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(54) WIRE SAW APPARATUS, A METHOD OF SAWING AN OBJECT, AND A METHOD OF PRODUCING ETCHED WAFERS

(57) A method of sawing an object (700) includes providing a wire saw apparatus (2), which includes tank (20) defining a receiving space (21) having an opening (211) and receiving a cutting liquid (200), an ultrasonic vibrator (3) disposed in the tank (20), and multiple sawing wires (4) located above the opening (211) and spaced apart from the cutting liquid (200) . The method further includes driving the ultrasonic vibrator (3), reciprocating the sawing wires (4), and moving the object (700) toward the sawing wires (4), so that the object (700) is cut by the sawing wires (4) to form multiple cut grooves (400), and subsequently a part of the object (700) is immerged into the cutting liquid (200), each of the cut grooves (400) having a width (W) allowing the cutting liquid (200) to enter the cut grooves (400) by capillary action.

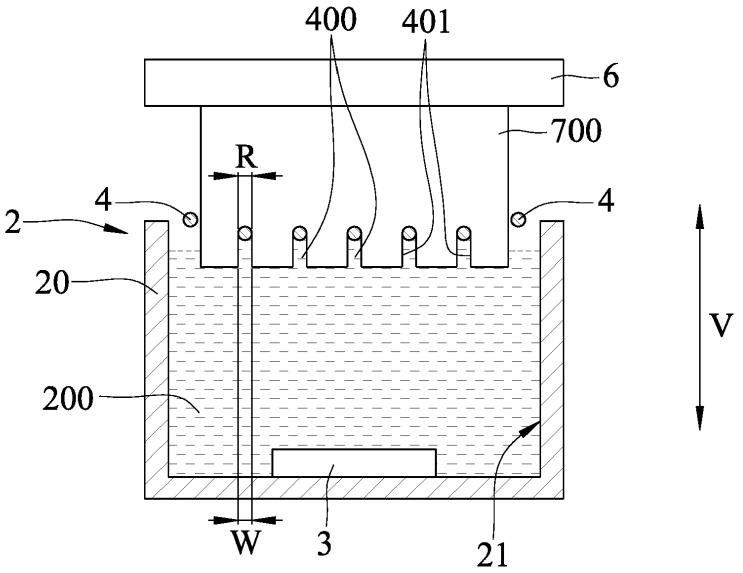

FIG.10

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Description

[0001] The disclosure relates to a wire saw apparatus, a method of sawing an object, and a method of producing a plurality of etched wafers.

[0002] Referring to FIGS . 1 and 2, Chinese Patent Application Publication No. CN 103085179 A discloses a conventional wire saw apparatus 1, and a method of sawing an ingot 100 using the wire saw apparatus 1 . The wire saw apparatus 1 includes a tank 12 that receives a cutting liquid 11 (i.e., slurry), an ultrasonic vibrating plate 13 that is received in the tank 12, two guiding rollers 14 that are respectively located at opposites sides of the tank 12, and a plurality of sawing wires 15 (only one is shown in FIGS. 1 and 2) that are wound on the guiding rollers 14 and that define a sawing section 151 for cutting the ingot 100, which is located directly above the sawing section 151 of the sawing wires 15.

[0003] In cutting the ingot 100, the sawingwires 15 are driven by the guiding rollers 14 to reciprocate between the guiding rollers 14, and the ingot 100 is moved toward the sawing section 151 of the sawing wires 15. When the ingot 100 is in contact with the sawing section 151, the sawing section 151 is deformed by the ingot 100 to be immerged into the cutting liquid 11 and cuts the ingot 100, in which an ultrasonic wave generated by the ultrasonic vibrating plate 13 is transmitted into the sawing section 151 of the sawing wires 15 through the cutting liquid 11, such that the sawing section 151 is vibrated by the ultrasonic wave to increase cutting precision. However, the immersion of the sawing section 151 of the sawing wires 15 in the cutting liquid 11 may impede reciprocating movement of the sawing section 151 and may cause wobbling of the sawing wires 15 or even break the sawing wires 15.

[0004] Therefore, an object of the present disclosure is to provide a wire saw apparatus, a method of sawing an obj ect, and a method of producing etched wafers.

[0005] According to a first aspect of the present disclosure, a method of sawing an object includes:

providing a wire saw apparatus including a tank that defines a receiving space having an opening, an ultrasonic vibrator that is disposed on the tank, and a plurality of sawing wires that are located above the opening of the receiving space, the receiving space receiving a cutting liquid, the sawing wires being spaced apart from the cutting liquid; and

driving the ultrasonic vibrator, reciprocating the sawing wires, and moving the object located above the sawing wires toward the sawing wires, so that the object is cut by the sawing wires to form a plurality of cut grooves respectively corresponding to the sawing wires, and subsequently a part of the object is immerged into the cutting liquid such that lower end openings of the cut grooves of the object are located in the cutting liquid, each of the cut grooves having a horizontal width that allows the cutting liquid to enter the cut grooves by capillary action when the part of the object is immerged into the cutting liquid.

[0006] According to a second aspect of the present disclosure, a wire saw apparatus includes a tank, an ultrasonic vibrator, a plurality of sawing wires, and a control device.

[0007] The tank has a receiving space that has an opening and that is adapted to receive a cutting liquid. The ultrasonic vibrator is disposed on the tank. The sawing wires are located above the opening of the receiving space. The control device is operable for reciprocating the sawing wires. When moved toward the cutting liquid into contact with the sawing wires, the object is cut by the sawing wires to form a plurality of cut grooves respectively corresponding to the sawing wires. When a part of the object is immerged into the cutting liquid so that lower end openings of the cut grooves of the object are located in the cutting liquid, the cutting liquid enters the cut grooves of the object by capillary action, and at least a part of the sawing wires is not in contact with the cutting liquid.

[0008] According to a third aspect of the present disclosure, a method of producing a plurality of etched wafers includes:

providing a wire saw apparatus including a tank that defines a receiving space having an opening, an ultrasonic vibrator that is disposed on the tank, and a plurality of sawing wires that are located above the opening of the receiving space, the receiving space receiving a cutting liquid, the sawing wires being spaced apart from the cutting liquid;

driving the ultrasonic vibrator, reciprocating the sawing wires, and moving the object located above the sawing wires toward the sawing wires, so that the object is cut by the sawing wires to form a plurality of cut grooves respectively corresponding to the sawing wires, and subsequently a part of the object is immerged into the cutting liquid such that lower end openings of the cut grooves of the object are located in the cutting liquid, each of the cut grooves having a horizontal width that allows the cutting liquid to enter the cut grooves by capillary action when the part of the object is immerged into the cutting liquid, and the object is cut into a plurality of wafers by the sawing wires; and

etching the wafers to obtain a plurality of etched wafers.

[0009] According to a fourth aspect of the present disclosure, an ultrasonic-assisted wire saw apparatus is adapted for use with a plurality of sawing wires to cut an object. The ultrasonic-assisted wire saw apparatus includes a tank, and an ultrasonic vibrator.

[0010] The tank has a receiving space that has an opening and that is adapted to receive a cutting liquid. The sawing wires cooperate to constitute a sawing net

located above the opening of the receiving space. The ultrasonic vibrator is disposed in the receiving space and is adapted to generate an ultrasonic wave. When the object is cut by the sawing net of the sawing wires to form a plurality of cut grooves, the ultrasonic wave is transmitted into the sawing wires through the cutting liquid entering the cut grooves by capillary action.

[0011] Other features and advantages of the present disclosure will become apparent in the following detailed description of the embodiment with reference to the accompanying drawings, of which:

FIG. 1 is a schematic view of a conventional wire saw apparatus disclosed by Chinese Patent Application Publication No. CN 103085179 A;
FIG. 2 is a schematic view of the conventional wire saw apparatus, showing an ingot being cut by a sawing section of a sawing wire;
FIG. 3 is a flow chart showing a method of sawing an object according to the present disclosure;
FIG. 4 is a schematic sectional view of a wire saw apparatus according to the present disclosure;
FIG. 5 is a schematic sectional view of the wire saw apparatus taken along line V-V of FIG. 6;
FIG. 6 is a schematic sectional view similar to FIG. 5, showing an alternative structure of an ultrasonic vibrator of the wire saw apparatus;
FIG. 7 is a schematic top view of the alternative structure of the ultrasonic vibrator;
FIG. 8 is a schematic top view of another alternative structure of the ultrasonic vibrator;
FIGS. 9 to 12 are schematic views of the wire saw apparatus, showing an object being cut by the wire saw apparatus;
FIG. 13 is a schematic view of the wire saw apparatus, showing a part of the wire saws of the wire saw apparatus being immersed into a cutting liquid;
FIGS. 14 and 15 respectively show optical microscope images of a rich-side region and a poor-side region of a wafer of a comparative example;
FIGS. 16 and 17 respectively show optical microscope images of the rich-side region and the poor-side region of a wafer of this disclosure;
FIGS. 18 and 19 respectively show optical microscope images of the rich-side region and the poor-side region of an etched wafer of the comparative example; and
FIGS. 20 and 21 respectively show optical microscope images of the rich-side region and the poor-side region of an etched wafer of this disclosure.

[0012] Before the disclosure is described in greater detail, it should be noted that where considered appropriate, reference numerals or terminal portions of reference numerals have been repeated among the figures to indicate corresponding or analogous elements, which may optionally have similar characteristics.

[0013] Referring to FIGS. 3 to 5, an embodiment of a method of sawing an object 700, and a wire saw apparatus 2 used by the method are described in details as following.

[0014] The method includes a preparing step 301 and a cutting step 302 . In the preparing step 301, the wire saw apparatus 2 is provided, which includes a tank 20, an ultrasonic vibrator 3 disposed in the tank 20, two control devices 5 respectively located at opposite sides of the tank 20, and a plurality of sawing wires 4 connected to the control devices 5 and located directly above the opening 211 of the receiving space 21. The tank 20 defines a receiving space 21 having an opening 211 disposed at upper end thereof, and adapted for receiving a cutting liquid 200 therein. In this embodiment, the ultrasonic vibrator 3 is disposed at a bottom side of the tank 20 and has a center aligned vertically with that of the opening 211 . The sawing wires 4 are spaced apart from the cutting liquid 200, and are driven by the control devices 5 to reciprocate in a reciprocating direction (X) to achieve cutting effect. In this embodiment, each of the control devices 5 is a driving roller. In certain embodiments, each of the control devices 5 may include a driving roller, and a driven roller that has a diameter smaller than that of the main roller and that is driven by the driving roller. It should be noted that the structure and arrangement of the control devices 5 may be changed according to practical requirements as long as the sawing wires 4 can be driven by the control devices 5 to reciprocate in the reciprocating direction (X).

[0015] Each of the sawing wires 4 has a radial width (R) such that, further referring to FIG. 10, the object 700 can be cut by the sawing wires 4 to form a plurality of cut grooves 400 each having a horizontal width (W) that is substantially equal to the radial width (R) of each of the sawing wires 4, and that is small enough to allow the cutting liquid 200 to enter the cut grooves 400 by capillary action when a part of the object 700 is immerged into the cutting liquid 200. In this embodiment, the radial width (R) of each of the sawing wires 4 is not greater than 300 μm. In certain embodiments, the radial width (R) of each of the sawing wires 4 ranges from 40 μm to 150 μm. In certain embodiments, the cutting liquid 200 may be made from water, oil, alcohol, heavy liquid, etc.

[0016] FIGS. 6 and 7 show an alternative structure of the ultrasonic vibrator 3 that includes a plurality of transducers 31 that are arranged in two groups respectively located at opposite sides of the tank 20. The transducers 31 of each group are arranged along a direction (Y) along which the sawing wires 4 are arranged. Noted that the sawing wires 4 are omitted in FIG. 7 to clearly show the arrangement of the transducers 31. In this embodiment, each of the transducers 31 is an ultrasonic transducer.

[0017] FIG. 8 shows another alternative structure of the ultrasonic vibrator 3 that includes a first transducer 31' and a second transducer 31". In certain embodiments, the first and second transducers 31', 31" maybe disposed in the tank 20 adjacent to each other, and the second transducer 31" generates an ultrasonic wave

having an energy different from (e.g., greater than) that of an ultrasonic wave generated by the first transducer 31'. Such arrangement may be beneficial for removing cutting dusts of different size. Noted that the sawing wires 4 are omitted in FIG. 8 to clearly show the arrangement of the first and second transducers 31', 31''.

[0018] In certain embodiments, the second transducer 31" has a vibration frequency different from (e.g., greater than) that of the first transducer 31' . Such arrangement may be beneficial for removing cutting dusts of different size.

[0019] It should be noted that the number, arrangement and types of the transducers 31, 31', 31" may be changed according to practical requirements.

[0020] Referring further to FIGS. 9 and 10, in the cutting step 302, the wire saw apparatus 2 is used for cutting the object 700 mounted to a holder 6.

[0021] The object 700 may be a semiconductor ingot, a metal or an alloy ingot, or a ceramic block. In the cutting step 302, the ultrasonic vibrator 3 is driven to operate, and the control devices 5 are driven to drive reciprocating movement of the sawing wires 4, and the object 700 located directly above the sawing wires 4 is moved toward the sawing wires 4, so that the object 700 is cut by the sawing wires 4 to form the cut grooves 400 located at a lower end thereof and respectively corresponding to the sawing wires 4 in position along a vertical direction (V). Subsequently, a part of the object 700 is immerged into the cutting liquid 200 such that lower end openings 401 of the cut grooves 400 of the object 700 are located in the cutting liquid 200. With further reference to FIG. 12, a liquid level 201 of the cutting liquid 200 and the sawing wires 4 are separated by a spacing (H) . During cutting, the sawing wires 4 are slightly deformed by the object 700, but are kept away from the cutting liquid 200. With further reference to FIG. 13, in certain embodiments, the sawing wires 4 are diamond wire saws. After long-term use, the diamond particles on the diamond wire saws may fall off or be worn out. Therefore, greater force should be exerted on the sawing wires 4 when cutting, resulting in more deformation of the sawing wires 4, and a part of the sawing wires 4 may be immersed into the cutting liquid 200. However, by controlling the spacing (H), at least a part of the sawing wires 4 is always not in contact with the cutting liquid 200, thereby alleviating the wobbling or breakage issues associated with the conventional wire saw apparatus 1 (see FIGS. 1 and 2) caused by immersion of the sawing section 151 (see FIGS. 1 and 2) of the sawing wires 15 (see FIGS. 1 and 2) in the cutting liquid 11. Afterwards, referring to FIG. 11, the object 700 is cut into a plurality of wafers 800 by the sawing wires 4.

[0022] Referring to FIGS. 10 to 12, when the cutting liquid 200 enters the cut grooves 400 of the object 700 by capillary action, an ultrasonic wave generated by the ultrasonic vibrator 3 is transmitted into the sawing wires 4 through the cutting liquid 200 in the cut grooves 400 and the object 700, causing high frequency vibration of the sawing wires 4 and the object 700, resulting in better cutting efficiency and precision. In addition, cavitation effect caused by the ultrasonic wave may occur in the cutting liquid 200 in the cut grooves 400. The bubbles formed in the cutting liquid 200 in the cut grooves 400 may facilitate removal of cutting dust and cleaning of the cut grooves 400 of the object 700 and the sawing wires 4. Moreover, after cutting, the holder 6 and the wafers 800 are moved away from the sawing wires 4, so that the wafers 800 may be cleaned further by the sawing wires 4.

[0023] In certain embodiments, the transducers 31 of the ultrasonic vibrator 3 may generate ultrasonic waves of different frequencies to accommodate different applications.

[0024] It should be noted that, when the spacing (H) between the liquid level 201 of the cutting fluid 200 and the sawing wires 4 is too large, the intensity of the ultrasonic wave transmitted to the sawing wires 4 is lowered. Therefore, the spacing (H) should be controlled based on practical requirements . In certain embodiments, the object 700 is an eight-inch ingot, and the spacing (H) is not greater than 200 mm. In certain embodiments, the spacing (H) ranges from 20 mm to 160 mm. In certain embodiments, the spacing (H) ranges from 10 mm to 60 mm.

[0025] In certain embodiments, the tank 20 may be formed with liquid inlet and outlet (not shown) allowing for control of the liquid level 201 of the cutting liquid 200, thereby controlling the spacing (H).

[0026] After the object 700 is cut into the wafers 800, the wafers 800 may be subjected to etching so as to be formed into a plurality of etched wafers 800', which have roughened surfaces for subsequent applications.

[0027] FIGS. 16, 17, 20 and 21 show cut surfaces of the wafers made by the method according to the present disclosure. FIGS. 14, 15, 18 and 19 show cut surfaces of wafers 900 of a comparative example, in which the wafers were made without using an ultrasonic vibrator.

[0028] After cutting, each of the cut grooves 400 is defined between two opposite side wall surfaces, each of which may has a rich-side region and a poor-side region. The formation of rich-side region is caused by more contact with a corresponding sawing wire 4, and the rich-side region therefore has more cut marks. On the other hand, the formation of the poor-side region is the result of less contact with the corresponding sawing wire 4, and the poor-side region therefore has less cut marks.

[0029] FIGS. 14 and 15 respectively show optical microscope images of the rich-side region and the poor-side region of one of the wafers 900 of the comparative example . FIGS . 16 and 17 respectively show optical microscope images of the rich-side region and the poor-side region of one of the wafers 800 of this disclosure. FIGS. 18 and 19 respectively show optical microscope images of the rich-side region and the poor-side region of one of an etched wafers 900' of the comparative example. FIGS. 20 and 21 respectively show optical microscope images of the rich-side region and the poor-side

region of one of the etched wafers 800' of this disclosure. As can be seen from FIGS. 14 to 21, the use of the ultrasonic vibrator 3 results in more evenly distributed brittle structures, which are beneficial for subsequent device applications.

[0030] In summary, by use of the capillary action to allow the cutting liquid 200 to flow into the cut grooves 400 of the object 700 and by controlling the spacing (H) between the liquid level 201 of the cutting liquid 200 and the sawing wires 4, at least a part of the sawing wires 4 is controlled to be not immerged into the cutting liquid 200 during cutting, thereby alleviating the wire wobbling or breakage issues associated with the conventional wire saw apparatus 1. In addition, the ultrasonic wave generated by the ultrasonic vibrator 3 may be transmitted into the sawing wires 4 through the cutting liquid 200 in the cut grooves 400 and the object 700, thereby achieving better cutting efficiency and precision. Moreover, the cavitation effect occurs in the cutting liquid 200 in the cut grooves 400 is beneficial for removal of cutting dust and cleaning of the cut grooves 400 of the object 700 and the sawing wires 4.

[0031] In the description above, for the purposes of explanation, numerous specific details have been set forth in order to provide a thorough understanding of the embodiment. It will be apparent, however, to one skilled in the art, that one or more other embodiments may be practiced without some of these specific details. It should also be appreciated that reference throughout this specification to "one embodiment, " "an embodiment, " an embodiment with an indication of an ordinal number and so forth means that a particular feature, structure, or characteristic may be included in the practice of the disclosure. It should be further appreciated that in the description, various features are sometimes grouped together in a single embodiment, figure, or description thereof for the purpose of streamlining the disclosure and aiding in the understanding of various inventive aspects.

Claims

1. A method of sawing an object (700), **characterized by**:

   providing a wire saw apparatus (2) including a tank (20) that defines a receiving space (21) having an opening (211), an ultrasonic vibrator (3) that is disposed on the tank (20), and a plurality of sawing wires (4) that are located above the opening (211) of the receiving space (21), the receiving space (21) receiving a cutting liquid (200), the sawing wires (4) being spaced apart from the cutting liquid (200); and
   driving the ultrasonic vibrator (3), reciprocating the sawing wires (4), and moving the object (700) located above the sawing wires (4) toward the sawing wires (4), so that the object (700) is cut by the sawing wires (4) to form a plurality of cut grooves (400) respectively corresponding to the sawing wires (4), and subsequently a part of the object (700) is immerged into the cutting liquid (200) such that lower end openings (401) of the cut grooves (400) of the object (700) are located in the cutting liquid (200), **characterized in that** each of the cut grooves (400) has a horizontal width (W) that allows the cutting liquid (200) to enter the cut grooves (400) by capillary action when the part of the object (700) is immerged into the cutting liquid (200).

2. The method as claimed in Claim 1, where, in providing the wire saw (2), a spacing (H) between a fluid level (201) of the cutting fluid (200) and the sawing wires (4) is greater than 200 mm.

3. The method as claimed in Claim 1, wherein each of the sawing wires (4) has a radial width (R) ranging from 40 μm to 150 μm.

4. A wire saw apparatus (2) **characterized by**:

   a tank (20) having a receiving space (21) that has an opening (211) and that is adapted to receive a cutting liquid (200);
   an ultrasonic vibrator (3) disposed on said tank (20) ;
   a plurality of sawing wires (4) located above said opening (211) of said receiving space (21); and
   a control device (5) operable for reciprocating said sawing wires (4);
   wherein, when moved toward the cutting liquid (200) into contact with said sawing wires (4), the object (700) is cut by said sawing wires (4) to form a plurality of cut grooves (400) respectively corresponding to said sawing wires (4), and
   wherein, when a part of the object (700) is immerged into the cutting liquid (200) so that lower end openings (401) of the cut grooves (400) of the object (700) are located in the cutting liquid (200), the cutting liquid (200) enters the cut grooves (400) of the object (700) by capillary action, and at least a part of the sawing wires (4) is not in contact with the cutting liquid (200) .

5. The wire saw apparatus (2) as claimed in Claim 4, **characterized in that** each of said sawing wires (4) has a radial width (R) ranging from 40 μm to 150 μm.

6. The wire saw apparatus (2) as claimed in Claim 4, **characterized in that** a spacing (H) between a liquid level (201) of the cutting liquid (200) and said sawing wires (4) is not greater than 200 mm.

7. The wire saw apparatus (2) as claimed in Claim 4, **characterized in that** said ultrasonic vibrator (3) is

received in said receiving space (21) and is located under said sawing wires (4).

8. The wire saw apparatus (2) as claimed in Claim 4, **characterized in that** said ultrasonic vibrator (3) includes a plurality of transducers (31) that are arranged in two groups respectively located at opposite sides of said tank (20), said ultrasonic vibrating members (31) of each group being arranged along a direction (Y) along which said sawing wires (4) are arranged.

9. The wire saw apparatus (2) as claimed in Claim 4, **characterized in that** said ultrasonic vibrator (3) includes a first transducer (31') and a second transducer (31'') that generates an ultrasonic wave having an energy different from that of an ultrasonic wave generated by said first transducer (31').

10. The wire saw apparatus (2) as claimed in Claim 4, **characterized in that** said ultrasonic vibrator (3) includes a first transducer (31') and a second transducer (31") that has a vibration frequency different from that of said first transducer (31').

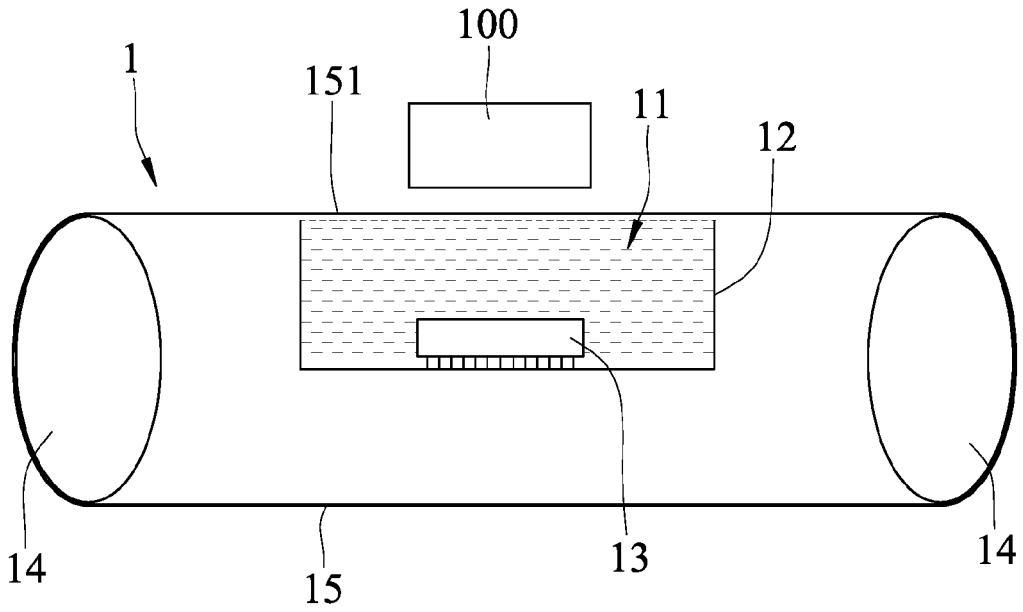

FIG.1
PRIOR ART

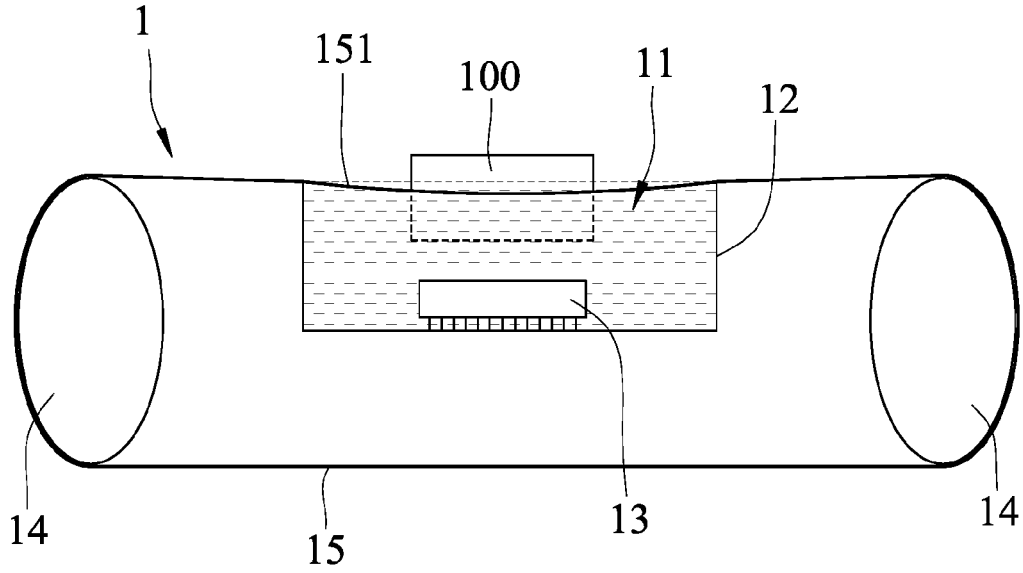

FIG.2
PRIOR ART

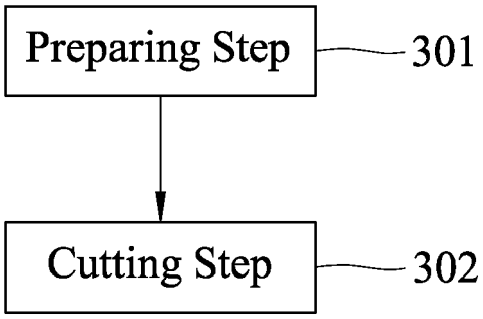

FIG.3

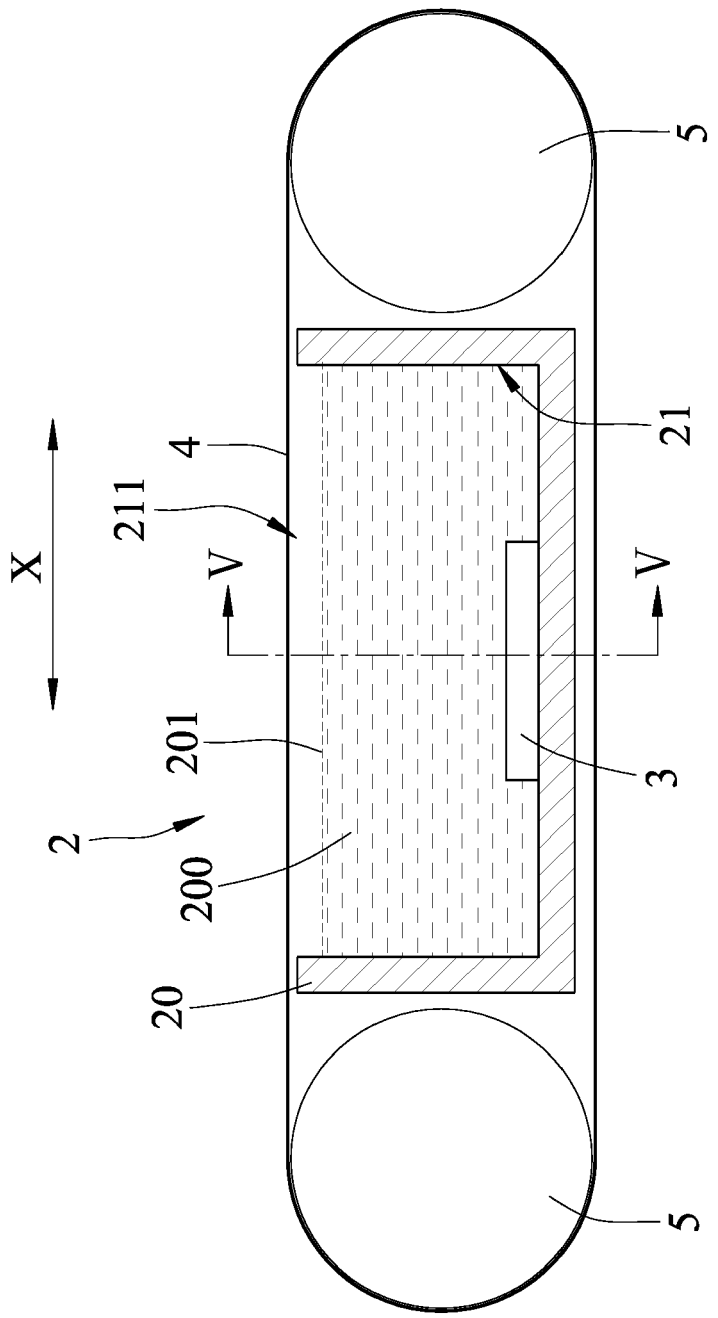

FIG.4

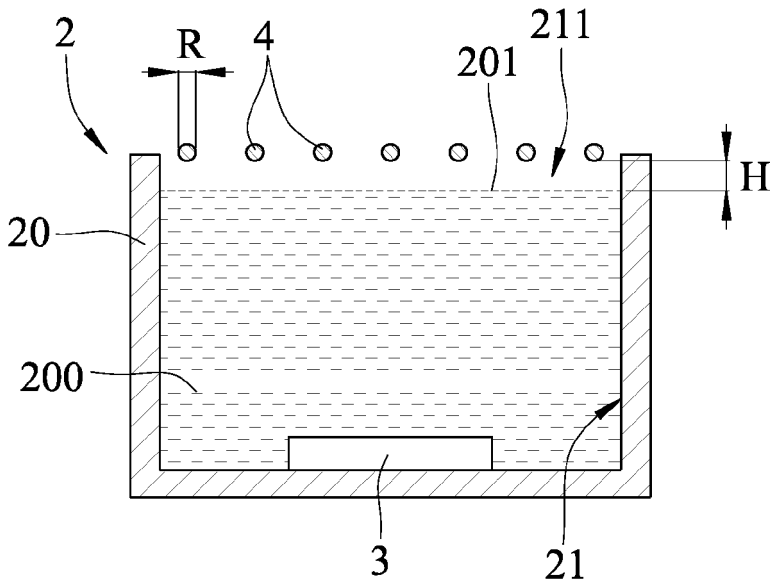

FIG.5

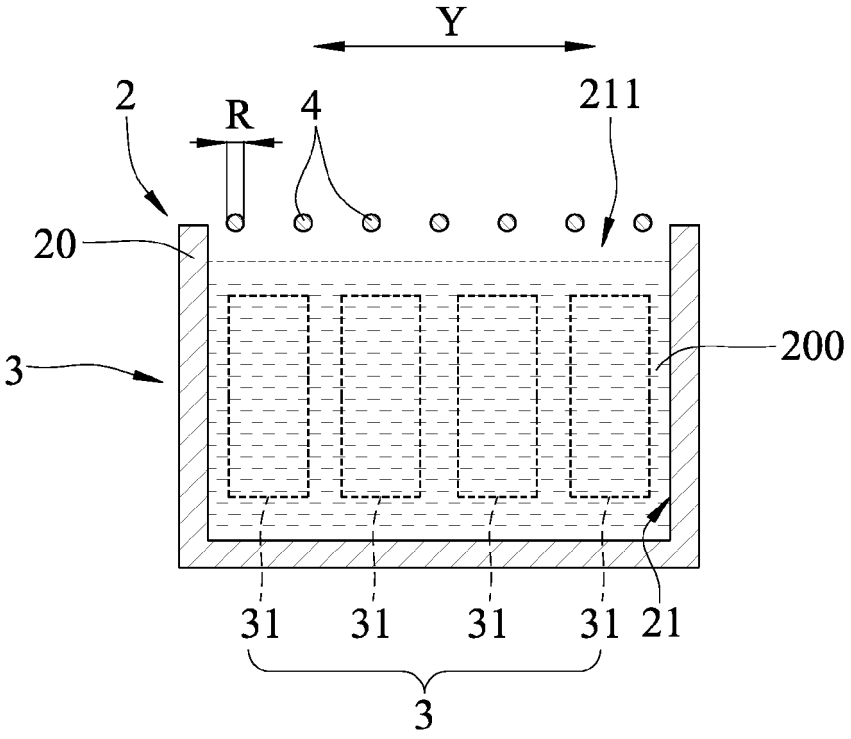

FIG.6

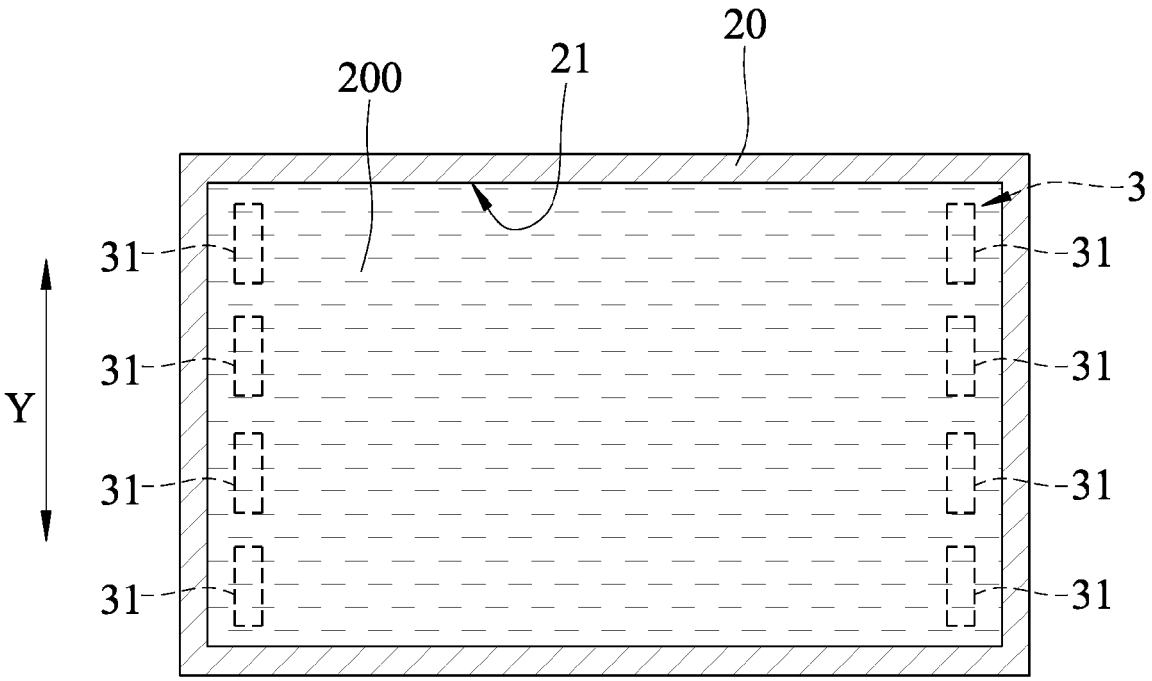

FIG.7

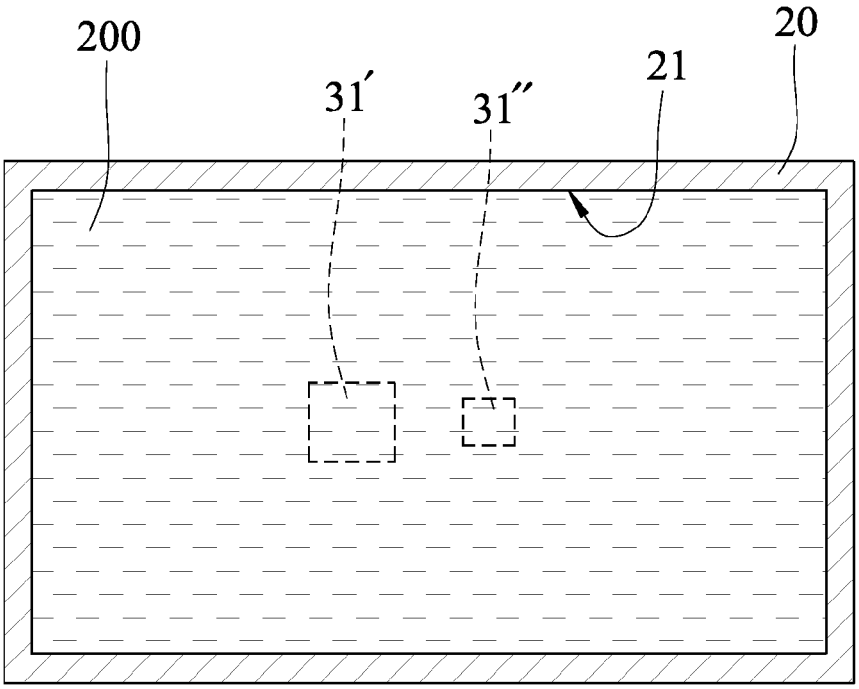

FIG.8

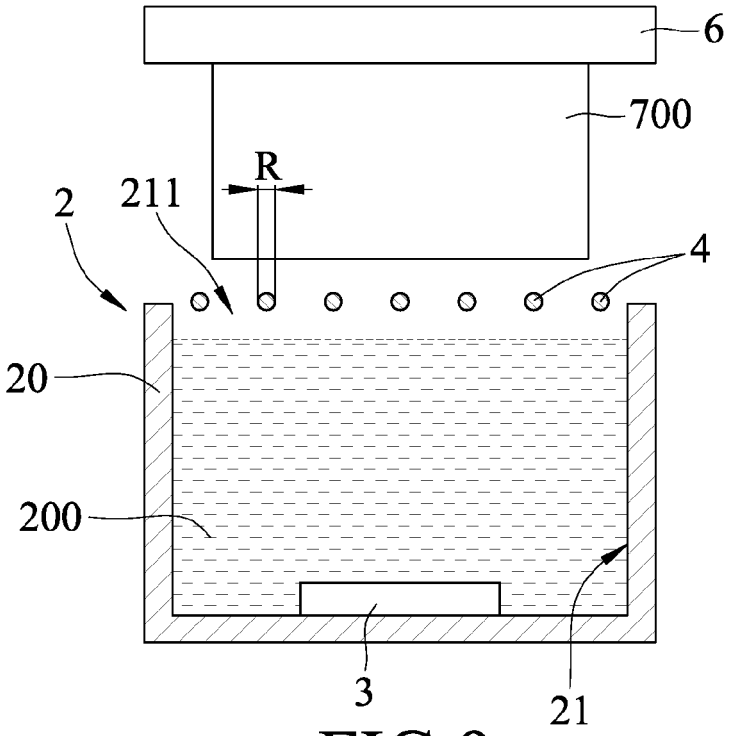

FIG.9

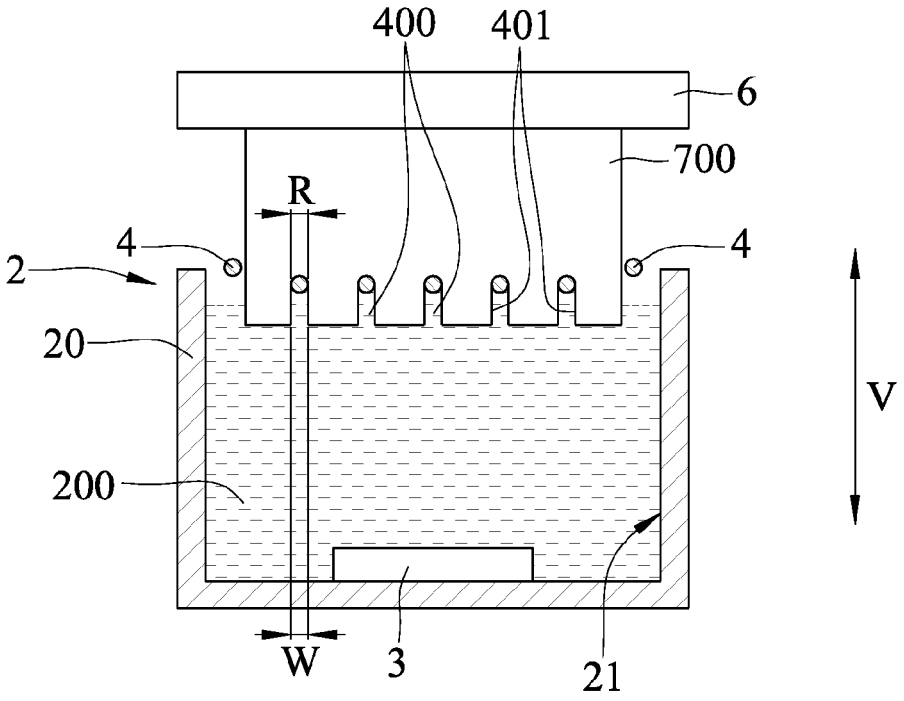

FIG.10

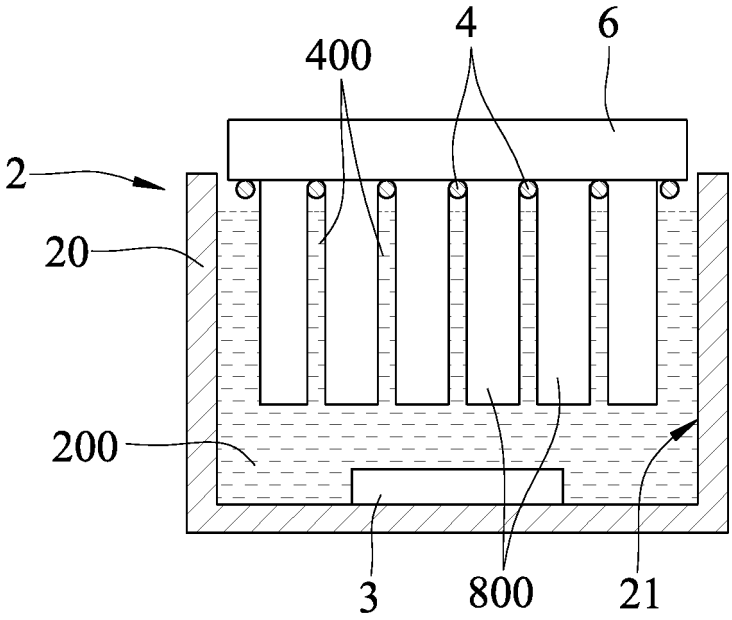

FIG.11

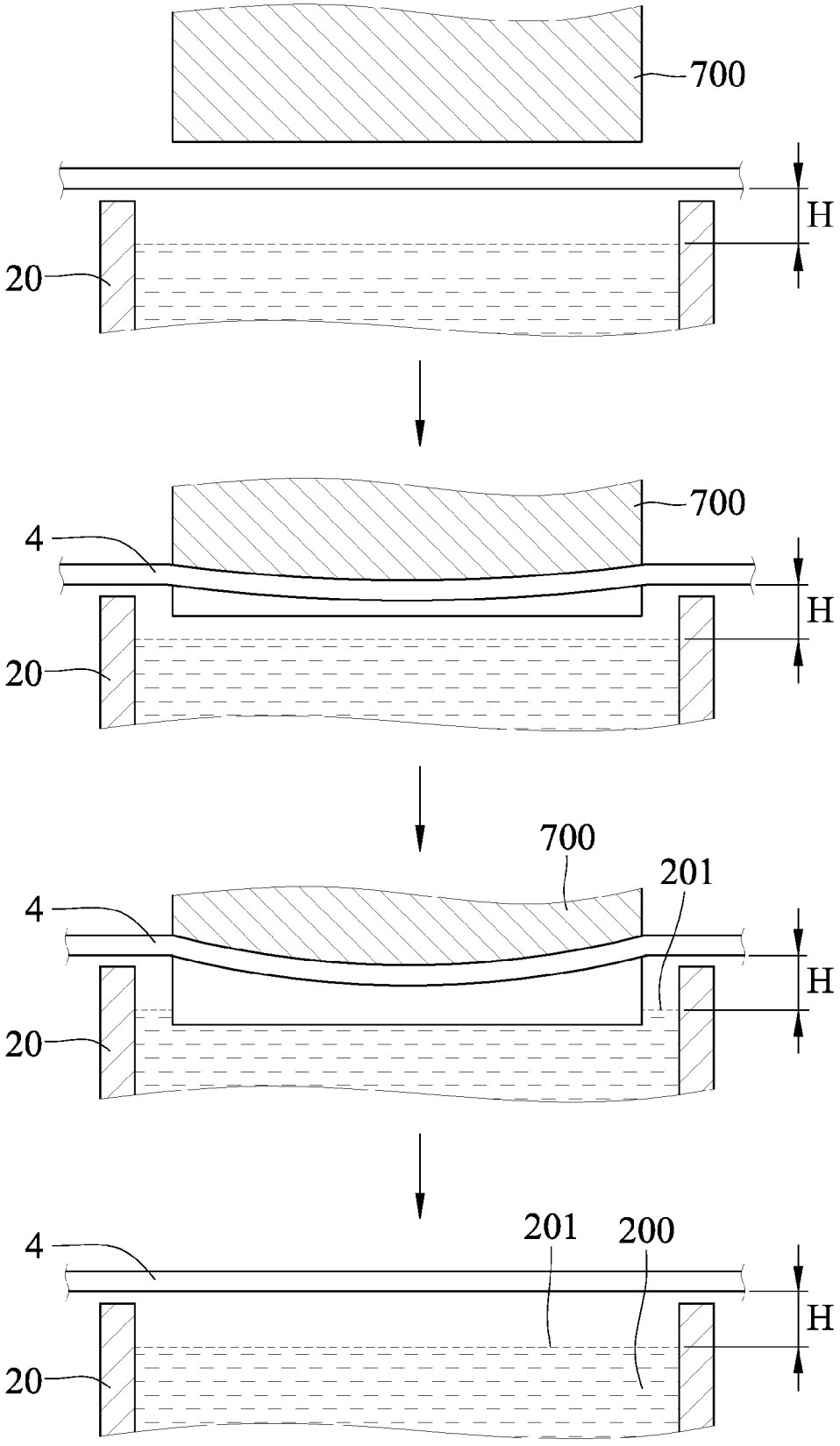

FIG.12

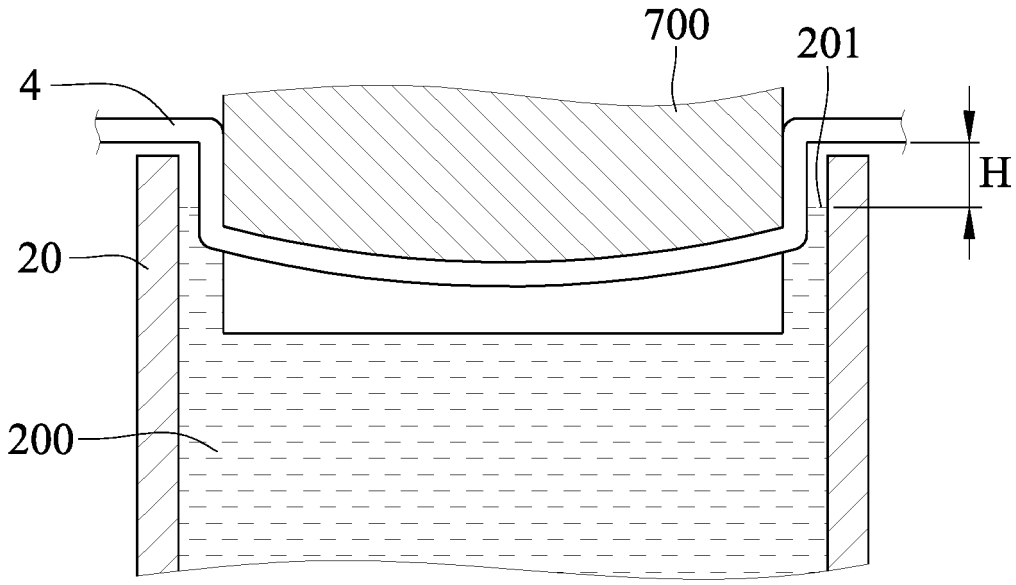

FIG.13

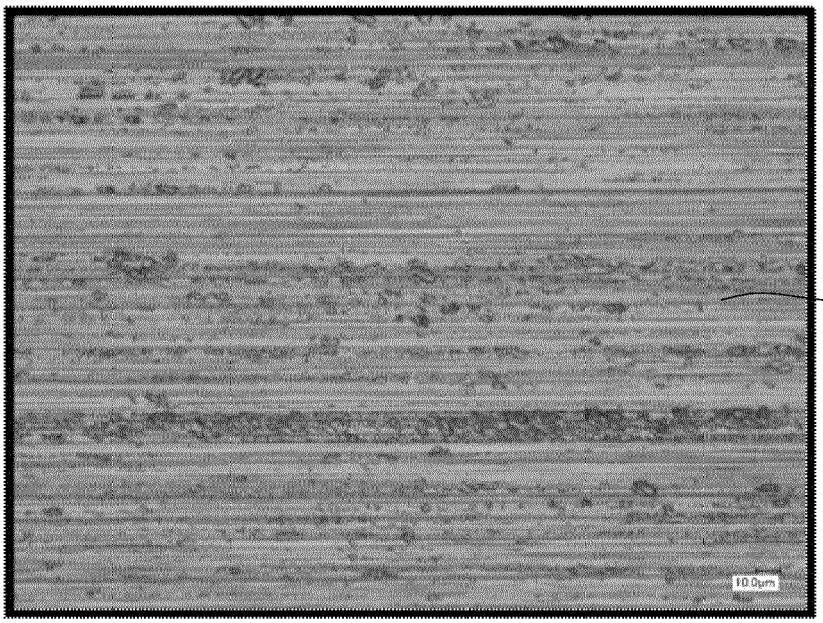

FIG.14

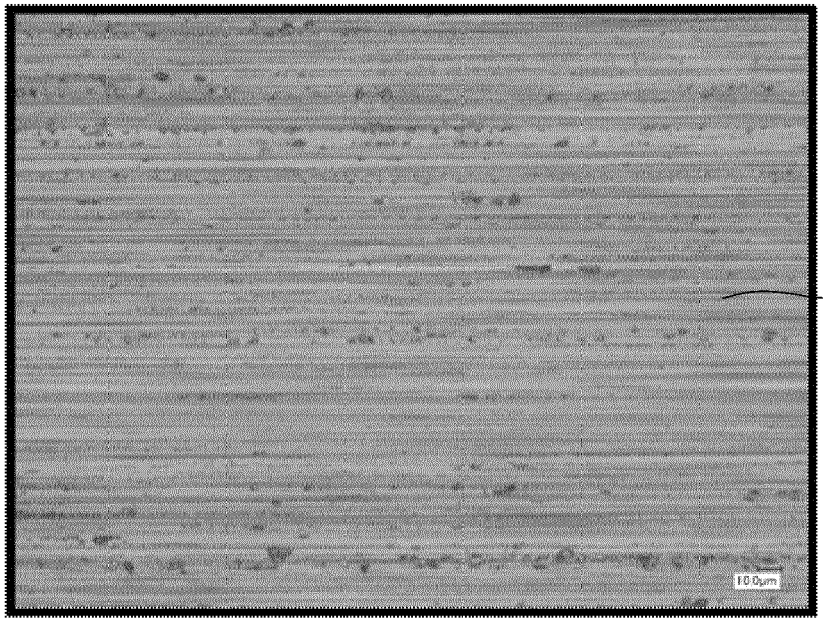

FIG.15

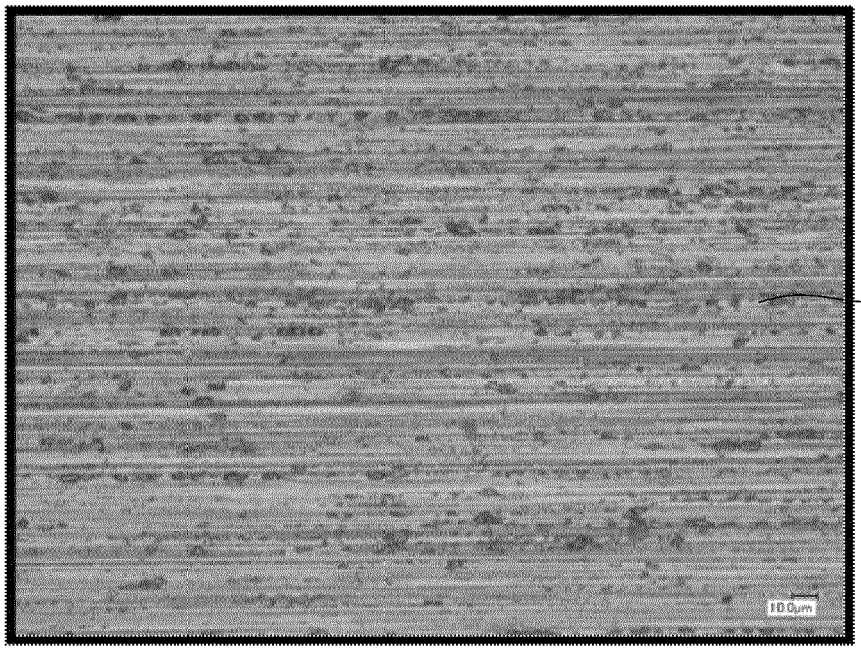

FIG.16

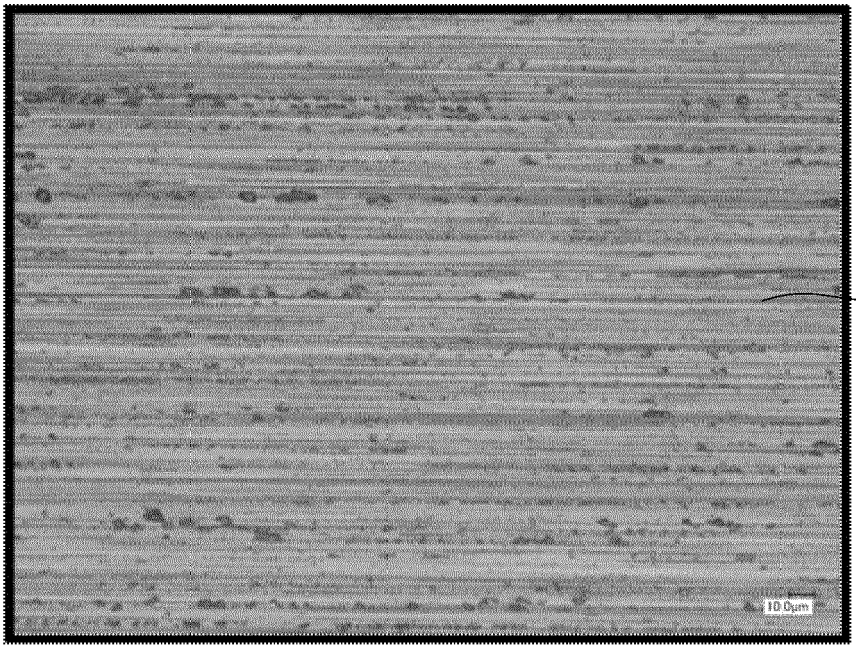

FIG.17

FIG.18

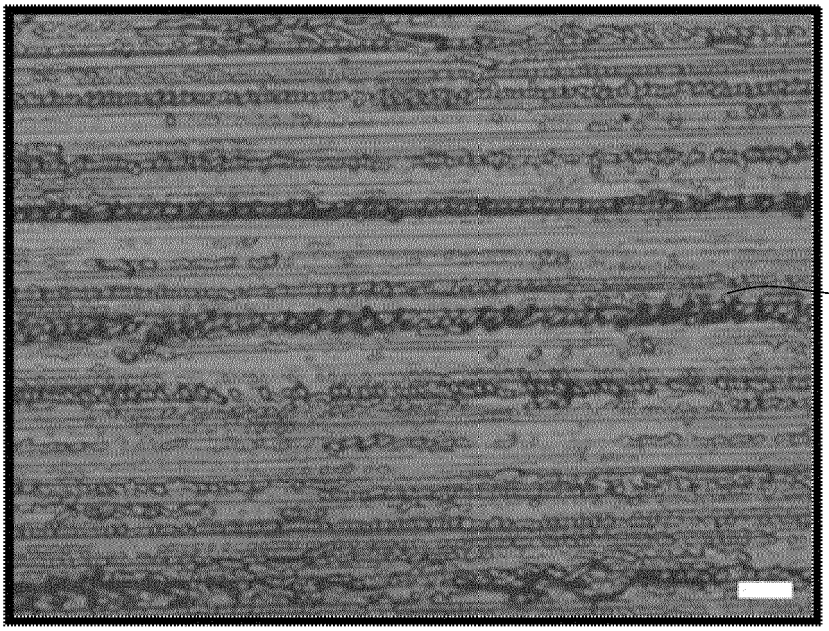

FIG.19

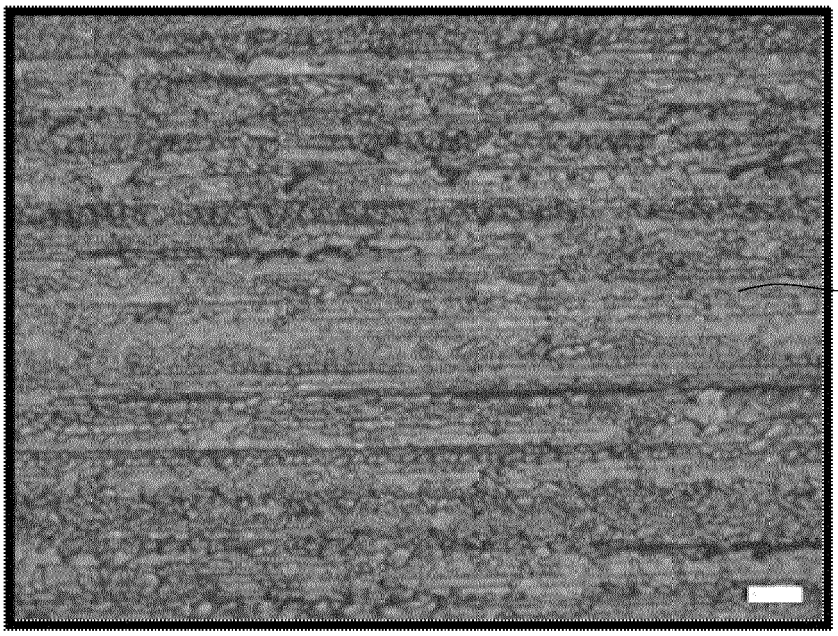

FIG.20

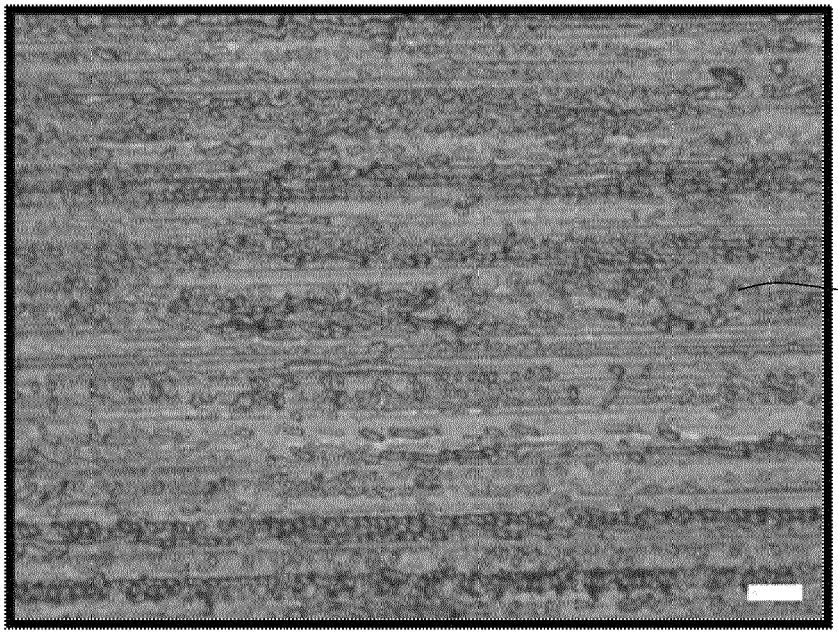

FIG.21

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EUROPEAN SEARCH REPORT

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	4 January 2018	Chariot, David

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