



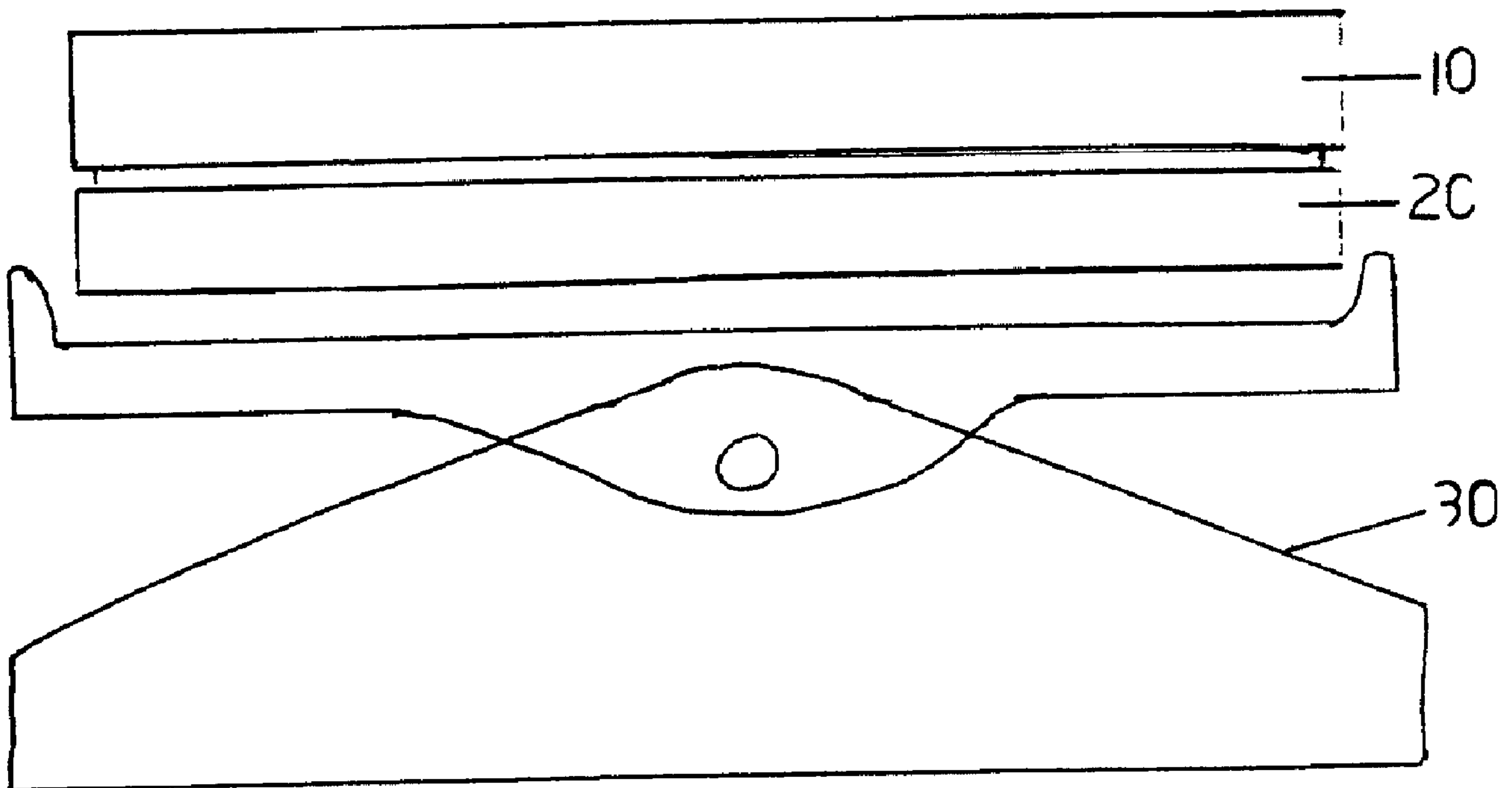
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(54) Titre : INCUBATION DE BIOFILMS
(54) Title: BIOFILM INCUBATION



(57) Abrégé/Abstract:

Biofilm forming organisms are incubated to form a biofilm on projections by providing a flow of liquid growth medium across projections, the direction of the flow of liquid being repeatedly changed, and an assay made of the resulting biofilm. Biofilm forming organisms are incubated to form a biofilm on projections arranged in rows, with several projections in each row, while providing a flow of liquid growth medium across each row of projections, and an assay made of the resulting biofilm. Sensitivity of the biofilm to antimicrobial reagent may be determined by treating the projections with antimicrobial reagent before carrying out the assay, by treating each row of projections with a different antimicrobial reagent, and each of the projections in a row with a different concentration of antibacterial reagent. A biofilm assay device includes a vessel including at least one channel for flow of liquid growth medium, projections arranged in at least one row and having a support for supporting the projections within the channel,



(57) **Abrégé(suite)/Abstract(continued):**

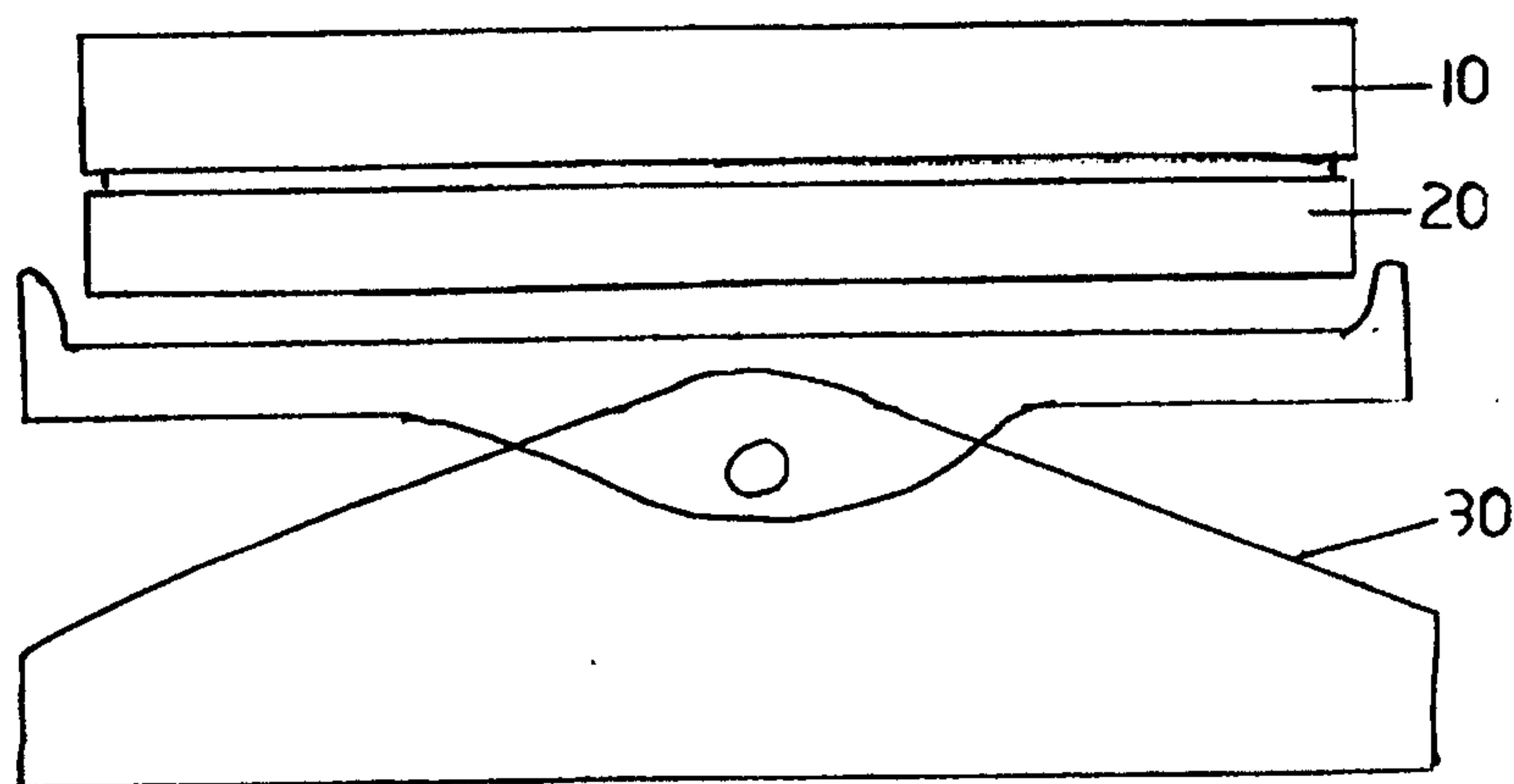
and a tilt table to flow liquid growth medium along each channel in different directions across the projections. A further biofilm assay device includes a vessel including channels for flow of liquid growth medium, projections arranged in rows and having a support for supporting the projections within the channels, and a rocking table to rock the vessel and flow liquid growth medium along each channel across the projections.

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(21) International Application Number: PCT/CA97/00171 (22) International Filing Date: 12 March 1997 (12.03.97) (30) Priority Data: 08/614,593 13 March 1996 (13.03.96) US (60) Parent Application or Grant (63) Related by Continuation US 08/614,593 (CON) Filed on 13 March 1996 (13.03.96) (71) Applicant (for all designated States except US): UNIVERSITY TECHNOLOGIES INTERNATIONAL INC. [CA/CA]; Suite 204, 609 - 14 Street N.W., Calgary, Alberta T2N 2A1 (CA). (72) Inventors; and (75) Inventors/Applicants (for US only): CERI, Howard [CA/CA]; 3824 Brooklyn Crescent N.W., Calgary, Alberta T2N 1N4 (CA). OLSON, Merle, Edwin [CA/CA]; 5420 Dalrymple Crescent N.W., Calgary, Alberta, T3A 1R3 (CA). MORCK, Douglas, Walter [CA/CA]; 208 Mountain Circle, Airdrie, Alberta T4A 1X4 (CA). READ, Ronald, Rae [CA/CA]; 63 Millband Close S.W., Calgary, Alberta T2Y 2E9 (CA).	BURET, Andre, Gerald [CA/CA]; 4523 - 41 Street N.W., Calgary, Alberta T3A 0N3 (CA). (74) Agent: LAMBERT, Anthony, R.; Thompson Lambert, Suite 103, 10328 - 81 Avenue, Edmonton, Alberta T6E 1X2 (CA). (81) Designated States: AU, CA, JP, US, European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE). Published <i>With international search report.</i>	

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(57) Abstract

Biofilm forming organisms are incubated to form a biofilm on projections by providing a flow of liquid growth medium across projections, the direction of the flow of liquid being repeatedly changed, and an assay made of the resulting biofilm. Biofilm forming organisms are incubated to form a biofilm on projections arranged in rows, with several projections in each row, while providing a flow of liquid growth medium across each row of projections, and an assay made of the resulting biofilm. Sensitivity of the biofilm to antimicrobial reagent may be determined by treating the projections with antimicrobial reagent before carrying out the assay, by treating each row of projections with a different antimicrobial reagent, and each of the projections in a row with a different concentration of antibacterial reagent. A biofilm assay device includes a vessel including at least one channel for flow of liquid growth medium, projections arranged in at least one row and having a support for supporting the projections within the channel, and a tilt table to flow liquid growth medium along each channel in different directions across the projections. A further biofilm assay device includes a vessel including channels for flow of liquid growth medium, projections arranged in rows and having a support for supporting the projections within the channels, and a rocking table to rock the vessel and flow liquid growth medium along each channel across the projections.

5 **TITLE OF THE INVENTION:** BIOFILM INCUBATION**FIELD OF THE INVENTION**

 This invention relates to methods and apparatus
for the incubation and analysis of biofilms, and analysis
10 of sensitivity of biofilms to antimicrobial reagents.

BACKGROUND OF THE INVENTION

 Extensive study into the growth properties of
bacteria in recent years has shown that they form complex
layers that adhere to surfaces. These complex forms of
15 bacteria are known as biofilms, or sessile bacteria.
Biofilms may cause problems in a variety of areas including
the bodies of humans and animals, food processing, health
care facilities, metal-working shops, dairy farms and other
industries.

20 It is now widely known that bacteria in the form
of biofilms are more resistant to antimicrobial reagents
than planktonic bacteria. Yet testing for the presence of
bacteria and the testing of the efficacy of antibiotics
against bacteria has traditionally involved testing for
25 planktonic bacteria. Thus, bacterial inhibitory
concentration of the antimicrobial reagent may be
underestimated, with the result that the wrong
antimicrobial reagent or wrong amount of antimicrobial
reagent may be used for the treatment of the bacteria.

30 One type of device for monitoring biofilm buildup
is described in the Canadian Journal of Microbiology
(1981), volume 27, pages 910 to 917, in which McCoy et al
describe the use of a so-called Robbins device which
comprises a tube through which water in a recycling circuit
35 can flow. The tube has a plurality of ports in its walls,
each being provided with a stud having a biofoulable
surface and being capable of being retained in the port in
fixed relationship with respect to the tube so that the
biofoulable surface forms part of the internal surface of

the tube. The studs may be removed from the ports after a desired time interval and the test surfaces by microscopy of the surfaces analyzed for the growth of microorganisms or by removal of the microorganisms from the surfaces and subsequent estimation of the degree of growth. The number of microorganisms can be estimated for instance by physical or chemical means, e.g. by detection of bacterial ATP or by further culturing the microorganisms and analyzing the products.

10 In another device described in United States patent no. 5,349,874, biofilm growth in a water carrying conduit is determined by providing plural removable studs in the conduit or in a second conduit parallel to the first. The studs may be removed for analysis of biofilm on the studs. Such devices as the Robbins device, or others using removable studs in a single conduit, result in rather lengthy processing times, and do not provide rapid response times for the testing of several different antimicrobial reagents.

20 In a still further device, described in "Simple Method for Measuring the Antibiotic Concentration Required to Kill Adherent Bacteria", Miyake et al, Chemotherapy 1992; 38, 286-290, staphylococcus aureus cells adhered to the bottom of a 96 well plastic tissue culture plate were treated with serially diluted antibiotic solutions, and viability of the cells was judged by their growth after a further 24 hours incubation. This method has the disadvantage of inconsistent colonization of sessile bacteria and settling of planktonic bacteria.

30 The device described in this patent document allows for an efficient and automated biofilm killing assay that has particular use with the 96 well platform common to many diagnostic assay systems.

SUMMARY OF THE INVENTION

There is therefore provided in accordance with one aspect of the invention, a method of growing a biofilm, in which biofilm forming organisms are incubated to form a biofilm on plural biofilm adherent sites by providing a flow of liquid growth medium across the plural biofilm adherent sites, the direction of the flow of liquid being repeatedly changed.

In a further aspect of the invention, biofilm forming organisms are incubated to form a biofilm on plural biofilm adherent sites arranged in plural rows, with plural biofilm adherent sites in each row, while providing a flow of liquid growth medium across the plural biofilm adherent sites.

In a further aspect of the invention, an assay is made of a characteristic of the resulting biofilms.

In a further aspect of the invention, the characteristic of the biofilm is the sensitivity of the biofilm to antimicrobial reagent and the method further includes, before assaying the biofilm, treating the biofilm adherent sites with antimicrobial reagent.

In a further aspect of the invention, there is also included the step of, after treating the biofilm adherent sites with antimicrobial reagent, dislodging the biofilm from the biofilm adherent sites and further incubating the biofilm. Dislodging the biofilm from the biofilm adherent sites may include dislodging the biofilm from each biofilm adherent site into a separate well of a microtiter plate.

When the biofilm adherent sites are formed in rows, treating the biofilm adherent sites with an antimicrobial reagent may include treating each row of biofilm adherent sites with a different antimicrobial reagent, and treating each of the biofilm adherent sites in

a row with a different concentration of antimicrobial reagent.

5 In a further aspect of the method of the invention, different biofilm adherent sites are treated with different antimicrobial reagents, such as different combinations of antimicrobial reagents as might be used in testing the efficacy of various modifications of a single antimicrobial reagent.

10 Preferably, the flow direction of the liquid growth medium is repeatedly reversed. In this aspect of the invention, the liquid growth medium may flow in channels of a vessel, and the direction of flow of the liquid growth medium is reversed by rocking of the vessel.

15 In a further aspect of the invention, the biofilm adherent sites are projections from a lid and incubating the biofilm includes suspending the projections in liquid growth medium in the channels while rocking the vessel so as to provide shear forces on the biofilm during growth of the biofilm.

20 There is further provided, in accordance with an aspect of the invention, apparatus for analyzing biofilms, the apparatus comprising a vessel including at least one channel for flow of liquid growth medium. Plural biofilm adherent sites are arranged in at least one row and have a support for supporting the plural biofilm adherent sites within the channel.

25 In accordance with a further aspect of the apparatus according to the invention, there is provided means to flow liquid growth medium along each channel, preferably in different directions, across the plural biofilm adherent sites.

30 In accordance with a still further aspect of the apparatus of the invention, there is provided means to avoid contamination of the inside of the vessel.

Preferably, the plural biofilm adherent sites are formed in plural rows, with plural sites in each row, and the vessel includes plural channels, with one channel for each row of plural biofilm adherent sites.

5 In a further aspect of the invention, the support for the plural biofilm adherent sites forms a lid for the vessel.

In a still further aspect of the invention, the means to flow liquid growth medium across the plural
10 biofilm adherent sites is a tilt table.

These and other aspects of the invention will be made apparent in the description and claims that follow.

15 **BRIEF DESCRIPTION OF THE DRAWINGS**

There will now be described preferred embodiments of the invention, with reference to the drawings, by way of illustration, in which like numerals denote like elements and in which:

20 Fig. 1 is a bottom view of plural biofilm adherent sites on a lid of a vessel;

Fig. 2 is a top view of a vessel for receiving the plural biofilm adherent sites of Fig. 1;

25 Fig. 3 is a side view, partly broken away, of the lid and vessel of Figs. 1 and 2;

Fig. 4 is a side view schematic of a lid and vessel combination as shown in Fig. 3 on a tilt table;

Fig. 5 is a top view of a 96 well plate for use with the invention; and

Fig. 6 is a side section of hollow projection for use with the invention showing how it may be sealed.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS/BEST MODE FOR CARRYING OUT THE INVENTION

As shown most particularly in Figs. 1, 2 and 3, the biofilm assay device includes a biofilm lid 10 composed of ELISA grade plastic or other suitable material (eg. stainless steel, titanium) with projections 12 from the lid 10. The projections 12 form biofilm adherent sites to which a biofilm may adhere. The projections 12 are preferably formed in at least eight rows 14 of at least twelve projections each. Other numbers of rows or numbers of projections in a row may be used, but this is a convenient number since it matches the 96 well plates commonly used in biomedical devices. Additional projections as shown may be used to determine the initial biofilm concentration after incubation. The exemplary projections 12 shown are about 1.5 cm long and 2 mm wide.

The biofilm assay device also includes a vessel 20 which includes a liquid holding basin 22 divided into plural channels (troughs) 24 by moulded ridges 26. The channels 24 are wide enough to receive the projections 12. There should be one channel 24 for each projection 12 of any given row 14. The lid 10 forms a support for the projections 12 for supporting the biofilm adherent sites within the channels 24. The lid 10 has a surrounding lip 16 that fits tightly over a surrounding wall 28 of the vessel 20 to avoid contamination of the inside of the vessel during incubation.

If existing devices are used to carry out the invention, then they should be modified for use with the invention. In the case of the Falcon system, wherein projections are fitted in removable strips, the strips

should be sealed, for example by using a plastic sheet placed over the strips. In the Falcon system, there is also a trough barrier that extends across the entire vessel. This isolates one channel, and if the Falcon device is to
5 be used, should be removed or modified to terminate like one of the ridges 26.

If the NUNC system is used, which uses hollow projections, as for example shown in Fig. 6, a sheet should also be used to cover the projections in the case when they
10 are broken off. Thus, as shown in Fig. 6, the projection 12a is covered with a sheet 13 to prevent contamination of the inside of the vessel. The NUNC device also requires modification of the connection of the lid to the vessel in order to avoid contamination of the inside of the vessel,
15 such as by raising an internal barrier to seal against the lid.

The biofilm incubation vessel 20 serves two important functions for biofilm development. The first is as a reservoir for liquid growth medium containing the
20 biofilm forming organisms which will form a biofilm on the projections 12 of the biofilm lid 10. The second function is to generate shear force across the projections, which allows for optimal biofilm production on the projections. The biofilm forming organisms may be for example, bacteria,
25 yeast and fungi, such as filamentous fungi.

As shown, in Fig. 4, shear force on the projections 12 is generated by rocking the vessel 20 with lid 10 on a tilt table 30. The projections 12 sit suspended in the channels 24, so that the tips of the projections 12
30 may be immersed in liquid growth medium flowing in the channels 24. The ridges 26 channel the liquid growth medium along the channels 24 past and across the projections 12, and thus generate a shear force across the projections. Rocking of the vessel 10 causes a repeated

change in direction of flow, in this case a repeated reversal of flow of liquid growth medium, across the projections 10, which helps to ensure a biofilm of equal proportion on each of the projections 12 of the lid 10. While it is possible to grow biofilm with only one direction of flow of liquid growth medium, the use of an array of projections 12 suspended in several channels makes the arrangement difficult to construct, since then some method would need to be found to recirculate fluid around from one end of each channel to the other end. Rocking of the vessel, with liquid flowing backwards and forwards along the channels, provides an excellent biofilm growth environment that simulates natural occurring conditions of turbulent flow.

Each projection 12 and each channel 24 should have substantially the same shape (within manufacturing tolerances) to ensure uniformity of shear flow across the projections during biofilm formation. In addition, the uniform channels 24 should all be connected so that they share the same liquid nutrient and mixture filling the basin 22. With sharing of the same biofilm forming soup and channel configuration being the same for each channel, biofilms are produced at each projection that are equivalent for the purpose of testing antimicrobial reagents. In this way, different concentrations of different antibiotics may be compared to each other without regard to positional variance of the projections. Biofilms thus produced are considered to be uniform. Results have been obtained within $P < .05$ for random projections on the plate.

Sensitivity of a biofilm to antibiotic or biocide, referred to in this patent document collectively as "antimicrobial reagent", is measured by treating the biofilm adherent sites with an antimicrobial reagent, and

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then assaying the biofilm. This may be accomplished by placing the lid 10, which was colonized with a bacterial biofilm in an incubation vessel 20, into a conventional 96 well plate 40 such as illustrated in Fig. 5, the number of wells 42 being determined by the number of projections 12, in which growth medium containing antibiotic or biocide dilutions has been dispensed. The lid 10 and plate 40 fit such that bacterial contamination from outside the plate cannot take place. Projections 12 that have been incubated in the same channel 24 of the vessel 20 should each be treated with a different antimicrobial reagent. In this manner, consistent results may be obtained since the growth conditions in any one channel will be very similar along the entire channel and thus for each projection 12 suspended in that channel. This helps improve the reliability of treatment of different projections 12 with different antimicrobial reagents.

In addition, for the step of incubating the biofilm after treatment with an antimicrobial reagent, a conventional cover (not shown) made of the same plastic as the 96 well plate 40 is required so as to prevent contamination of the 96 well plates 40 during incubation and to form a very low profile with the plate 40 as to make the covered plate accessible to standard ELISA plate readers. For each assay, two 96 well plates 40 and plate covers will be needed to provide the traditional Minimum Inhibitory Concentration (MIC) and the Minimum Biofilm Eliminating Concentration (MBEC).

Procedure

For each organism a biofilm growth curve should be determined to ensure the biofilm has reached satisfactory proportion to be tested for antibiotic/biocide sensitivity.

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Day 1 - incubate bacteria of choice in a suitable growth medium, which may be tryptic soy broth (TSB), overnight with shaking at a suitable incubation temperature under optimal oxygen tension. The temperature may be, in each case of incubation described in this patent disclosure, 37°C .

Day 2 - Fill the vessel 20 of the biofilm assay device system with 20 ml of a 2% overnight culture suspended in fresh growth medium (eg TSB); cover with projection covered lid 10 and incubate on a rocking platform (Bellco Rocker Platform), for example at setting 3 in a 37°C incubator. Aseptically remove 2 projections per hour starting at hour 2 of the growth curve and continuing for 7 hours. Each projection is rinsed by gentle dipping in sterile phosphate buffered saline (PBS), and then placed in 1 ml of sterile phosphate buffered saline and sonicated for 5 min. using a DoALL Ultrasonic Cleaner at 21 kc to dislodge the biofilm. The sonicate is serially diluted (10^{-1} through 10^{-6}) in phosphate buffered saline and spot plated to determine biofilm count.

Day 3 - Plates are counted to determine the rate of colonization and to calculate the incubation time required to achieve a biofilm of $\sim 10^5$ colony forming units (cfu)/ projection, which is an optimal biofilm thickness for measuring antibiotic/ biocide killing.

MBEC Assay

Day 1 - Inoculate growth medium (eg TSB) with bacteria and grow overnight, for example at 37°C with shaking.

Day 2: (1) Place 20 ml of a 2% overnight culture diluted in fresh growth medium (for example TSB) in the vessel 20 of the biofilm assay device system, cover with the biofilm lid 10 and incubate on the rocking platform 30,

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for example at 37°C for the time required to reach a biofilm of $\sim 10^5$ cfu/projection 12. Change of direction of flow of liquid growth medium caused by the rocking of the tilt table 30 enhances the growth of a biofilm.

5 (2) While the biofilm is incubating, in a sterile hood prepare antibiotic stock solutions at 5 mg/ml in sterile double distilled water (ddw) or biocide as per directions of the producer, and prepare antibiotic/biocide dilutions in growth medium (for example TSB) in a 96 well
10 plate. Up to 8 different antibiotics or biocides can be tested by using 1 row (A-H) for each antimicrobial reagent. Plates are set up as follows:

Rows A-H each contain a specific antibiotic/biocide. Wells in each row are set up with
15 different concentrations of antimicrobial reagent as follows:

Well #1 TSB no antibiotic
Well #2 TSB plus 1 mg/ml antibiotic
Well #3 TSB plus 2^{-2} mg/ml antibiotic
20 Well #4 TSB plus 2^{-3} mg/ml antibiotic
Well #5 TSB plus 2^{-4} mg/ml antibiotic
Well #6 TSB plus 2^{-5} mg/ml antibiotic
Well #7 TSB plus 2^{-6} mg/ml antibiotic
Well #8 TSB plus 2^{-7} mg/ml antibiotic
25 Well #9 TSB plus 2^{-8} mg/ml antibiotic
Well #10 TSB plus 2^{-9} mg/ml antibiotic
Well #11 TSB plus 2^{-10} mg/ml antibiotic
Well #12 TSB plus 2^{-11} mg/ml antibiotic

(3) After the incubation period, break off 2
30 projections 12 (from an area of lid 10 that will not be used in the antibiotic assay, i.e. an unused row) rinse and sonicate in PBS, dilute and spot on plates to determine the initial biofilm concentration (exactly as done on the growth curve). Rinse the remaining projections in PBS

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using a troughed vessel 20 and place the colonized projections into the 96 well antibiotic plate and incubate overnight at 37°C.

Day 3: Depending on the technology used to assay the incubated and treated biofilm, the biofilm may be assayed in place, without dislodging, or may be dislodged from the projections and then assayed, or may be dislodged, further incubated and then assayed. The following steps show an example in which the biofilm is dislodged, incubated and assayed.

(1) In a sterile hood remove biofilm lid 10 from the 96 well antibiotic plate (do not discard the plate), rinse the projections in a 96 well plate containing sterile PBS, then place the lid 10 in a fresh 96 well plate containing fresh TSB (0.25 ml per well) and sonicate the entire biofilm lid 10 to dislodge the surviving biofilm bacteria, with the biofilm from any one projection 12 being dislodged into a separate well of the 96 well plate. Again in the hood remove the biofilm lid 10 and replace with a flat cover.

(2) Read the antibiotic plate at 490 nm for indication of planktonic survival, or use some other method, such as are known in the art, for assaying planktonic survival.

(3) From the freshly sonicated plate remove 0.02 ml of the medium from each well and spot plate neat; and 0.025 ml from each well to prepare a serial dilution (10^{-1} to 10^{-6}) and spot plate 0.02 ml (dilutions can be done in microtiter plates, one for each antibiotic). Place the plate containing the remaining medium and bacteria to incubate at 37°C, overnight.

Day 4: Assay the sessile survival, by for example reading the plate incubated overnight at 490 nm or by counting the colonies on the plates to determine the actual

number of surviving bacteria, or by using some other method known in the art.

Several different conventional methods may be used to count the bacteria. It may be done by incubating the sonicated bacteria, taking serial dilutions and visually counting the colony forming units, or automated methods may be used, as for example using an optical reader to determine optical density. It has been found however that the optical reader of turbidity is too imprecise for practical application, and it is preferred that vital dye technology be applied to automate the measurement of viability, by treating the biofilm with a vital dye, and measuring the intensity of light given off by the dyed biofilm. In the case of using vital dye technology, the biofilm need not be further incubated. In a further embodiment, the assay may be carried out by sonicating the cells until they lyse and release ATP and then adding luciferase to produce a mechanically readable light output. In a still further embodiment, the assay may be carried out directly on the biofilm on the projections using a confocal microscope, although it should be considered that this is difficult to automate. In the examples that follow, the results are obtained from a manual count following serial dilution. Examples are given to show a comparison between counts of planktonic bacteria and counts of sessile bacteria for the same growth conditions.

Example #1

Table 1 shows the results of incubation of staphylococcus epidermidis biofilm on projections 12 in channels 24 while rocking the vessel 20, followed by treatment with antibiotics A (Ancef, cefazolin), B (Orbenin-2000, cloxacillin), C (Primaxin, imipenem and cilastatin), D (Vancomycin), E (Dalacin, clindamycin) and F (Tazadine, ceftazidine) in doubling dilutions. The

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antibiotic was applied to the wells 2-12 in rows A-F of a 96 well plate as follows: well 2: no antibiotic, well 3: 1000 $\mu\text{g/mL}$, well 4: 500 $\mu\text{g/mL}$ well 12: 2 $\mu\text{g/mL}$. Results are given in Table 1 terms of cfu/projection from a manual reading.

TABLE 1

		2	3	4	5	6	7	8	9	10	11	12
10	A	5.5 $\times 10^4$	1.1 $\times 10^4$	4.5 $\times 10^3$	4.0 $\times 10^3$	4.5 $\times 10^3$	1.2 $\times 10^4$	6.0 $\times 10^4$	5.5 $\times 10^4$	3.0 $\times 10^5$	1.4 $\times 10^5$	2.1 $\times 10^5$
	B	1.7 $\times 10^4$	6.0 $\times 10^2$	1.1 $\times 10^3$	1.2 $\times 10^3$	2.0 $\times 10^3$	2.0 $\times 10^3$	2.2 $\times 10^4$	1.6 $\times 10^3$	1.6 $\times 10^4$	2.6 $\times 10^4$	9.5 $\times 10^4$
15	C	9.0 $\times 10^3$	8.5 $\times 10^2$	1.2 $\times 10^3$	1.9 $\times 10^3$	3.2 $\times 10^4$	6.5 $\times 10^4$	5.5 $\times 10^4$	6.5 $\times 10^4$	1.0 $\times 10^5$	1.5 $\times 10^5$	1.1 $\times 10^6$
	D	1.2 $\times 10^4$	1.1 $\times 10^3$	7.0 $\times 10^2$	1.3 $\times 10^3$	1.9 $\times 10^3$	6.5 $\times 10^3$	8.0 $\times 10^3$	2.5 $\times 10^3$	2.5 $\times 10^3$	5.0 $\times 10^3$	2.5 $\times 10^5$
20	E	1.0 $\times 10^4$	3.5 $\times 10^3$	6.5 $\times 10^3$	5.0 $\times 10^3$	1.2 $\times 10^4$	1.0 $\times 10^4$	7.5 $\times 10^4$	8.0 $\times 10^4$	2.5 $\times 10^4$	8.5 $\times 10^4$	1.9 $\times 10^6$
25	F	5.5 $\times 10^4$	1.9 $\times 10^3$	2.3 $\times 10^3$	4.5 $\times 10^3$	3.5 $\times 10^4$	1.4 $\times 10^4$	1.9 $\times 10^5$	2.5 $\times 10^4$	4.0 $\times 10^4$	3.5 $\times 10^4$	2.7 $\times 10^5$

Table 2 gives the optical density readings of turbidity of the same staphylococcus epidermidis biofilm, treated in the same manner as the samples of Table 1, to show a comparison between the manually counted cfu and the automated reading.

TABLE 2

		2	3	4	5	6	7	8	9	10	11	12
	A	.951	.856	.971	1.010	.961	.984	.993	1.036	.996	.967	.980
	B	.900	.935	.890	.915	.902	.998	.944	.919	.909	.963	.938
35	C	.914	.843	.768	.792	.870	.907	.869	.927	.863	.908	.959
	D	.898	.524	.708	.805	.884	.898	.854	.835	.901	.907	.958
	E	.901	.869	.894	.851	.858	.936	.873	.907	.874	.937	.938
	F	.905	.897	.888	1.013	.855	.992	.903	.920	.850	.843	.902

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Table 3 shows the optical density readings of turbidity of staphylococcus epidermidis planktonic bacteria incubated and treated with antimicrobial reagent under the same conditions as for the results shown in Table 1. This table clearly shows how the assay of planktonic bacteria gives a lower count in many instances than the assay of sessile bacteria incubated and treated under the same conditions.

TABLE 3

	2	3	4	5	6	7	8	9	10	11	12
A	.959	.353	.381	.411	.403	.409	.413	.411	.599	.574	.610
B	.927	.346	.375	.400	.404	.442	.422	.408	.430	.562	.585
C	.950	.409	.411	.431	.426	.447	.475	.476	.504	.553	.620
D	.907	.351	.374	.403	.410	.409	.421	.404	.415	.413	.406
E	.903	.861	.845	.907	.913	.887	.959	.878	.910	.890	.929
F	.905	.359	.383	.397	.410	.466	.540	.615	.627	.694	.853

Example #2

Table 4 shows the results of incubation of staphylococcus aureus biofilm on projections 12 in channels 24 while rocking the vessel 20, followed by treatment with antibiotics A (Ancef, cefazolin), B (Orbenin-2000, cloxacillin), C (Primaxin, imipenem and cilastatin), D (Vancomycin), E (Dalacin, clindamycin) F (Tazadine, ceftazidine) and G (Ciprofloxacin) in doubling dilutions. The antibiotic was applied to the wells 2-12 of the rows A-G of a 96 well plate as follows: well 2: no antibiotic, well 3: 1000 µg/mL, well 4: 500 µg/mL well 12: 2 µg/mL.

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TABLE 4

		2	3	4	5	6	7	8	9	10	11	12
5	A	2.0 $\times 10^5$	0	0	0	50	50	50	50	5.0 $\times 10^2$	1.0 $\times 10^4$	2.0 $\times 10^4$
	B	5.0 $\times 10^5$	0	50	0	0	50	1.0 $\times 10^3$	0	4.5 $\times 10^2$	50	9.0 $\times 10^2$
10	C	1.5 $\times 10^5$	0	0	0	0	0	0	0	0	0	1.0 $\times 10^2$
	D	6.0 $\times 10^5$	0	0	0	0	0	0	0	0	0	1.5 $\times 10^4$
15	E	4.5 $\times 10^5$	0	0	0	0	0	5.0 $\times 10^2$	50	0	0	2.0 $\times 10^3$
20	F	2.0 $\times 10^5$	0	1.0 $\times 10^2$	0	1.0 $\times 10^2$	50	0	0	1.0 $\times 10^5$	4.0 $\times 10^5$	9.0 $\times 10^5$
	G	3.5 $\times 10^5$	0	0	0	50	1.0 $\times 10^2$	50	0	0	0	0

Table 5 shows the optical density readings of turbidity of the same staph. aureus biofilm, treated in the same manner as the samples of Table 4, to show a comparison between the manually counted cfu and the automated reading.

TABLE 5

		2	3	4	5	6	7	8	9	10	11	12
30	A	.963	.333	.414	.461	.758	.666	.647	.649	.673	.845	.853
	B	.924	.073	.626	.072	.791	.771	.832	.071	.803	.858	.838
	C	.913	.073	.073	.071	.073	.073	.071	.072	.071	.617	.822
	D	.903	.073	.073	.071	.093	.071	.071	.070	.071	.073	.903
	E	.942	.073	.074	.070	.071	.072	.487	.627	.069	.096	.867
35	F	.938	.779	.830	.777	.739	.719	.840	.806	.882	.924	.916
	G	.929	.073	.072	.073	.778	.822	.793	.121	.071	.072	.068

Table 6 shows the optical density readings of turbidity of staph. aureus planktonic bacteria incubated and treated with antimicrobial reagent under the same conditions as for the results shown in Table 4. This table

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clearly shows how the assay of planktonic bacteria gives a lower count in many instances than the assay of sessile bacteria incubated and treated under the same conditions.

TABLE 6

	2	3	4	5	6	7	8	9	10	11	12
5											
A	.935	.064	.061	.065	.067	.066	.067	.068	.063	.058	.057
B	.691	.070	.071	.077	.071	.069	.069	.073	.068	.067	.059
C	.880	.116	.106	.097	.087	.081	.078	.078	.081	.074	.072
D	.891	.071	.074	.081	.077	.075	.078	.078	.076	.075	.075
10											
E	.857	.069	.074	.080	.077	.080	.075	.078	.076	.084	.264
F	.895	.073	.076	.081	.079	.076	.079	.078	.111	.564	.717
G	.895	.094	.072	.077	.077	.079	.077	.077	.080	.074	.069

Example #3

15 Table 7 shows the results of incubation of Escherichia coli biofilm on projections 12 in channels 24 while rocking the vessel 20, followed by treatment with antibiotics A (Ticarcillin, Sigma T-5639), B (Carbenicillin, Sigma C-1389), C (Tobramycin, Sigma T-4014), D (Gentamicin sulphate, Sigma G-3632), E (Ampicillin, Sigma A-9518), F (Tazadine, ceftazidine), G (Primaxin, imipenem and cilastatin) and H (Ciprofloxacin) in doubling dilutions. The Escherichia coli was started with an inoculum of 2% of overnight growth in fresh TSB. 20 ml were placed in the main basin of the vessel 20 (channels 2-12), with 1.5 ml in the channel 1 to provide a sampling of initial colonization on the projections of the first row. The initial biofilm was colonized for four hours. The antibiotic was applied to the wells 2-12 of the rows A-H of a 96 well plate as follows: well 2: no antibiotic, well 3: 1000 $\mu\text{g/mL}$, well 4: 500 $\mu\text{g/mL}$ well 12: 2 $\mu\text{g/mL}$. 250 μL final volume of diluted antibiotic was applied to the wells.

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TABLE 7

		2	3	4	5	6	7	8	9	10	11	12
5	A	1.9 $\times 10^5$	0	0	0	0	0	3.5 $\times 10^2$	2.0 $\times 10^2$	2.5 $\times 10^2$	1.5 $\times 10^4$	3.0 $\times 10^4$
	B	2.0 $\times 10^8$	1.5 $\times 10^2$	0	0	0	1.5 $\times 10^2$	0	2.0 $\times 10^2$	2.0 $\times 10^3$	1.2 $\times 10^5$	1.1 $\times 10^7$
10	C	1.0 $\times 10^7$	0	0	0	0	0	0	0	2.5 $\times 10^4$	1.1 $\times 10^6$	1.3 $\times 10^7$
	D	1.5 $\times 10^7$	0	0	0	0	0	0	0	1.5 $\times 10^3$	1.5 $\times 10^6$	2.5 $\times 10^6$
15	E	8.5 $\times 10^7$	2.0 $\times 10^5$	0	1.1 $\times 10^5$	4.0 $\times 10^5$	2.0 $\times 10^6$	0	1.5 $\times 10^5$	8.5 $\times 10^5$	6.5 $\times 10^7$	5.0 $\times 10^7$
20	F	1.2 $\times 10^8$	0	0	0	0	0	0	0	2.0 $\times 10^3$	1.5 $\times 10^4$	1.5 $\times 10^4$
	G	1.0 $\times 10^7$	0	0	2.0 $\times 10^2$	0	0	0	0	0	0	0
25	H	1.1 $\times 10^3$	0	0	0	0	0	0	1.5 $\times 10^2$	0	0	2.0 $\times 10^2$

Table 8 shows the optical density readings of turbidity of the same Escherichia coli biofilm, treated in the same manner as the samples of Table 7, to show a comparison between the manually counted cfu and the automated reading.

TABLE 8

	2	3	4	5	6	7	8	9	10	11	12
A	1.296	.120	.118	.121	1.064	1.099	.661	1.097	1.130	1.244	1.250
B	1.328	1.181	.669	1.247	.876	.769	.653	1.114	1.177	1.192	1.297
C	1.289	.121	.122	.121	.122	.122	.119	.666	.647	.829	1.299
D	1.260	.124	.121	.123	.121	.132	.123	.672	1.184	1.296	1.294
E	1.345	1.053	.124	1.046	1.114	1.544	.797	1.334	1.303	1.573	1.332
F	1.341	.121	.123	1.158	.121	.125	.120	.123	1.152	1.249	1.268
G	1.313	.124	1.142	1.215	1.235	1.284	.773	1.180	1.117	1.274	.637
H	1.317	.122	.126	.118	.119	.123	.786	1.011	.969	.940	1.233

Table 9 shows the optical density readings of turbidity of Escherichia coli planktonic bacteria incubated and treated with antimicrobial reagent under the same conditions as for the results shown in Table 7. This table clearly shows how the assay of planktonic bacteria gives a lower count in many instances than the assay of sessile bacteria incubated and treated under the same conditions.

TABLE 9

	2	3	4	5	6	7	8	9	10	11	12
A	1.080	.119	.132	.137	.135	.137	.138	.154	.143	.159	.273
B	1.212	.120	.135	.134	.134	.132	.137	.136	.185	.252	.652
C	.828	.122	.132	.136	.136	.133	.141	.133	.588	.601	.873
D	1.040	.125	.133	.138	.135	.141	.141	.136	.334	.837	.936
E	1.040	.124	.129	.133	.138	.142	.139	.254	.231	.629	1.425
F	1.098	.123	.129	.134	.137	.128	.137	.137	.140	.147	.152
G	.560	.206	.190	.177	.161	.146	.148	.141	.135	.139	.153
H	1.147	.131	.136	.136	.140	.132	.139	.136	.138	.133	.138

5 The concentration (MBEC) of antimicrobial reagent at which the survival of bacteria falls to zero may be assessed readily from the assay. Likewise, the MIC may also be determined from the assay.

10 The inventors have found that in some instances a biofilm will not form without the inclusion of host components in the biofilm. Host components may therefore be added to the growth medium in the vessel during incubation of the bacteria or other biofilm forming organisms to form the biofilm. Host components that may be added include
15 serum protein and cells from a host organism. For the testing of the effect of different host cells and components, the ends 25 of the channels 24 may be sealed by walls to prevent growth medium in one channel from flowing into another, thus isolating the biofilm growth in each
20 channel from other channels.

The device thus described may also be used to test coatings used to inhibit biofilm growth and to test coatings which may enhance biofilm formation. In an initial step, the projections 12 may be coated with a coating to be tested, and then the biofilm grown on the projections. The biofilm may then be assayed, or treated with antimicrobial reagent and then assayed. The assay may be in situ or after dislodging of the biofilm. Different coatings may be tested on different rows of pegs. Enhanced biofilm formation may be used to create large viable biofilms for bio-fermentation under varying growth conditions at different sites. In this instance, the assay step is not required, except to assay the fermentation product, if desired, and the biofilm is incubated in the wells of, for example, a 96 well plate as a micro-reactor vessel. In general, the biofilm incubation system disclosed may be used whenever rapid and uniform growth of biofilm is desired at plural sites.

While the preferred technique is to reverse flow of the liquid growth medium, the array could have a unidirectional flow of liquid, with recircling of fluid from one end of each channel to the other end of the same channel, but this complicates the arrangement.

The method of the invention may be used to screen potential antimicrobial candidates for efficacy. After incubation of the biofilm each biofilm adherent site may be treated with a different antimicrobial reagent or combination of antimicrobial reagents. For example, the different reagents may be modifications of a single reagent, such as might be produced in recombinatorial development of antibiotics. In a plate with 340 pins, 340 different combinations of antimicrobial reagents may be tested.

A person skilled in the art could make immaterial modifications to the invention described in this patent document without departing from the essence of the invention that is intended to be covered by the scope of
5 the claims that follow.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. Apparatus for making biofilms, the apparatus comprising:

a vessel including plural channels for flow of liquid-growth medium;

plural biofilm-adherent sites arranged in plural rows and a support for supporting those plural biofilm-adherent sites within said channels, the support for the plural biofilm-adherent sites forming a lid for the vessel; and

means for causing the liquid-growth medium to flow along each channel and across the plural biofilm-adherent sites supported within the channel.

2. The apparatus of claim 1, in which each channel has substantially the same shape.

3. The apparatus of claim 1 or 2, in which the plural biofilm-adherent sites are projections from the lid.

4. Apparatus for making biofilms, the apparatus comprising:

a vessel including a plurality of recesses for receiving a liquid-growth medium; and

a plate forming a cover for the vessel, the plate including a plurality of protrusions which form biofilm-adherent sites arranged to be received within the plurality of recesses.

5. The apparatus of claim 4, further comprising a movable support for the vessel which causes the liquid-growth medium to flow over the protrusions within the recesses.

6. The apparatus of claim 4 or 5, wherein the plurality of recesses are a plurality of channels.

7. The apparatus of claim 4, 5 or 6, wherein the protrusions are arranged in a plurality of rows and a plurality of columns.

8. The apparatus of any one of claims 4 to 7, wherein the plurality of recesses each have substantially the same shape.

9. The apparatus of any one of claims 4 to 8, wherein the plate is substantially impermeable to contaminants.

10. The apparatus of claim 9, wherein the plate remains substantially impermeable to contaminants both before and after the protrusions are removed from the plate.

11. The apparatus of any one of claims 4 to 10, further comprising a coating on the plurality of protrusions.

12. The apparatus of claim 11, wherein the coating inhibits or enhances biofilm growth.

13. Apparatus for making biofilms, the apparatus comprising:

a vessel including plural channels for flow of liquid-growth medium, the plural channels having substantially the same shape;

plural biofilm-adherent sites formed in plural rows with more than one biofilm-adherent site in each row and a support for supporting those plural biofilm-adherent sites

within said channels, the support for the plural biofilm-adherent sites forming a lid for the vessel; and

means for causing the liquid-growth medium to flow along each channel in different directions across the plural biofilm-adherent sites supported within the channel.

14. The apparatus of claim 13, in which the biofilm-adherent sites have substantially the same shape.

15. The apparatus of claim 13 or 14, in which the means for causing flow of the liquid-growth medium across the plural biofilm-adherent sites is a tilt table.

16. Apparatus for making biofilms, the apparatus comprising:

a vessel including plural channels for flow of liquid-growth medium, each of said channels having substantially the same shape;

plural biofilm-adherent sites arranged in plural rows and a support for supporting those plural biofilm-adherent sites within said channels, each of said sites having substantially the same shape, and the support for the plural biofilm-adherent sites forming a lid for the vessel; and

means for causing the liquid-growth medium to flow along each channel and across the plural biofilm-adherent sites supported within the channel.

17. The apparatus of claim 16, in which the means for causing flow of the liquid-growth medium along each channel across the plural biofilm-adherent sites is a tilt table.

18. The apparatus of claim 17, in which the plural biofilm-adherent sites are projections from the lid.

19. Apparatus for growing biofilms, the apparatus comprising:

a vessel including plural channels for flow of liquid-growth medium;

plural biofilm-adherent sites arranged in plural rows and a support for supporting those plural biofilm-adherent sites within said channels, the support for the plural biofilm-adherent sites forming a lid for the vessel; and

means to avoid contamination of the inside of the vessel during incubation.

20. The apparatus of claim 19, in which each channel has substantially the same shape.

21. The apparatus of claim 19 or 20, in which each biofilm-adherent site has substantially the same shape.

22. The apparatus of claim 19, 20 or 21, further including means for causing the liquid-growth medium to flow along each channel across plural biofilm-adherent sites supported within the channel.

23. The apparatus of claim 22, in which the means for causing flow of the liquid-growth medium across the plural biofilm-adherent sites is a tilt table.

24. The apparatus of any one of claims 19 to 23, in which the plural biofilm-adherent sites are projections from the lid.

25. A method of growing a biofilm, the method comprising:

providing a vessel having plural channels for flow of liquid-growth medium and plural biofilm-adherent sites arranged in plural rows and supported within those channels, the support for the plural biofilm-adherent sites forming a lid for the vessel;

providing means for causing liquid-growth medium to flow along each channel and across the plural biofilm-adherent sites supported within the channel;

incubating biofilm-forming organisms on those plural biofilm-adherent sites while causing a flow of liquid-growth medium across the plural biofilm-adherent sites; and

repeatedly changing the direction of flow of liquid-growth medium, thereby creating a biofilm at the plural biofilm-adherent sites.

26. The method of claim 25, further comprising the step of assaying the biofilm at the plural biofilm-adherent sites to analyze the biofilm for an optimal biofilm thickness for sensitivity of the biofilm to an antimicrobial reagent.

27. The method of claim 25 or 26, further comprising the steps of assaying the biofilm at plural biofilm-adherent sites to analyze the sensitivity of the biofilm to antimicrobial reagent, and, before assaying the biofilm, treating the biofilm-adherent sites with antimicrobial reagent.

28. The method of claim 27, further comprising, after treating the biofilm-adherent sites with antimicrobial reagent, dislodging the biofilm from the biofilm-adherent sites before performing the step of assaying the biofilm at

the plural biofilm-adherent sites to analyze the sensitivity of the biofilm to an antimicrobial reagent.

29. The method of claim 28, further including, after dislodging the biofilm from the biofilm-adherent sites, incubating the biofilm.

30. The method of claim 28 or 29, in which dislodging the biofilm from the biofilm-adherent sites includes dislodging the biofilm from each biofilm-adherent site into a separate well of a well plate.

31. The method of any one of claims 27 to 30, in which the biofilm-adherent sites are formed in rows, and treating the biofilm-adherent sites with an antimicrobial reagent includes treating each row of biofilm-adherent sites with a different antimicrobial reagent.

32. The method of claim 31, further including treating each biofilm-adherent site in a row with a different concentration of antimicrobial reagent.

33. The method of any one of claims 27 to 30, further including treating each of the biofilm-adherent sites with a different concentration of antimicrobial reagent.

34. The method of claim 33, further including, before incubating biofilm-forming organisms on plural biofilm-adherent sites, applying a biofilm-resistant coating to the plural biofilm-adherent sites.

35. The method of claim 34, further including applying different coatings to different biofilm-adherent sites.

36. The method of any one of claims 27 to 30, in which different biofilm-adherent sites are treated with different antimicrobial reagents.

37. The method of any one of claims 25 to 36, in which flow direction of the liquid-growth medium is repeatedly reversed.

38. The method of claim 37, in which the liquid-growth medium flows in channels of a vessel, and the direction of flow of the liquid-growth medium is reversed by rocking of the vessel.

39. The method of claim 38, in which the biofilm-adherent sites are projections from the lid, and incubating the biofilm includes suspending the projections in liquid-growth medium in the channels while rocking the vessel so as to provide shear forces on the biofilm during growth of the biofilm.

40. The method of any one of claims 25 to 39, further including incubating the biofilm-forming organisms in the presence of a host component in the liquid-growth medium.

41. The method of any one of claims 25 to 40, further including the step of, after initially incubating the biofilm-forming organisms on plural biofilm-adherent sites to create a biofilm, subsequently incubating the biofilm-forming organisms in separate microtiter plates.

42. The method of any one of claims 25 to 41, wherein the liquid-growth medium flows in a plurality of recesses.

43. The method of claim 42, wherein the biofilm-adherent sites are projections which extend into the plurality of recesses.

44. The method of any one of claims 25 to 43, wherein each of the biofilms are equivalent.

45. The method of any one of claims 25 to 44, wherein bacteria in one or more of the biofilms are different from bacteria in other of the biofilms.

46. The method of claim 45, wherein the bacteria in the biofilms on each biofilm-adherent site is different.

47. A method of making a plurality of biofilms, the method comprising the steps of:

- providing a vessel with a plurality of recesses and with a cover having a plurality of protruding biofilm-adherent sites;

- providing a flowing liquid-growth medium in the recesses of the vessel; and

- incubating biofilm-forming organisms on the biofilm-adherent sites while flowing the liquid-growth medium across the biofilm-adherent sites, so as to form a biofilm on each of the biofilm-adherent sites.

48. The method of claim 47, wherein the liquid-growth medium is caused to flow by placing the vessel on a moving support surface.

49. The method of claim 47 or 48, further comprising a step of dislodging the biofilm from the biofilm-adherent sites.

50. The method of claim 47, 48 or 49, wherein the protruding biofilm-adherent sites are pins which are suspended in the liquid-growth medium in the recesses.

51. The method of any one of claims 47 to 50, wherein the plurality of recesses are a plurality of channels.

52. The method of any one of claims 47 to 51, wherein the protruding biofilm-adherent sites are arranged in a plurality of rows and a plurality of columns.

53. The method of any one of claims 47 to 52, wherein the plurality of recesses have substantially the same shape.

54. The method of any one of claims 47 to 53, wherein the cover remains substantially impermeable to contaminants before and after the protruding biofilm-adherent sites are removed from the cover.

55. The method of any one of claims 47 to 54, further comprising a coating on the plurality of protruding biofilm-adherent sites.

56. The method of claim 55, wherein the coating inhibits or enhances biofilm growth.

57. A method of growing and analyzing a biofilm, the method comprising the steps of:

providing a vessel having plural channels for flow of liquid-growth medium and plural biofilm-adherent sites arranged in plural rows and supported within those channels, the support for the plural biofilm-adherent sites forming a lid for the vessel;

providing means for causing liquid-growth medium to flow along each channel and across the plural biofilm-adherent sites supported within the channel;

incubating biofilm-forming organisms on the plural biofilm-adherent sites arranged in an array while causing a flow of liquid-growth medium across the plural biofilm-adherent sites, the plural biofilm-adherent sites sharing the liquid-growth medium and the direction of flow of liquid-growth medium being repeatedly changed, thereby to create a uniform biofilm at the plural biofilm-adherent sites; and

assaying the biofilm at the plural biofilm-adherent sites to analyze the biofilm for an optimal biofilm thickness for sensitivity of the biofilm to antimicrobial reagent.

58. The method of claim 57, further comprising the steps of assaying the biofilm at plural biofilm-adherent sites to analyze the sensitivity of the biofilm to reagents, and, before assaying the biofilm, treating the biofilm-adherent sites with reagents selected from the group consisting of antibiotics and biocides.

59. The method of claim 58, further comprising, after treating the biofilm-adherent sites with reagents, dislodging the biofilm from the biofilm-adherent sites before performing the assay.

60. The method of claim 59, further including, after dislodging the biofilm from the biofilm-adherent sites, further incubating the biofilm.

61. The method of claim 59 or 60, in which dislodging the biofilm from the biofilm-adherent sites includes dislodging the biofilm from each biofilm-adherent site into a separate well of a well plate.

62. The method of any one of claims 58 to 61, in which the biofilm-adherent sites are formed in rows, and treating the biofilm-adherent sites with reagents includes treating each row of biofilm-adherent sites with a different reagent.

63. The method of claim 62, further including treating each biofilm-adherent site in a row with a different concentration of reagent.

64. The method of any one of claims 57 to 63, in which flow direction of the liquid-growth medium is repeatedly reversed.

65. The method of claim 64, in which the liquid-growth medium flows in channels of a vessel, and the direction of the flow of the liquid-growth medium is reversed by rocking of the vessel.

66. The method of claim 65, in which the biofilm-adherent sites are projections from a lid, and incubating the biofilm includes suspending the projections in liquid-growth medium in the channels while rocking the vessel so as to provide shear forces on the biofilm during growth of the biofilm.

67. The method of any one of claims 57 to 61, further including treating each of the biofilm-adherent sites with a different concentration of reagent.

68. The method of claim 67, further including, before incubating biofilm-forming organisms on plural biofilm-adherent sites, applying a biofilm-resistant coating to the plural biofilm-adherent sites.

69. The method of claim 68, further including applying different coatings to different biofilm-adherent sites.

70. The method of any one of claims 57 to 69, wherein the method is used to analyze biofilm-forming organisms that may grow in a host component and the host component comprises host organisms, the method further including incubating the biofilm-forming organisms in the presence of host organisms in the liquid-growth medium.

71. A method of growing and analyzing biofilm, the method comprising the steps of:

providing a vessel having plural channels for flow of liquid-growth medium and plural biofilm-adherent sites arranged in plural rows and supported within those channels, the support for the plural biofilm-adherent sites forming a lid for the vessel;

providing means for causing liquid-growth medium to flow along each channel and across the plural biofilm-adherent sites supported within the channel;

incubating biofilm-forming organisms on plural biofilm-adherent sites arranged in plural rows, with plural biofilm-adherent sites in each row, while causing a flow of

a liquid-growth medium across the plural biofilm-adherent sites, the plural biofilm-adherent sites sharing the liquid-growth medium, thereby to create a uniform biofilm at each of the plural biofilm-adherent sites; and

assaying the number of organisms forming the biofilm at the plural biofilm-adherent sites to analyze the biofilm for an optimal biofilm thickness for sensitivity of the biofilm to antimicrobial reagent.

72. The method of claim 71, in which providing a flow of liquid-growth medium includes flowing liquid-growth medium backwards and forwards along uniform channels of a vessel, to create a uniform biofilm at each biofilm-adherent site.

73. The method of claim 72, further comprising the steps of assaying the biofilm at plural biofilm-adherent sites to analyze the sensitivity of the biofilm to reagents, and, before assaying the biofilm, treating the biofilm-adherent sites with reagents selected from the group consisting of antibiotics and biocides.

74. The method of claim 73, further comprising, after treating the biofilm-adherent sites with reagents, dislodging the biofilm from the biofilm-adherent sites before assaying the biofilm.

75. The method of claim 74, further including, after dislodging the biofilm, further incubating the biofilm.

76. The method of claim 74 or 75, in which dislodging the biofilm from the biofilm-adherent sites includes dislodging the biofilm from each biofilm-adherent site into a separate well of a well plate.

77. The method of claim 76, in which treating the biofilm-adherent sites with reagents includes treating each row of biofilm-adherent sites with a different reagent.

78. The method of claim 77, further including treating each biofilm-adherent site in a row with a different concentration of reagent.

79. The method of any one of claims 72 to 78, in which the biofilm-adherent sites are projections from a lid, and incubating the biofilm includes suspending the projections in liquid-growth medium in uniform channels of a vessel while rocking the vessel so as to provide uniform shear forces on the projections during growth of the biofilm.

80. The method of any one of claims 71 to 79, in which assaying the biofilm comprises applying a vital dye to the biofilm to form a dyed biofilm which produces light having an intensity, and automatically measuring the intensity of light given off by the dyed biofilm.

81. The method of any one of claims 71 to 80, further including, before incubating the biofilm-forming organisms on the plural biofilm-adherent sites, applying a biofilm-resistant coating to the plural biofilm-adherent sites.

82. The method of claim 81, further including applying different coatings to different biofilm-adherent sites.

83. The method of any one of claims 71 to 82, wherein the method is used to analyze biofilm-forming organisms that may grow in a host component and the host component

comprises host organisms, the method further including incubating the biofilm-forming organisms in the presence of host organisms in the liquid-growth medium.

84. A method of screening antimicrobial agents, the method comprising the steps of:

- providing a vessel having plural channels for flow of liquid-growth medium and plural biofilm-adherent sites arranged in plural rows and supported within those channels, the support for the plural biofilm-adherent sites forming a lid for the vessel;

- providing means for causing liquid-growth medium to flow along each channel and across the plural biofilm-adherent sites supported within the channel;

- forming a plurality of biofilms on a plurality of biofilm-adherent sites;

- contacting the biofilms with at least one antimicrobial agent; and

- assaying the biofilms at a plurality of biofilm-adherent sites to analyze the sensitivity of the biofilm to the antimicrobial agents.

85. The method of claim 84, wherein the biofilms are formed by a method comprising a step of incubating bacteria on the biofilm-adherent sites while flowing liquid-growth medium across the biofilm-adherent sites.

86. The method of claim 84 or 85, further comprising a step of dislodging the biofilms from the biofilm-adherent sites prior to performing the step of assaying the biofilm at the plural biofilm-adherent sites to analyze the sensitivity of the biofilm to antimicrobial reagents.

87. The method of claim 84, 85 or 86, wherein the step of analyzing the sensitivity of the biofilm to antimicrobial reagents is performed on biofilms on the biofilm-adherent sites.

88. The method of any one of claims 84 to 87, wherein a plurality of identical biofilms are formed, and at least one of those biofilms is contacted with a different antimicrobial agent or a different concentration of antimicrobial agent than the other of the biofilms.

89. The method of claim 88, wherein each of the biofilms is contacted with a different antimicrobial agent or a different concentration of antimicrobial agent.

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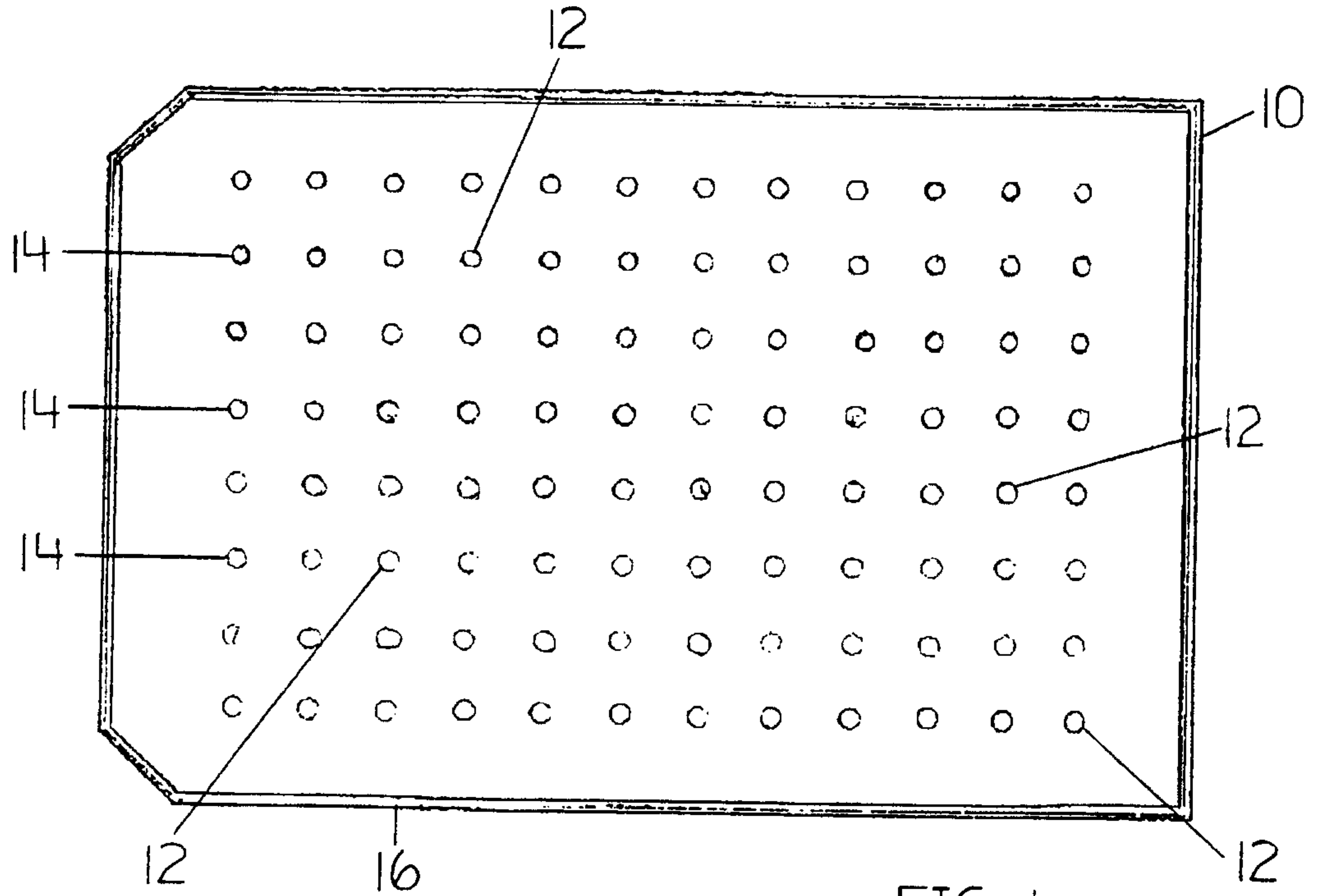


FIG. 1.

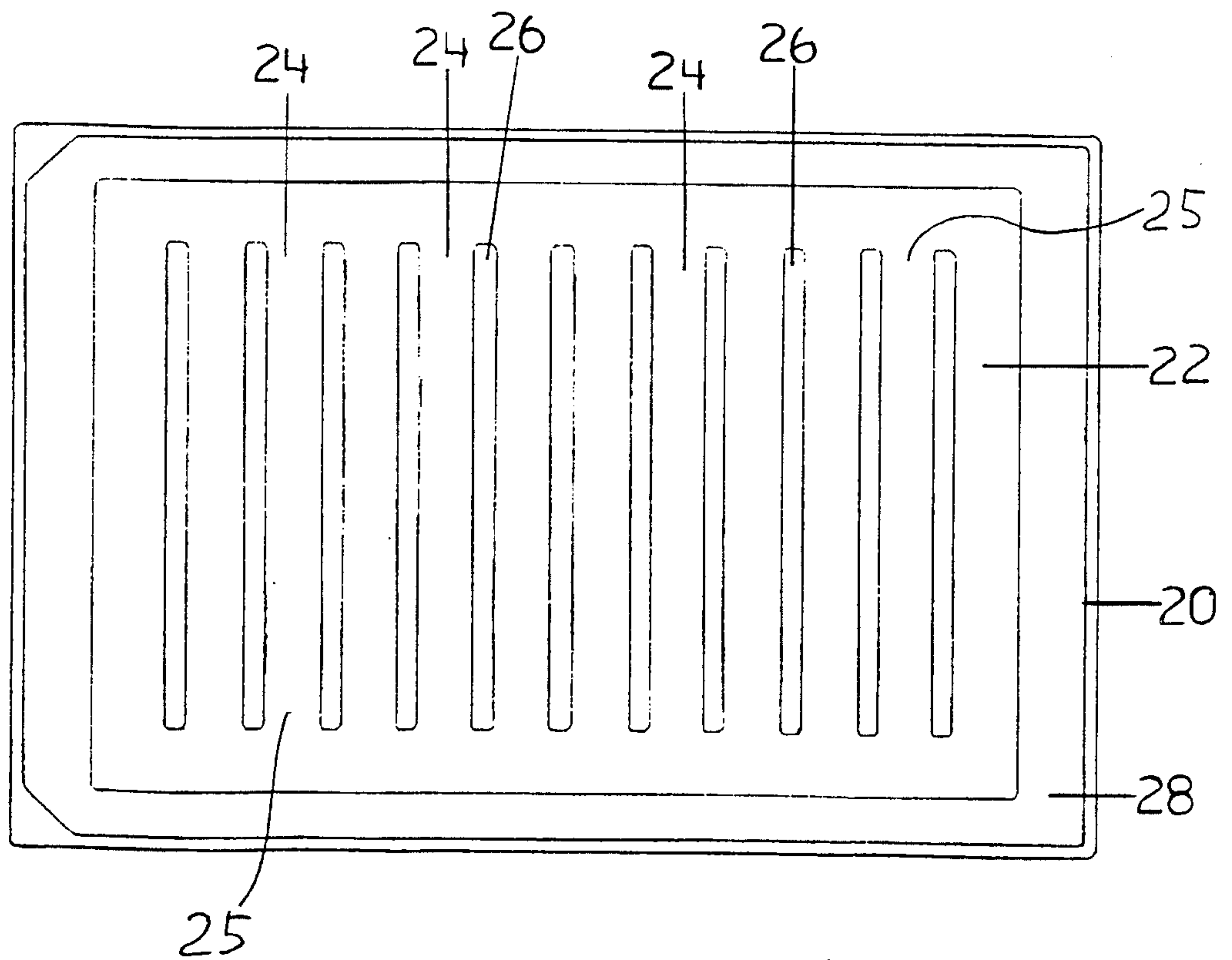


FIG. 2

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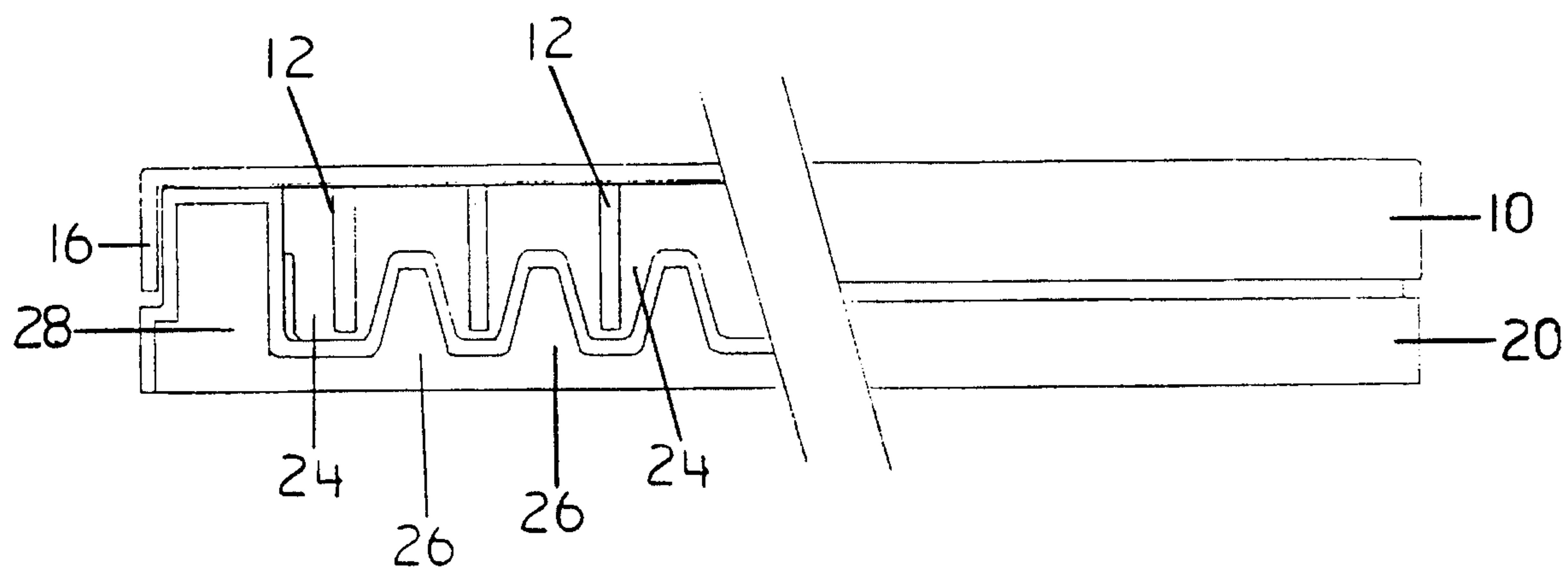


FIG. 3

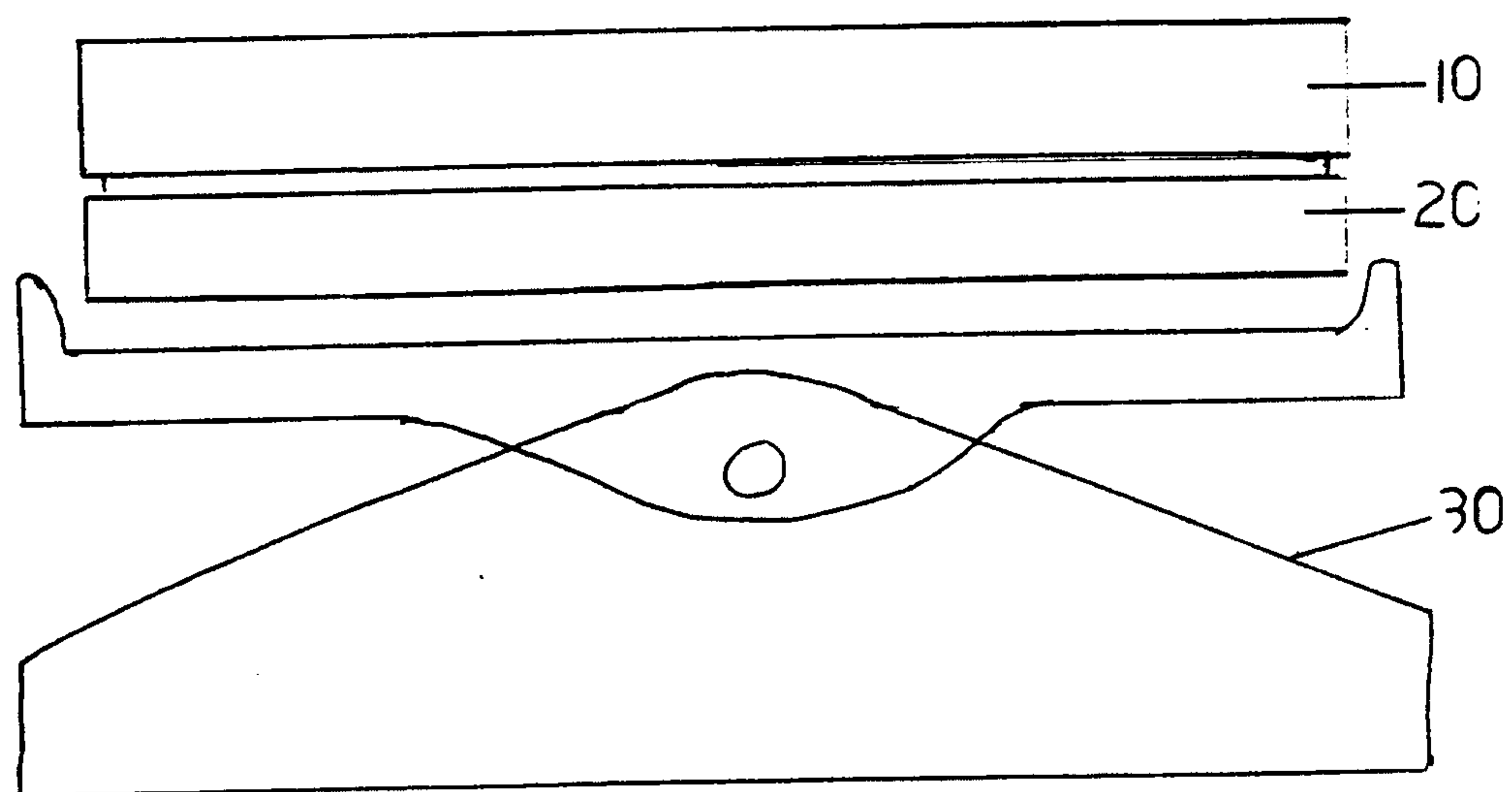


FIG. 4

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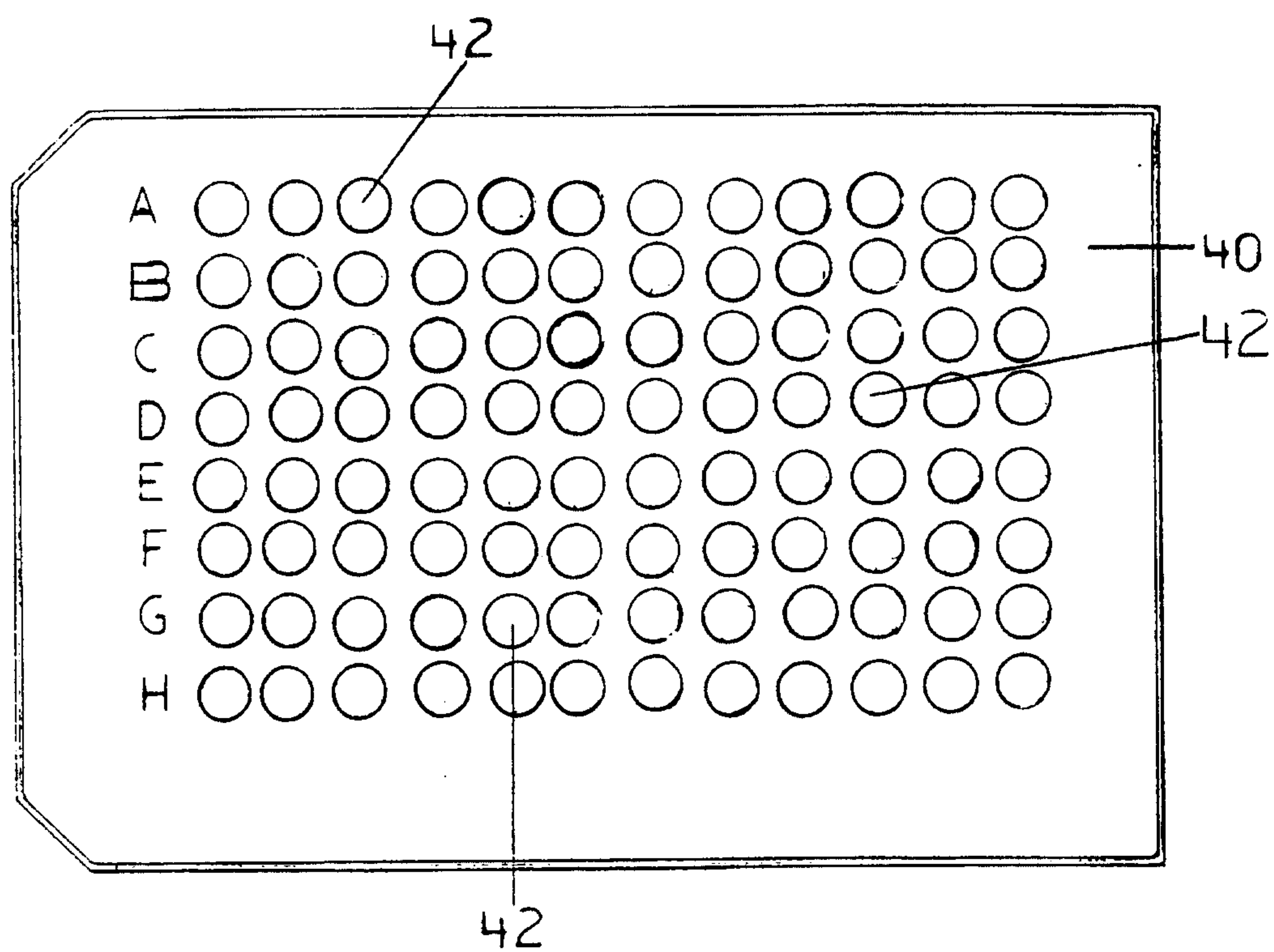


FIG. 5

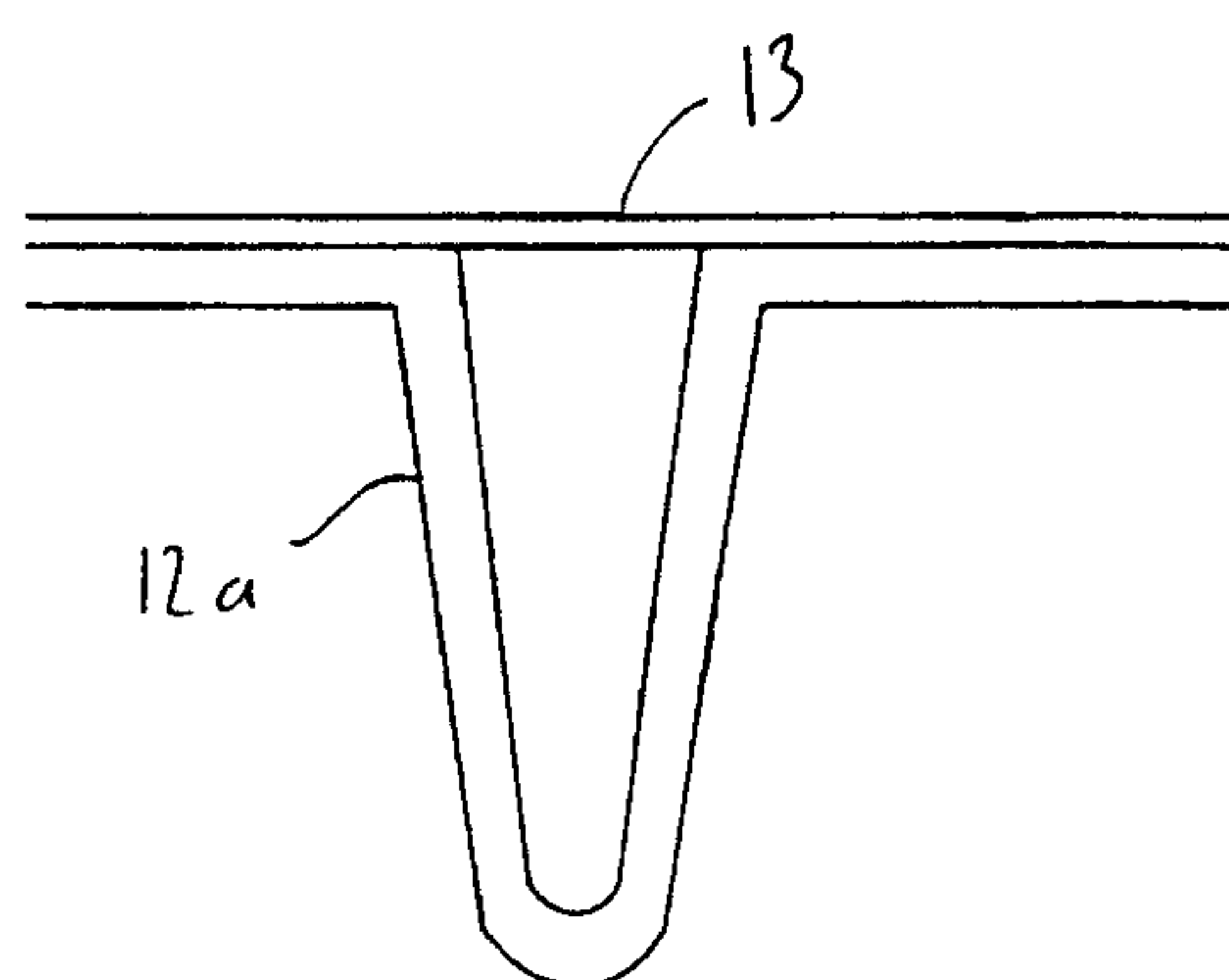


FIG. 6

