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LLP

(54) Titre : SYSTEME DE MESURE SANS CONTACT
(54) Title: CONTACTLESS MEASURING SYSTEM

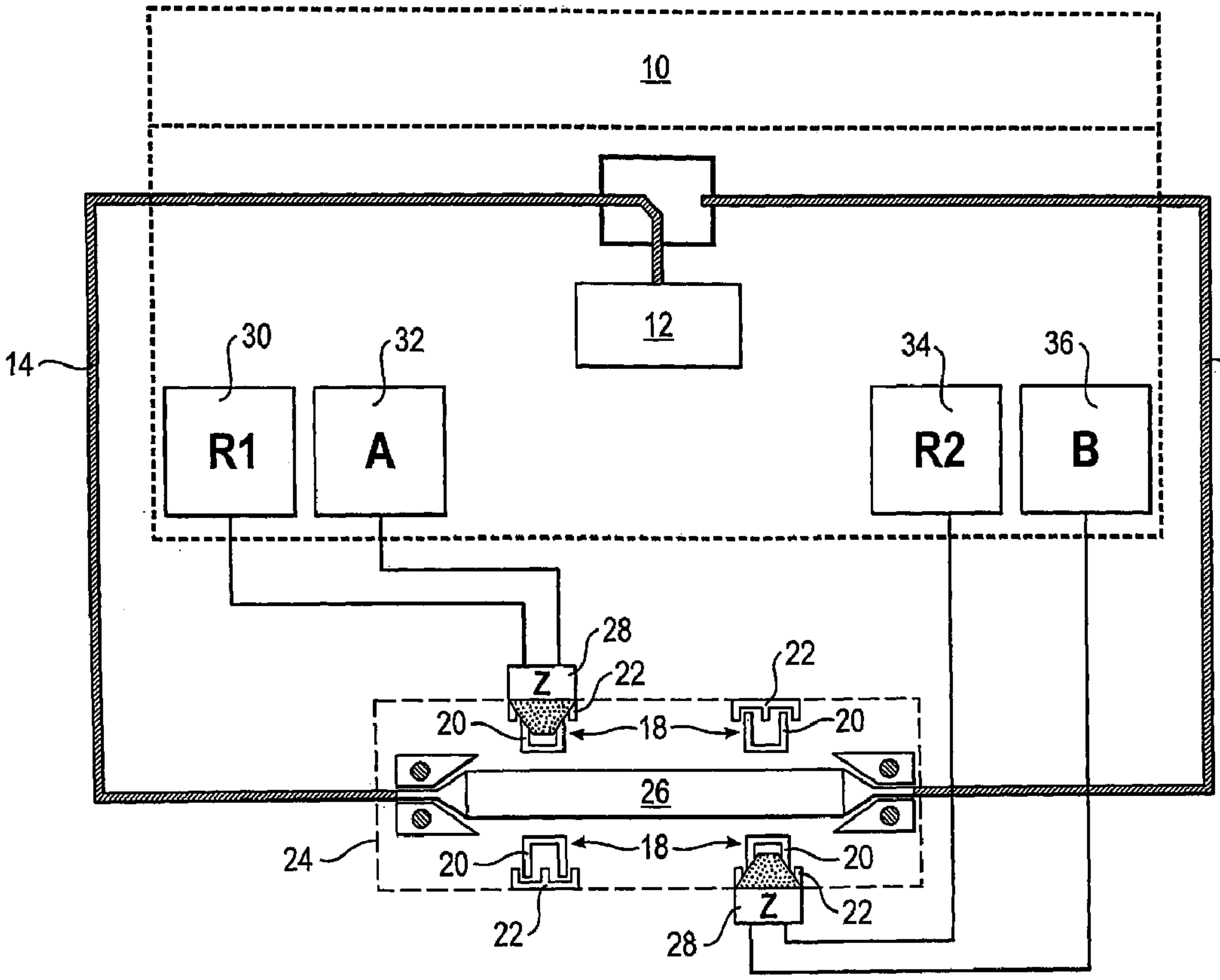


Fig. 1

(57) Abrégé/Abstract:
The invention relates to a contactless measuring system having at least one test prod (28) forming part of a coupling structure for the contactless decoupling of a signal running on a signal waveguide (26), wherein the signal waveguide (26) is designed as a

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

conductor of the electric circuit on a circuit board (24) and as part of an electric circuit (52). To this end, at least one contact structure (18; 44) is configured and disposed on the circuit board (24) such that said contact structure (18; 44) is galvanically separated from the signal waveguide (26), forms part of the coupling structure, is displaced completely within the near field of the signal waveguide (26), and has at least one contact point (42), which may be electrically contacted by a contact of the test prod (28).

Abstract

The invention relates to a contactless measuring system having at least one test prod (28) forming part of a coupling structure for the contactless decoupling of a signal running on a signal waveguide (26), wherein the signal waveguide (26) is designed as a conductor of the electric circuit on a circuit board (24) and as part of an electric circuit (52). To this end, at least one contact structure (18; 44) is configured and disposed on the circuit board (24) such that said contact structure (18; 44) is galvanically separated from the signal waveguide (26), forms part of the coupling structure, is displaced completely within the near field of the signal waveguide (26), and has at least one contact point (42), which may be electrically contacted by a contact of the test prod (28).

CONTACTLESS MEASURING SYSTEM

Description

The present invention relates to a contactless measuring system comprising at least one test probe forming part of a coupling structure for contactless decoupling of a signal running on a signal waveguide, wherein the signal waveguide is configured as a conductor track and as part of an electric circuit on a circuit board of the electrical circuit, according to the preamble of claim 1. The invention also relates to a calibration substrate for a contactless measuring system comprising at least one test probe forming part of a coupling structure for contactless decoupling of a signal running on a signal waveguide, wherein at least one calibration element, in particular a short-circuit standard, an open circuit standard, a resistance standard or a conductor standard is provided on the calibration substrate, wherein the at least one calibration element is electrically connected to at least one signal waveguide, in particular a microstrip transmission line or a coplanar waveguide, according to the preamble of claim 17.

The determination of scattering parameters of electrical components embedded within a complex circuit by means of a contactless vector network analysis is known, for example from T. Zelder, H. Eul, "Contactless network analysis with improved dynamic range using diversity calibration", Proceedings of the 36th European Microwave Conference, Manchester, UK, pages 478 to 481, September 2006 or T. Zelder, H. Rabe, H. Eul, "Contactless electromagnetic measuring system using conventional calibration algorithms to determine scattering parameters", Advances in Radio Science - Kleinheubacher Berichte 2006, vol. 5, 2007. Compared with conventional contact-bound network analysis methods, the internal directional couplers of a network analyser are replaced with contactless near field measuring probes which are directly connected to the vectorial measuring points of the analyser. The measuring probes are positioned over the signal lines of the object being measured. The probes can act inductively and/or capacitively on the electromagnetic field of the planar conductor. In order to measure the scattering parameters, conventional calibration methods are used, such as are used for contact-bound network analysis.

In contactless vector network analysis, for each measuring port of an unknown test object (DUT - Device Under Test), at least one measuring probe, for example, a conductor loop or two capacitive probes are needed. It is known from, for example, F. De Groote, J. Verspecht, C. Tsironis, D. Barataud and J.-P. Teyssier, "An improved coupling method for time domain load-pull measurements", European Microwave Conference, vol. 1, pages 4 ff., October 2005, to use contactless conductor loops made from coaxial semi-rigid lines. By contrast, it is known from T. Zelder, H. Eul, "Contactless network analysis with improved dynamic range using diversity calibration", Proceedings of the 36th European Microwave Conference, Manchester, UK, pages 478 to 481, September 2006 or T. Zelder, H. Rabe, H. Eul, "Contactless electromagnetic measuring system using conventional calibration algorithms to determine scattering parameters", Advances in Radio Science - Kleinheubacher Berichte 2006, vol. 5, 2007, to use exclusively capacitive probes in contactless measuring systems. From T. Zelder, I. Rolfes, H. Eul, "Contactless vector network analysis using diversity calibration with capacitive and inductive coupled probes", Advances in Radio Science - Kleinheubacher Berichte 2006, vol. 5, 2007 and J. Stenarson, K. Yhland, C. Wingqvist, "An in-circuit noncontacting measurement method for S-parameters and power in planar circuits", IEEE Transactions on Microwave Theory and Techniques, vol. 49, No. 12, pages 2567 to 2572, December 2001, measuring systems are known which are realised with a combination of capacitive and inductive probes.

Although contactless vector network analysis has the potential of characterising components contactlessly, to date no contactless scattering parameter measurement of HF and microwave components embedded within a circuit has been performed. If measurements are to be made within a circuit, the positions of the contactless probes must be changed during and after the calibration. However, this implies a high level of complexity in order to reproduce the test probe positions during measurement of the calibration standard and of the test object, since the smallest deviations in the probe positioning lead to significant measuring errors.

It is an object of the invention to provide a contactless measuring system of the aforementioned type such that expensive and complex positioning of coupling probes can be dispensed with.

This aim is achieved according to the invention with a contactless measuring system of the aforementioned type having the characterising features of claim 1 and with a calibration substrate of the aforementioned type having the characterising features of claim 17. Advantageous embodiments of the invention are described in the further claims.

With a contactless measuring system of the aforementioned type, it is provided according to the invention that at least one contact structure is configured and arranged on the circuit board such that said contact structure is galvanically separated from the signal waveguide, forms part of the coupling structure, is arranged completely within the near field of the signal waveguide and comprises at least one contact point which can be electrically contacted by a contact of a test probe.

This has the advantage that the contact structure and thus the whole coupling structure has a precisely defined geometrical arrangement relative to the signal waveguide, wherein manual positioning of the coupling structure can be dispensed with. Reproducible coupling between the signal waveguide and the coupling structure can be easily achieved.

Suitably, the contact structure is configured as a conductor track on the circuit board.

Particularly good signal coupling can be achieved in that the contact structure is configured so that said contact structure can be contacted by a test probe in impedance-controlled manner.

At least one contact structure is configured, for example, as a coupling waveguide with an inner conductor and an outer conductor or as at least one contact point or contact surface for a contact of a test probe.

Suitably, the contact structure and/or the signal waveguide is configured as printed conductor tracks on the circuit board.

For example, the circuit board is configured as a printed circuit board (PCB) or a wafer.

Optimal directional damping or a port with wide-band insulation is achieved in that the contact structure is configured as a waveguide, wherein the ratio of the inductive to the capacitive coupling factor is equal to the product of the wave impedances of the individual waveguides of the contact structure.

In an exemplary embodiment, the coupling structure has at least one, in particular two, contact structures per measuring port.

In a preferred embodiment, the circuit board is a multi-layer board with a plurality of substrate layers, wherein the signal waveguide is configured on a first substrate layer of the multi-layer board and at least one contact structure is configured on the first or at least one other substrate layer of the multi-layer board.

As an example, at least two of the contact structures are arranged on different substrate layers of the multi-layer board.

In a particularly preferable embodiment, the at least one contact structure has contact points which are configured and arranged such that contacting with on-wafer or PCB test probes results in an impedance-controlled interface.

For rapid and simple calibration of the contactless measuring system, also arranged on the circuit board is at least one calibration element, which is connected to at least one signal waveguide on which at least one contact structure is arranged such that the arrangement of the contact structure on the signal waveguide of a calibration element corresponds to the arrangement of the contact structures on the signal waveguides of the electrical circuit.

At least one calibration element is connected to a number of signal waveguides which corresponds to the number of measuring ports of the contactless measuring system.

In order to provide the calibration elements and the electrical circuit with identical coupling conditions and optimum calibration, at least one contact structure on the signal waveguides of the calibration elements, said contact structure being assigned to a measuring port of the contactless measuring system, is configured identically to the at least one contact structure on the signal waveguides of the electrical circuit, said contact structure being assigned to said measuring port of the contactless measuring system.

With a calibration substrate of the aforementioned type it is provided, according to the invention, that the calibration substrate is configured as a circuit board, on which at least one contact structure is configured and arranged such that this contact structure is galvanically separated from the signal waveguide, forms part of the coupling structure, is arranged completely within the near field of the signal waveguide and has at least one contact point which is electrically contactable with a contact of a test probe.

This brings the advantage that the contact structure and thus the overall coupling structure has a precisely defined geometrical arrangement to the signal waveguide, wherein manual positioning of the coupling structure can be dispensed with. Reproducible coupling between the signal waveguide and the coupling structure is achieved by simple means.

The contactless measuring system is preferably configured as described above, wherein it is particularly preferable that at least one contact structure on the signal waveguides of the calibration elements, said contact structure being assigned to a measuring port of the contactless measuring system, is configured identically to the at least one contact structure on the signal waveguides of the electrical circuit, said contact structure being assigned to said measuring port of the contactless measuring system.

At least one calibration element is connected to a number of signal waveguides which corresponds to the number of measuring ports of the contactless measuring system.

Suitably, on the circuit board of the calibration substrate, at least one electrical circuit is configured with at least one signal waveguide on which at least one contact structure is arranged such that the arrangement of the contact structure on the signal waveguide corresponds to the arrangement of the contact structures on the signal waveguides of a calibration element.

In a preferred embodiment, at least one contact structure on the signal waveguides of the calibration elements, said contact structure being assigned to a measuring port of the contactless measuring system, is configured identically to the at least one contact structure on the calibration substrate on the signal waveguides of the electrical circuit, said contact structure being assigned to said measuring port of the contactless measuring system.

The invention will now be described in greater detail making reference to the drawings, in which:

Fig. 1 shows a schematic block circuit diagram of a preferred embodiment of a contactless measuring system according to the invention with a vector network analyser,

Fig. 2 shows a first preferred embodiment of a contact structure for the contactless measuring system according to the invention,

Fig. 3 shows a second preferred embodiment of a contact structure for the contactless measuring system according to the invention,

Fig. 4 shows a first preferred embodiment of a calibration substrate according to the invention for the contactless measuring system according to the invention in plan view,

Fig. 5 shows an exemplary alternative embodiment of a contact structure for the contactless measuring system according to the invention,

Fig. 6 shows a further exemplary alternative embodiment of a contact structure for the contactless measuring system according to the invention,

Fig. 7 shows a further exemplary alternative embodiment of a contact structure for the contactless measuring system according to the invention,

Fig. 8 shows a further exemplary alternative embodiment of a contact structure for the contactless measuring system according to the invention,

Fig. 9 shows a further exemplary alternative embodiment of a contact structure for the contactless measuring system according to the invention,

Fig. 10 shows a further exemplary alternative embodiment of a contact structure for the contactless measuring system according to the invention,

Fig. 11 shows a further exemplary alternative embodiment of a contact structure for the contactless measuring system according to the invention,

Fig. 12 shows a further exemplary alternative embodiment of a contact structure for the contactless measuring system according to the invention,

Fig. 13 shows a further exemplary alternative embodiment of a contact structure for the contactless measuring system according to the invention,

Fig. 14 shows a second preferred embodiment of a calibration substrate according to the invention for the contactless measuring system according to the invention in plan view, and

Fig. 15 shows a third preferred embodiment of a calibration substrate according to the invention for the contactless measuring system according to the invention in plan view.

The preferred embodiment of a contactless measuring system according to the invention shown in Fig. 1 comprises a vector network analyser 10 having a signal source 12, signal lines 14 and 16 and a contact structure with four coupling waveguides 18, each of which has an inner conductor 20 and an outer conductor 22. The coupling waveguides 18 are configured as printed conductor tracks on a printed circuit board 24. Also arranged on this printed circuit board 24 is a signal waveguide 26 configured as a printed conductor track. The signal waveguide 26 is part of an electronic circuit (not show in detail) provided on the printed circuit board 26 with corresponding electronic components.

The coupling waveguides 18 together with a test probe 28 form a coupling structure for the contactless measuring system in order to decouple contactlessly an electromagnetic wave running along the signal waveguide 26. The test probes 28 each create an electrical contact with a coupling waveguide 18 on one side, and with the measuring ports 30, 32, 34, 36 of the vector network analyser 10 on the other side.

The coupling waveguides 18 can be shaped almost arbitrarily. It is particularly advantageous for the coupling waveguides 18 to be configured in impedance-controlled manner, i.e. the characteristic wave impedance values of the arrangement are known and are optimised for low reflection. The advantage of an impedance-controlled contact structure lies therein that optimum directional damping and a port which is insulated over a broad bandwidth can be achieved.

Two examples of an impedance-controlled coupling waveguide 18 of this type are shown in Figs. 2 and 3. The coupling waveguide 18 shown in Fig. 2 comprises a U-shaped inner conductor 20 and an outer conductor 22. The outer conductor 22 can be variously configured. Firstly, the outer conductor 22 can be closed, i.e. the outer conductor arms 38 and 40 close at the coordinate $z = 0$, as indicated in Fig. 2 with dashed lines and secondly, the ends of the outer conductor arms 38, 40 can be separated along z. For example, the arms 38, 40 then end at the positions $+z_1$ and $-z_1$ or, as shown in Fig. 2, at the positions $+z_2$ and $-z_2$. Through the arrangement of the outer conductor 22 relative to the inner conductor 20, the coupling waveguide 18 corresponds to a bent coplanar waveguide. Different variants of this coupling waveguide 18 are possible. A variant without corners is shown in Fig. 3. By way of example here, the outer conductor arms 38 and 40 are joined to one another at the position $z = 0$.

A further advantage of the contact structure according to the invention is that no through contacts to earth (rear-sided base metalizing of the circuit board 24) are necessary. However, the possibility of connecting the outer conductors 22 of the coupling waveguides 18 to earth with through contacts is not ruled out.

For decoupling energy from the signal waveguide 26 of a test object (DUT - Device Under Test) at least one contact structure or coupling waveguide 18 is brought into the near field of the respective signal waveguide 26. The coupling waveguide 18 can be situated on the same substrate as the respective signal waveguide 26, or in the case of a multi-layer board, on another substrate. The contact structure with the coupling waveguides 18 is then connected, for example, to a commercial symmetrical on-wafer or PCB test probe. The reference sign 42 in Figs. 2 and 3 denotes the contact positions of the contacts of test probes with the contact structure or the respective coupling waveguide 18. In order to characterise an N-port test object, at least N coupling waveguides 18 situated within the near field of the N signal waveguides 26 are needed. Fig. 1 shows the example of a 2-port test object (in this case, a simple conductor = DUT) with four coupling waveguides 18.

The geometry of the coupling waveguides 18 and of the test probes 28 both influence the coupling factor of the arrangement. The test probes 28 are connected to (vectorial) receivers of, for example, a conventional network analyser, as shown in Fig. 1.

The procedure for measuring test objects embedded within planar circuits with the aid of at least one impedance-controlled contact structure or at least one non-impedance-controlled contact structure within planar circuits will now be described.

The method is essentially based on the method of contactless vector network analysis. The disadvantage of contactless vector network analysis is that the use of the method for achieving accurate measured values is very heavily dependent on the positioning accuracy of the contactless test probes. According to the invention, it is also provided that printed contact structures are used in combination with conventional test probes, rather than a complex automatic positioning system in combination with completely contactless probes. All the signal lines of the test objects and of the calibration elements which are necessary for system error calibration, must be provided with at least one coupling waveguide 18 (contact structure).

An example of a practical implementation of a calibration substrate with embedded test objects (DUT3, DUT4) making use of contact structures with printed coupling waveguides 18 is shown in Fig. 4. For 2-port calibration, the contact structure comprises two coupling waveguides 18 for each signal waveguide 26, said coupling waveguides being configured, for example, according to the embodiment of Fig. 2. For N-port calibration, a contact structure with at least N coupling waveguides 18 per signal waveguide 26 is necessary. When using a diversity calibration method, it is also useful to utilise a contact structure with more than N coupling waveguides 18 per signal waveguide 26.

Due to the small dimensions of the coupling waveguides 18, for example, on-wafer or PCB test probes can be reproducibly positioned on the identical coupling waveguides 18 of the individual calibration elements (LINE1, LINE2, LINE3, LINE4, OPEN, SHORT). Once the system has been calibrated, the scattering parameters of, for example, embedded components can be determined. However, the signal lines of the components must have the same properties (geometry, wave impedance, etc.) as those of the calibration elements. In addition, the same contact structure must be present on the planar circuit at every signal waveguide 26 of the embedded test object (DUT) as used for the calibration.

The method therefore involves the placement of a contact structure, for example, in the form of a coupling waveguide 18 within the near field of the signal waveguide 26 of the calibration and test objects on a circuit board 24. The coupling waveguides 18 are arranged and configured on the circuit board 24 such that they barely disrupt the function of a circuit and also can be connected to, for example, conventional on-wafer or PCB test probes.

Figs. 5 to 13 illustrate various exemplary embodiments of contact structures 44. The contact structures 44 can have very particular forms. In principle, any desirable form can be used. In order to create a reproducible coupling between the signal waveguide 26 and the coupling waveguide 18 or the signal waveguide 26 and the test probe 28 or the signal waveguide 26 and the coupling waveguide 18 and the test probe 28, the contact structure 44, if said contact structure comprises a material surface, either has holes in which the test probe is positioned, or has a marked geometry on which the test probe is positioned. Alternatively, the contact structure 44 can also be configured as a notch in the substrate.

Fig. 14 shows a second preferred embodiment of a calibration substrate according to the invention which is configured on a circuit board 46. Parts with the same function are identified with the same reference numbers as in Figs. 1 and 4, so that reference is made to the description relating to Figs. 1 and 4 above for their elucidation. A plurality of calibration elements 48 is arranged on the calibration substrate and each calibration element 48 is connected to one, two or three signal waveguides 26. As distinct from the first embodiment according to Fig. 4, no coupling waveguides are provided on the signal waveguides 26, but rather contact structures 44 as shown in Figs. 5 to 13. Signals are optionally fed to the signal waveguide 26 at suitable contact sites 50. This calibration substrate comprises different 1-port, 2-port and 3-port calibration standards 48 and different contact structures 44.

Fig. 15 shows a third preferred embodiment of a calibration standard according to the invention, which is configured on a circuit board 46. Parts with the same function are identified with the same reference signs as in Figs. 1, 4 and 14, so that reference is made to the description relating to Figs. 1, 4 and 14 above for their elucidation. In this embodiment, an electronic circuit 52 is also provided with components 54 (DUTs) to be tested on the circuit board 46 of the calibration substrate. Conversely, it can also be said that calibration elements 48 are also arranged on the circuit board 46 with the electronic circuit 52. The contact structure 44 for a particular measuring port on the signal waveguides 26 of the calibration elements are configured identically to the contact structure 44 for this measuring port on the signal waveguides 26 of the electronic circuit 52.

For the correct measurement of the scattering parameters of an N-port, the measuring system must be calibrated. Depending on the calibration, M different N-port calibration standards (calibration elements 48), which are known or only partially known, are needed. For calibration using M calibration standards, the geometry and the position of the contact structure and of the signal waveguide 26 must be identical for each measuring port, although it can be different between the N measuring ports.

If, for example, the scattering parameters of a 2-port object are to be measured, then for an LLR calibration, three 2-port calibration standards are needed. These can be, for example, two lines of different length and two short-circuits, wherein the short-circuits each represent a 1-port object, but together correspond to a 2-port object. The three 2-port standards can comprise two different supply lines (signal waveguides 26) per port. The contact structures 44 can also be different on each supply line (each signal waveguide) in terms of position and geometry. However, the signal waveguides 26 and the contact structure 44 must be identical at the respective ports 1 of the calibration standard and the DUTs 48. Also, at the port 2 of the calibration standard, the signal waveguides 26 and the contact structure 44 must match one another, although they can differ from those at the port 1.

Claims

1. Contactless measuring system comprising at least one test probe (28) forming part of a coupling structure for contactless decoupling of a signal running on a signal waveguide (26), wherein the signal waveguide (26) is configured as a conductor track and as part of an electric circuit (52) on a circuit board (24) of the electrical circuit, characterised in that at least one contact structure (18; 44) is configured and arranged on the circuit board (24) such that this contact structure (18; 44) is galvanically separated from the signal waveguide (26), forms part of the coupling structure, is arranged completely within the near field of the signal waveguide (26) and comprises at least one contact point (42) which can be electrically contacted by a contact of a test probe (28).

2. Contactless measuring system according to claim 1, characterised in that the contact structure is configured as a conductor track on the circuit board (24).

3. Contactless measuring system according to one of the preceding claims, characterised in that the contact structure is configured so that said contact structure can be contacted by a test probe (28) in impedance-controlled manner.

4. Contactless measuring system according to one of the preceding claims, characterised in that at least one contact structure is configured as a coupling waveguide (18) with an inner conductor (20) and an outer conductor (22).

5. Contactless measuring system according to one of the preceding claims, characterised in that at least one contact structure (44) is configured as at least one contact point or contact surface for a contact of a test probe (28).

6. Contactless measuring system according to one of the preceding claims, characterised in that the contact structure (18; 44) and/or the signal waveguide (26) is configured as printed conductor tracks on the circuit board (24).

7. Contactless measuring system according to one of the preceding claims, characterised in that the circuit board (24) is configured as a printed circuit board (PCB) or a wafer.

8. Contactless measuring system according to one of the preceding claims, characterised in that the contact structure is configured as a waveguide, wherein the ratio of the inductive to the capacitive coupling factor is equal to the product of the wave impedances of the individual waveguides of the contact structure.

9. Contactless measuring system according to one of the preceding claims, characterised in that the coupling structure has at least one, in particular two, contact structures (18; 44) per measuring port.

10. Contactless measuring system according to one of the preceding claims, characterised in that the circuit board (24) is a multi-layer board with a plurality of substrate layers, wherein the signal waveguide (26) is configured on a first substrate layer of the multi-layer

board and at least one contact structure (18; 44) is configured on the first or at least one other substrate layer of the multi-layer board.

11. Contactless measuring system according to claim 10, characterised in that at least two of the contact structures (18; 44) are arranged on different substrate layers of the multi-layer board (24).

12. Contactless measuring system according to one of the preceding claims, characterised in that the at least one contact structure (18; 44) has contact points (42) which are configured and arranged such that contacting with on-wafer or PCB test probes results in an impedance-controlled interface.

13. Contactless measuring system according to one of the preceding claims, characterised in that also arranged on the circuit board (24; 46) is at least one calibration element (48), which is connected to at least one signal waveguide (26) on which at least one contact structure (18; 44) is arranged such that the arrangement of the contact structure (18; 44) on the signal waveguide (26) of a calibration element (48) corresponds to the arrangement of the contact structures (18; 44) on the signal waveguides (26) of the electrical circuit (52).

14. Contactless measuring system according to claim 13, characterised in that as the calibration element (48) a short-circuit standard, an open circuit standard, a resistance standard and/or a conductor standard is provided on the circuit board (24; 46).

15. Contactless measuring system according to claim 13 or 14, characterised in that at least one calibration element (48) is connected to a number of signal waveguides (26) which corresponds to the number of measuring ports of the contactless measuring system.

16. Contactless measuring system according to at least one of the claims 13 to 15, characterised in that at least one contact structure (18; 44) on the signal waveguides (26) of the calibration elements (48), said contact structure being assigned to a measuring port of the contactless measuring system, is configured identically to the at least one contact structure (18; 44) on the signal waveguides (26) of the electrical circuit (52), said contact structure being assigned to said measuring port of the contactless measuring system.

17. Calibration substrate for a contactless measuring system, comprising at least one test probe which forms part of a coupling structure for contactless decoupling of a signal running on a signal waveguide (26), wherein at least one calibration element (48), in particular a short-circuit standard, an open circuit standard, a resistance standard, or a conductor standard is provided on the calibration substrate, wherein the at least one calibration element is electrically connected to at least one signal waveguide (26), in particular a microstrip transmission line or a coplanar waveguide, characterised in that the calibration substrate is configured as a circuit board (46) on which at least one contact structure (44) is configured and arranged such that said contact structure (44) is galvanically separated from the signal waveguide (26), forms part of

the coupling structure, is arranged completely within the near field of the signal waveguide (26) and comprises at least one contact point (42) which can be electrically contacted by a contact of a test probe (28).

18. Calibration substrate according to claim 17, characterised in that the contactless measuring system is configured according to at least one of the claims 1 to 12.

19. Calibration substrate according to claim 18, characterised in that at least one contact structure (44) on the signal waveguides (26) of the calibration elements (48), said contact structure being assigned to a measuring port of the contactless measuring system is configured identically to the at least one contact structure (44) on the signal waveguides (26) of the electrical circuit (52), said contact structure being assigned to said measuring port of the contactless measuring system.

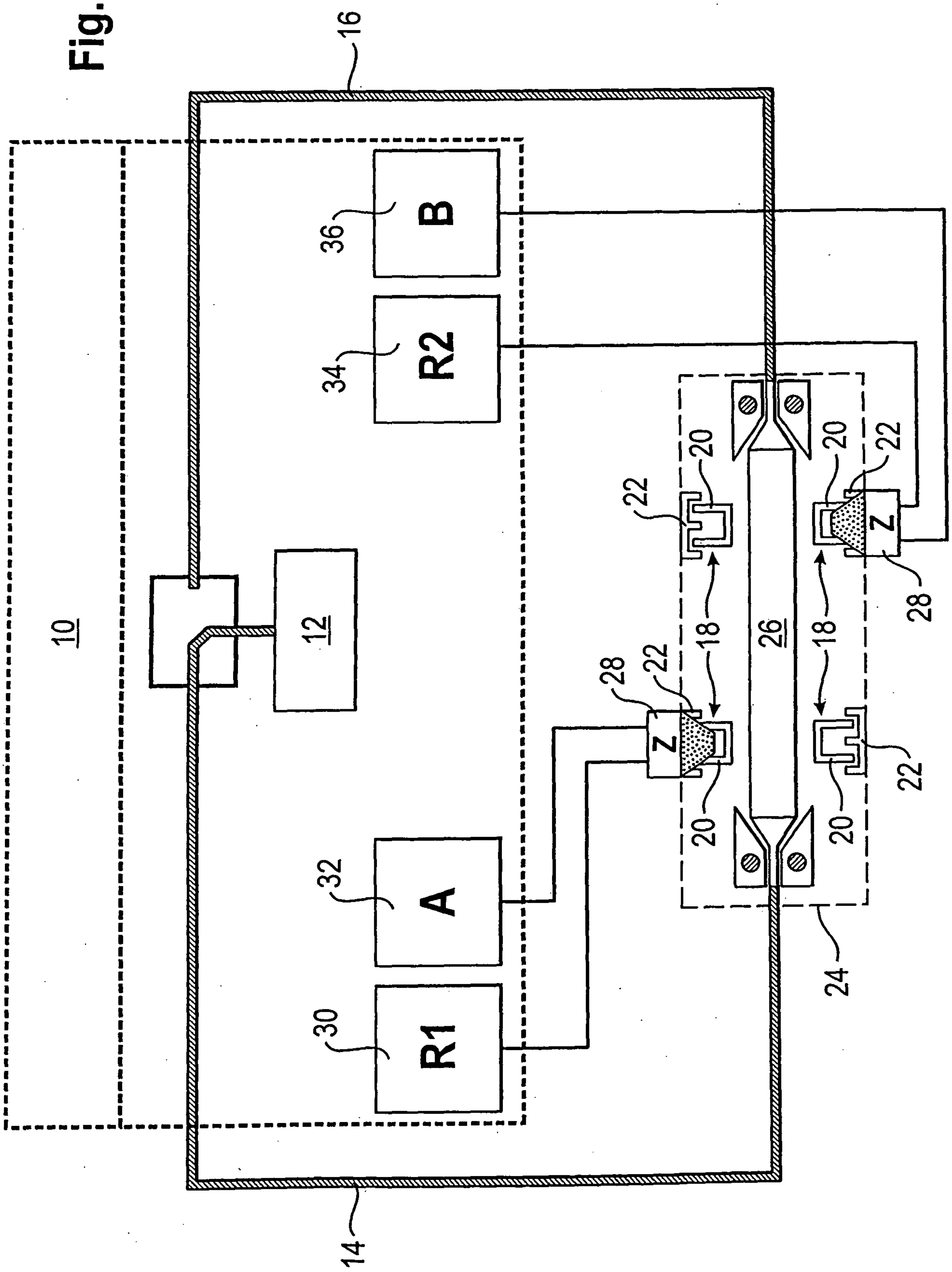
20. Calibration substrate according to at least one of the claims 17 to 19, characterised in that at least one calibration element (48) is connected to a number of signal waveguides (26) which corresponds to the number of measuring ports of the contactless measuring system.

21. Calibration substrate according to at least one of the claims 17 to 20, characterised in that at least one electrical circuit (52) having at least one signal waveguide (26) is arranged on the circuit board (46) of the calibration substrate and at least one contact structure (44) is arranged on said signal waveguide such

that the arrangement of the contact structure (44) on the signal waveguide (26) of the electrical circuit (52) corresponds to the arrangement of contact structures (44) on the signal waveguides (26) of a calibration element (44).

22. Calibration substrate according to claim 21, characterised in that at least one contact structure (44) on the signal waveguides (26) of the calibration elements (48), said contact structure being assigned to a measuring port of the contactless measuring system, is configured identically to the at least one contact structure (44) on the calibration substrate on the signal waveguides (26) of the electrical circuit (52), said contact structure being assigned to said measuring port of the contactless measuring system.

Fig. 1



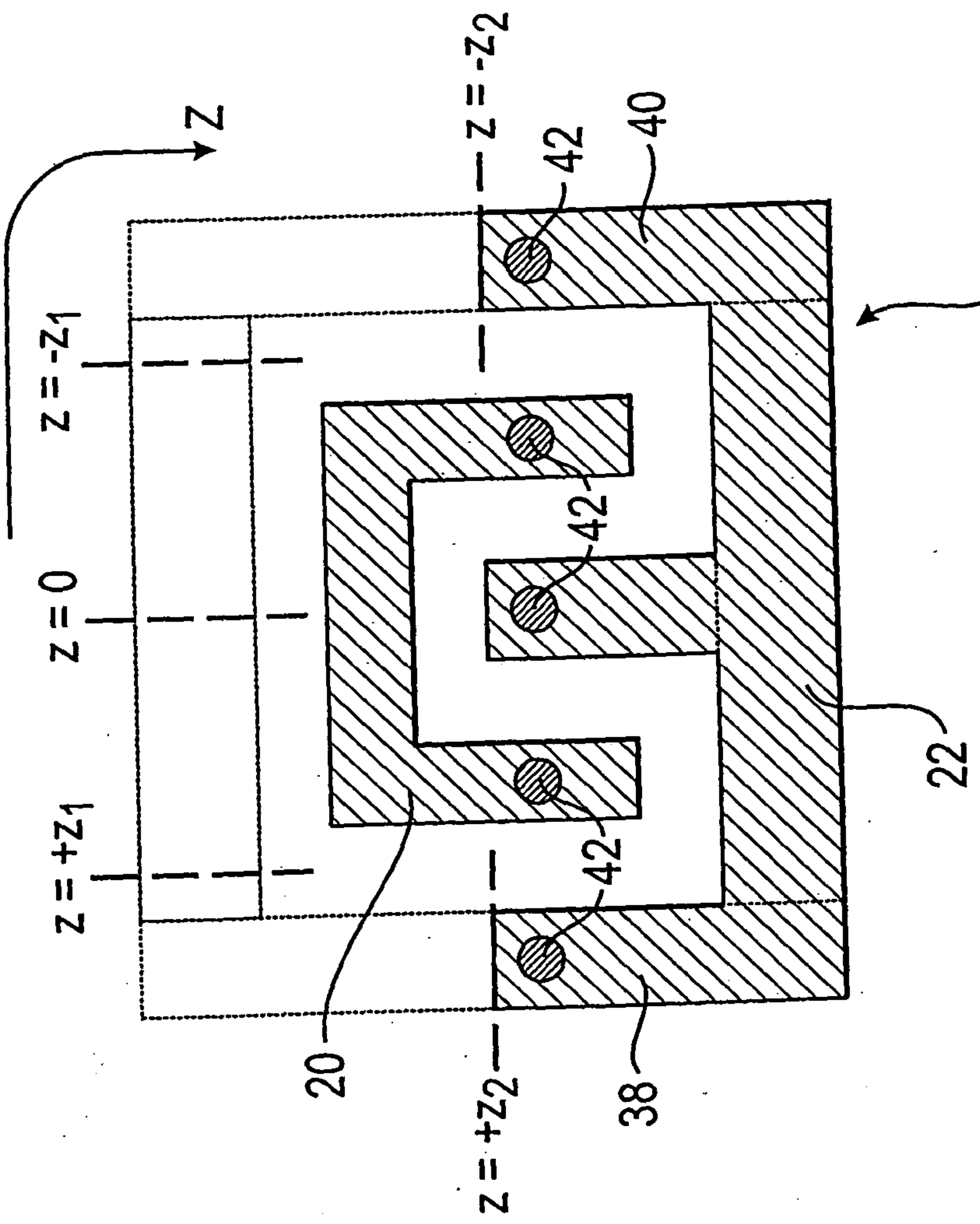

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Fig. 2

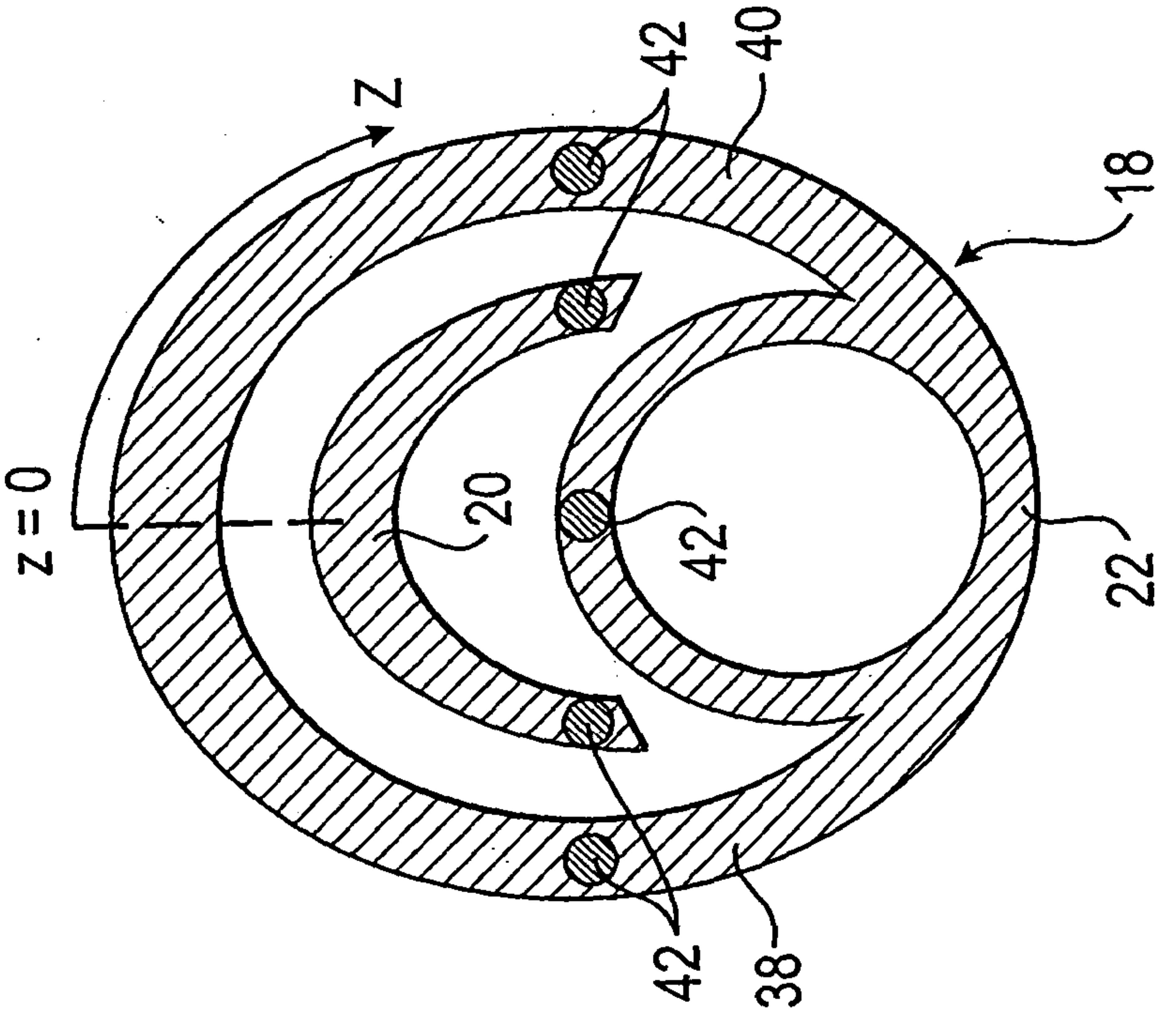
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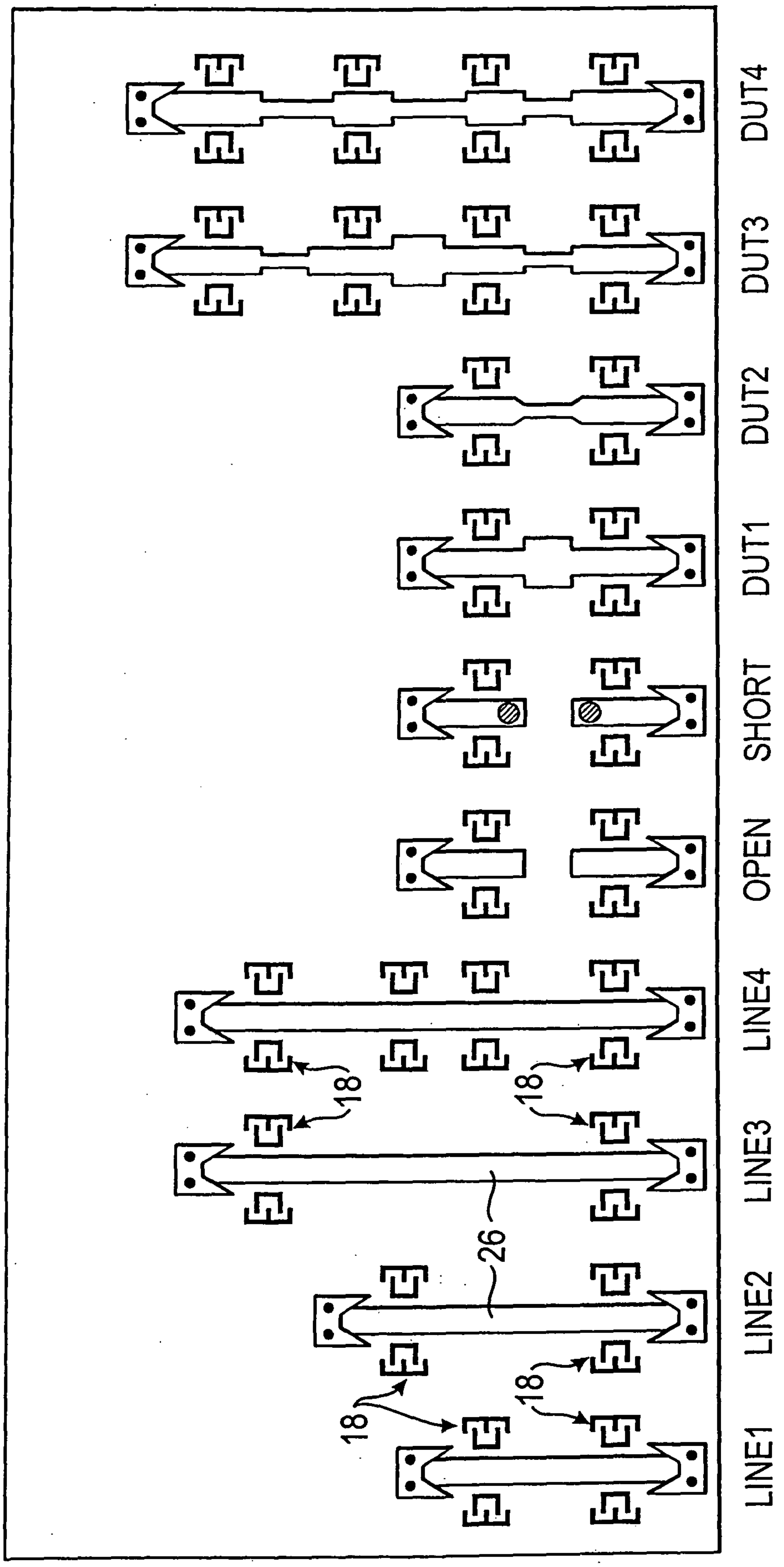
Fig. 3

Fig. 4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LINE2
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18
18
18
26

Fig. 5

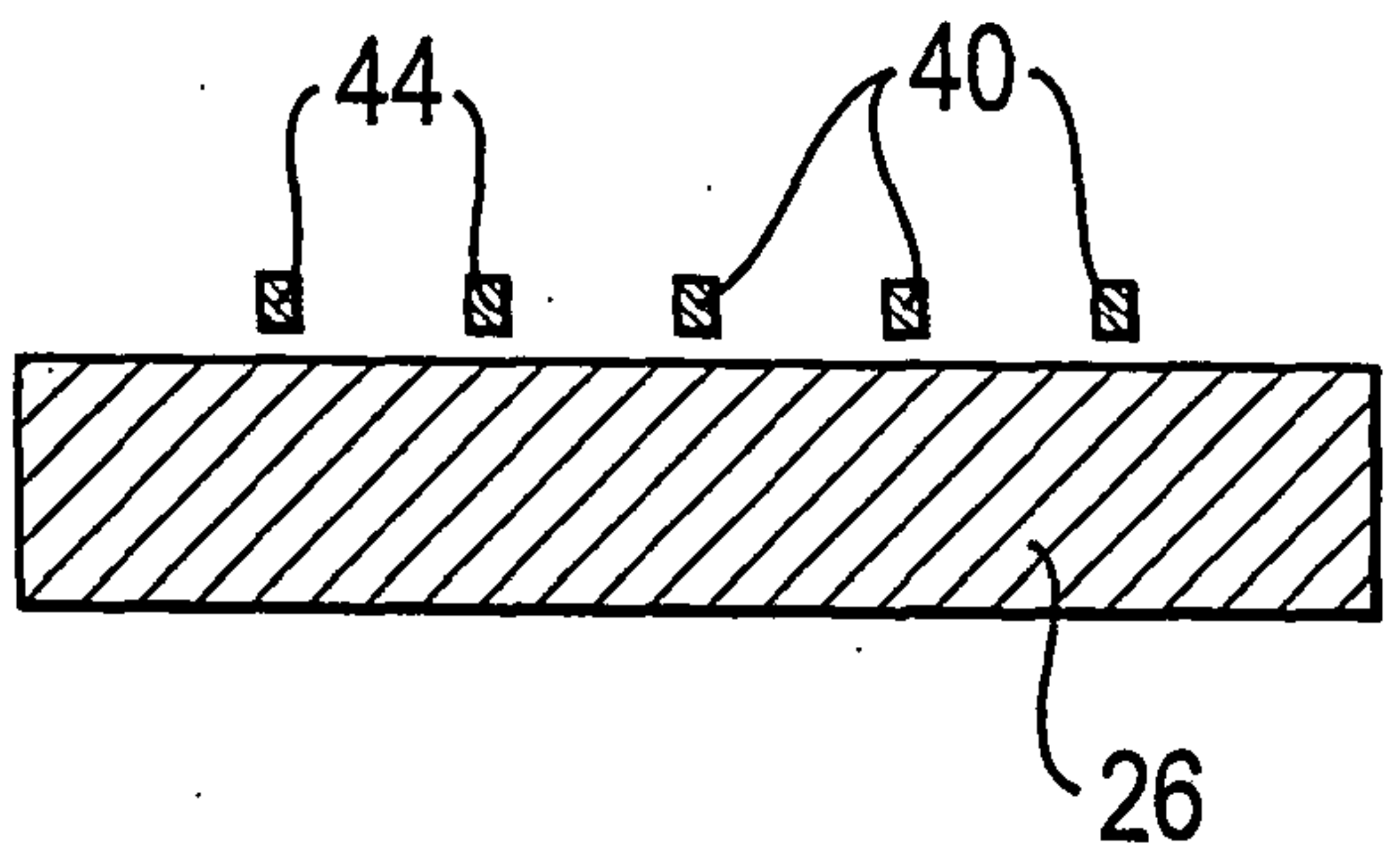

Fig. 6

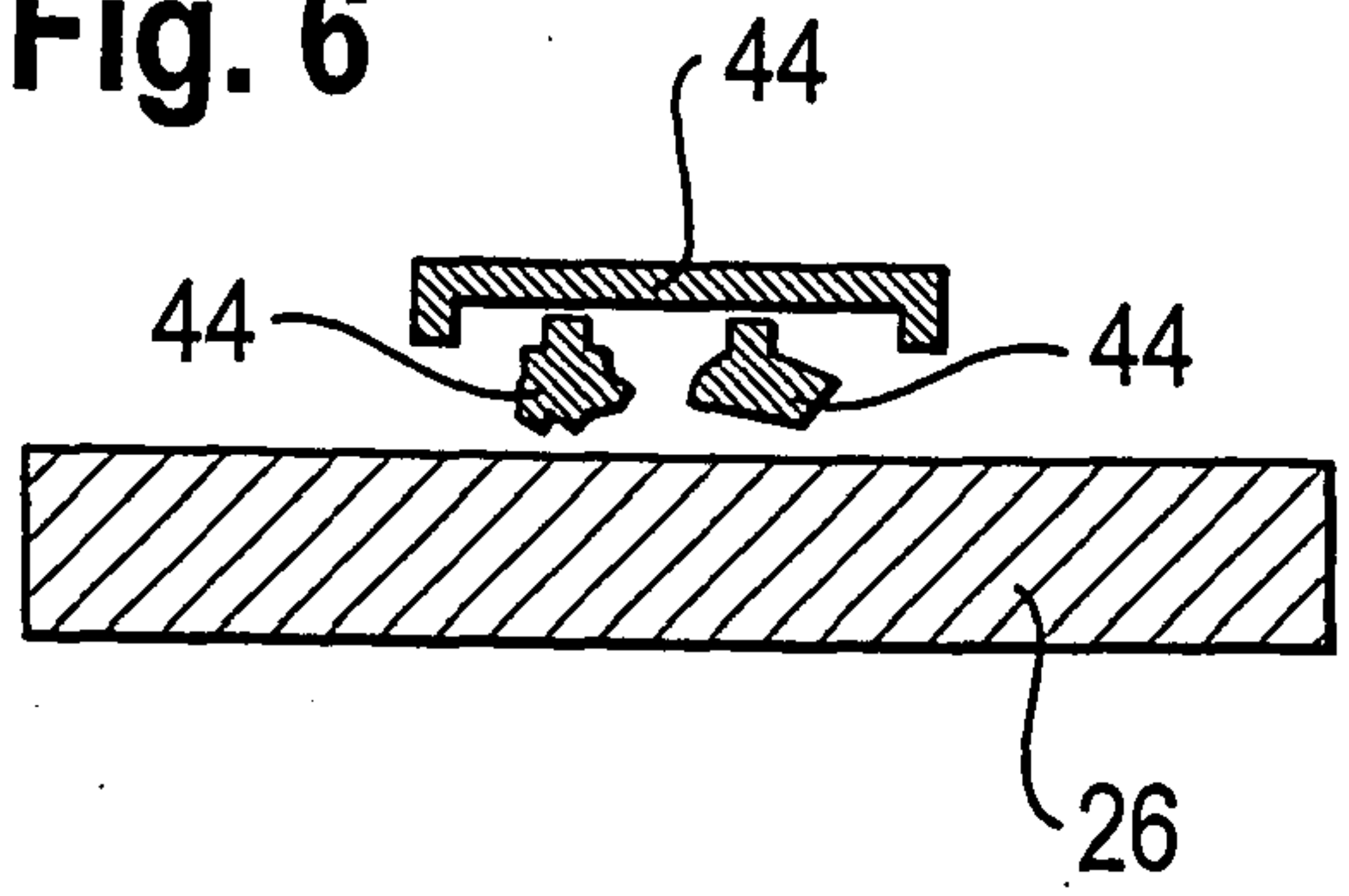

Fig. 7

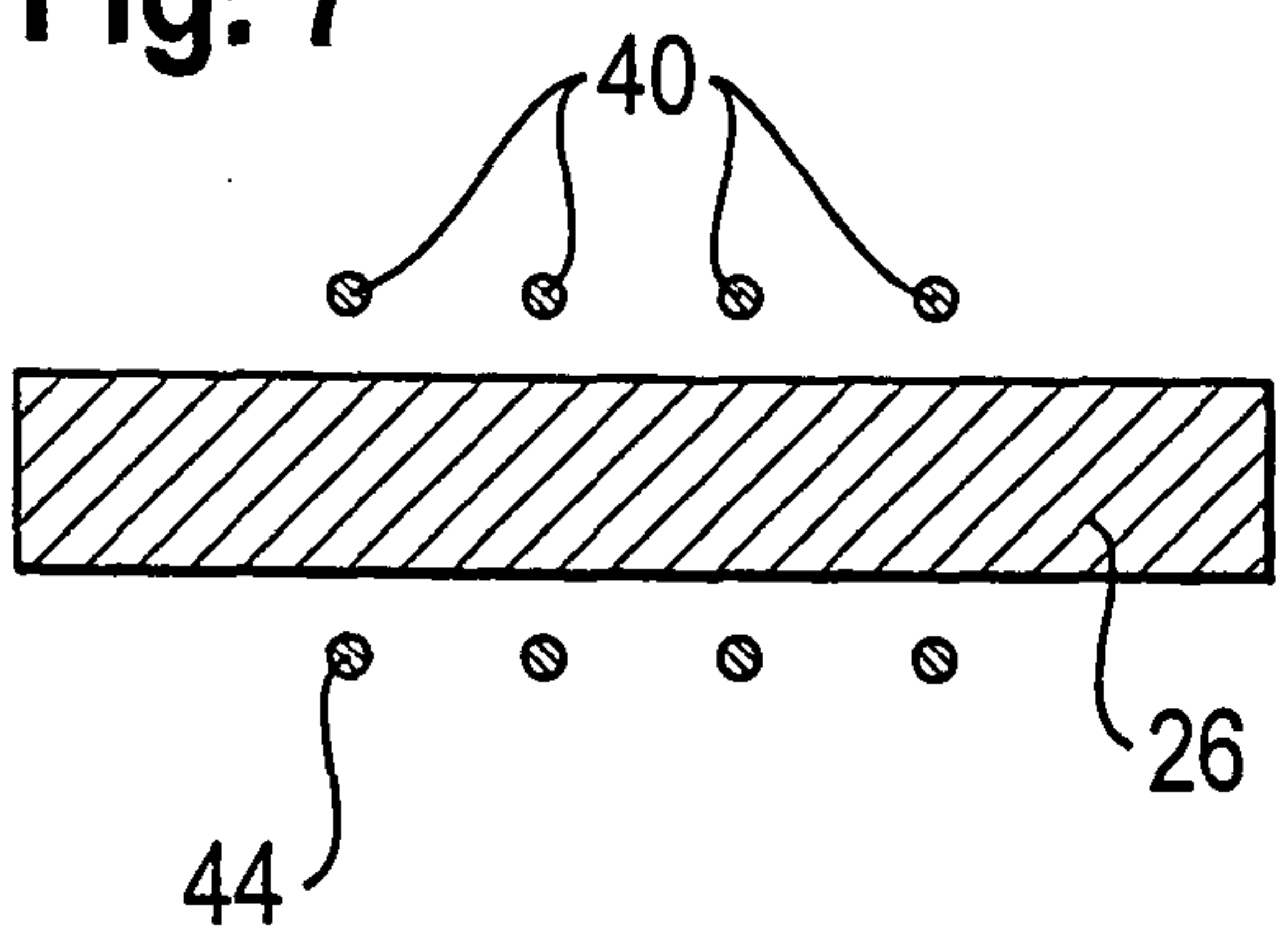

Fig. 8

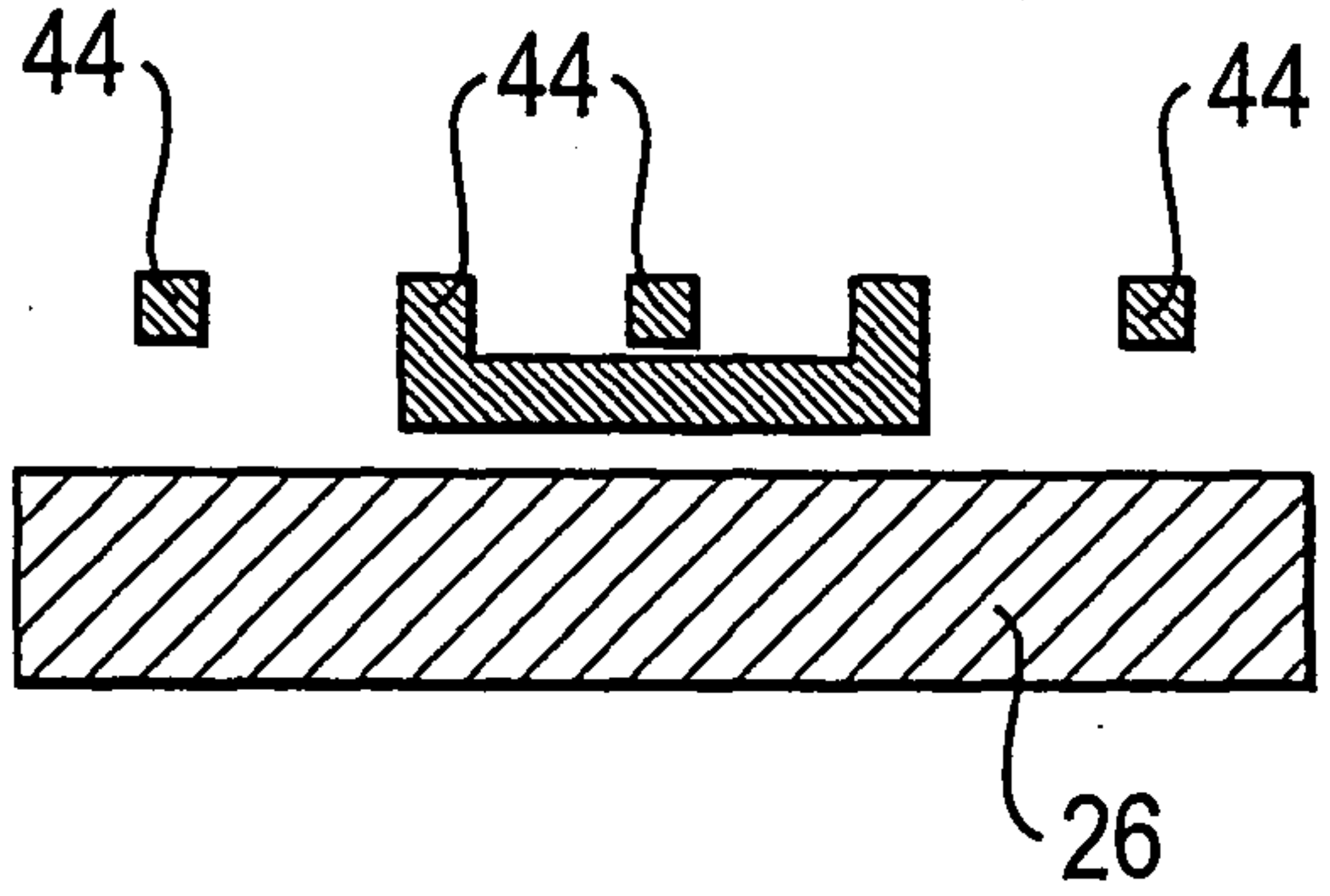

Fig. 9

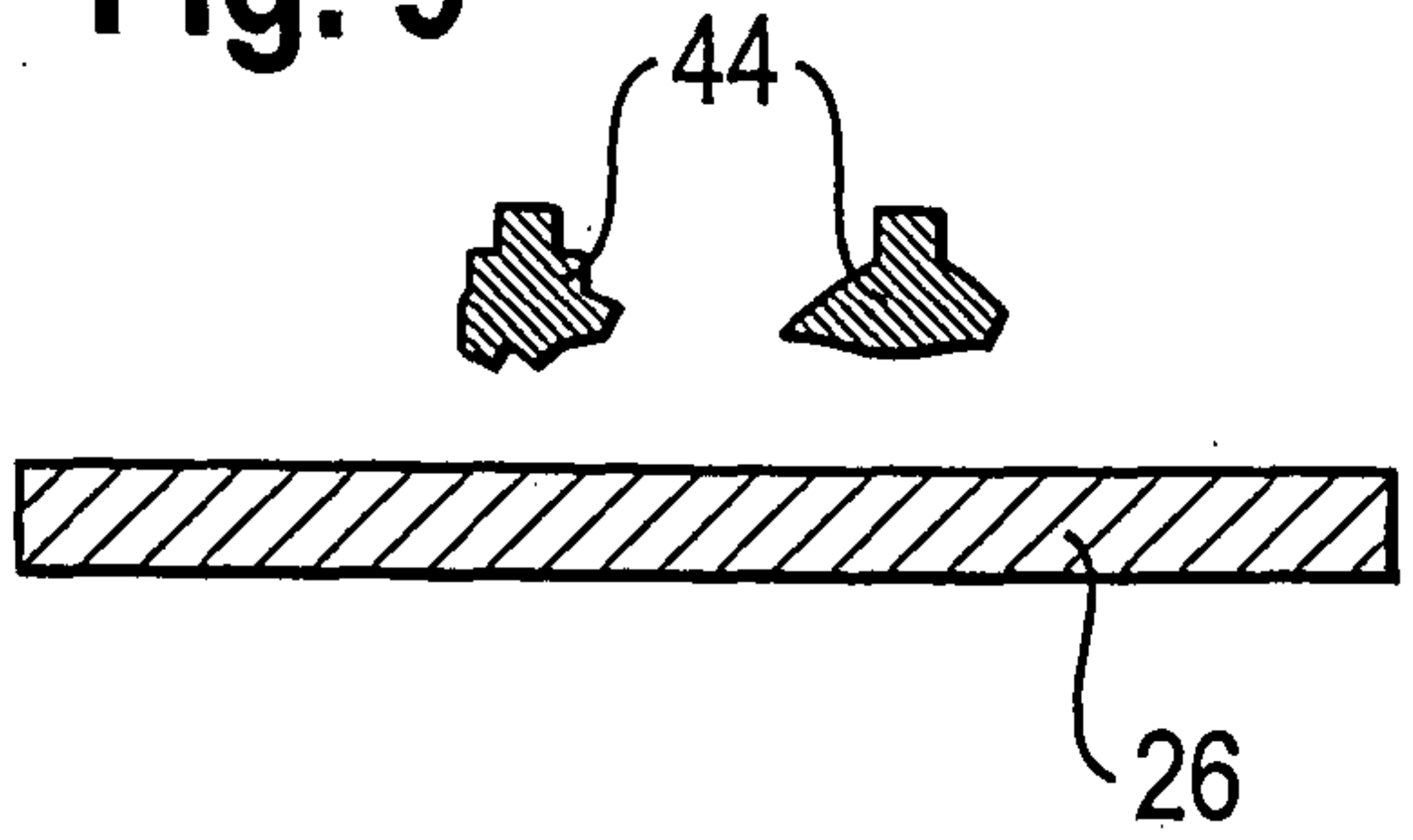

Fig. 10

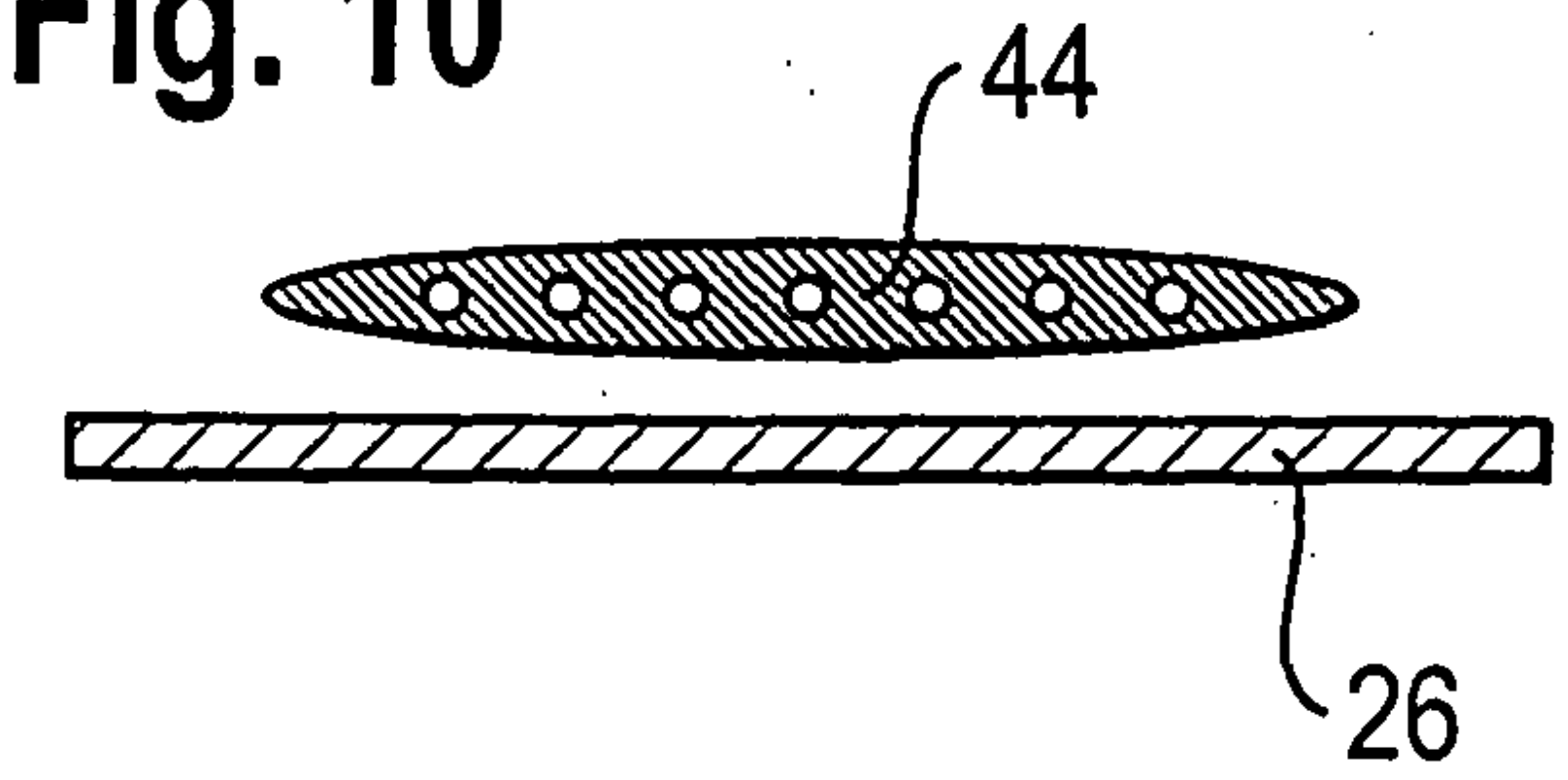

Fig. 11

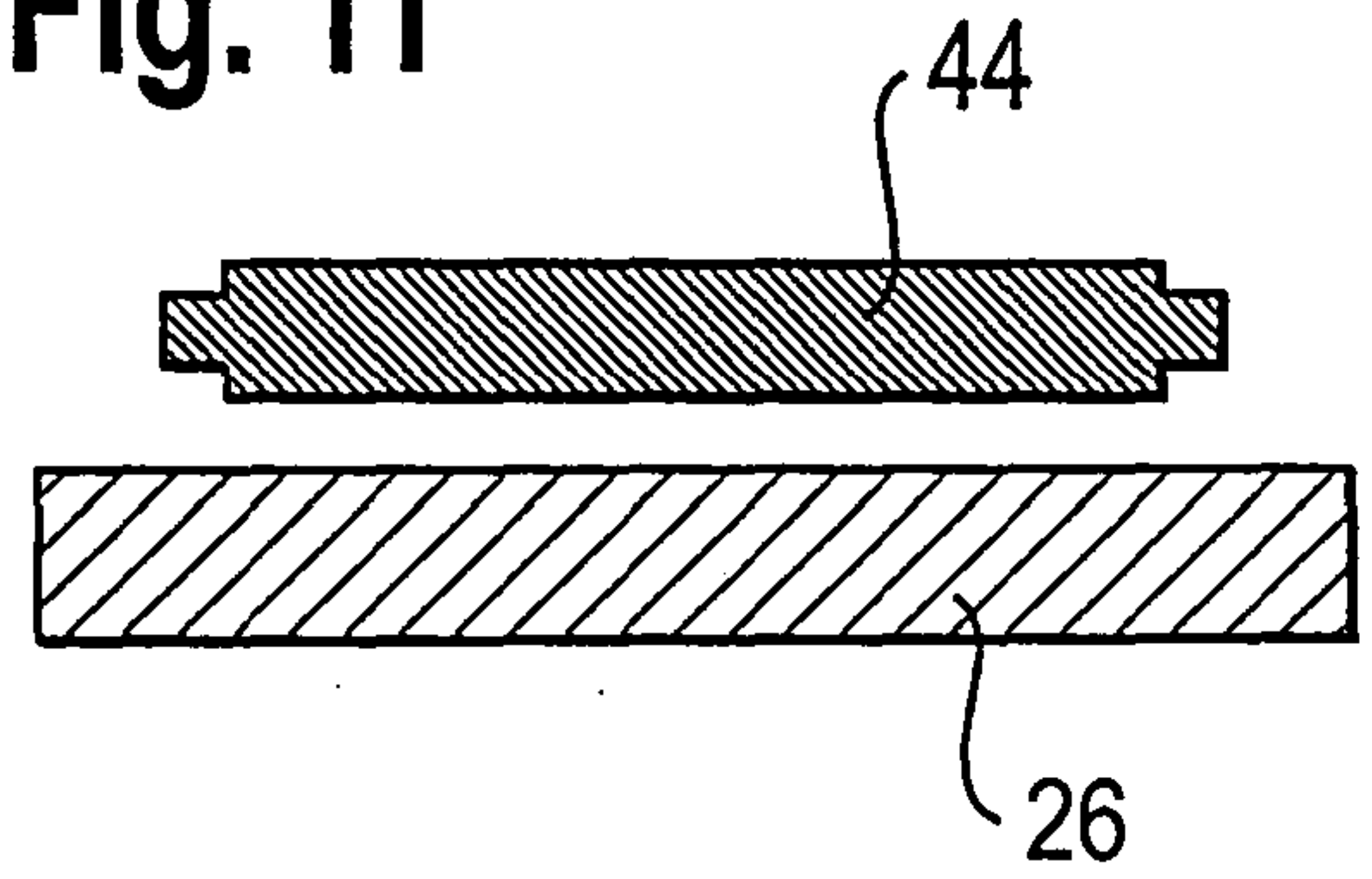

Fig. 12

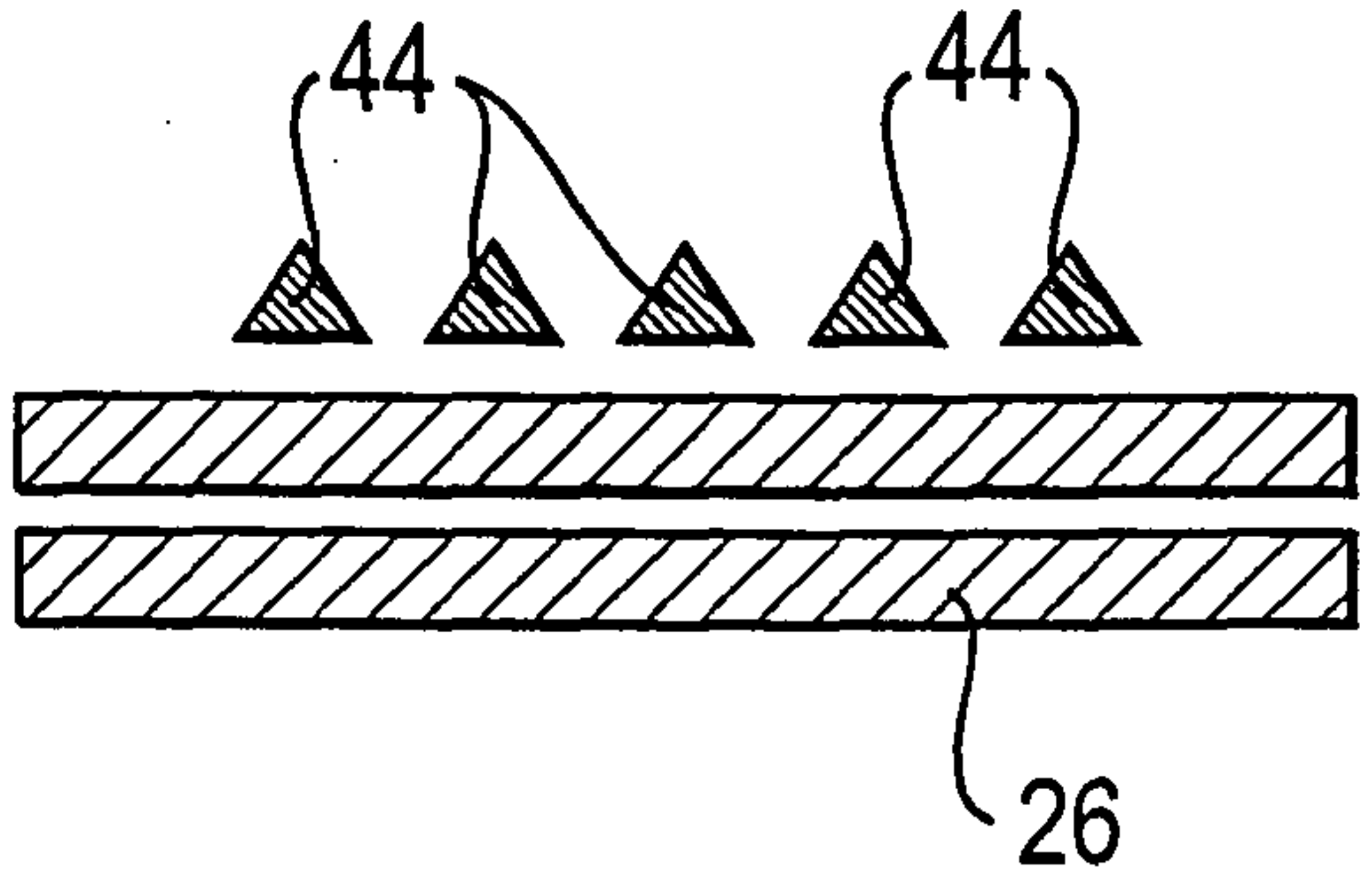

Fig. 13

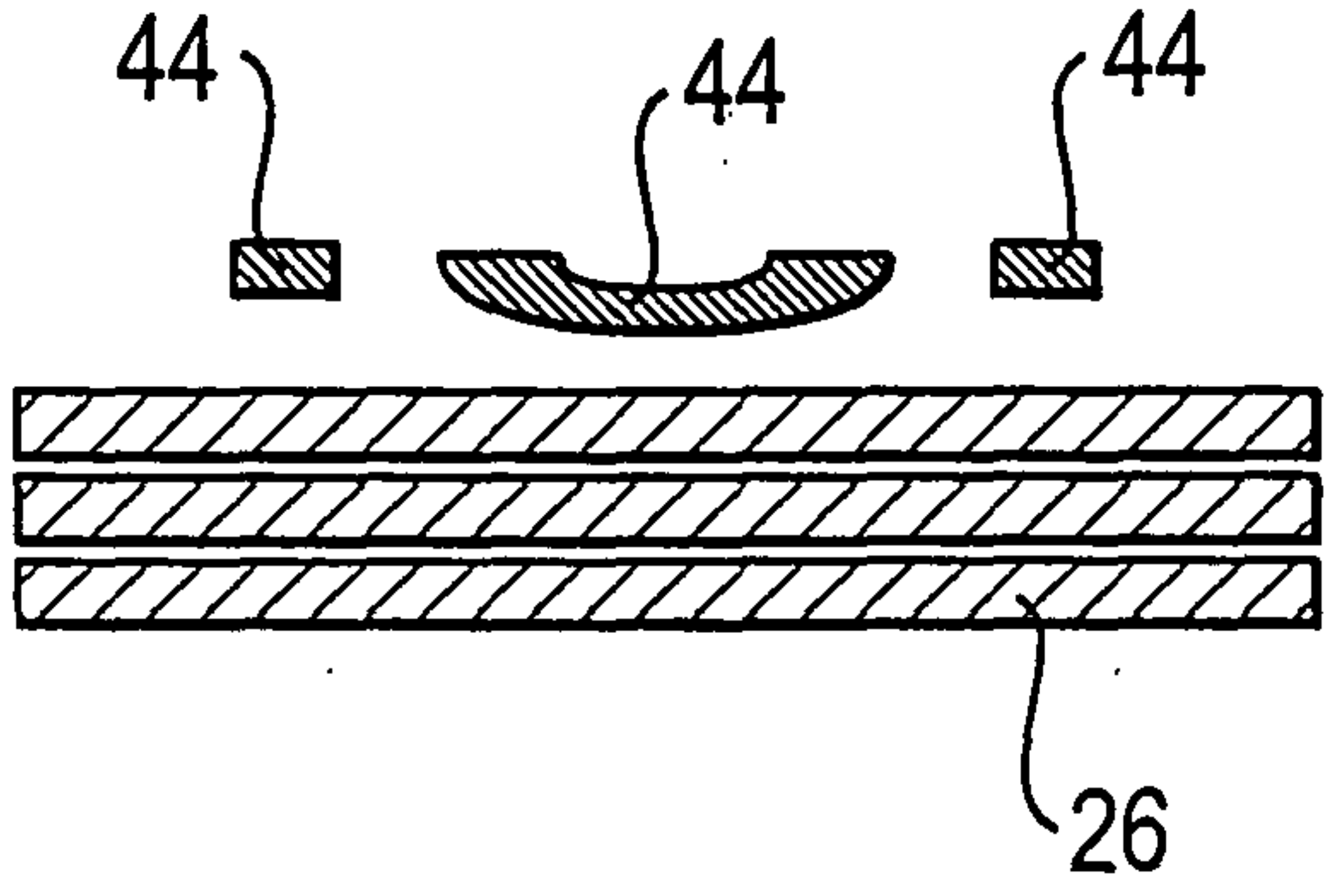

Fig. 14

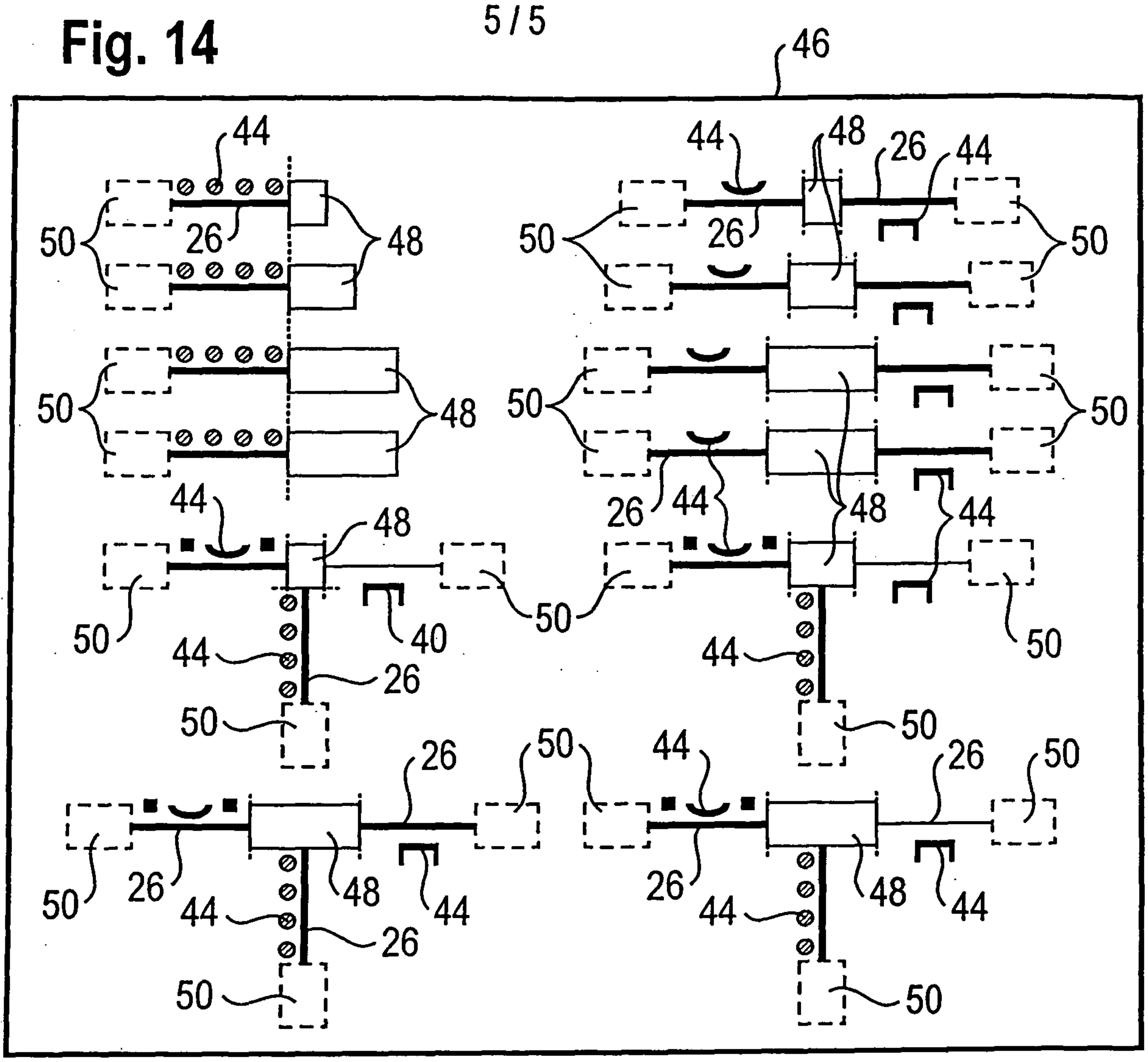
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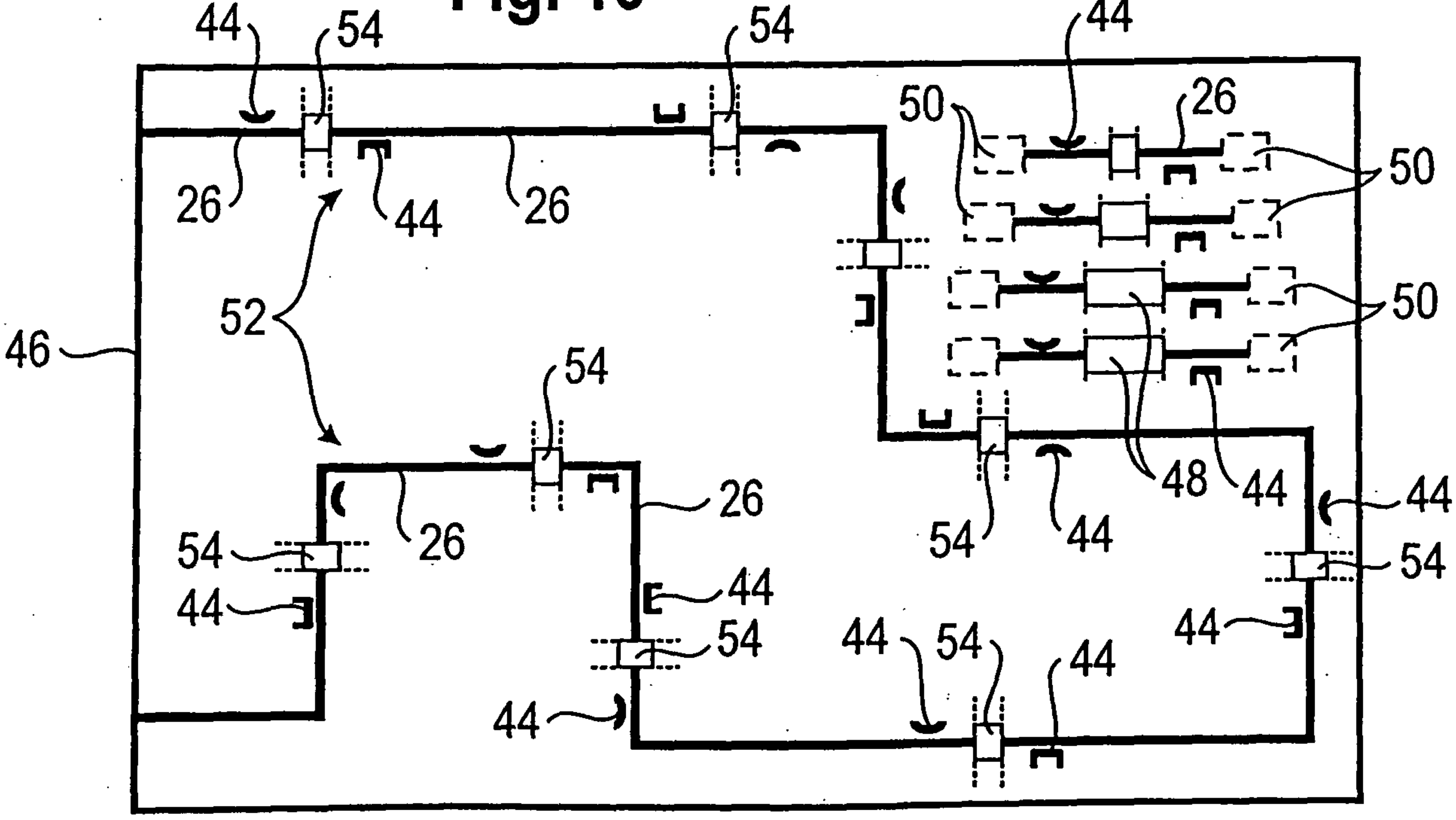
Fig. 15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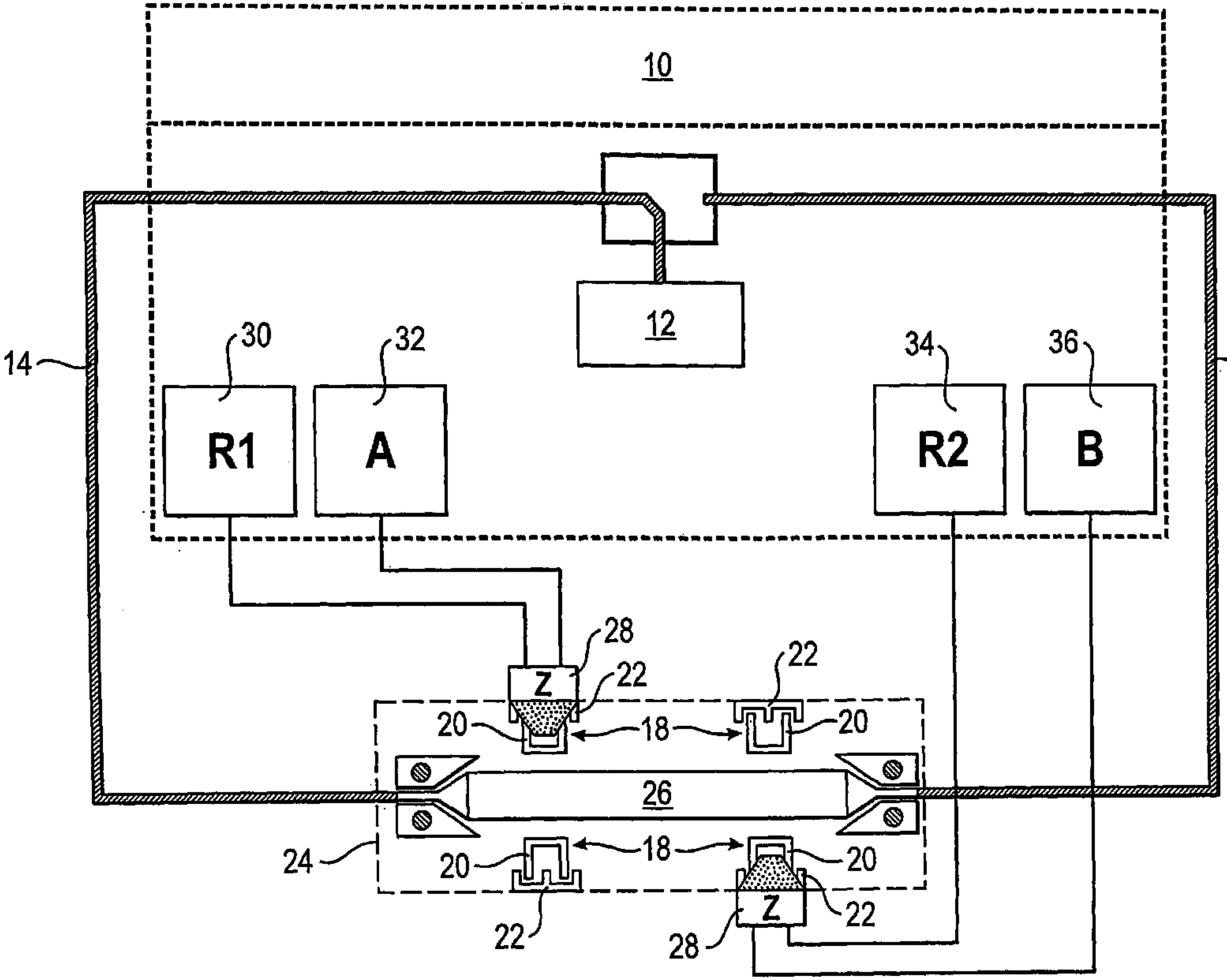

Fig. 1