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(54) **HEAT EXCHANGER**

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F28F 7/00

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(57) **ABSTRACT**

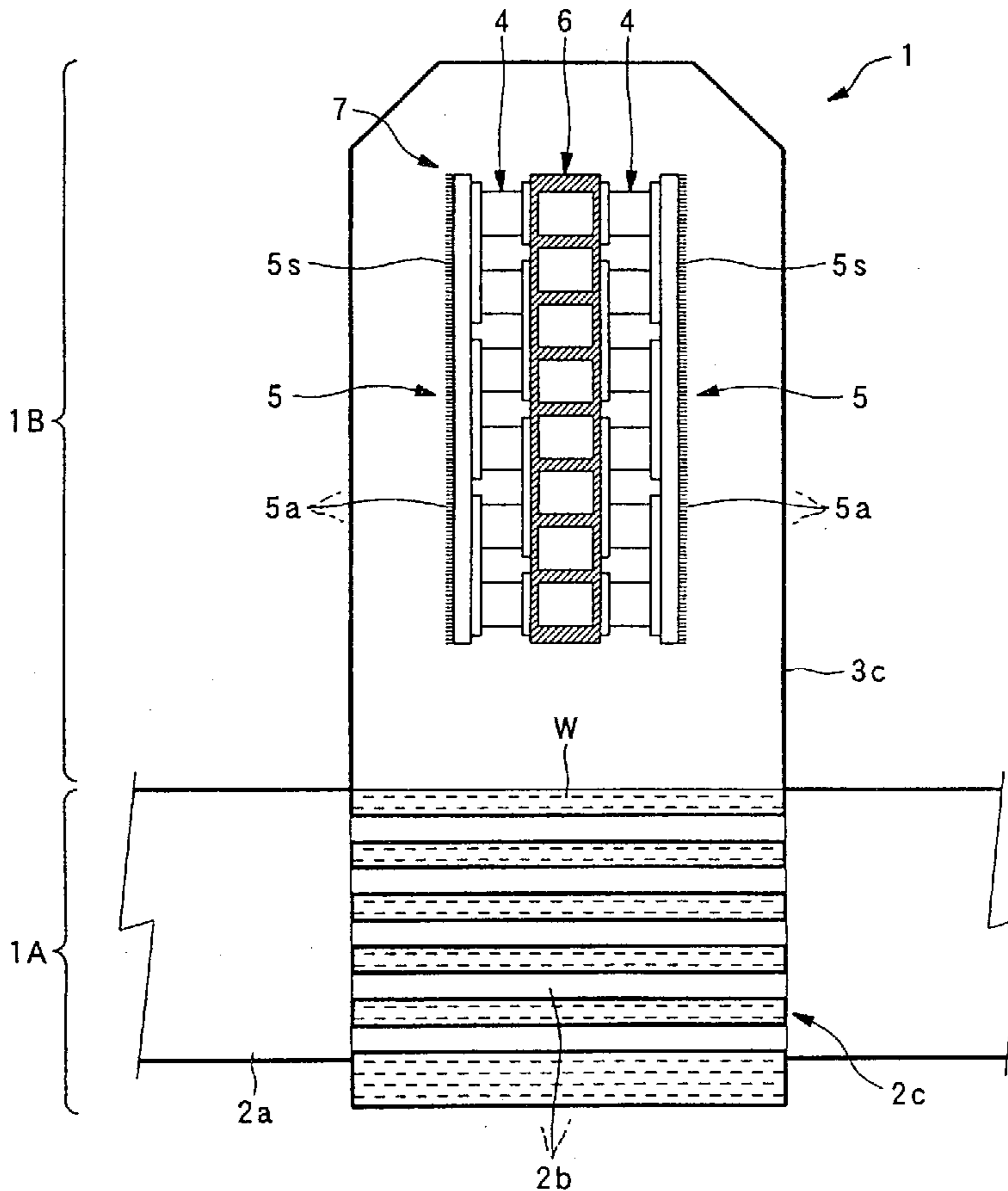
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(30) **Foreign Application Priority Data**

Nov. 16, 2001 (JP) 2001-351720

In a thermoelectric power generation module (7) serving as a heat exchanger, a large number of protrusions (5a) at least the surface of which is made of a material with low wettability are formed with a height and width of less than 0.01 mm and arranged with a pitch of less than 0.01 mm on the heat transfer surface (5s) of a heat transfer plate 5, thereby to increase in heat exchange efficiency.



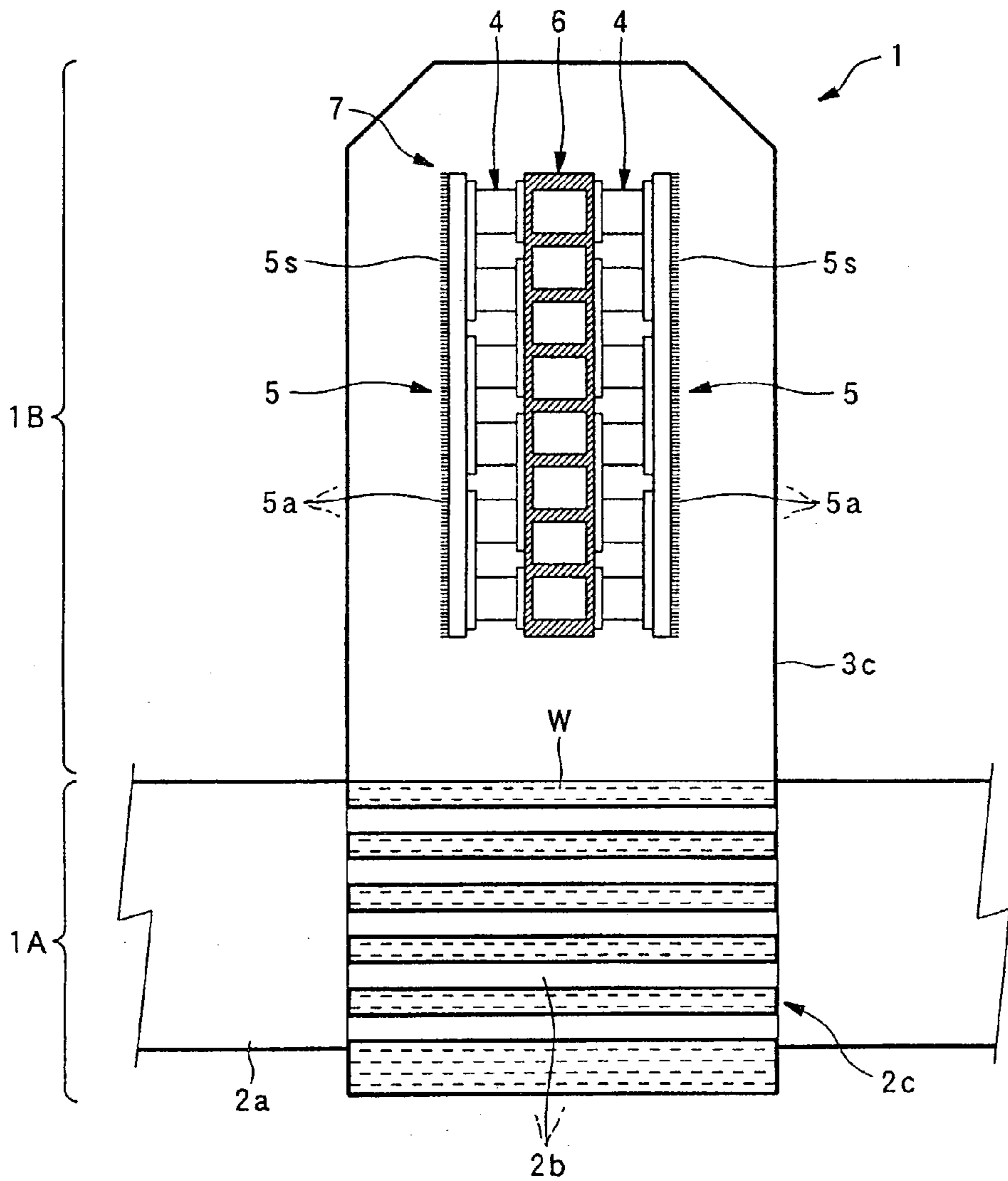


FIG. 1

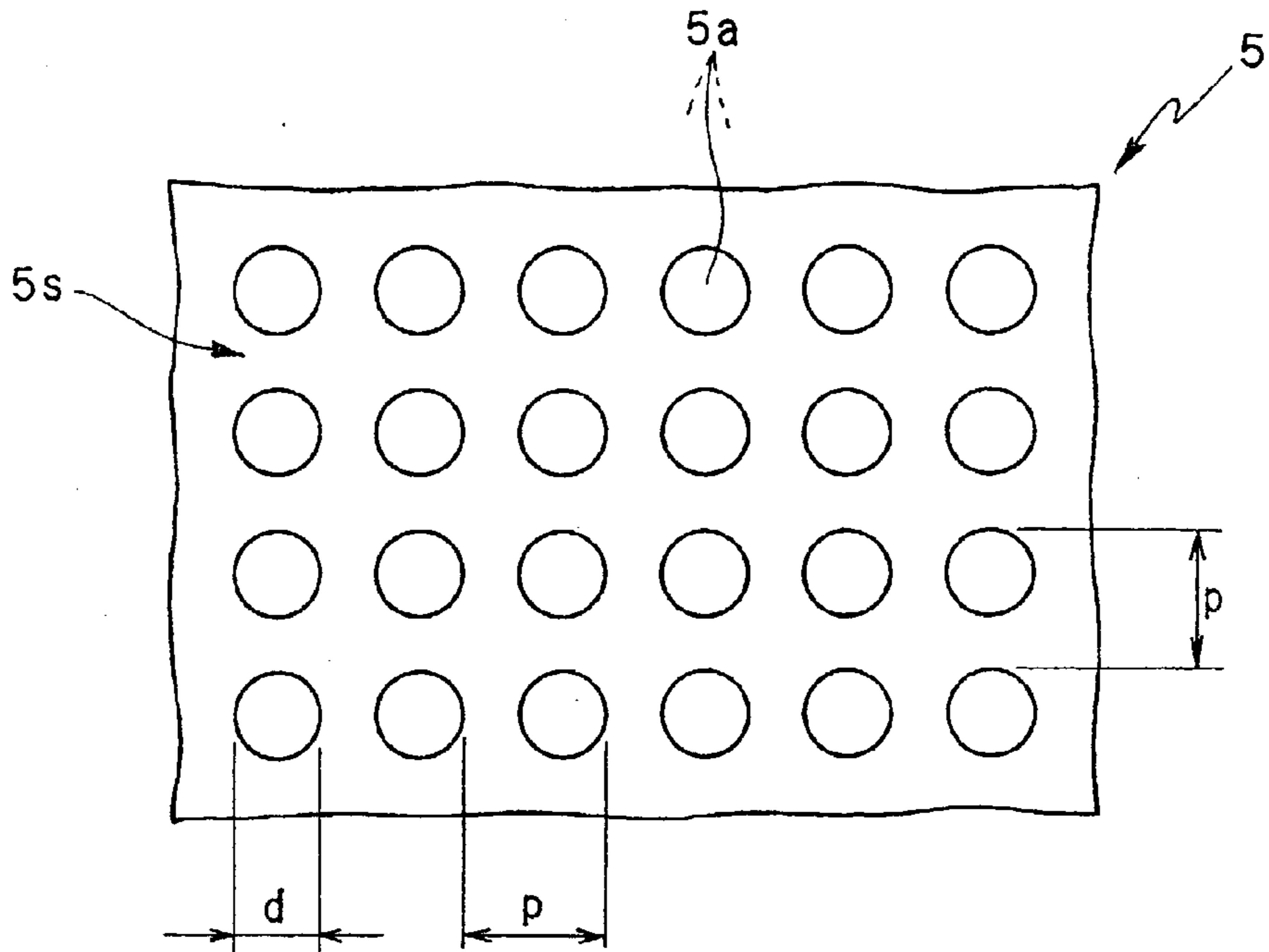


FIG. 2A

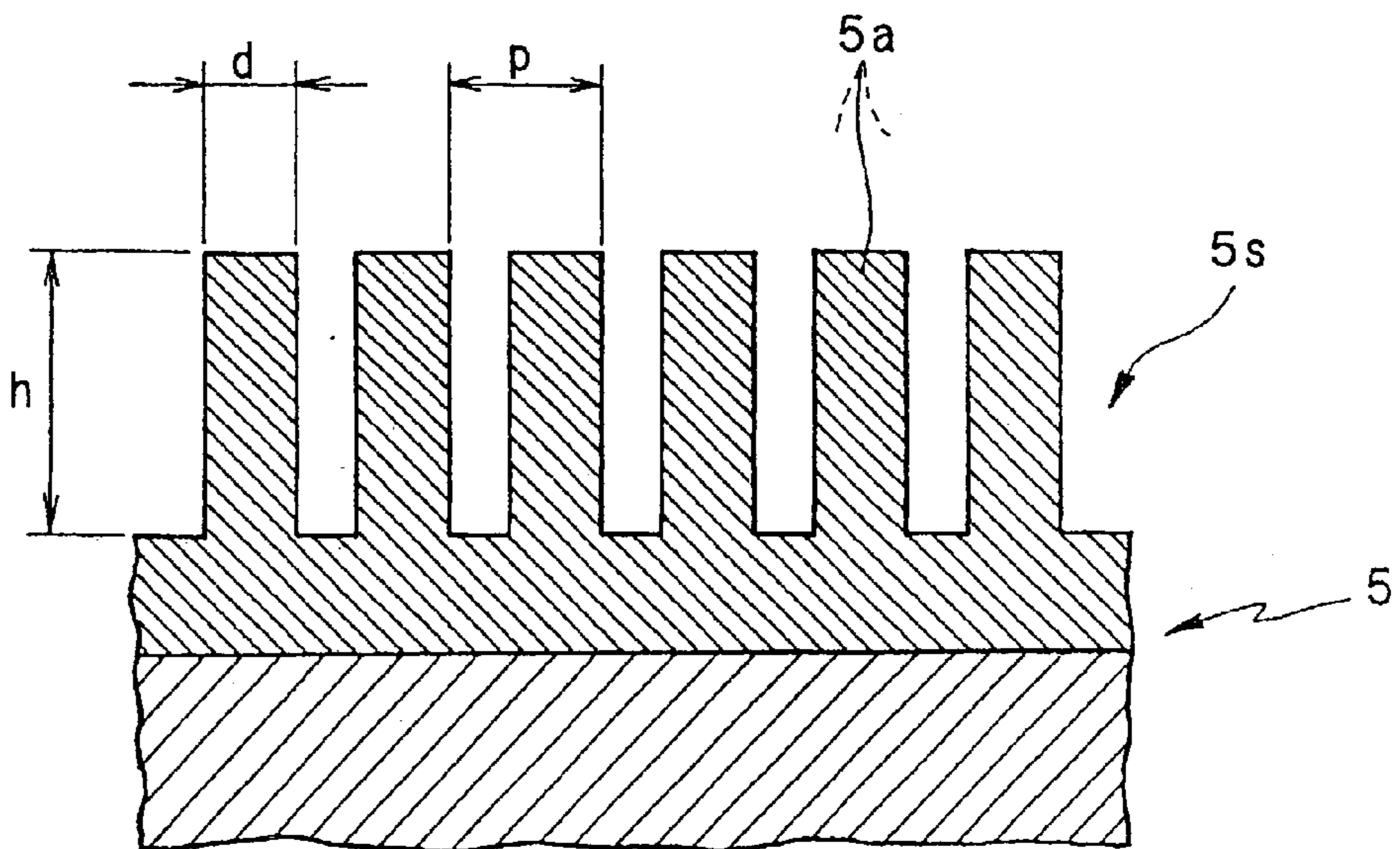


FIG. 2B

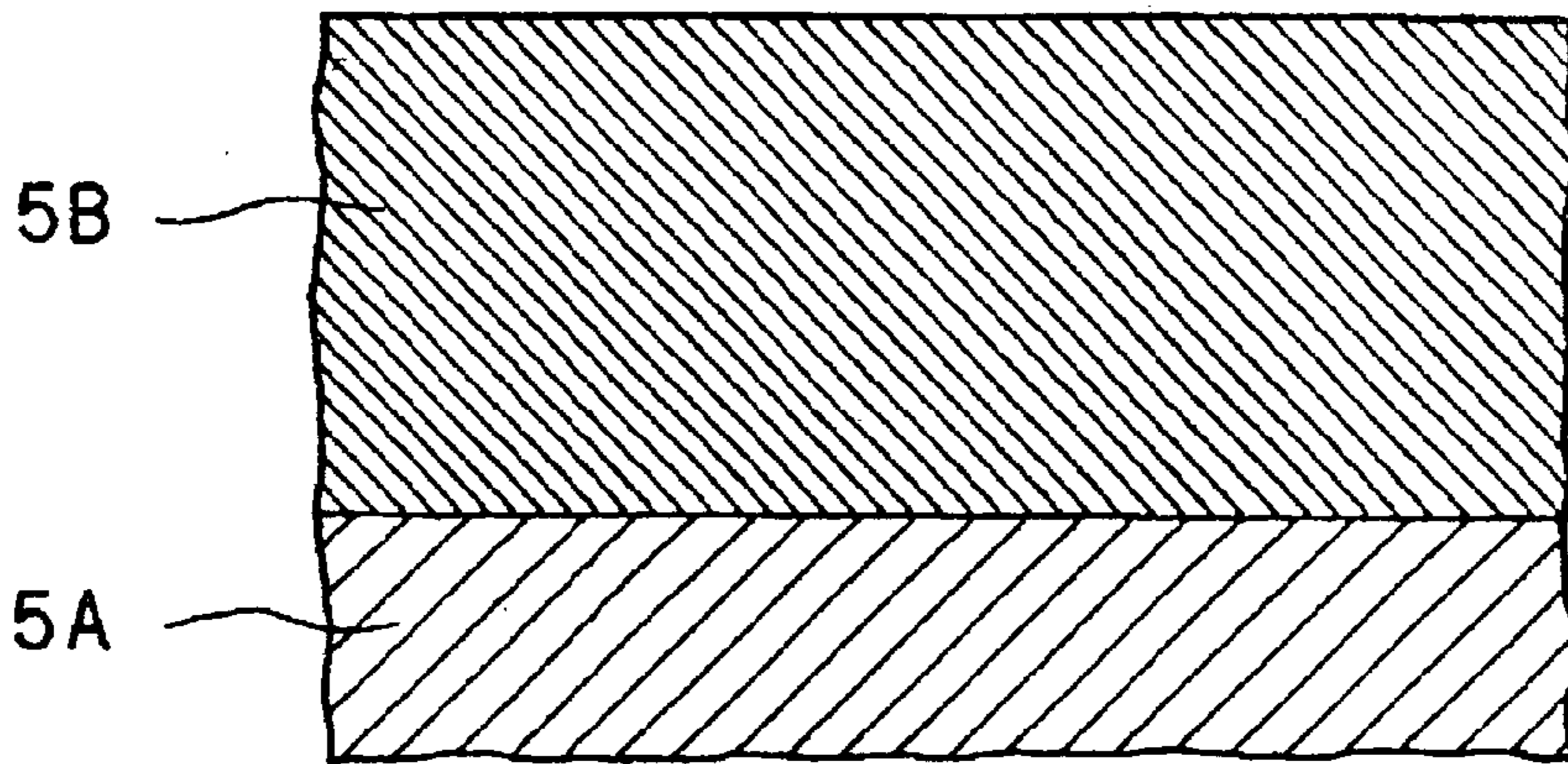


FIG. 3A

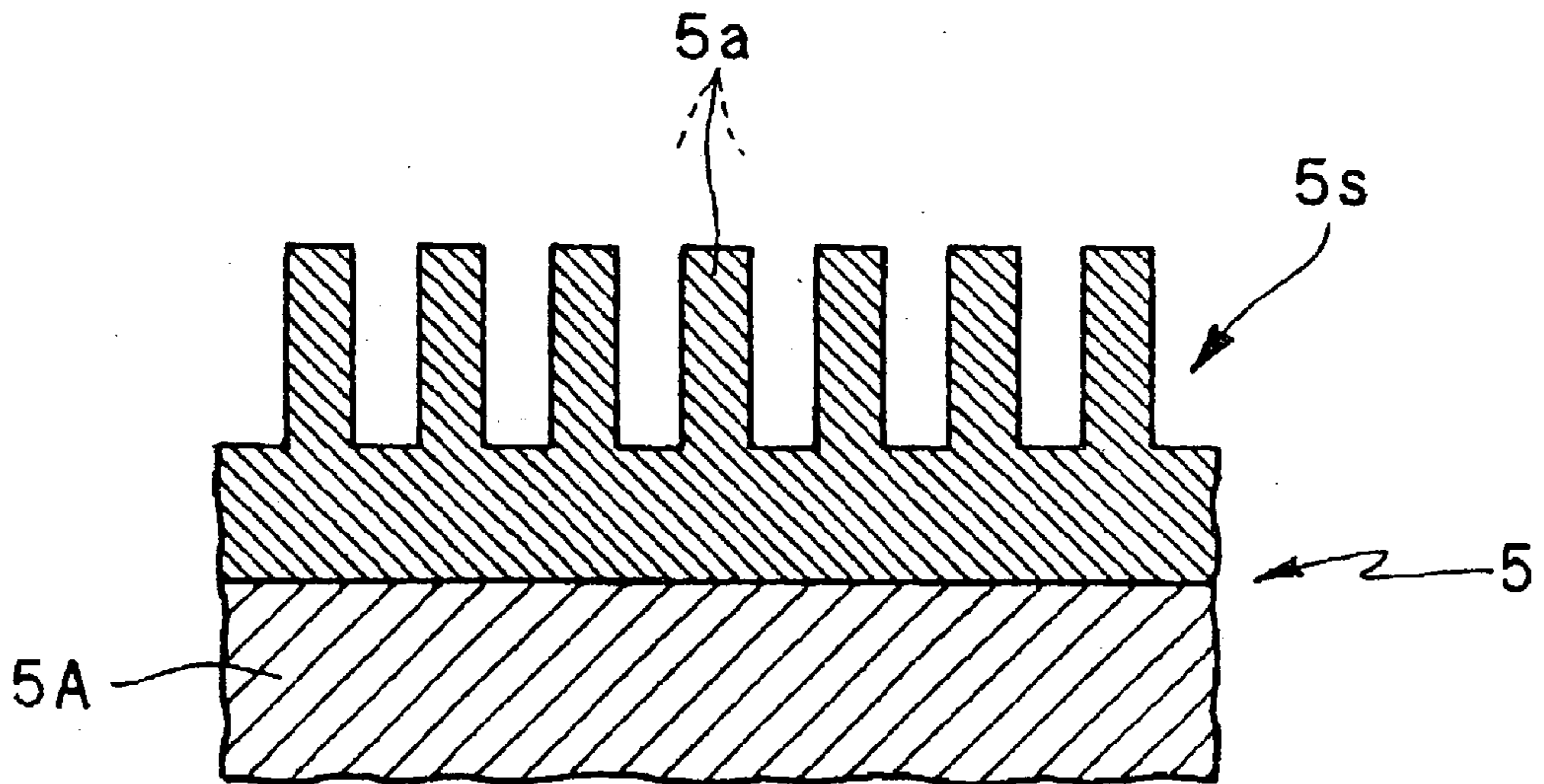


FIG. 3B

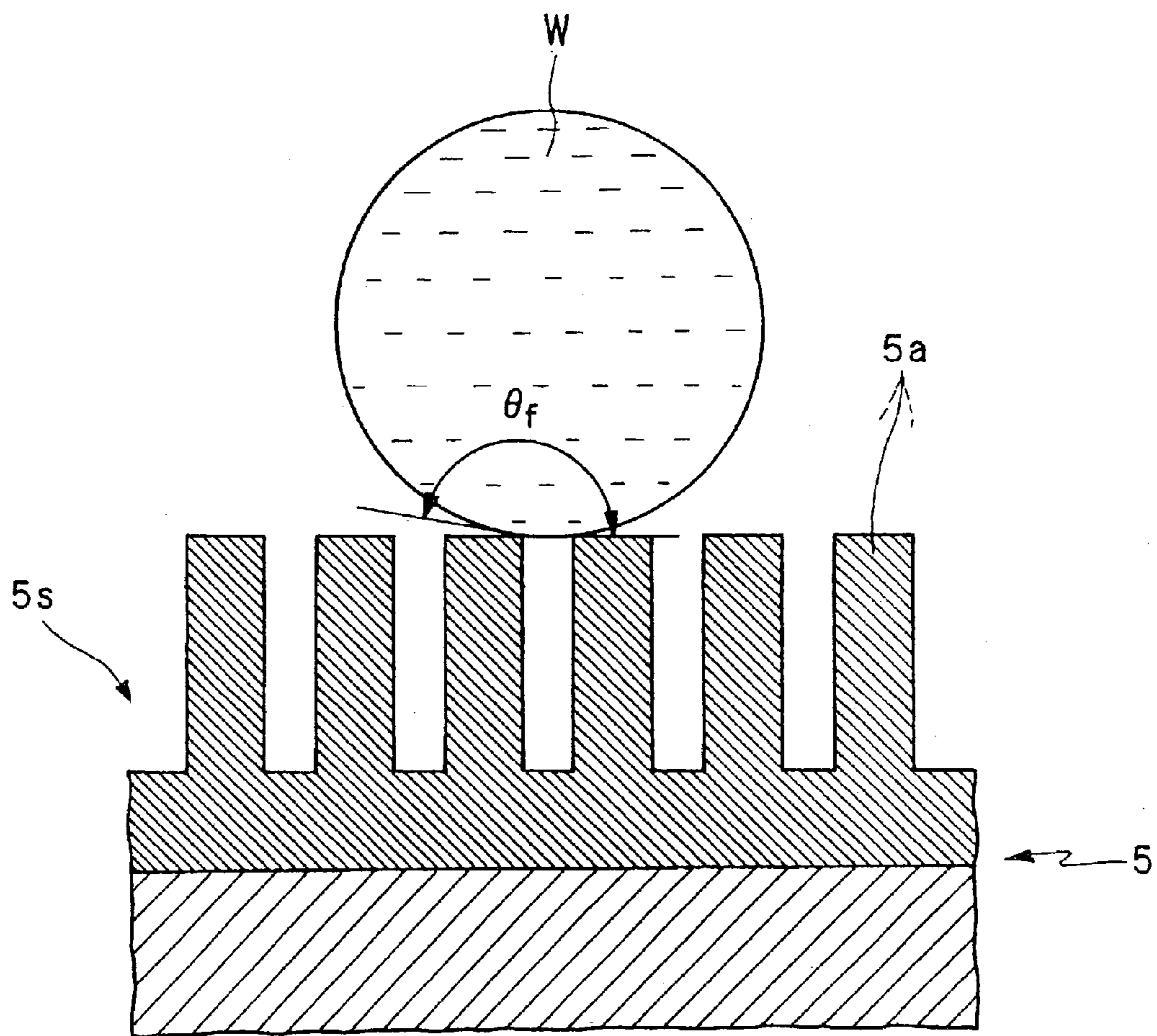


FIG. 4

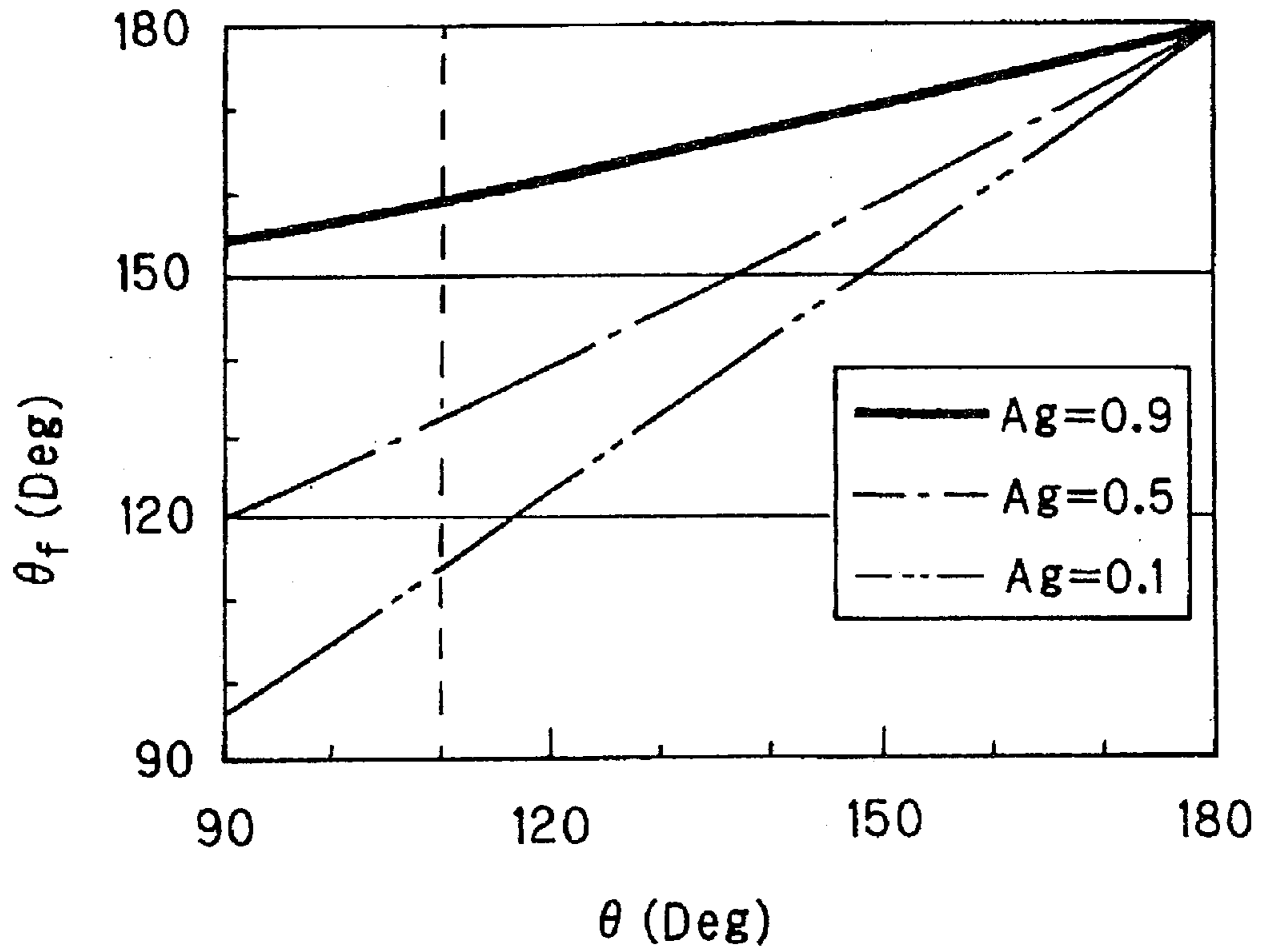


FIG. 5

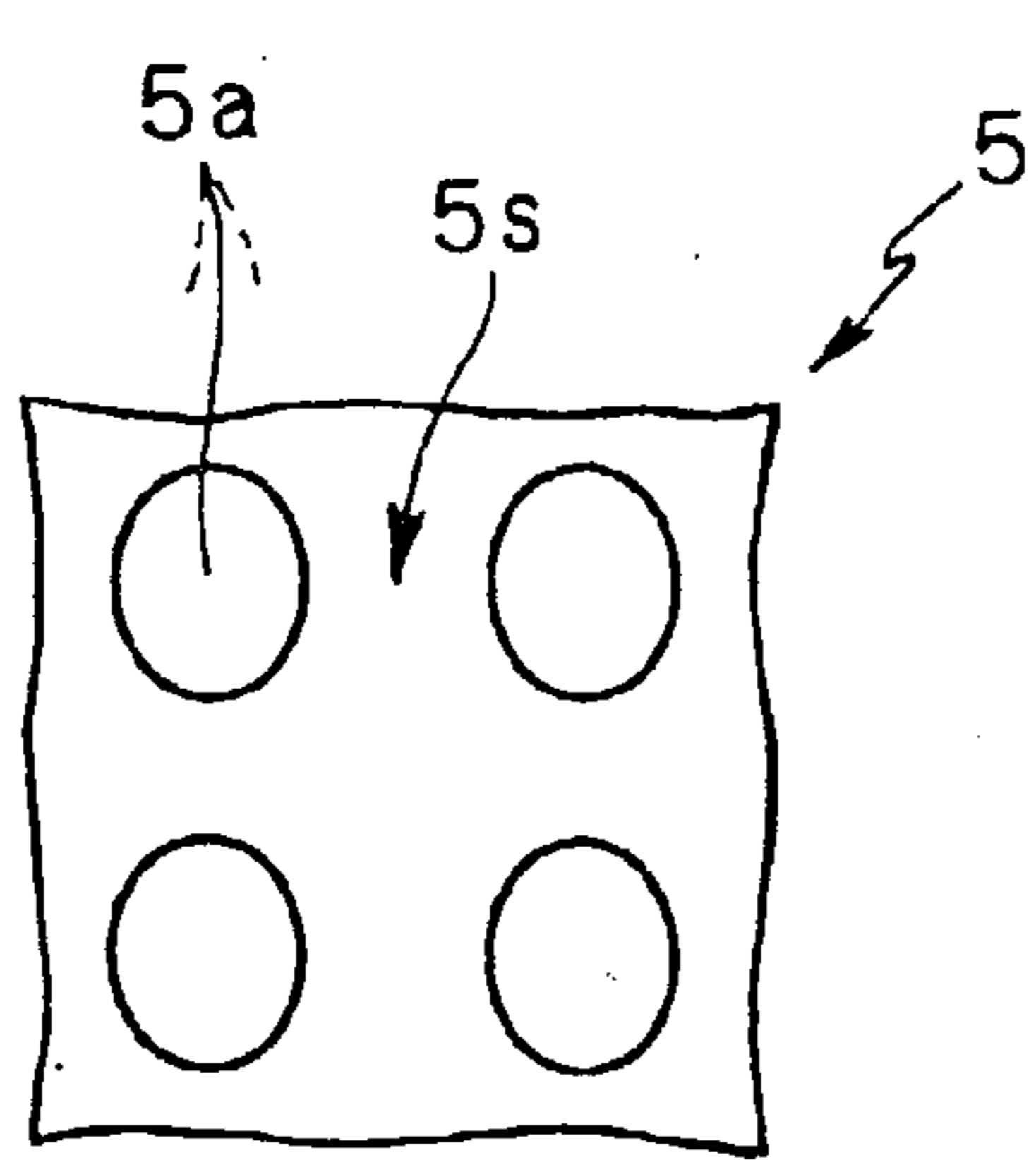


FIG. 6A

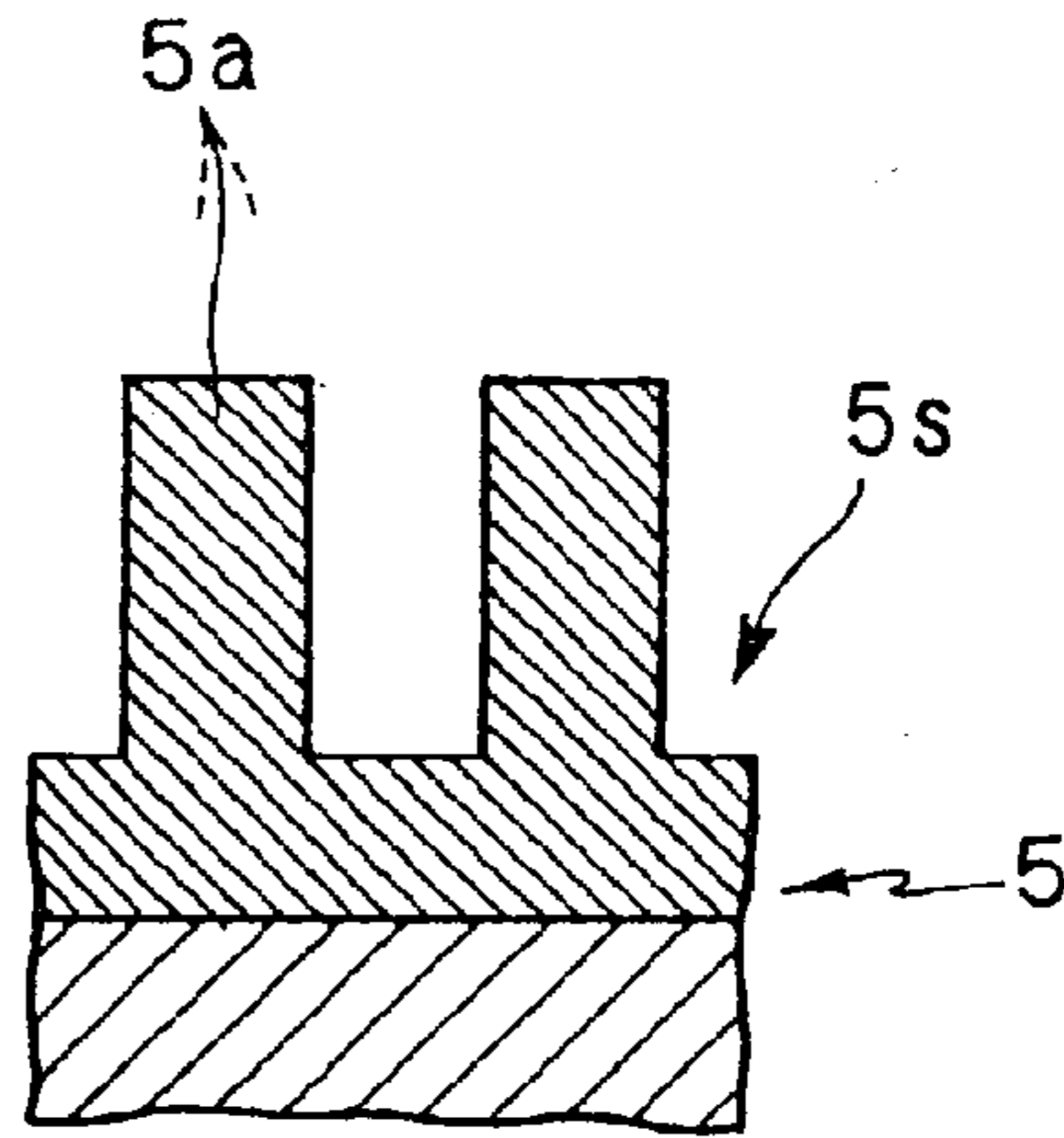


FIG. 6B

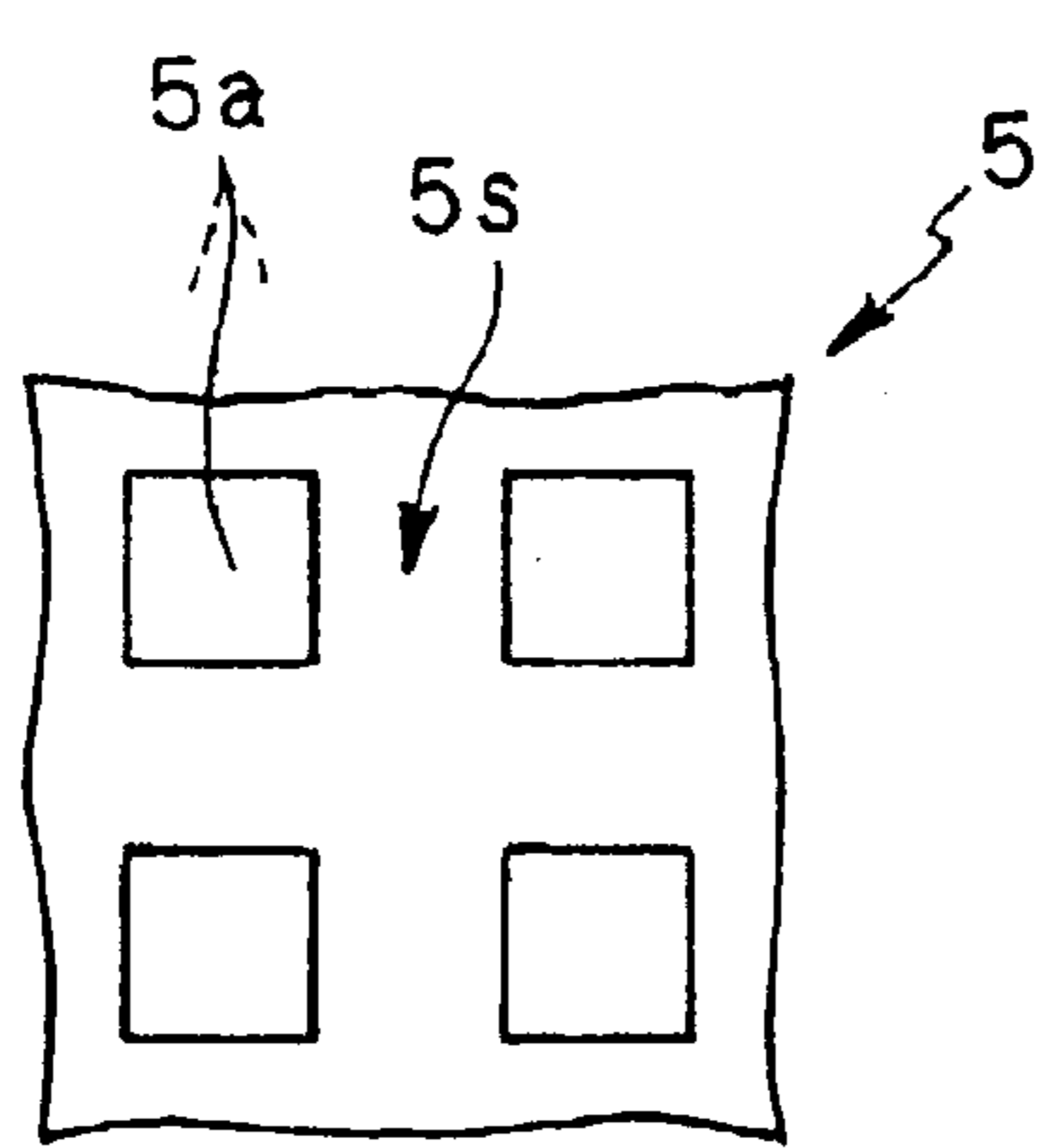


FIG. 7A

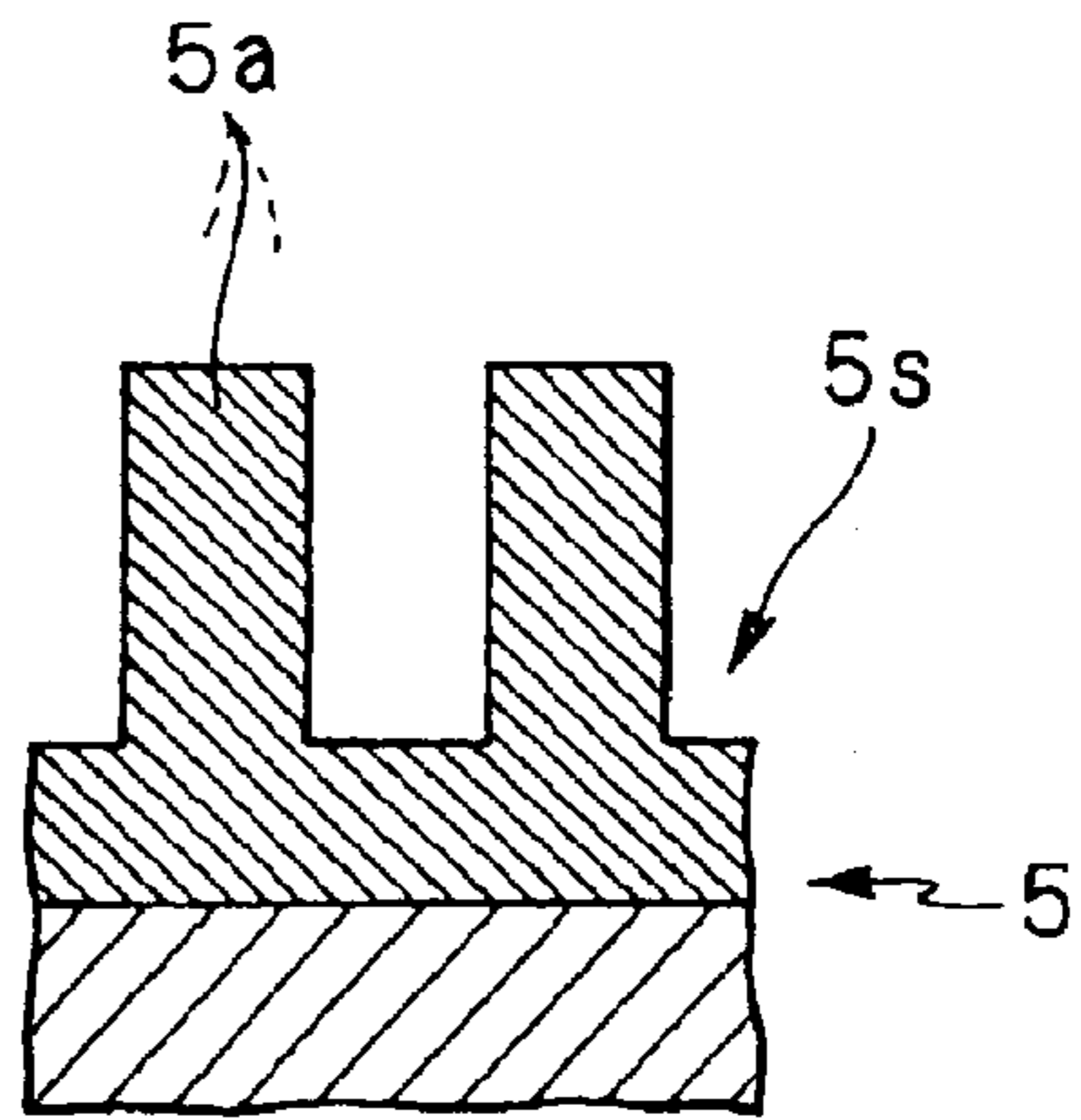


FIG. 7B

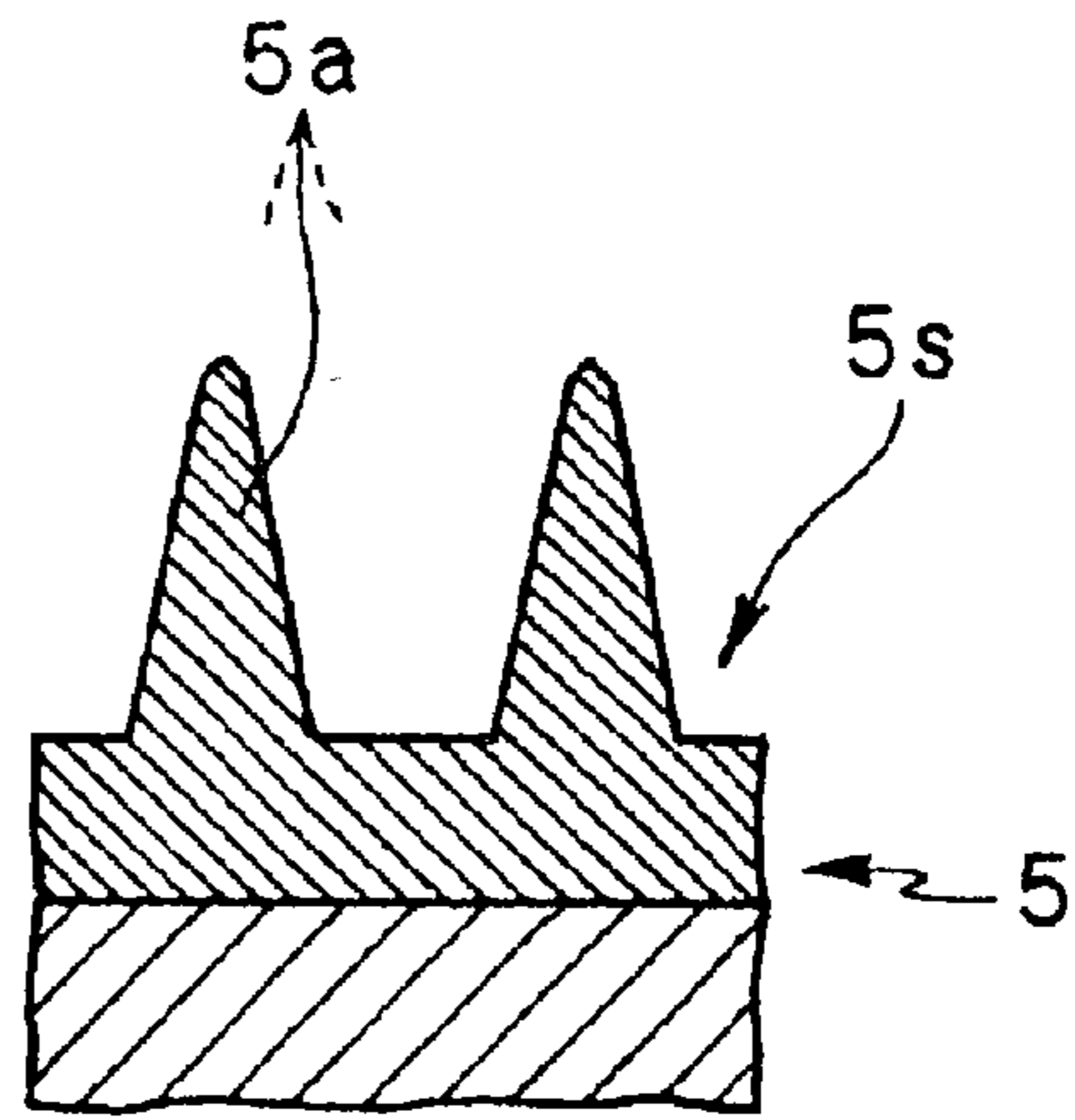
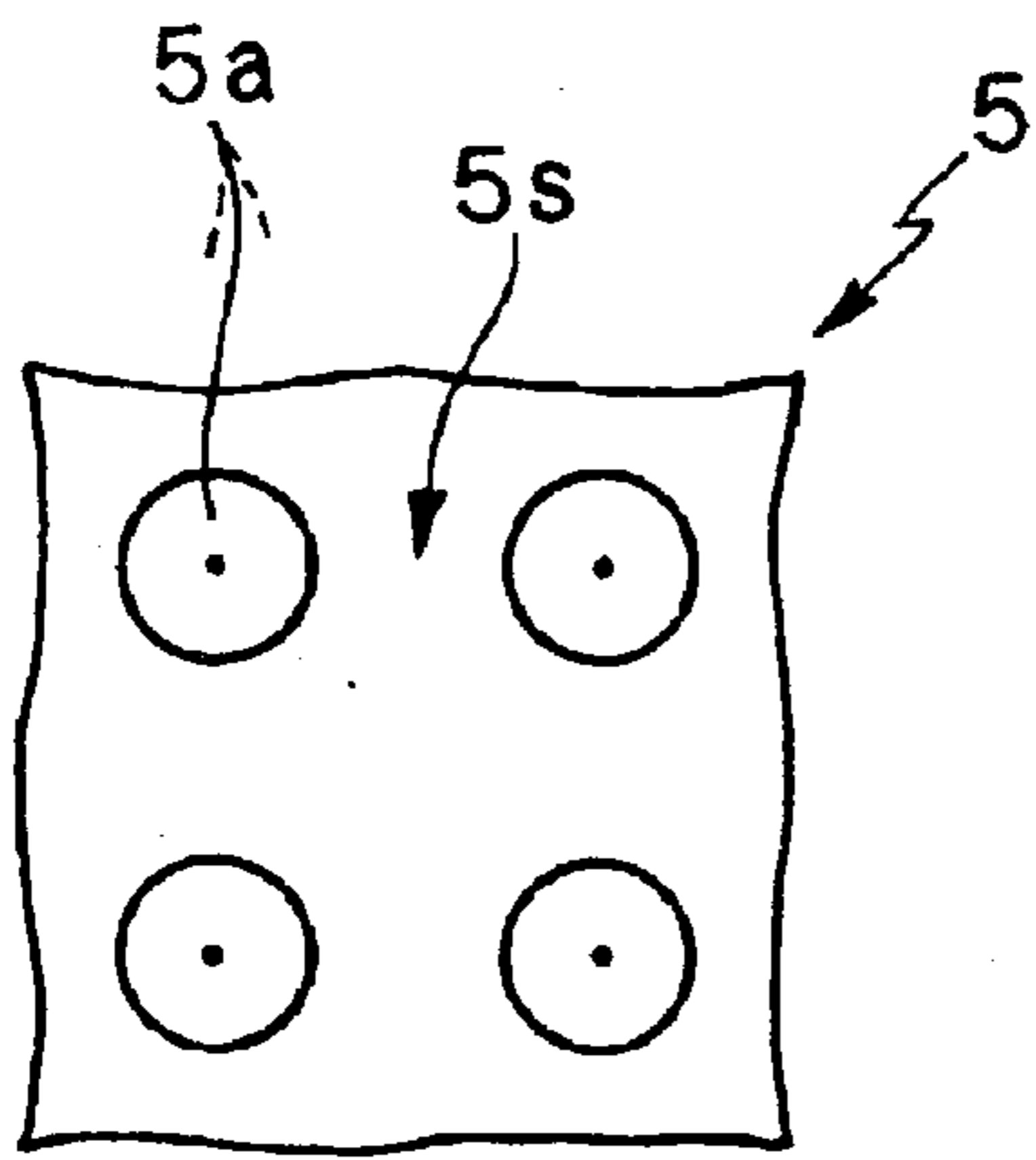


FIG. 8A

FIG. 8B

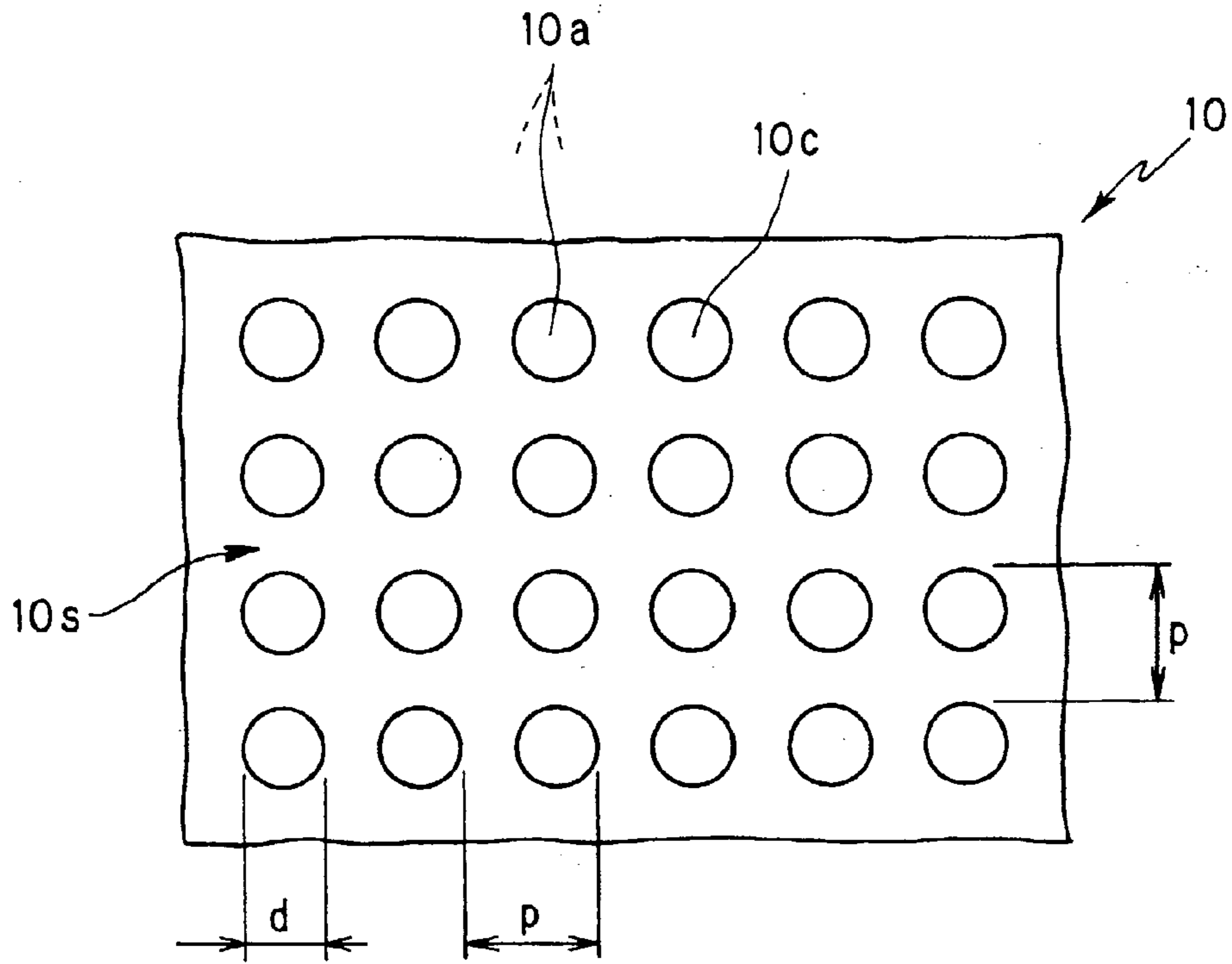


FIG. 9A

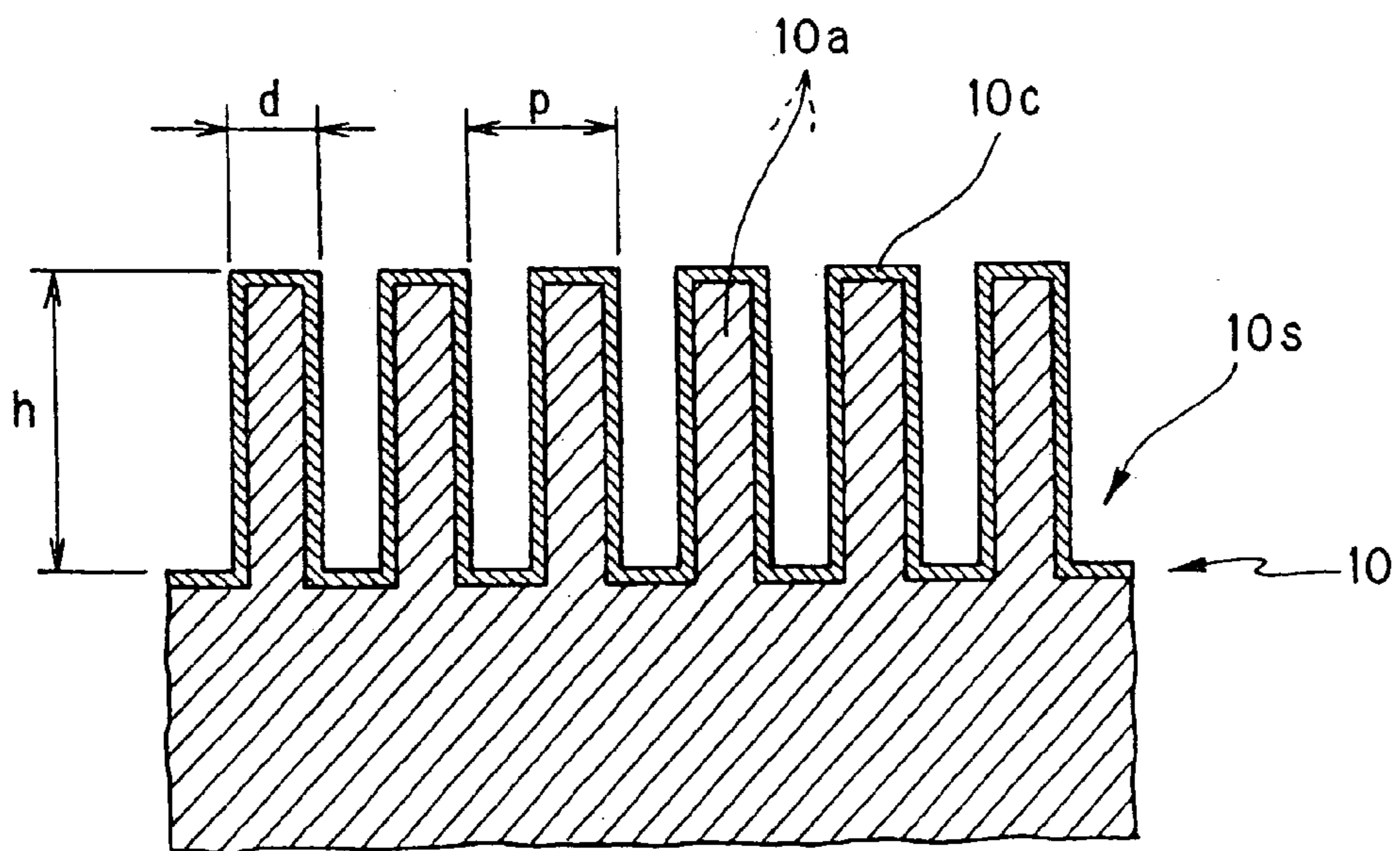


FIG. 9B

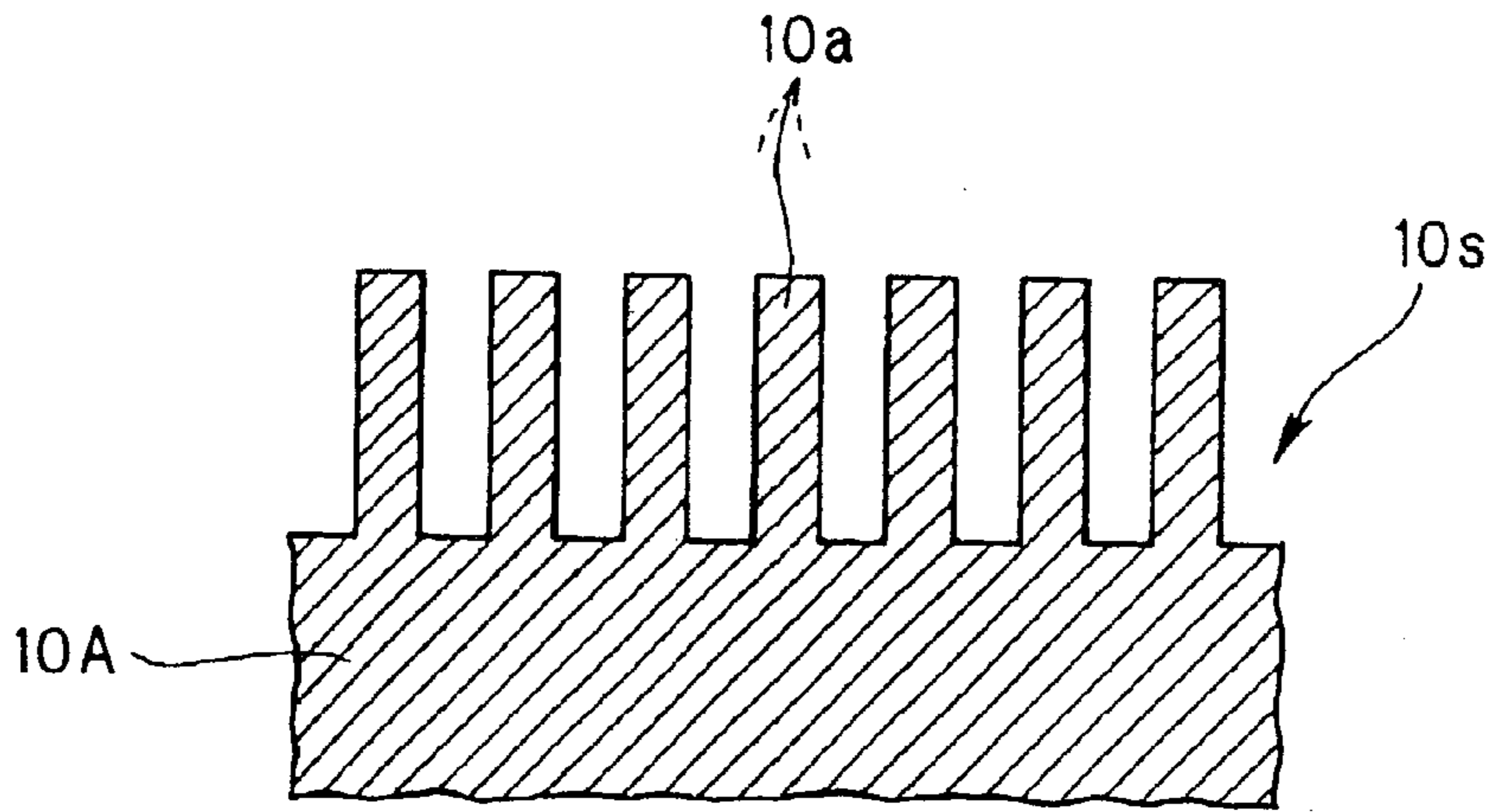


FIG. 10A

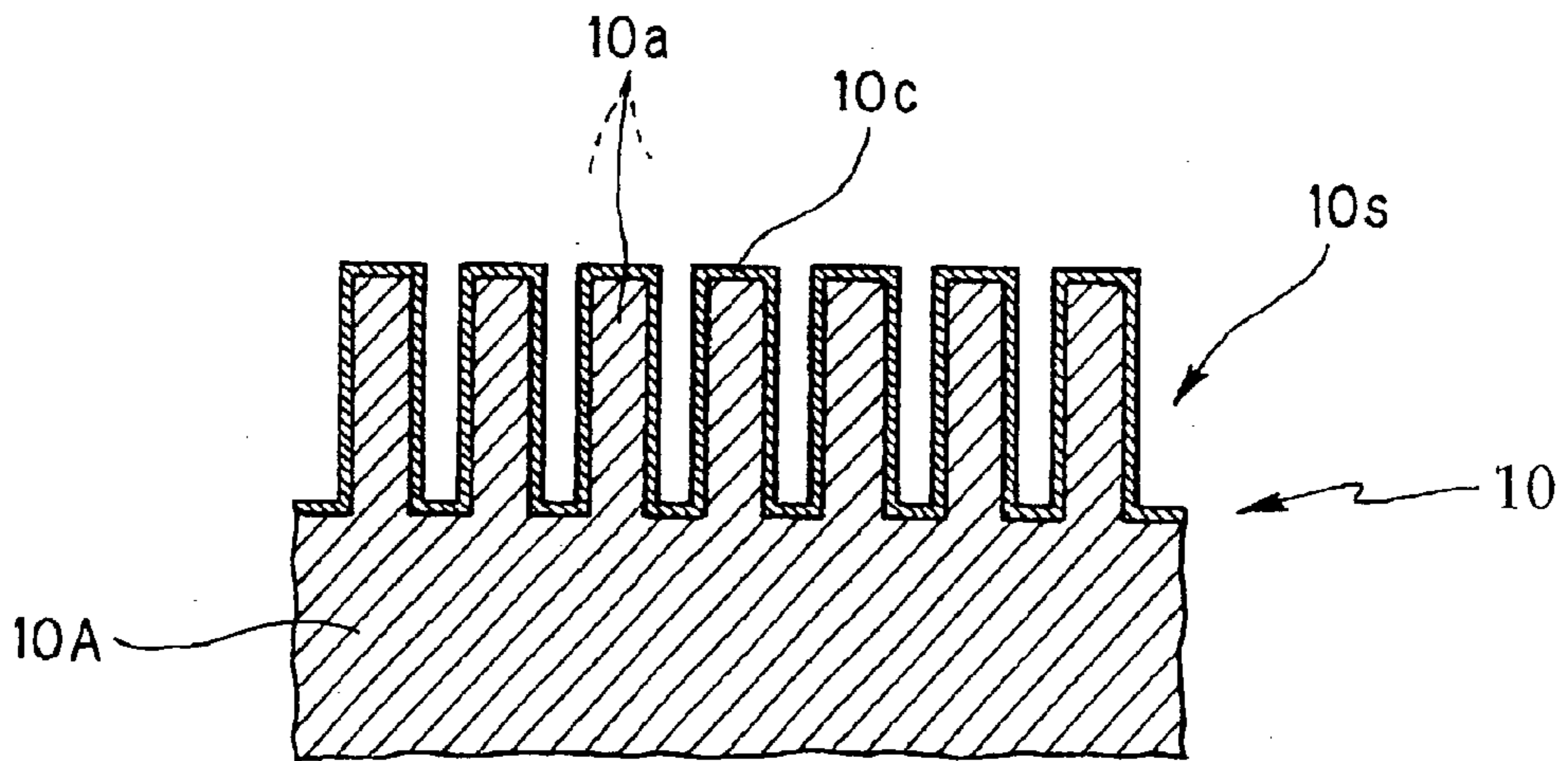


FIG. 10B

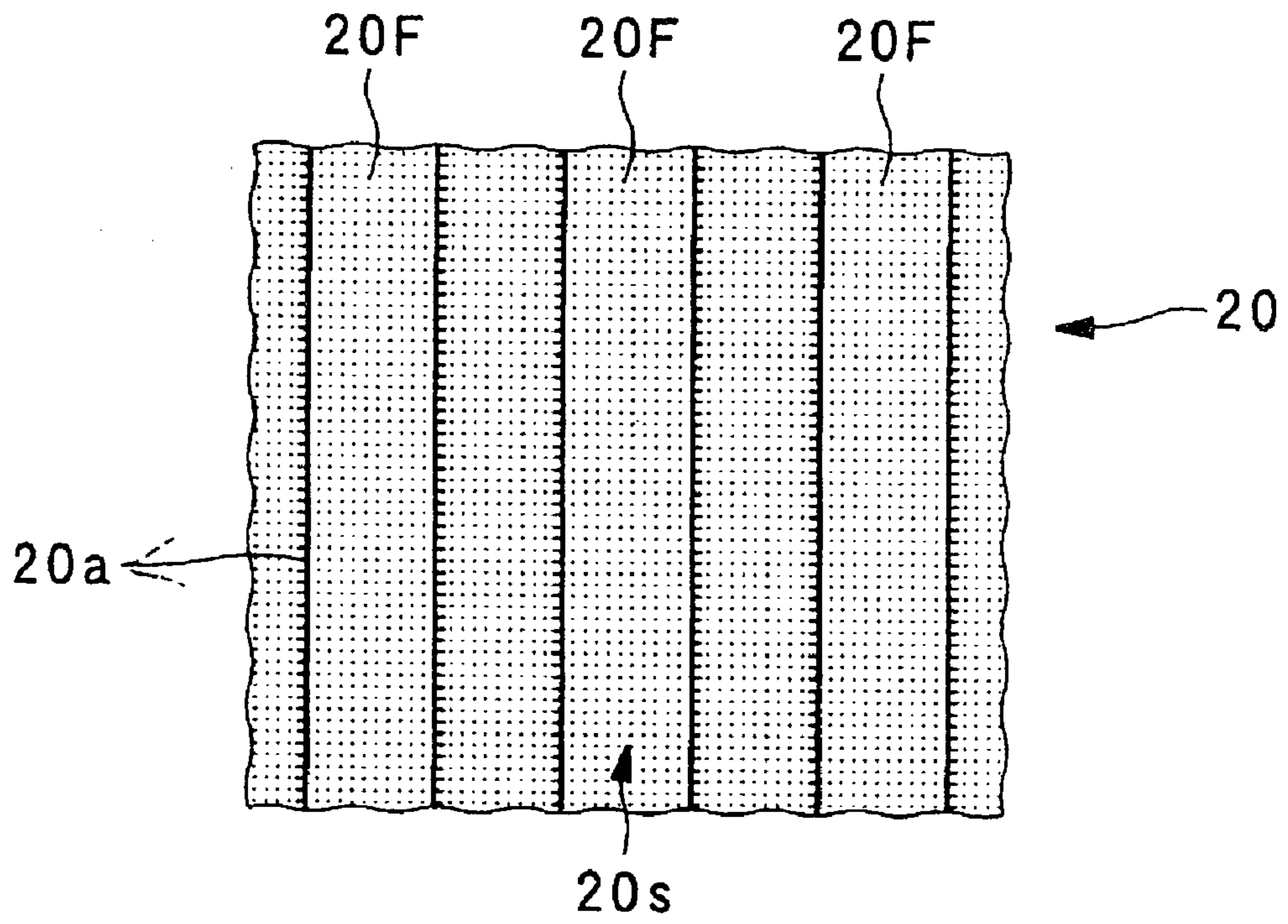


FIG. 11A

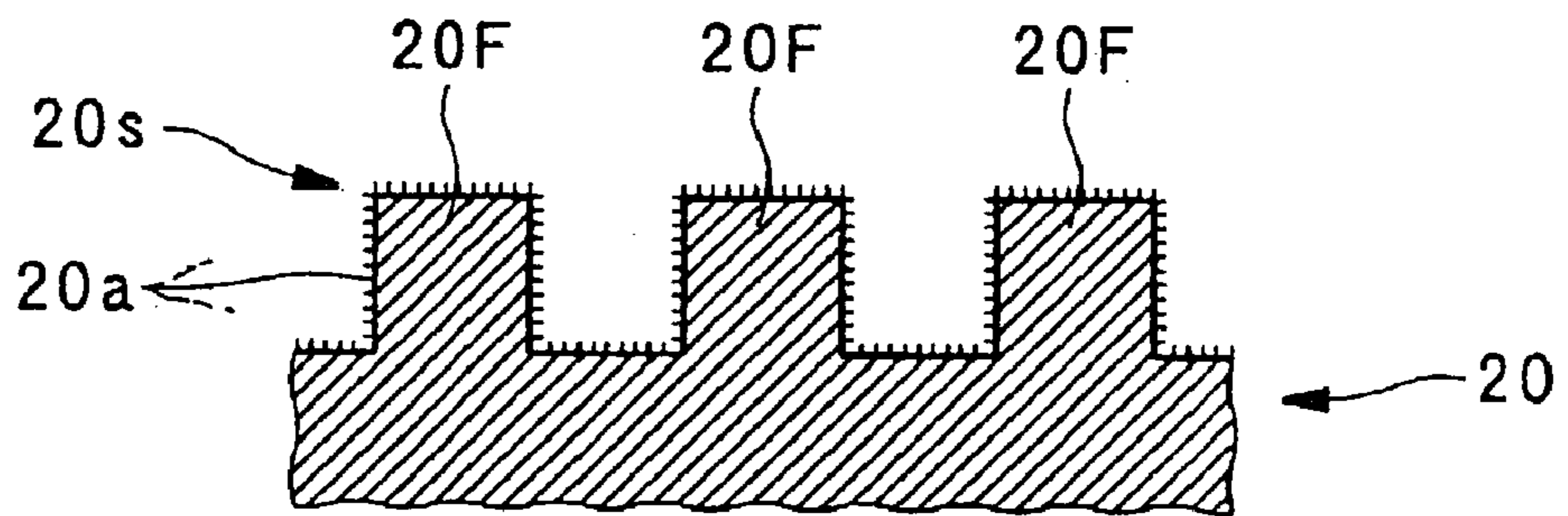


FIG. 11B

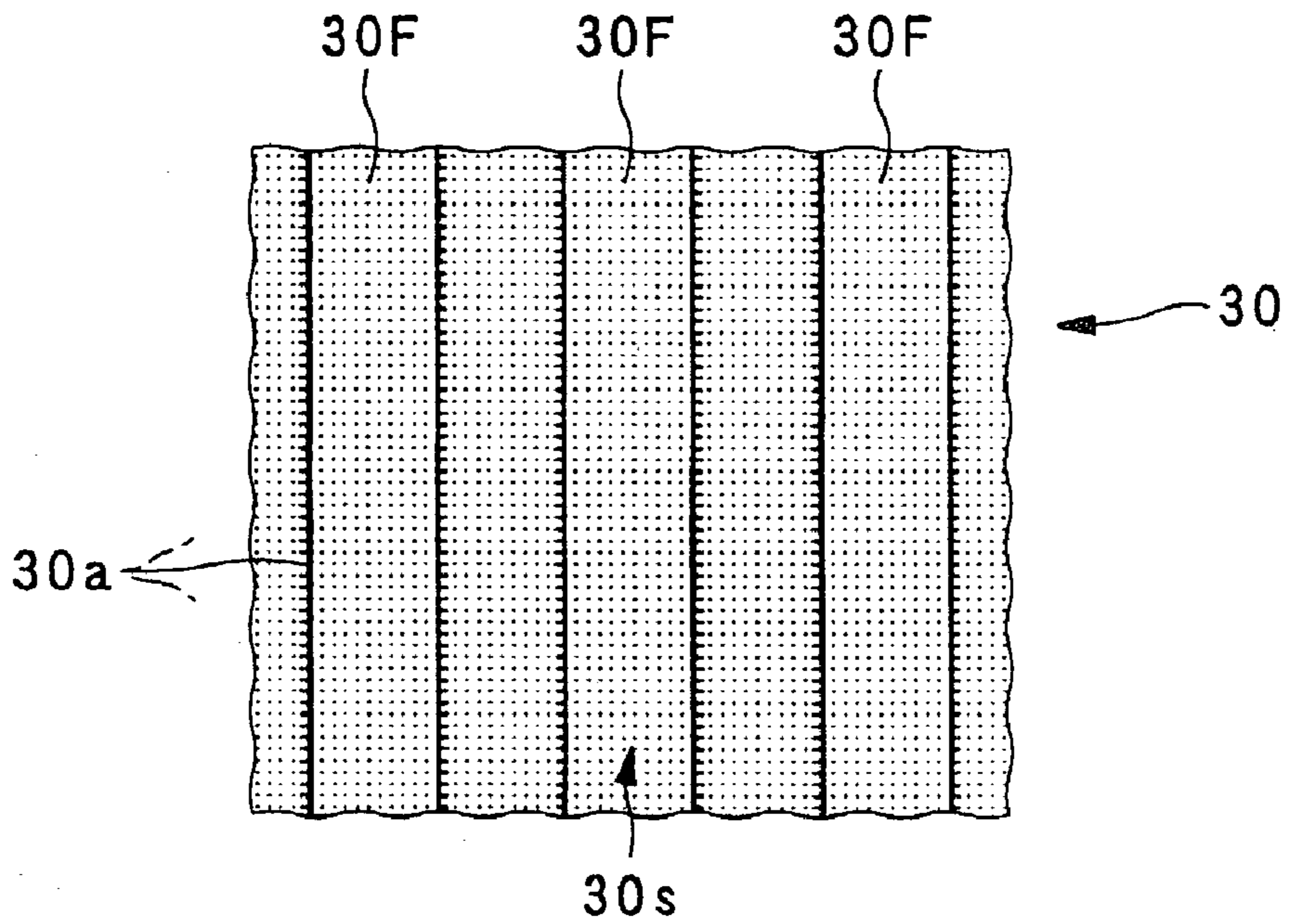


FIG. 12A

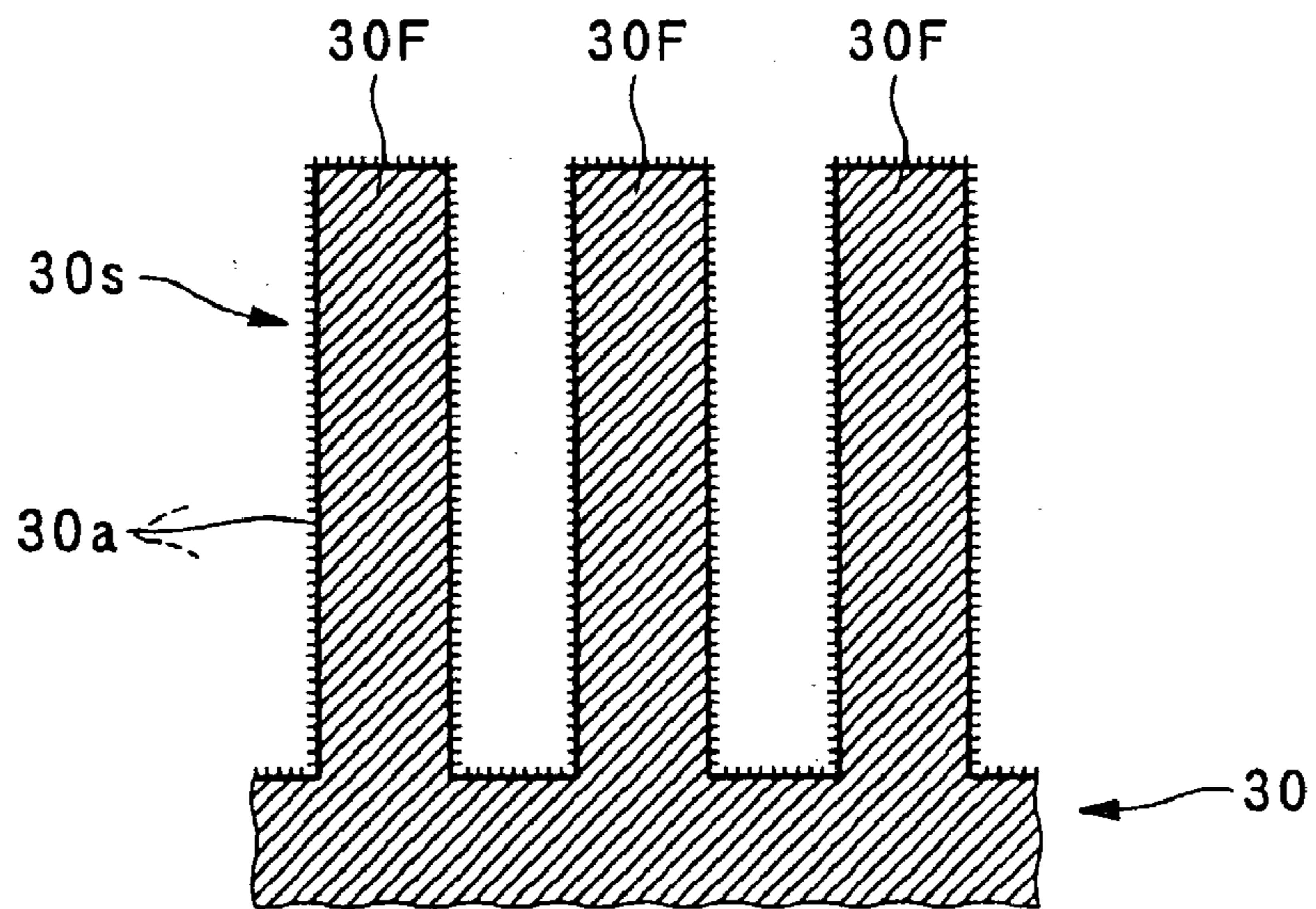


FIG. 12B

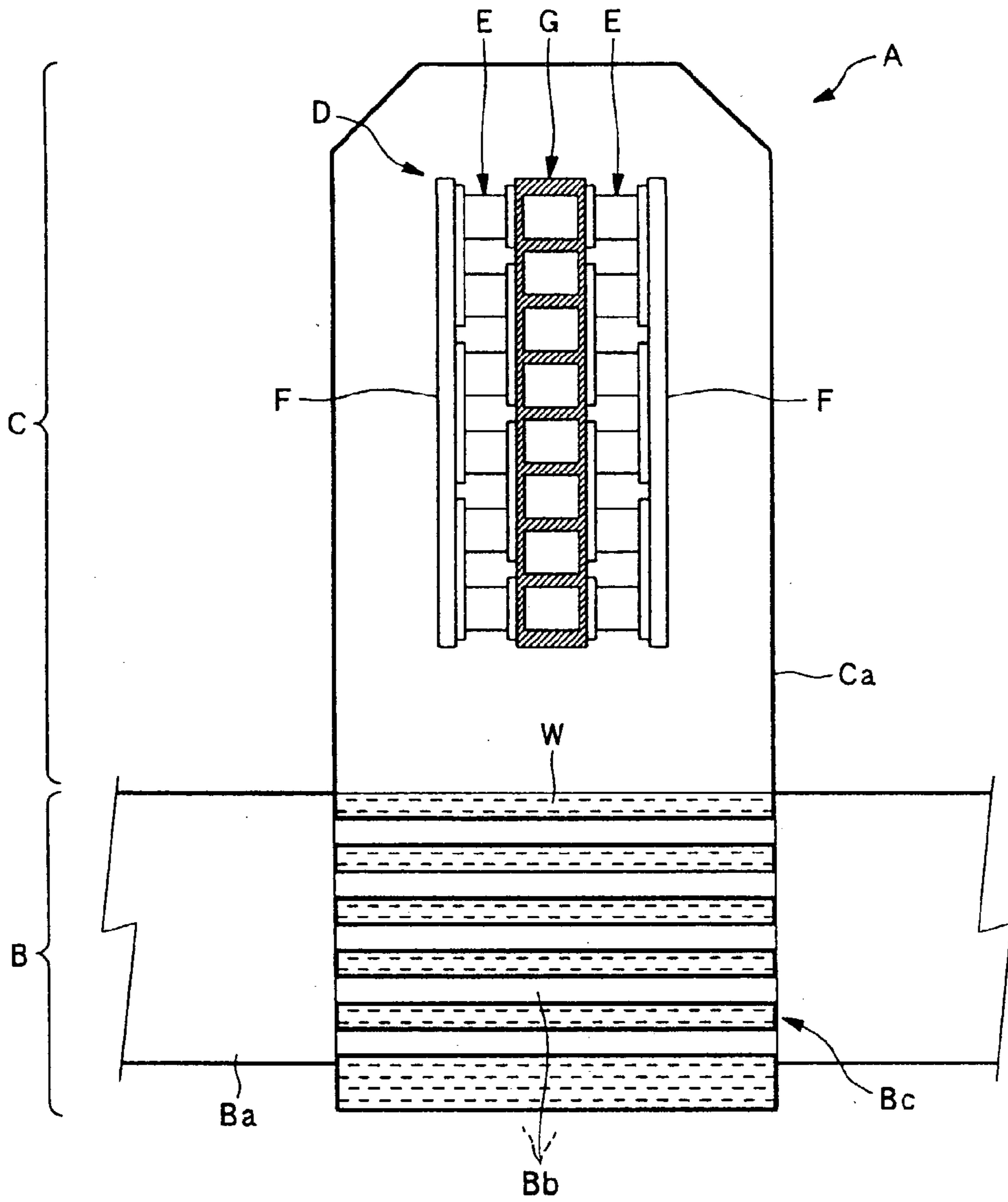


FIG. 13
(PRIOR ART)

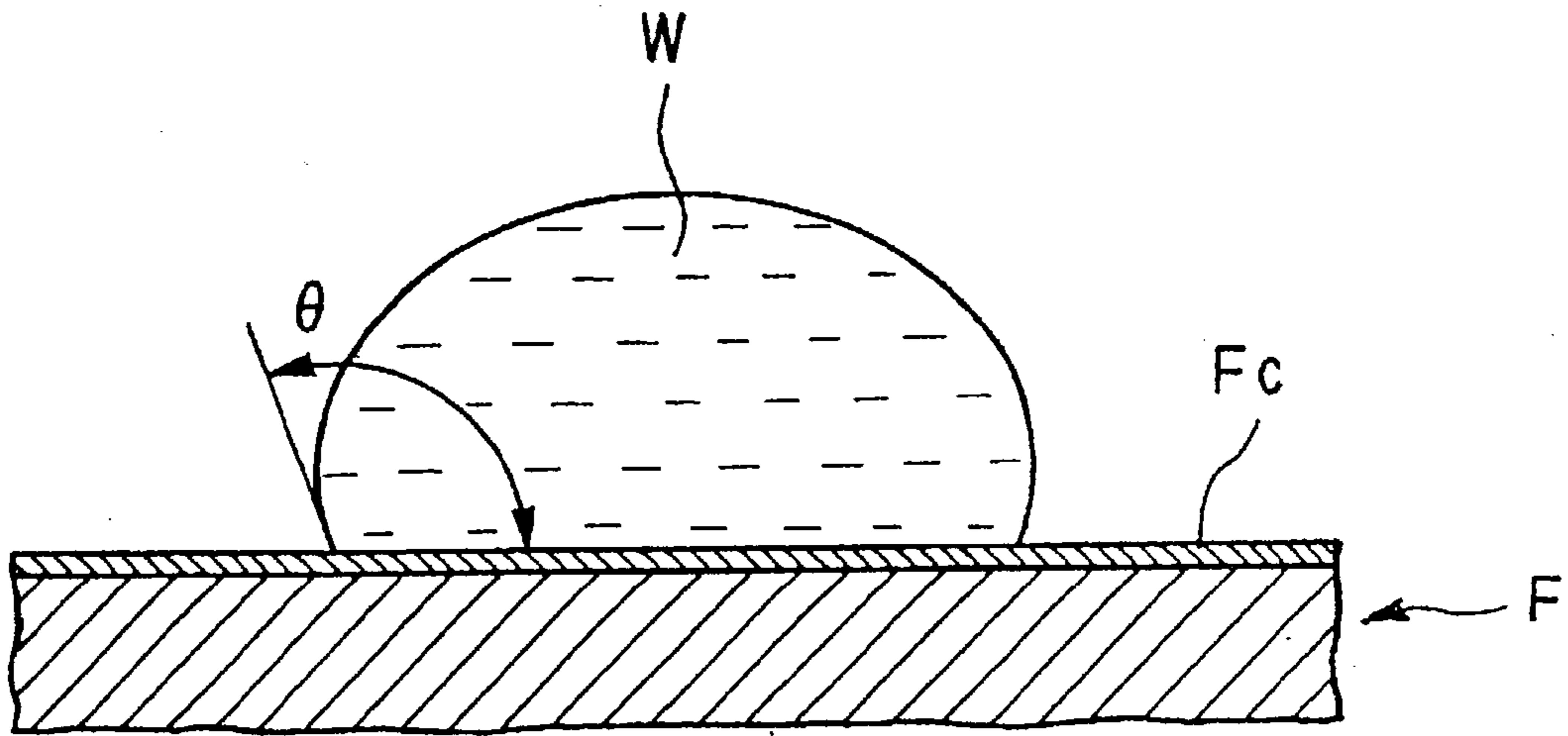


FIG. 14
(PRIOR ART)

HEAT EXCHANGER

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application is based on and claims the benefit of priority from the prior Japanese patent application No. 2001-351720 filed on Nov. 16, 2001; the entire contents of the prior application being incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present invention relates to a heat exchanger for conducting heat exchange via a heat transfer member, and more specifically, to the configuration of the heat transfer surface in the heat transfer member of the heat exchanger.

[0004] 2. Description of the Related Art

[0005] Thermoelectric power generation apparatus A of a thermo-siphon type shown in FIG. 13, for example, comprises an evaporation unit B in which heat transfer tubes Bb are heated with high-temperature fluid flowing through a duct Ba and vapor is generated by heating a heat medium W stored in a storage unit Bc, and a thermoelectric converter C accommodating a thermoelectric power generation module D comprising a thermoelectric module E, a heat transfer plate (heat-transfer member) F and a water-cooled plate G in a chamber Ca linked to the evaporation unit B.

[0006] Here, the thermoelectric power generation module D is a heat exchanger in the broad sense of the word. In the module D, heat transfer plate F and water-cooled plate G are provided on the high-temperature and low-temperature sides of thermoelectric module E, respectively. When vapor of heat medium W generated in evaporation unit B condenses upon contact with the surface (heat transfer surface) of heat transfer plate F, heat is radiated and the high-temperature side of thermoelectric module E is heated. As a result, power is generated by the operation of a P-type/N-type semiconductor constituting thermoelectric module E, based on the temperature difference between the high-temperature side and low-temperature side of thermoelectric module E that is cooled by water-cooled plate G.

[0007] It is well known that, in the heat transfer with condensation, the heat exchange efficiency of drop condensation is higher than that of film-shaped condensation. For this reason, a coating film Fc made of a material with a very low wettability, that is, a material having no affinity to condensate, such as polyfluoroethylene resin (such as Teflon: trademark), is coated on the surface (heat transfer surface) of heat transfer plate F thereby causing condensate W brought in contact with heat transfer plate F to form drops, as shown in FIG. 14.

[0008] On the other hand, in a heat exchanger in which the temperature of the heat transfer surface of a heat transfer plate is no higher than 0° C., such as a heat exchanger for use in a refrigerator and the like (not shown in the figure), with the object of preventing as much as possible the decrease in heat exchange efficiency due to frost, which originates due to condensation and solidification of water molecules present in the air, a coating film made of a material with low wettability is formed on the heat transfer surface of the heat

transfer plate, as in the above-described thermoelectric power generation module D. With this construction, water that has initially condensed upon contact with the heat transfer plate is caused to form drops, thus weakening the frost base of the frost layer and facilitating peeling of the frost from the heat transfer surface of heat transfer plate.

[0009] However, in the structure in which a coating film Fc with low wettability was formed on the flat surface of heat transfer plate F, as in the above-described thermoelectric power generation module (heat exchanger) D as shown in FIG. 14, a contact angle θ of heat medium (condensate) W, which has assumed a drop-like shape, with respect to the heat transfer plate F (coating film Fc) was about 110° at most.

[0010] For this reason, the surface (heat transfer surface) of heat transfer plate F was far from the ideal drop condensation surface and was not sufficient from the standpoint of heat transfer efficiency. Accordingly, in heat exchangers, more significant increase in heat transfer efficiency was desired.

[0011] Further, in heat exchangers for use in cooling apparatuses, even in structures in which a coating film with low wettability was formed on the flat surface (heat transfer surface) of heat transfer plate, the contact angle between condensed water drops and heat transfer plate (coating film) was about 110° at most.

[0012] Therefore, wettability on the surface (heat transfer surface) of heat transfer plate was not sufficiently low, and peeling of the frost from the surface (heat transfer surface) of heat transfer plate, thereby causing significant decrease in heat exchange efficiency.

SUMMARY OF THE INVENTION

[0013] With the foregoing in view, it is an object of the present invention to provide a heat exchanger which makes it possible to attain further increase in heat exchange efficiency.

[0014] According to the present invention, in a heat exchanger for conducting heat exchange via a heat transfer member, the heat transfer member has a heat transfer surface on which a large number of protrusions each having a height and a width of less than 0.01 mm, respectively, are disposed with a pitch of less than 0.01 mm, at least surface of the protrusions being made of a material with low wettability.

[0015] With such a configuration as above, the heat transfer surface of the heat transfer member has very low wettability with an ultralow surface energy.

[0016] Therefore, the heat transfer surface of the heat transfer member that is a condensation heat transfer surface is close to the ideal drop condensation surface, which provides a good heat exchange efficiency.

[0017] Further, when the heat transfer surface of the heat transfer member is a low-temperature heat transfer surface, wettability is extremely low. Therefore, frost assumes a shape of spheres which are easy to peel so that accumulation of frost on the surface of heat transfer plate is suppressed, and hence a good heat exchange efficiency can be obtained.

[0018] Thus, with the heat exchanger in accordance with the present invention, a further increase in heat exchange efficiency can be attained.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] In the accompanying drawings:

[0020] **FIG. 1** is a schematic view illustrating an embodiment of the heat exchanger in accordance with the present invention;

[0021] **FIG. 2A** is a plan view illustrating a heat transfer member in the heat exchanger shown in **FIG. 1**;

[0022] **FIG. 2B** is a sectional side view illustrating the heat transfer member in the heat exchanger shown in **FIG. 1**;

[0023] **FIG. 3A** is a schematic view illustrating a process for manufacturing the heat transfer member in the heat exchanger shown in **FIG. 1**;

[0024] **FIG. 3B** is a schematic view illustrating a process for manufacturing the heat transfer member in the heat exchanger shown in **FIG. 1**;

[0025] **FIG. 4** is a schematic view illustrating a state in which liquid is brought in contact with the heat transfer member in the heat exchanger shown in **FIG. 1**;

[0026] **FIG. 5** illustrates how an apparent contact angle depends on the fraction of the surface area taken by air portions in the surface with fine peaks and valleys;

[0027] **FIG. 6A** is a plan view illustrating a modification of the heat transfer member in the heat exchanger shown in **FIG. 1**;

[0028] **FIG. 6B** is a cross-sectional view illustrating a modification of the heat transfer member in the heat exchanger shown in **FIG. 1**;

[0029] **FIG. 7A** is a plan view illustrating a modification of the heat transfer member in the heat exchanger shown in **FIG. 1**;

[0030] **FIG. 7B** is a cross-sectional view illustrating a modification of the heat transfer member in the heat exchanger shown in **FIG. 1**;

[0031] **FIG. 8A** is a plan view illustrating a modification of the heat transfer member in the heat exchanger shown in **FIG. 1**;

[0032] **FIG. 8B** is a cross-sectional view illustrating a modification of the heat transfer member in the heat exchanger shown in **FIG. 1**;

[0033] **FIG. 9A** is a plan view illustrating another embodiment of the heat transfer member;

[0034] **FIG. 9B** is a sectional side view illustrating another embodiment of the heat transfer member;

[0035] **FIG. 10A** is a schematic view illustrating a process for the manufacture of the heat transfer member in the heat exchanger shown in **FIG. 9**;

[0036] **FIG. 10B** is a schematic view illustrating a process for the manufacture of the heat transfer member in the heat exchanger shown in **FIG. 9**;

[0037] **FIG. 11A** is a plan view illustrating still another embodiment of the heat transfer member;

[0038] **FIG. 11B** is a sectional side view illustrating still another embodiment of the heat transfer member;

[0039] **FIG. 12A** is a plan view illustrating yet another embodiment of the heat transfer member;

[0040] **FIG. 12B** is a sectional side view illustrating yet another embodiment of the heat transfer member;

[0041] **FIG. 13** is a schematic view illustrating a conventional heat exchanger; and

[0042] **FIG. 14** is a sectional view illustrating a heat transfer member in the conventional heat exchanger of **FIG. 13**

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0043] Embodiments of the present invention will be described hereinbelow in greater detail with reference to the appended drawings.

[0044] **FIG. 1** illustrates an embodiment in which the present invention is employed in a thermoelectric power generator. The thermoelectric power generator **1** comprises an evaporation unit **1A** and a thermoelectric converter **1B**. In the evaporation unit **1A**, a heat transfer pipe **2b** is heated by high-temperature fluid flowing through a duct **2a** and a heat medium **W** stored in a storage unit **2c** becomes vapor. The thermoelectric converter **1B** comprises a chamber **3c** linked to the evaporation unit **1A**, which accommodates a thermoelectric power generation module **7** comprising a thermoelectric module **4**, a heat transfer plate (heat-transfer member) **5**, and a water-cooled plate **6**.

[0045] The thermoelectric power generation module **7** is a kind of heat exchanger, wherein heat transfer plate (heat-transfer member) **5** is provided on the high-temperature side and water-cooled plate **6** is provided low-temperature side of thermoelectric module **4**. When vapor of heat medium **W** generated in evaporation unit **1A** condenses upon contact with a heat transfer surface **5s** of heat transfer plate **5**, heat is radiated so that the high-temperature side of thermoelectric module **4** is heated. With the temperature difference of the high-temperature side of thermoelectric module **4** with the low-temperature side that is cooled by water-cooled plate **6**, electric power is generated through the operation of a P-type/N-type semiconductor constituting thermoelectric module **4**.

[0046] As shown in **FIG. 1** and **FIGS. 2A and 2B**, a large number of very fine pins (protrusions) **5a** are provided on heat transfer surface (condensation heat transfer surface) **5s** of heat-transfer plate **5**.

[0047] Each of the pins **5a** has a cylindrical shape of a very small size with a height h and a diameter (width) d being less than 0.01 mm. The pins **5a** are arranged to form a lattice with a very small spacing such that a pitch p between the adjacent pins **5a** is less than 0.01 mm.

[0048] Furthermore, the configuration of pins **5a** in heat transfer plate **5** is such that the entire pins are formed from a material that shows very low wettability with no affinity to condensate, such as a polyfluoroethylene resin (trade name: Teflon). With this structure, at least the surface of the pins is formed from the material with low wettability.

[0049] With the structure described above in which a large number of pins **5a** with the surface thereof being made of a material having low wettability are provided, heat transfer

surface **5s** of heat transfer member **5** is provided with fine peaks and valleys and has very low wettability and ultralow surface energy.

[0050] FIGS. 3A and 3B illustrate a process for the fabrication of the heat transfer member **5**. In order to fabricate the heat transfer member **5**, first, as shown in FIG. 3A, a surface layer **5B** made of a material with low wettability, such as a polyfluoroethylene resin or the like, is formed on the surface of a heat transfer plate base **5A** made of stainless steel or the like, this layer having a thickness greater than the height *h* of pins **5a** (see FIG. 2B) which are to be formed. Then, as shown in FIG. 3B, a prescribed number of pins **5a** are formed by processing the surface layer **5b** by using microfabrication technology.

[0051] Taking into account a heat conductivity and cost, various materials (for example, aluminum and the like) may be employed instead of stainless steel as a material for heat transfer plate base **5A**.

[0052] Further, various materials (for example, silicone resins and the like) other than the polyfluoroethylene resin may also be employed as the material constituting the surface layer **5B**, that is, pins **5a**, provided that the condition of low wettability is satisfied.

[0053] Referring to FIG. 4, when vapor of heat medium **W** condenses upon contact with heat transfer surface **5s** of the above-described heat transfer plate **5**, the heat medium (condensate) **W** assumes drops of almost a spherical shape that are supported by a large number of pins **5a**.

[0054] Furthermore, as seen from FIG. 4, the contact angle θ_f of drop-like heat medium (condensate) **W** with respect to heat transfer plate **5** is much larger than the contact angle θ of heat medium (condensate) **W** with respect to the conventional heating plate **F** shown in FIG. 14.

[0055] In a surface with ultralow surface energy, the contact angle θ_f is known to depend on A_g as shown by formula (1) below, where A_g is the fraction of area taken by gas portions in the peak-valley surface.

$$\cos \theta_f = (1 - A_g) \cos \theta - A_g \quad (1)$$

[0056] Water, freon, Florinate (trademark) or the like can be employed as the heat medium **W**. However, it goes without saying that the above-described relationship is established for a variety of heating media **W**.

[0057] FIG. 5 illustrates the relationship between the contact angle θ_f and A_g . Graph of this figure clearly shows that for the heat medium with a contact angle θ of 110° formed with respect to a plane, the contact angle θ_f increases to about 130° when A_g is 0.5, and the contact angle θ_f further increases to 160° when A_g is 0.9.

[0058] In the heat transfer plate **5** according to this embodiment, a large number of pins **5a** are formed on heat transfer surface **5s** so that A_g becomes no less than 0.5, preferably, 0.7-0.9.

[0059] For this reason, the contact angle θ_f of the heat medium (condensate) **W** that assumed a drop-like shape upon contact with heat transfer plate **5** greatly increases by comparison with the contact angle θ (see FIG. 14) with respect to a flat heat transfer plate. As a result, heat transfer surface **5a** of heat transfer plate **5** becomes close to an ideal drop condensation surface and a good heat exchange efficiency can be obtained.

[0060] Furthermore, when the present invention is applied to a heat exchanger for use in a refrigerator or the like, that is, when heat transfer surface **5a** in heat transfer member **5** shown in FIG. 1 through FIG. 5 is a low-temperature heat transfer surface, the wettability of heat transfer surface **5a** in heat transfer member **5** is extremely low as described above so that any frost that is present on heat transfer surface **5a** assumes a spherical shape, which is easy to peel off the surface. As a result, accumulation of the frost on heat transfer plate **5** can be effectively prevented and good heat exchange efficiency can be obtained.

[0061] Pins **5a** in the above-described embodiment had a cylindrical shape as shown in FIGS. 2A and 2B. However, the form of pins **5a** is not limited to a cylindrical shape and the pins can be in a variety of shapes such as elliptical cylinder shown in FIGS. 6A and 6B, quadrangular prism shown in FIGS. 7A and 7B, or circular cone shown in FIGS. 8A and 8B.

[0062] In heat transfer plate **5** shown in FIGS. 1 through 8, the entire pins **5a** are formed from a material with low wettability such as a polyfluoroethylene resin or the like. However, because thermal conductivity of polyfluoroethylene resins is lower than that of metals, heat transfer efficiency of heat transfer plate **5** is unavoidably decreased.

[0063] FIGS. 9A and 9B illustrate another embodiment of a heat transfer plate **10** designed to increase the heat transfer efficiency. In the heat transfer plate **10**, a large number of very fine pins (protrusions) **10a** are provided on a heat transfer surface **10s**. The pins **10a** are in the form of cylinders of a very small size with a height *h* and diameter (width) *d* being less than 0.01 mm and are arranged to form a lattice with a very small spacing such that a pitch *p* between the adjacent pins **10a** is less than 0.01 mm.

[0064] Furthermore, a film **10c** made of a material with a very low wettability because of having no affinity to condensate, such as polyfluoroethylene resin (trademark: Teflon), is formed on the surface of pins **10a** formed in heat transfer plate **10**.

[0065] FIGS. 10A and 10B illustrate a process for the fabrication of the heat transfer member **10**. In order to fabricate the heat transfer member **10**, first, as shown in FIG. 10A, a prescribed number of pins **10a** are formed by using microfabrication technology such as etching and the like on the surface of a heat transfer plate base **10A** made of copper or the like.

[0066] Then, as shown in FIG. 10B, a film **10c** made of a material with low wettability, such as a polyfluoroethylene resin or the like, is formed by an appropriate coating technique such as painting or deposition on the surface of heat transfer plate base **10A**, in other words, on the surface of pins **10a**.

[0067] Taking into account thermal conductivity and cost, various materials other than copper may be employed as the material of heat transfer plate base **5A**.

[0068] Further, it goes without saying that various materials (for example, silicone resins and the like) other than the polyfluoroethylene resin may be employed for film **10c**, provided that the condition of low wettability is satisfied.

[0069] With the heat transfer plate **10** of the above-described configuration, because the main bodies of pins

10a are made of a metal material such as copper or the like, heat transfer efficiency can be greatly increased by comparison with that of the heat transfer plate shown in **FIGS. 1 through 8**, in which the entire pins are formed of a material with low wettability completely.

[0070] **FIGS. 11A and 11B** illustrate a still another embodiment of the present invention in which a heat transfer plate **20** is provided with a large number of low fins **20F**. A large number of very small pins (protrusions) **20a** are provided on a surface **20s** of heat transfer plate **20**, including the outer surface of the low fins **20F**.

[0071] The configuration of those pins **20a**, that is, the shape, layout, and manufacturing process thereof are not substantially different from those relating to heat transfer plate **5** shown in **FIGS. 1 through 8** and heat transfer plate **10** shown in **FIGS. 9 and 10**.

[0072] With heat transfer plate **20** of the above-described configuration, heat exchange can be conducted with a very good efficiency due to the enlarged heat transfer surface effect provided by low fins **20F**, the surface tension effect of heat medium (condensate), and the condensation heat transfer effect resulting from the presence of a large number of pins **20a**.

[0073] **FIGS. 12A and 12B** illustrate yet another embodiment of the present invention in which a heat transfer plate **30** is provided with a large number of plate-shaped fins **30F**. A large number of very small pins (protrusions) **30a** are provided on a surface **30s** of heat transfer plate **30**, including the outer surface of those fins **30F**.

[0074] The configuration of those pins **30a**, that is, the shape, layout, and manufacturing process thereof are not substantially different from those relating to heat transfer

plate **5** shown in **FIGS. 1 through 8** and heat transfer plate **10** shown in **FIGS. 9 and 10**.

[0075] With heat transfer plate **30** of the above-described configuration, heat exchange can be conducted with a very good efficiency due to the enlarged heat transfer surface effect provided by low fins **30F**, the surface tension effect of heat medium, and the condensation heat transfer effect resulting from the presence of a large number of pins **30a**.

[0076] Furthermore, when heat transfer plate **30** of the above-described configuration is used in a heat exchanger, for example, of a refrigerator, providing a large number of pins **30a** makes it possible to realize a high-performance low-temperature heat exchanger by effectively preventing frost from accumulating and preventing the increase in ventilation resistance caused by the frost.

[0077] In the embodiments described above, the present invention was applied to heat exchangers in thermoelectric power generators or refrigerators. However, it goes without saying that the present invention can be also effectively applied to heat exchangers for use in various apparatuses in a variety of industrial fields, provided that the heat exchangers conduct heat exchange via a heat transfer member.

What is claimed is:

1. A heat exchanger for conducting heat exchange via a heat transfer member, wherein the heat transfer member has a heat transfer surface on which a large number of protrusions each having a height and a width of less than 0.01 mm, respectively, are disposed with a pitch of less than 0.01 mm, at least surface of the protrusions being made of a material with low wettability.

* * * * *