees into the laminate and/or to produce local increases in thickness.

For the purposes of the invention, the term "prepreg" means, in conventional manner, a semi-finished product comprising straight reinforcing fibres and a resin matrix in which the fibres are immersed. The fibres may be arranged in different configurations, for example in a unidirectional layer, in two layers having different orientations, or as fabric. The prepregs are generally prepared in tape form and wound in rolls.

The method then provides for the layer/s 1' of pre-infused material and the prepreg layer/s 31, 32 to be superimposed on one another in a predetermined arrangement so as to obtain a layered structure 1". This layering is performed by positioning the layers with the fibre orientations required by the design, in accordance with the design of the finished component. By way of example, prepreg layers are applied to the pre-infused preform 1' shown in Figure 7, in positions indicated P1 and P2, thus forming the layered structure 1". The axes 33 and 34 which are arranged in the positions P1 and P2 and are perpendicular to the principal axis S of the pre-infused preform 1' indicate the orientations of the straight fibres of the prepreg layers 31 and 32 relative to the principal axis S.

The layering operation may be performed in two different ways.

A first method provides for direct layering by:

- cutting each layer to shape with the use of templates and hand cutters or automatic, numerically-controlled cutting systems,
- lamination of each layer directly on a support tool for the polymerization of the component, indicated 30 in Figure 8, by performing suitable intermediate compaction steps by means of a vacuum bag, in accordance with conventional practice.

A second method provides for layering and hot forming in accordance with the following

steps:

- cutting of each layer to shape using templates, and hand cutters or automatic, numerically-controlled cutting systems,

- layering of the various layers in a flat arrangement, as shown in Figure 7,

- positioning on a forming tool and forming of the "raw" layered structure 1" in one or more stages by the application of vacuum and heat,

- positioning of the formed layered structure 1" on the support tool 30 for polymerization; as a variant of the method, the polymerization tool 30 may correspond to the forming tool.

Once the layering has been performed, a vacuum bag is put into effect with the use of the materials that are known in the field, for example, starting with the layered structure 1"', release film, breather fabric, and bag film sealed onto the edges of the polymerization tool, and the affixing of vacuum valves to the bag film.

Finally, the element is polymerized and compacted by the execution of a combined pressure and temperature cycle to bring about the compaction of the layers and activate the polymerization of the resin. In some applications, the application of the vacuum and heating alone suffices for the compaction and polymerization of the element.

As will be appreciated, the innovative process proposed affords considerable advantages over the prior art.

In fact, the reinforcement layers with curved, pre-infused fibres combined with conventional prepreg layers enable important curved structural elements to be produced without:

- risk of straying of the orientation of the fibres which is typical of processes in which the flat reinforcement layers have to be deformed to the final shape of the component without the stabilizing effect of the resin,

- limitations on the orientations of the fibres such as those that are imposed by the overbraiding technique which does not allow the layering to have fibres with orientations greater than 70° to the principal axis of the element (S in the embodiment illustrated);

- wrinkles in the fibres, which would be produced if it were attempted to deform conventional prepregs with straight fibres to cause them to adopt a curved shape.

CLAIMS

1. A method of manufacturing a curved element made of composite material, characterized in that it comprises the following steps:

a) preparing at least one dry, flat reinforcing layer (1) with curved fibres,

b) combining a resin film (2) with the dry, flat reinforcing layer (1),

c) applying heat and pressure to the combined reinforcing layer and resin film in controlled manner so as to bring about the infusion of the resin into the reinforcing layer and to obtain at least one layer of pre-infused material (1'),

d) preparing at least one prepreg layer (31, 32) with straight fibres impregnated with resin compatible with the resin of the pre-infused material,

e) superimposing the at least one layer of pre-infused material and the at least one prepreg layer on one another in accordance with a predetermined arrangement, so as to obtain a layered structure (1"), and

f) subjecting the layered structure (1"), arranged on a shaped support tool (30), to a polymerization cycle so as to obtain the curved element.

2. A method according to Claim 1 in which step c) takes place in a vacuum bag (7, 7', 7") in which the pressure is applied by the production of a vacuum.

3. A method according to Claim 2 in which step c) is preceded by a step of preparing a vacuum bag, in which the combined reinforcing layer and resin film are arranged on a base platform (3), and in which a layer of release film (5), a layer of breather fabric (6), and a layer of vacuum bag film (7) which is sealed peripherally onto the base platform (3) and is provided with valves (12) for the application of the vacuum, are positioned, in order, on the combined reinforcing layer and resin film.

4. A method according to Claim 2 in which step c) is preceded by a step of preparing a vacuum bag, in which the combined reinforcing layer and resin film are arranged on a base platform (3) provided with holes (12') for the application of the vacuum, and in which a vacuum bag membrane(7') which is sealed peripherally onto the base platform (3) is positioned on the combined reinforcing layer and resin film.

5. A method according to Claim 2 in which step c) takes place for a plurality of reinforcing layers which are combined with respective resin films and arranged in piles (13), in which each reinforcing layer combined with resin film is separated from the layer above it by means a layer of release film (11).

6. A method according to Claim 1 in which steps b) and c) take place continuously, in which a plurality of dry reinforcing layers (1) are transported by belt conveyor means (20), and in which the reinforcing layers are pre-infused by means of a continuous resin film (2) which is heated beforehand and is caused to penetrate into the reinforcing layers in succession by means of compression rollers (21).

7. A method according to Claim 6 in which the pre-infused reinforcing layers (1') are separated from one another by cutting (25) of the excess resin film.

8. A method according to Claim 1 in which step e) takes place directly on the shaped support tool.

9. A method according to Claim 1 in which step e) comprises:

- the superimposition of the at least one layer of pre-infused material and the at least one prepreg layer in a flat arrangement,

- the positioning of the structure (1") thus layered on a tool for a hot forming process, and

- the positioning of the layered and hot-formed structure (1") on the shaped support tool.

FIG.1

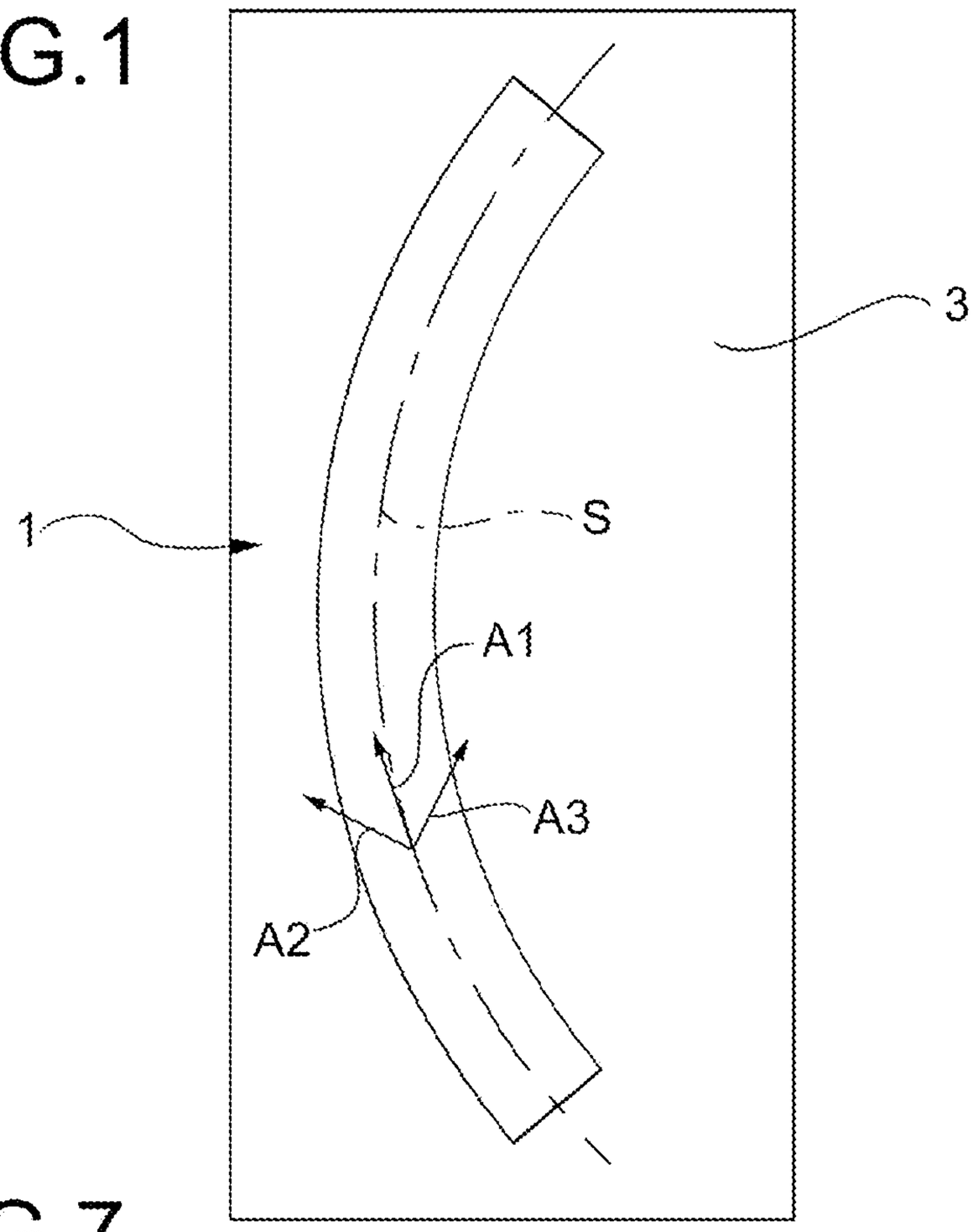


FIG.7

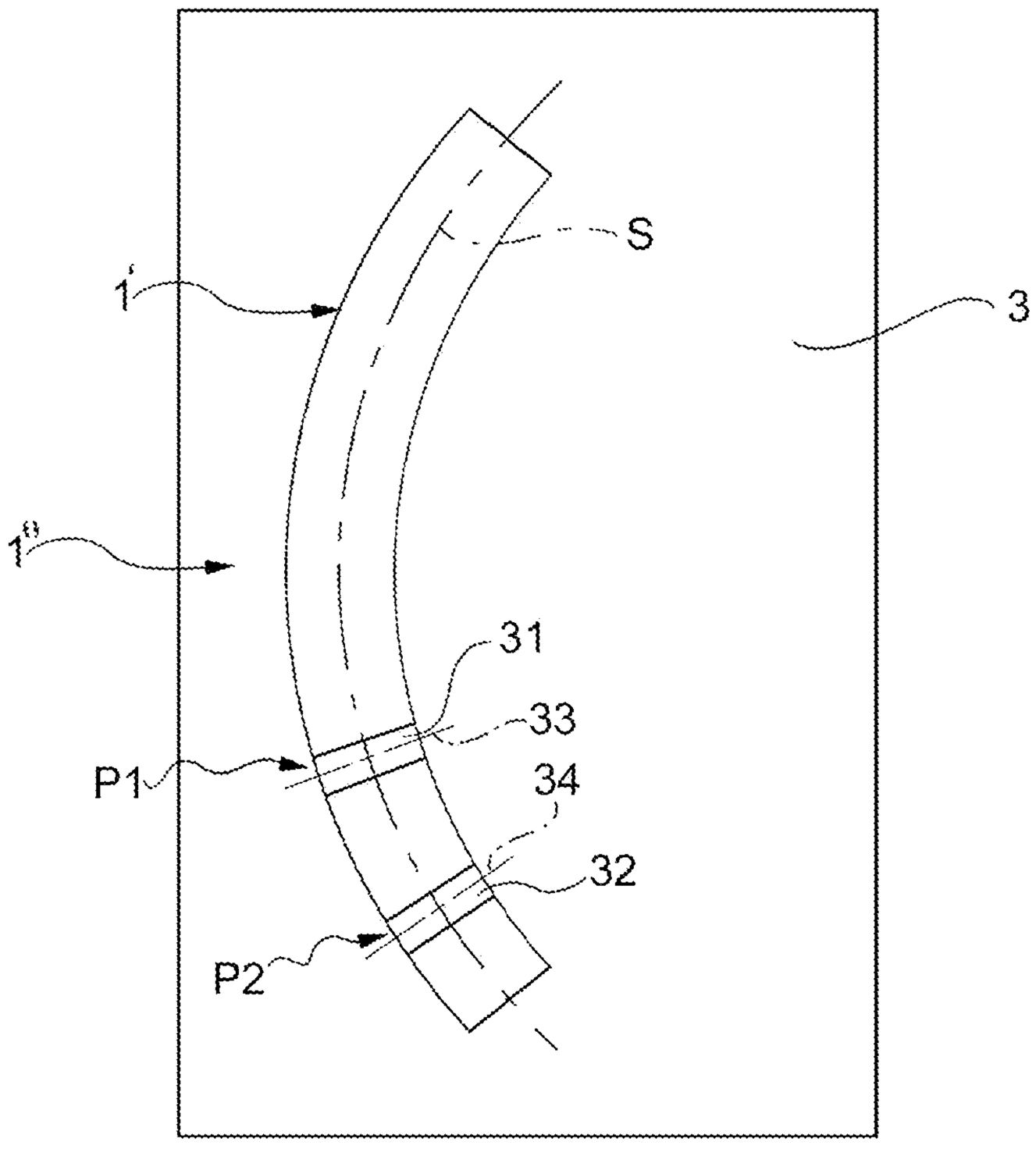


FIG.2

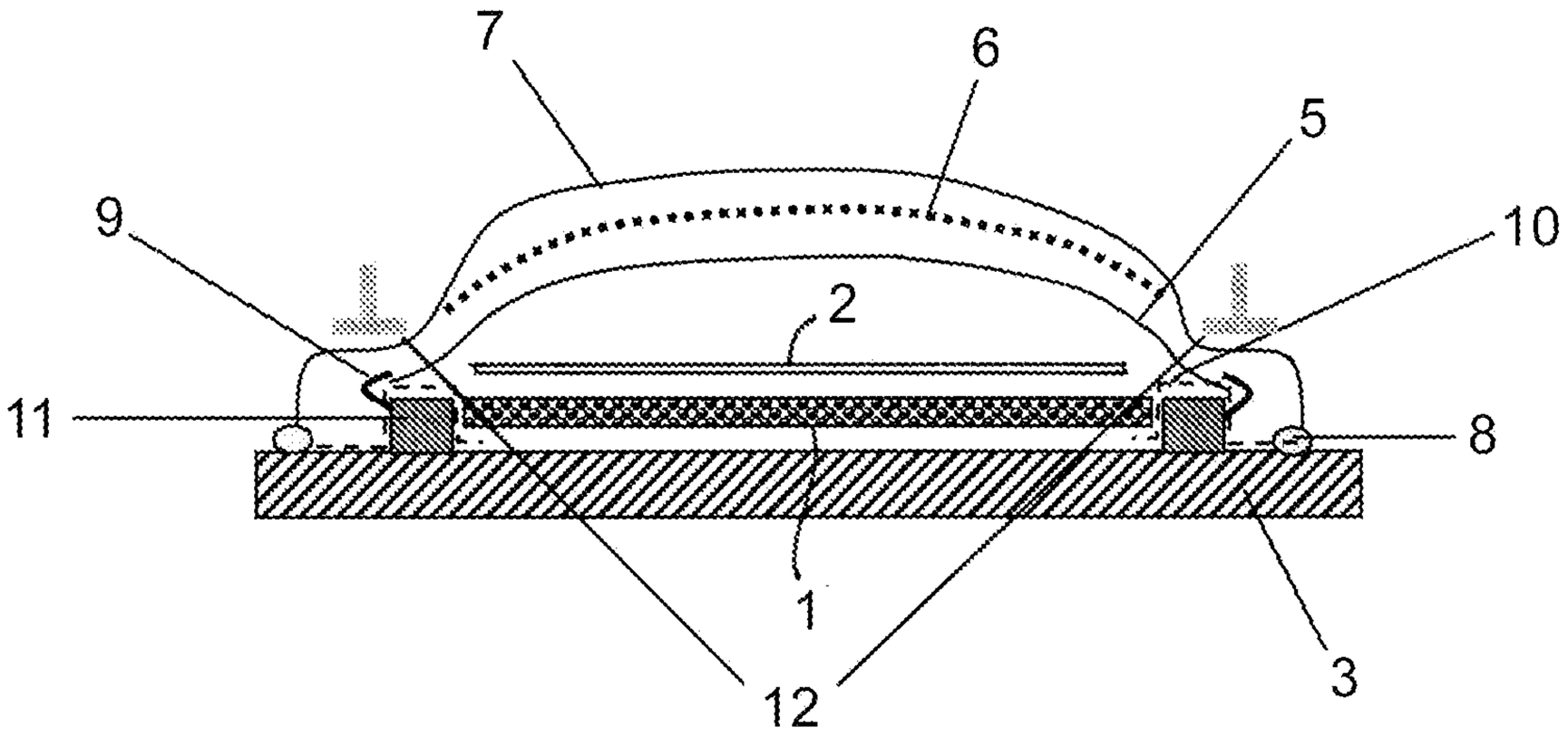


FIG.4

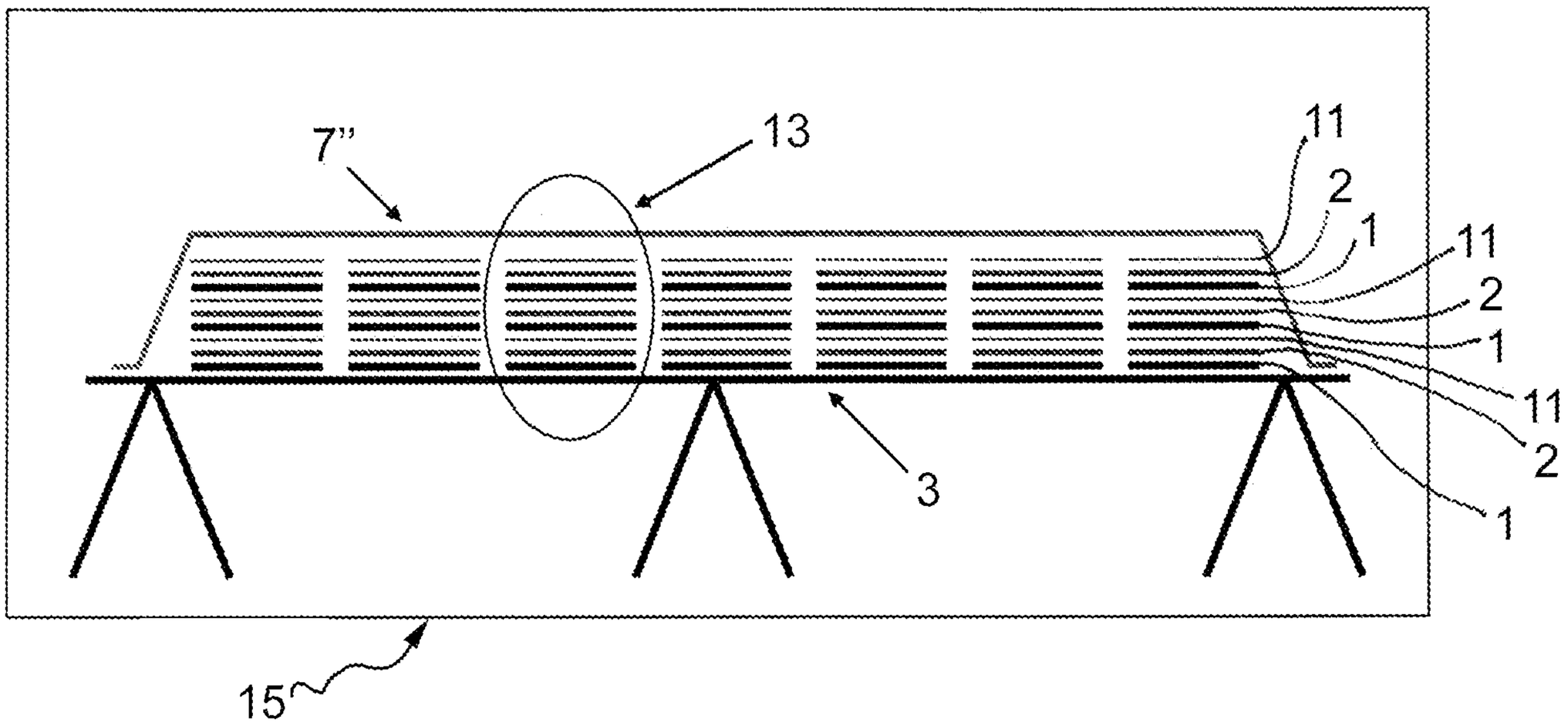


FIG.3

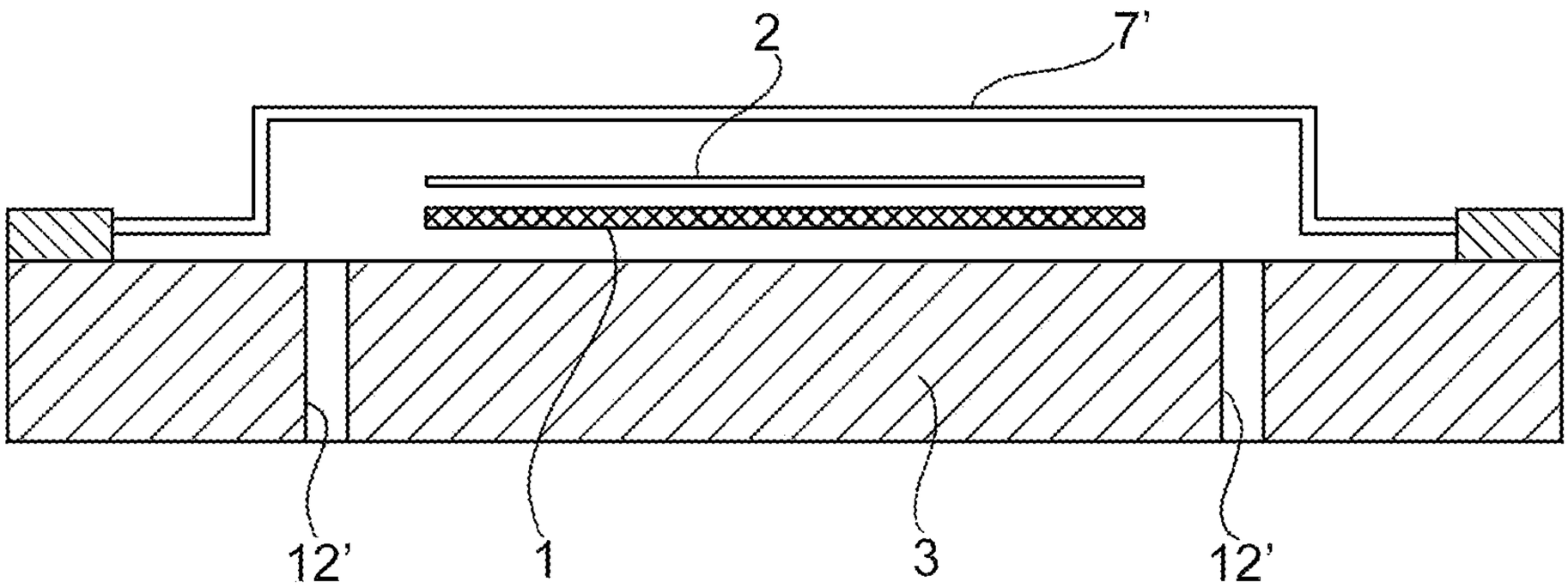
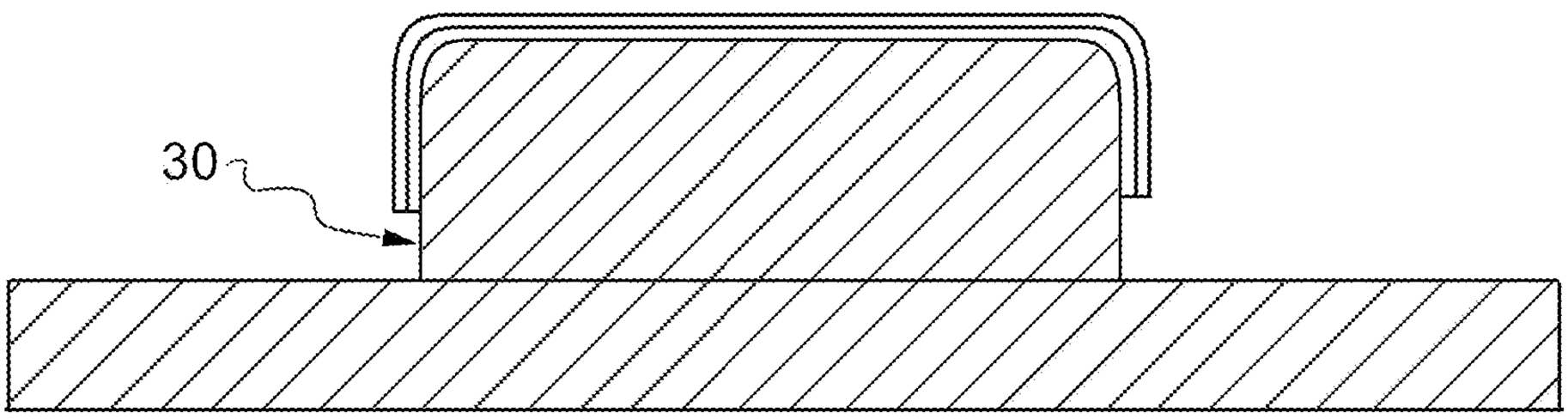


FIG.8



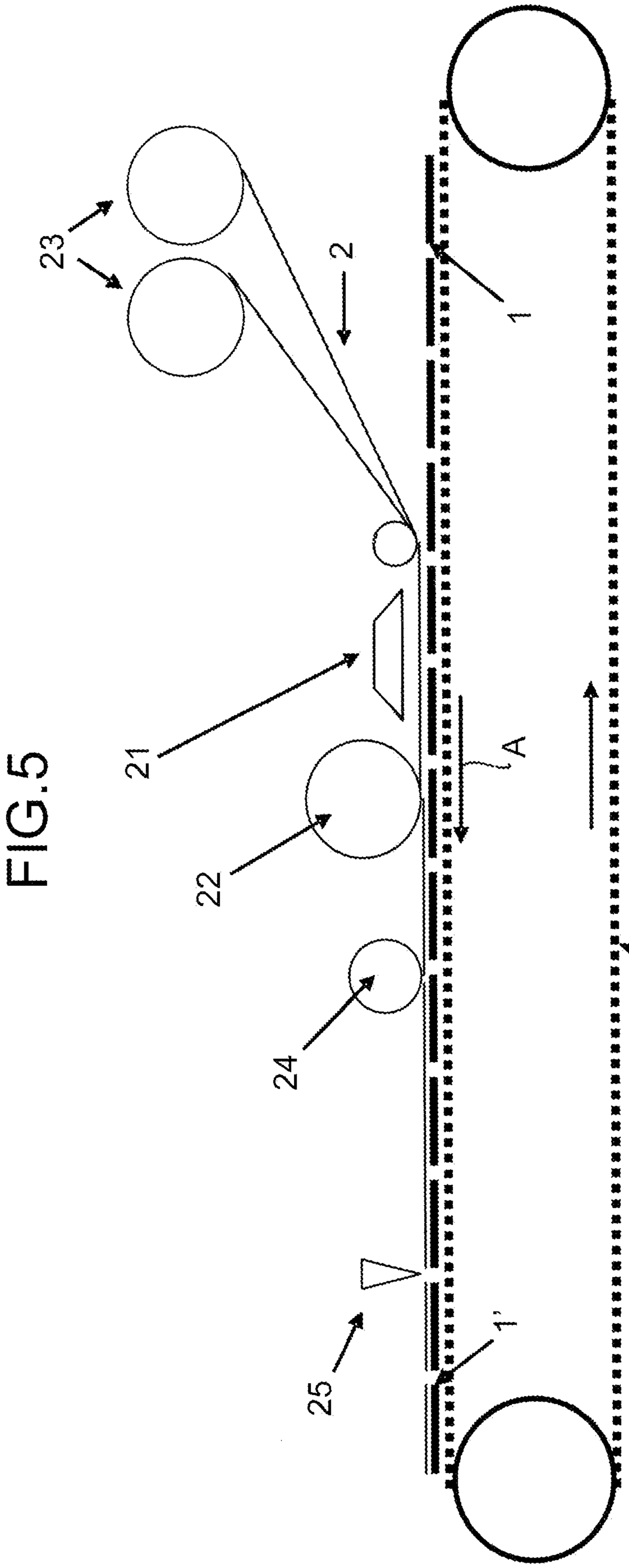
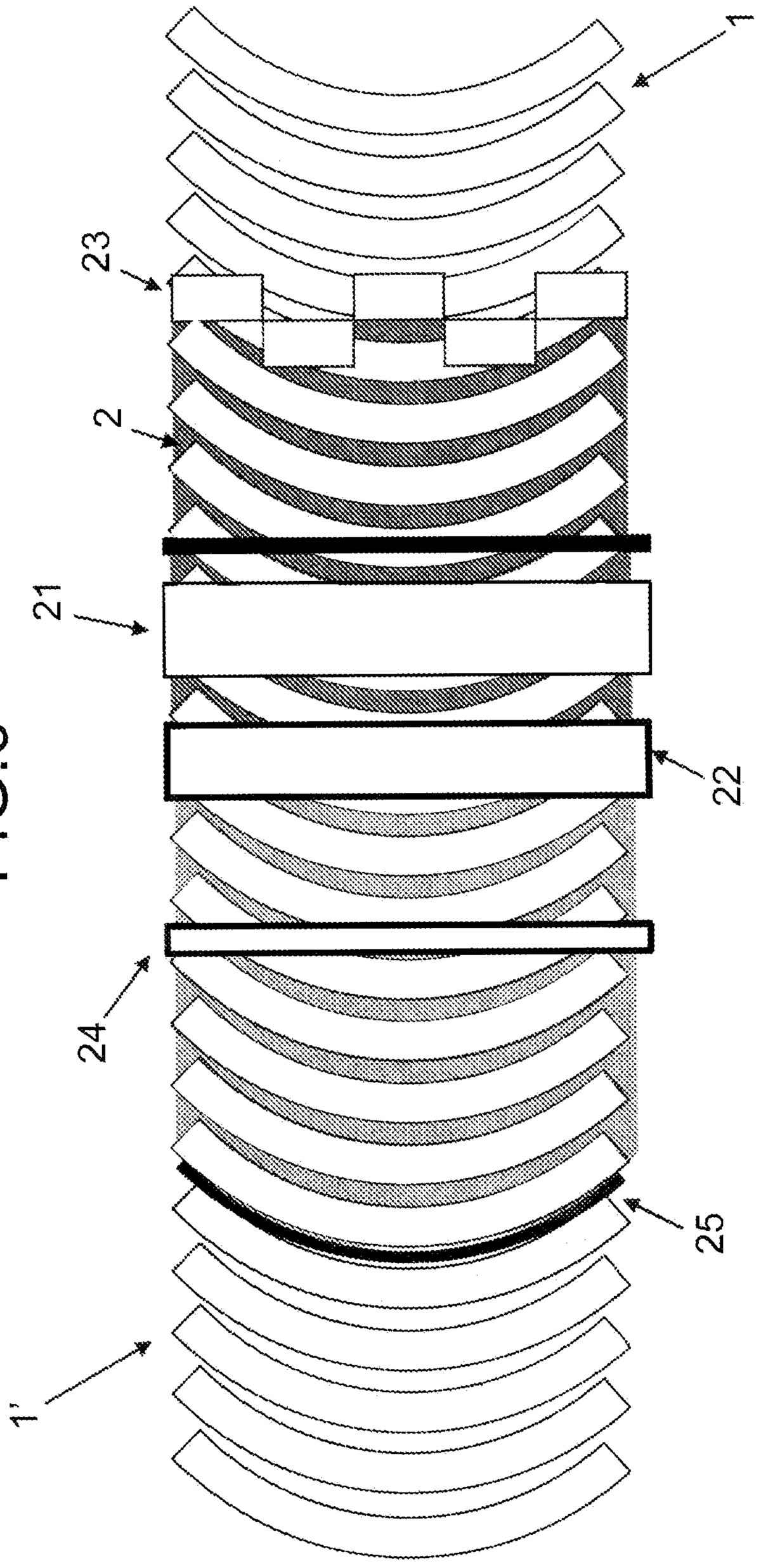
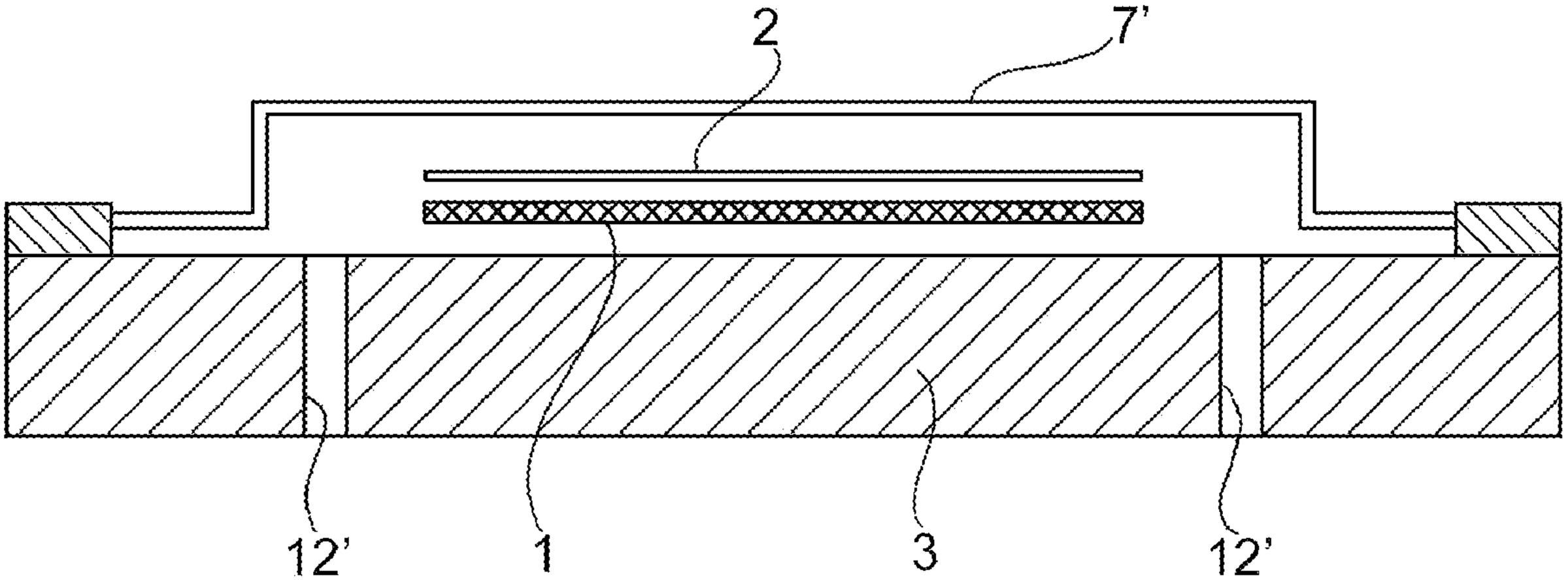


FIG.5

FIG.6




2
7'
12'
1
3
12'