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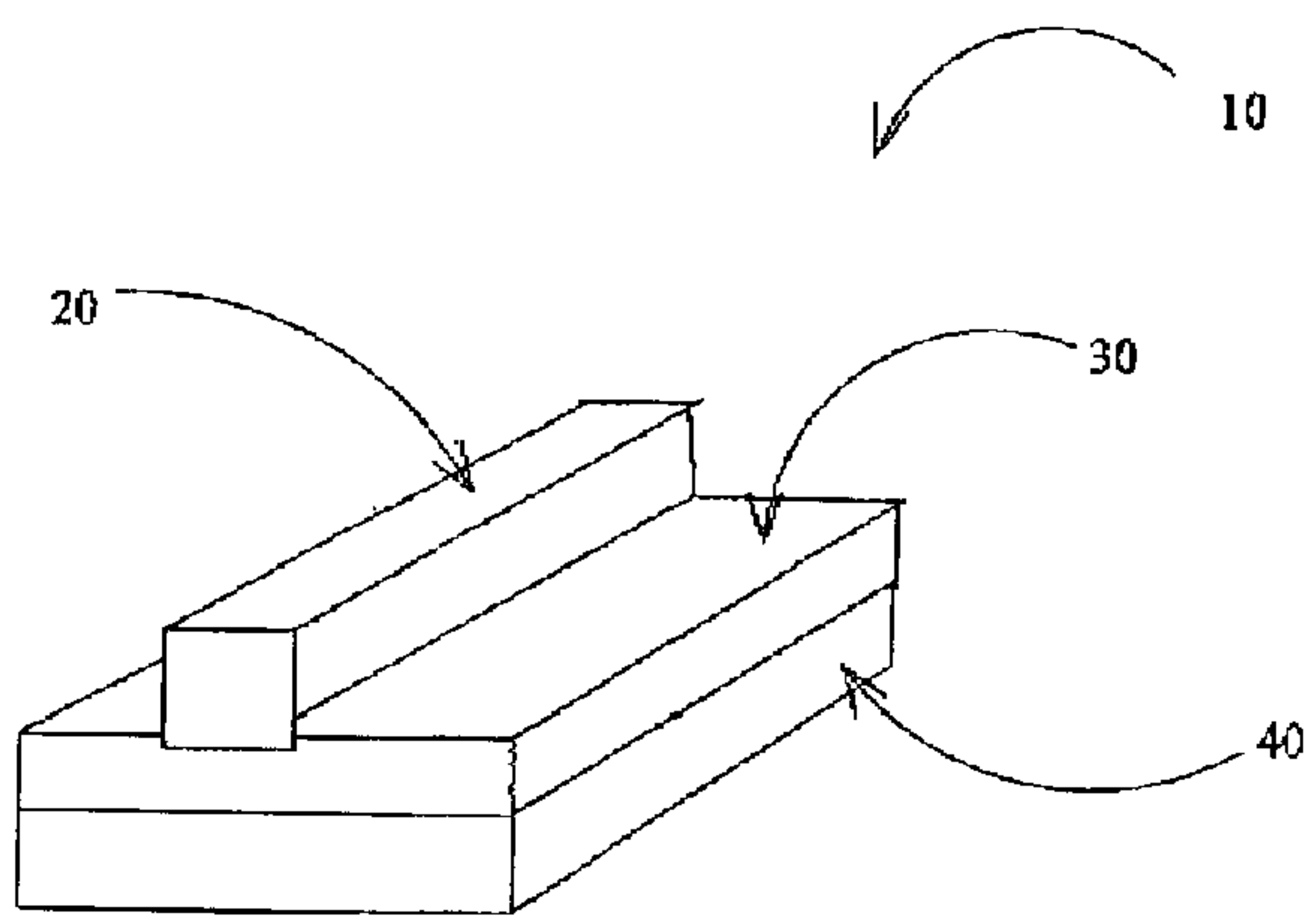
(54) **Titre : BIOCAPTEUR DE GUIDE D'ONDE PHOTONIQUE EN SILICIUM**
(54) **Title: SILICON PHOTONIC WIRE WAVEGUIDE BIOSENSOR**



(57) **Abrégé/Abstract:**
Methods and devices relating to a sensor for use in detecting and monitoring molecular interactions. A silicon waveguide sensing element is provided along with a layer of silicon. A silicon oxide layer is also provided between the waveguide element and the layer of silicon. The sensing element is adjacent to an aqueous solution in which the molecular interactions are occurring. A light beam travelling in the silicon waveguide creates an evanescent optical field on the surface of the sensing element adjacent to the boundary between the sensing element and the aqueous medium. Molecular interactions occurring on this surface affect the intensity or the phase of the light beam travelling through the waveguide by changing the effective refractive index of the medium. By measuring the effect on the intensity, phase, or speed of the light beam, the molecular interactions can be detected and monitored in real time.

ABSTRACT

Methods and devices relating to a sensor for use in detecting and monitoring molecular interactions. A silicon waveguide sensing element is provided along with a layer of silicon. A silicon oxide layer is also provided between the waveguide element and the layer of silicon. The sensing element is adjacent to an aqueous solution in which the molecular interactions are occurring. A light beam travelling in the silicon waveguide creates an evanescent optical field on the surface of the sensing element adjacent to the boundary between the sensing element and the aqueous medium. Molecular interactions occurring on this surface affect the intensity or the phase of the light beam travelling through the waveguide by changing the effective refractive index of the medium. By measuring the effect on the intensity, phase, or speed of the light beam, the molecular interactions can be detected and monitored in real time.

SILICON PHOTONIC WIRE WAVEGUIDE BIOSENSOR

Field of the Invention

The present invention relates to sensor technology. More specifically, the present invention relates to sensors for detecting and quantifying molecular interactions by determining how much of an effect these molecular interactions have on characteristics of light passing through a waveguide adjacent an aqueous medium where these interactions are occurring.

Background to the Invention

The recent increase in interest in and funding for the biochemical and pharmaceutical fields has created a need for more sensitive sensors that can detect and quantify molecular interactions. The detection of these molecular interactions determine whether chemical and biological processes are at work and, as such, are key to finding new and more effective pharmaceuticals.

Unfortunately, current biosensor technology suffers from a fragility and scarcity of the equipment. Current sensor technology, such as surface plasmon resonance (SPR), is quite well-known but the equipment requires delicate handling by technicians. Furthermore, such current technologies have sensitivities that are less then desirable. With SPR, the sensitivity of the equipment is limited by the short propagation length of the plasmon.

There is therefore a need for methods and devices that mitigate if not overcome the shortcomings of the prior art. Specifically, there is a need for techniques and devices which are easy to implement, robust, and whose sensitivity is not determined by the short propagation lengths of plasmons.

Summary of the Invention

The present invention provides methods and devices relating to a sensor for use in detecting and monitoring molecular interactions. A silicon waveguide sensing element is provided along with a layer of silicon. A silicon oxide layer is also provided between the waveguide element and the layer of silicon. The sensing element is adjacent to an aqueous solution in which the molecular interactions are occurring. A light beam travelling in the silicon waveguide creates an evanescent optical field on the surface of the sensing element adjacent to the boundary between the sensing element and the aqueous medium. Molecular interactions occurring on this surface affect the intensity or the phase of the light beam travelling through the waveguide by changing the effective refractive index of the medium. By measuring the effect on the intensity, phase, or speed of the light beam, the molecular interactions can be detected and monitored in real time.

In one aspect, the present invention provides a sensor for use in detecting molecules in a liquid or gas medium, the sensor comprising:

- a substrate layer,

- a light waveguide sensor element adjacent said medium

- a lower cladding layer between said sensor element and said substrate layer

wherein

- molecular interactions at the waveguide surface affect at least one characteristic of light travelling through said waveguide sensor element.

In another aspect, the present invention provides a method for detecting molecular interactions in a medium using a sensor having a light waveguide sensor element adjacent said aqueous medium, the method comprising:

a) determining characteristics of light prior to said light entering said sensor element

b) passing light through said sensor element

c) determining characteristics of light after it has exited said sensor element

d) comparing results of steps a) and c) to determine if changes in characteristics of said light occurred

e) in the event said changes in characteristics occurred, measuring said changes

wherein a presence of molecular interactions in said medium affect at least one characteristic of said light.

In another aspect, this document discloses a sensor for use in detecting molecules in a medium, the sensor comprising:

a substrate layer,

a light waveguide sensor element adjacent said medium,

a lower cladding layer between said sensor element and said substrate layer,

wherein

said sensor is for use in detecting molecules in a liquid medium;

molecular interactions at a waveguide surface affect at least one characteristic of light travelling through said waveguide sensor element;

said sensor element is a silicon photonic wire waveguide; and

said light travelling through said sensor element is only polarized in one mode.

In a further aspect, this document discloses a method for detecting molecular interactions in a liquid medium using a sensor having a light waveguide sensor element adjacent said liquid medium, the method comprising:

a) determining characteristics of light prior to said light entering said sensor element;

b) passing light through said sensor element;

c) determining characteristics of light after it has exited said sensor element;

d) comparing results of steps a) and c) to determine if changes in characteristics of said light occurred;

e) in the event said changes in characteristics occurred, measuring said changes;

wherein

said sensor element is a silicon photonic wire waveguide; and

said light travelling through said sensor element is only polarized in one mode.

Brief Description of the Figures

The invention will be described with reference to the accompanying drawings, wherein:

Figure 1 is an isometric view of a sensor according to one aspect of the invention.

Figure 2 is a front cut-away view of the sensor of Figure 1 illustrating the core of the waveguide.

Figure 3 is a side cut-away view of the sensor of Figure 1 illustrating the direction of propagation of light travelling in the waveguide and the evanescent optical field produced by such light.

Figure 4 illustrates the positioning of a molecular layer on a surface of the sensor of Figure 1

Figure 5 is a side cut-away view of the sensor of Fig 1 with a sensor window.

Figure 6A illustrates a configuration of a sensor in which the silicon dioxide layer is provided as pillars supporting the waveguide.

Figure 6B illustrates a top-down view of a configuration of the sensor which can be used as a ring resonator.

Figure 7 illustrates a sensor configuration in which the sensor can be used as a microdisk resonator.

Detailed Description

Referring to Figure 1, a sensor 10 according to one aspect of the invention is illustrated. The sensor 10 has an optical waveguide 20 (a sensor element) on top of a silicon dioxide layer 30. The silicon dioxide layer 20 (a lower cladding layer) is sandwiched between the waveguide 20 and a silicon substrate 40.

Referring to Fig 2, an end cut-away view of the sensor 10 is illustrated. In use, from Fig 2, a solution 50 (which may be water based) is adjacent the waveguide 20. The 50 contains the chemical or biochemical materials whose interactions are to be monitored or detected.

The sensor detects molecular interactions (or the presence of specific molecules) by having light passed through the sensor. The sensor detects the binding of specific, target molecules to receptor molecules on the waveguide surface. By detecting this binding, the presence of the target molecules is determined. The receptor molecules are previously attached (perhaps as a layer) to the waveguide surface. As an example, an antibody can be fixed to the sensor surface (the waveguide surface) to functionalize the antibody for detecting the presence of the corresponding antigen.

Referring to Fig 3, a side-cutaway view of the sensor is illustrated. The sensor 20 operates by detecting the effect of target molecules binding to the waveguide surface on the characteristics of light as the light travels through the waveguide.

As is well-known in the art, especially to those well-versed in SPR technology, target molecules are detected when they bind to the surface 50A of the sensor. Light travelling in the waveguide 20 (in the direction 60 of propagation) produces an evanescent optical field 70 on the surface of the waveguide 20. The molecular interactions occurring near or at the surface 50A affect the refractive index of the liquid solution, thereby slowing down or delaying the light travelling through the waveguide. This effectively changes the speed and other characteristics of the light in the waveguide. Characteristics such as the intensity and the phase of the light are affected by the extent and number of molecular interactions on the surface of the waveguide.

Molecular interactions, such as the adsorption of molecules onto the sensor surface affect the speed of light as well as the attenuation of the light. The attenuation of the light also depends on the absorption cross section at the optical wavelength of the light travelling in the waveguide. As noted above, a phase change in the light in the waveguide may also be induced due to the adsorption of a molecular layer on the surface of the waveguide.

The changes in the characteristic of the light in the waveguide can be detected and measured by the use of well-known devices and techniques. Such devices as Mach-Zehnder interferometers and resonators may be used to measure these changes in characteristic. These same devices may be used to determine the initial characteristics of the light prior to their entering the sensor. Once the initial characteristics of the light are determined, these can be compared to the characteristics of the light after the light has passed through the sensor. The differences between these two sets of characteristics (such as speed of light, phase, etc.) would indicate the presence and number of molecular interactions detected.

Referring to Fig 4, another cross-sectional view of the sensor is illustrated. As can be seen, the molecular layer 50B forms between the surface of the waveguide and the aqueous medium. Experiments have shown that sensor response increases with active sensor length and that sensor response increases with mode intensity at the perturbation location (i.e. the target molecule layer). The presence and number of target molecules can therefore be determined by sampling the characteristics (e.g. attenuation, phase, etc.) of the light travelling in the waveguide.

Experiments have shown that best results have been observed when silicon-on-insulator waveguides were used. Silicon photonic wire waveguides have been found to produce useful as the sensor elements in the sensor. For better results, a sensor window may be used to isolate the area where the waveguide core is exposed to the target molecules, to enable a comparison of the light travelling through the sensor waveguide with light travelling in an unexposed reference waveguide. Referring to Fig 5, such a sensor window is illustrated. An isolation layer 80 isolates the evanescent optical field 70 from the aqueous medium 50 and the molecular interactions. A sensor window 90, an area in which the isolation layer is not present, exposes the evanescent optical field 70 to the medium 50 and thereby to the changed refractive index due to target-receptor molecule interactions. It should be noted that the isolation layer may be fabricated using well-known photosensitive polymer coatings normally used in the fabrication of semiconductor devices.

It should be noted that various configurations of the above noted sensor are possible. Referring to Figs 6A, 6B and 7, two different configurations are illustrated. Figures 6A and 6B illustrate a bridge configuration with the waveguide core being supported by pillars 80 of silicon oxide. This configuration allows the aqueous medium to surround the waveguide and thereby increase the surface area on which the molecular interactions can occur. Such a configuration can also be used to create a ring resonator as in Fig 6B. In Fig 7, a microdisk resonator can be configured using a single silicon oxide pillar 80 to support a microdisk waveguide sensor.

Experiments have also shown that better results have been achieved when the waveguides were thin as well as having a high contrast in terms of refractive index. Thus, better results were found when the contrast between the effective refractive index (N_{eff}) and the refractive index of the cladding was at a maximum. Also, it has been found that better results were achieved when the polarization of the light travelling in the waveguide was perpendicular to the active surface (the so-called TM mode). One material which produced acceptable results (thin waveguide, high index contrast, and TM mode) were silicon photonic wire waveguides. However, other materials may also provide equally acceptable results.

It should also be noted that the presence of a thin layer (i.e. the layer must be thinner than the extent of the evanescent field above the waveguide) of silicon dioxide between the waveguide and the medium containing the molecular interactions does not significantly degrade the performance (sensitivity) of the sensor. As such, a layer of silicon dioxide (i.e. glass) may be deposited on the waveguide.

Based on the above, silicon or other established glass bio-chip chemistries may be used in the production of the above noted sensor elements.

What is claimed is:

1. A sensor for use in detecting molecules in a medium, the sensor comprising:

a substrate layer,

a light waveguide sensor element adjacent said medium,

a lower cladding layer between said sensor element and said substrate layer,

wherein

said sensor is for use in detecting molecules in a liquid medium;

molecular interactions at a waveguide surface affect at least one characteristic of light travelling through said waveguide sensor element;

said sensor element is a silicon photonic wire waveguide; and

said light travelling through said sensor element is only polarized in one mode.

2. A sensor according to claim 1, wherein a portion of said sensor element is exposed to said liquid medium through a sensor window in an isolation layer which isolates said sensor element from said liquid medium.

3. A sensor according to any of claims 1 to 2, wherein said lower cladding layer comprises a layer of silicon dioxide.

4. A sensor according to any of claims 1-3, wherein said lower cladding layer comprises at least one pillar of silicon oxide supporting said sensor element on said substrate layer.

5. A sensor according to any of claims 1-4, wherein said sensor element comprises a ridge waveguide.

6. A sensor according to any of claims 1-4, wherein said sensor element comprises a channel waveguide.

7. A sensor according to any of claims 1-6, wherein said sensor element is configured as a straight waveguide.

8. A sensor according to any of claims 1-6, wherein said sensor element is configured as a resonator.

9. A sensor according to any of claims 1-8, wherein said sensor element is incorporated in a Mach-Zehnder interferometer.

10. A sensor according to any of claims 1-9, wherein said sensor further comprises a silicon dioxide layer between said medium and said sensor element.

11. A sensor according to any of claims 1-10, wherein said at least one characteristic of light comprises a speed of said light.

12. A sensor according to any of claims 1-11, wherein said sensor element is a thin, high refractive index contrast waveguide.

13. A sensor according to any of claims 1-12, wherein polarization of said light travelling through the sensor element is perpendicular to an active sensor surface.

14. A method for detecting molecular interactions in a liquid medium using a sensor having a light waveguide sensor element adjacent said liquid medium, the method comprising:

a) determining characteristics of light prior to said light entering said sensor element;

b) passing light through said sensor element;

c) determining characteristics of light after it has exited said sensor element;

d) comparing results of steps a) and c) to determine if changes in characteristics of said light occurred;

e) in the event said changes in characteristics occurred, measuring said changes;

wherein

said sensor element is a silicon photonic wire waveguide; and

said light travelling through said sensor element is only polarized in one mode.

15. A method according to claim 14, wherein said sensor element comprises a thin, high refractive index contrast waveguide.

16. A method according to any of claims 14-15, wherein polarization of said light travelling through the sensor element is perpendicular to an active sensor surface.

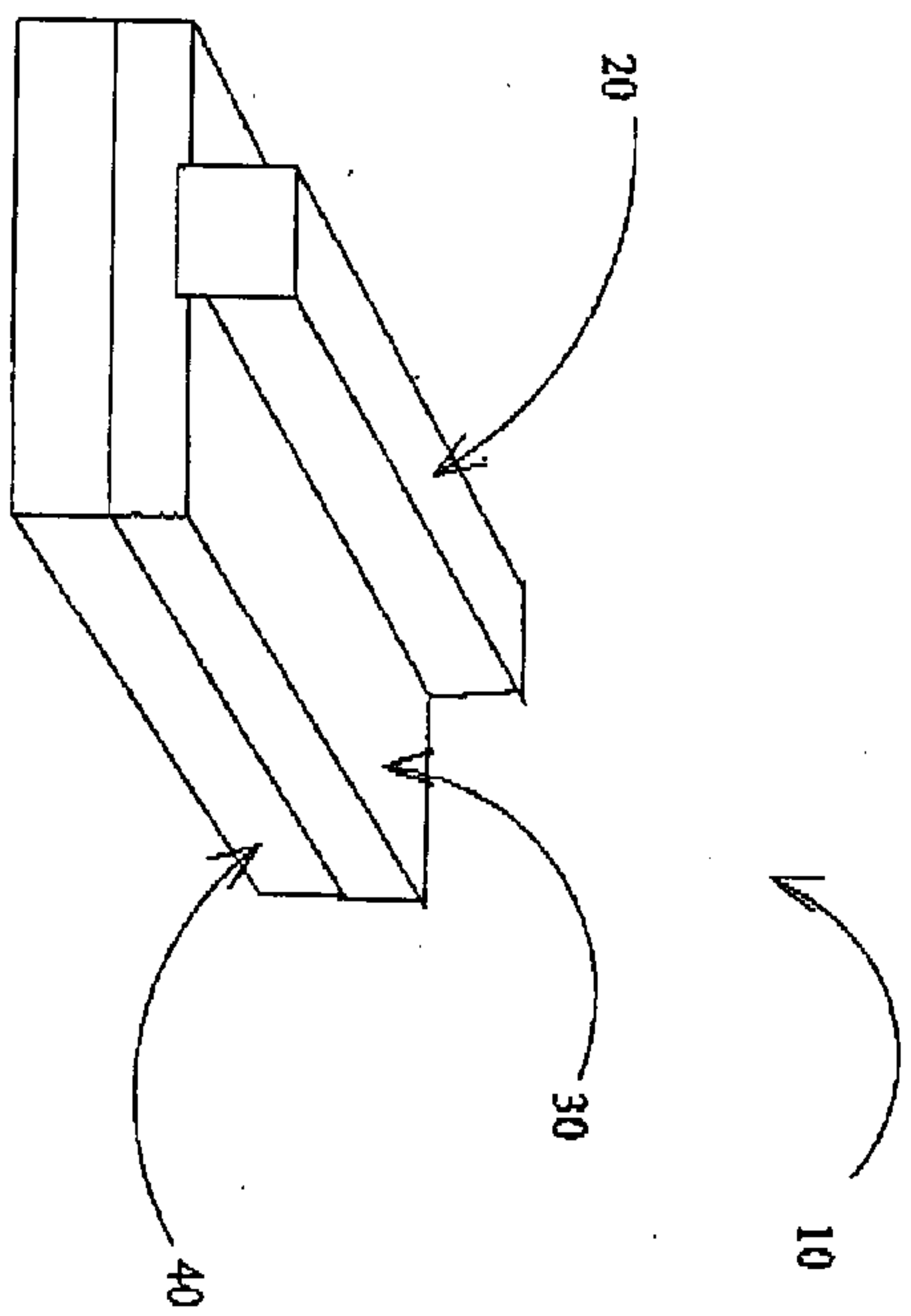


FIGURE 1

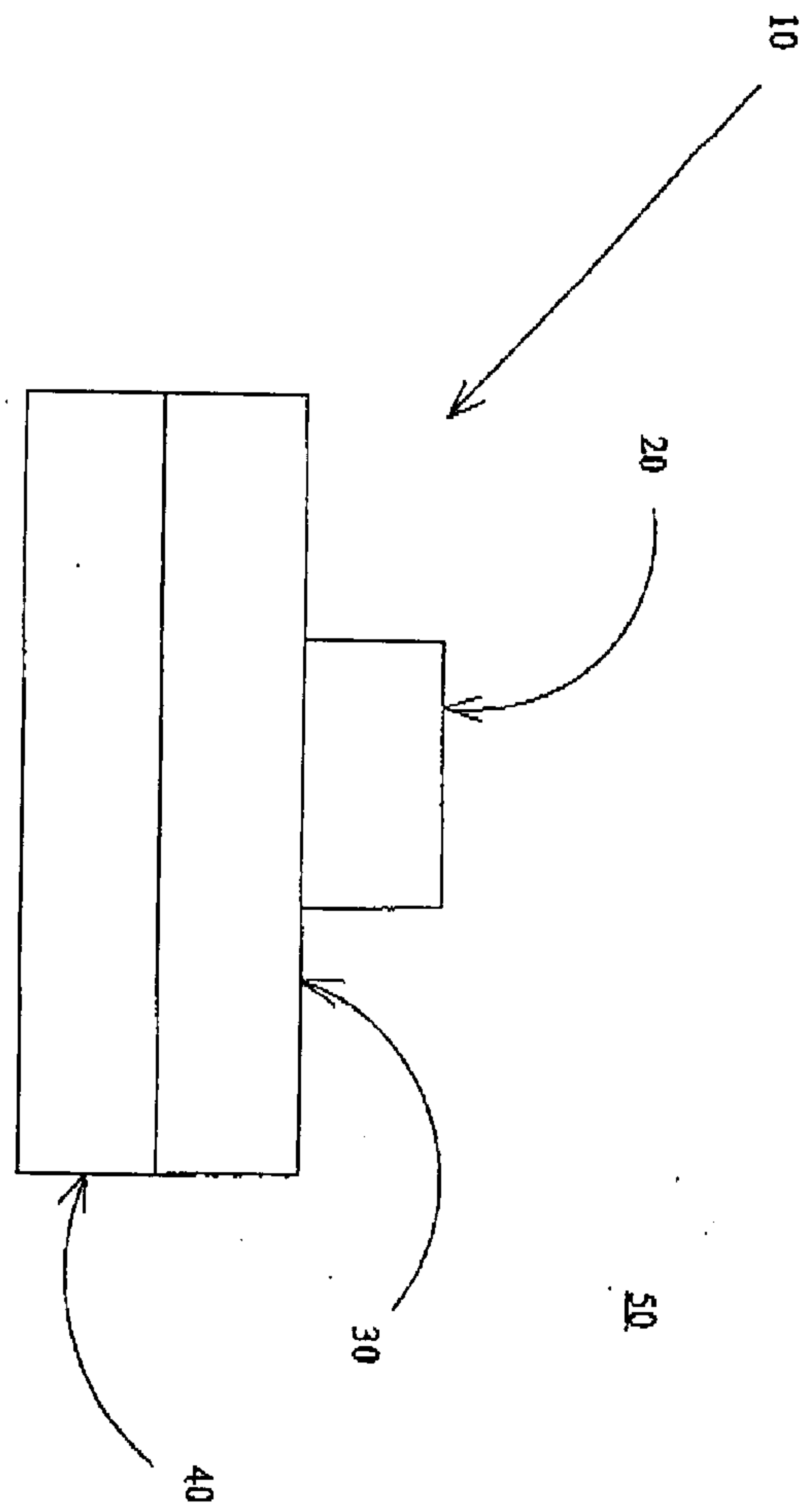


FIGURE 2

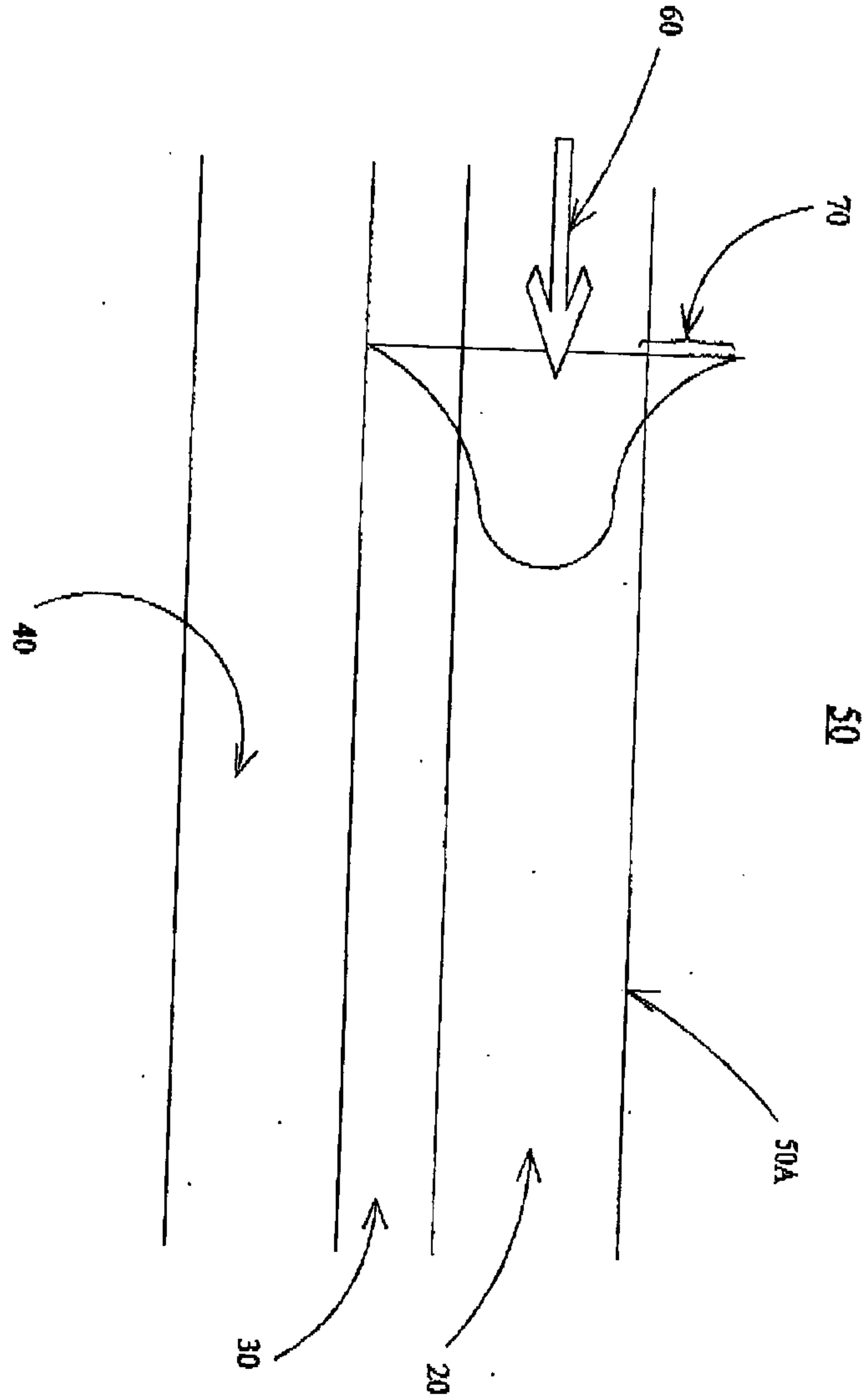


FIGURE 3

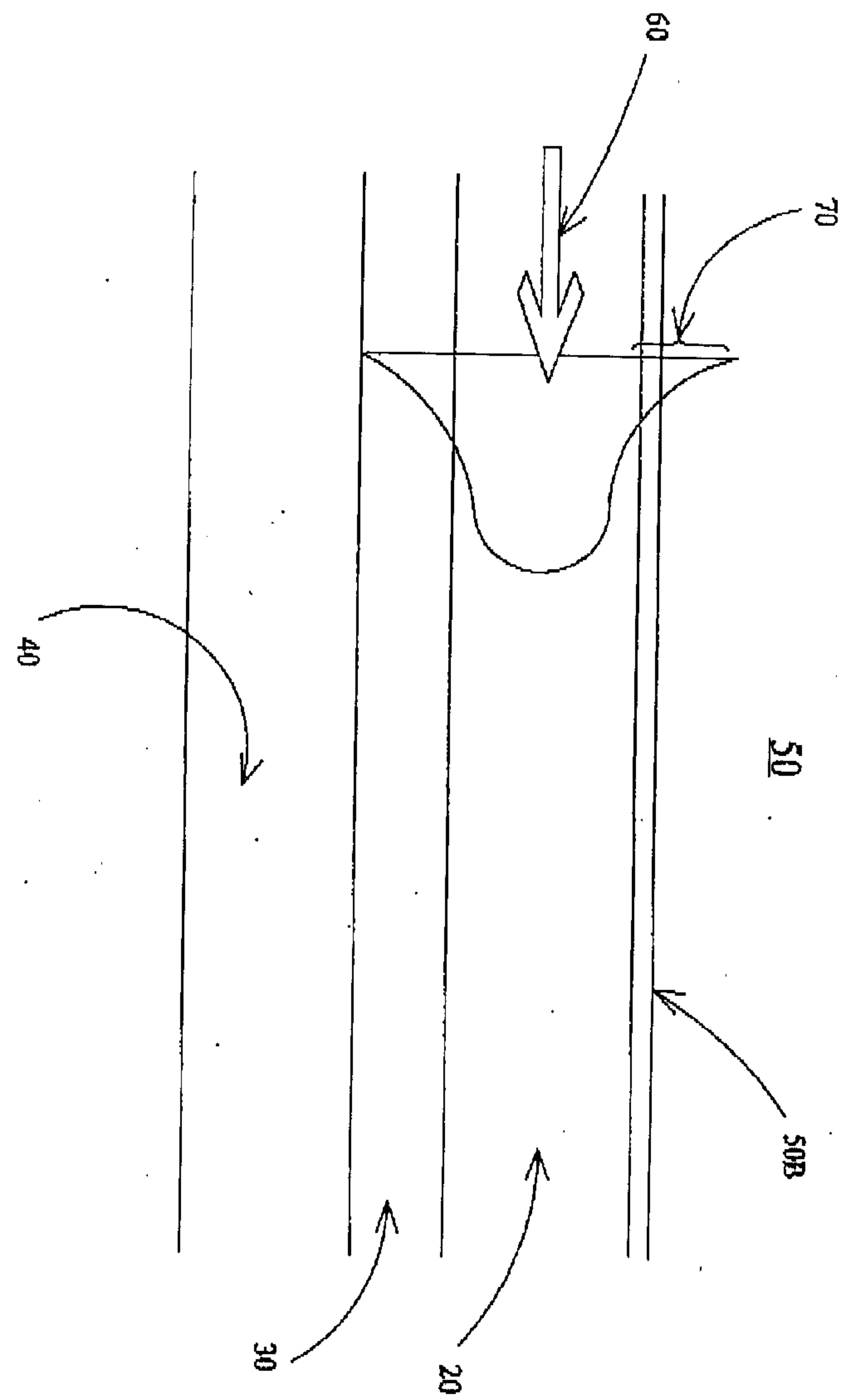


FIGURE 4

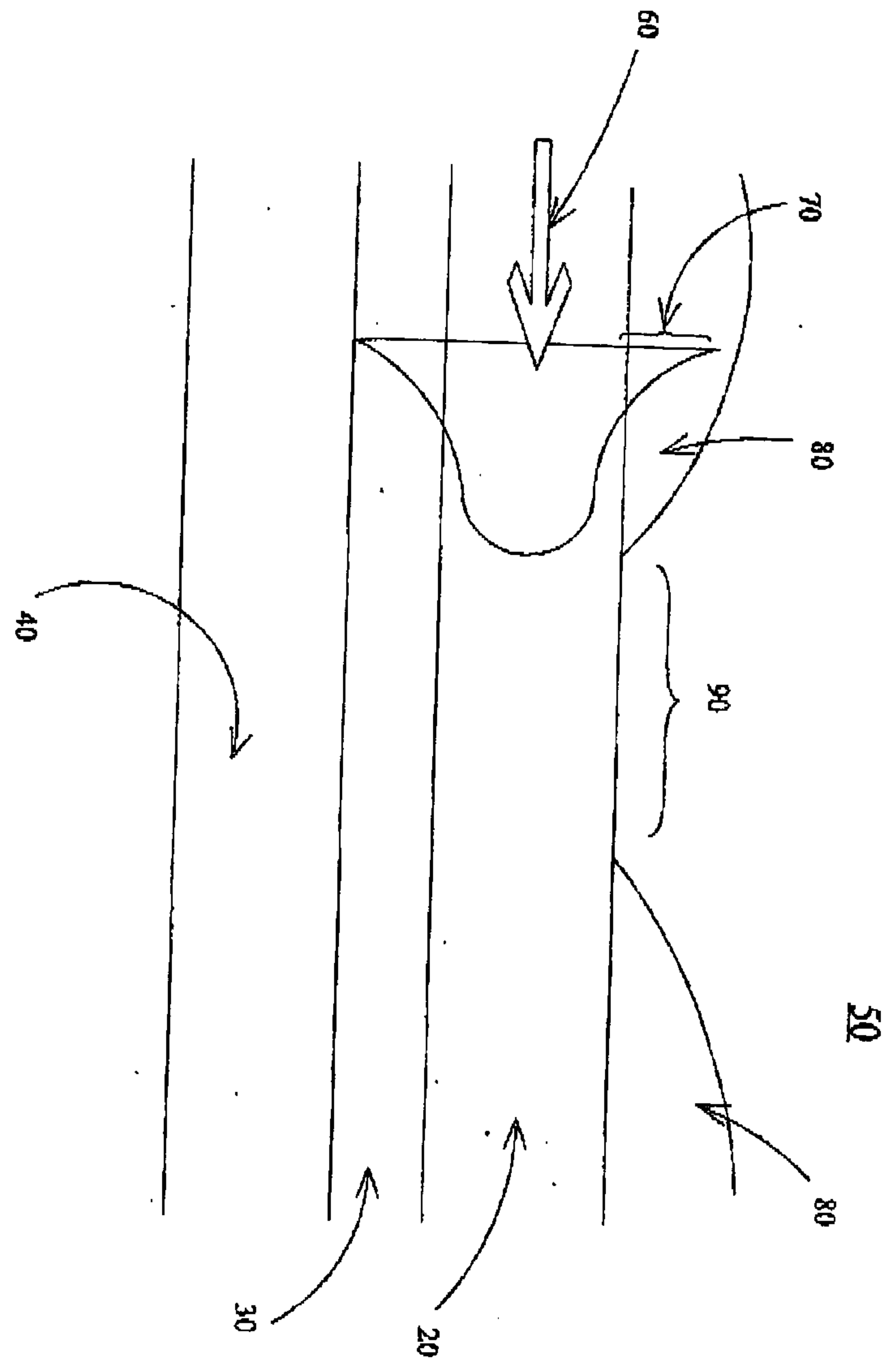


FIGURE 5

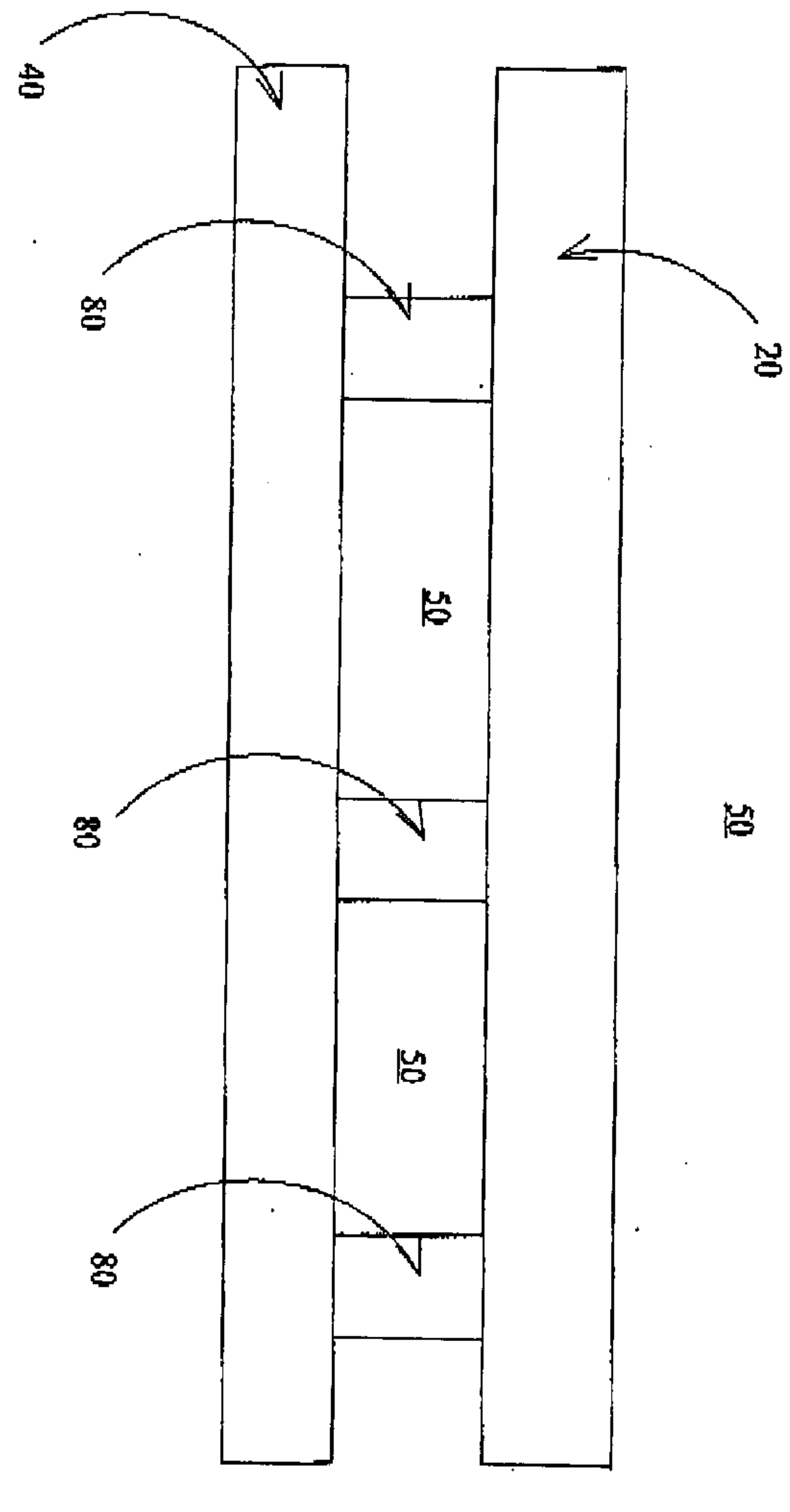


FIGURE 6A

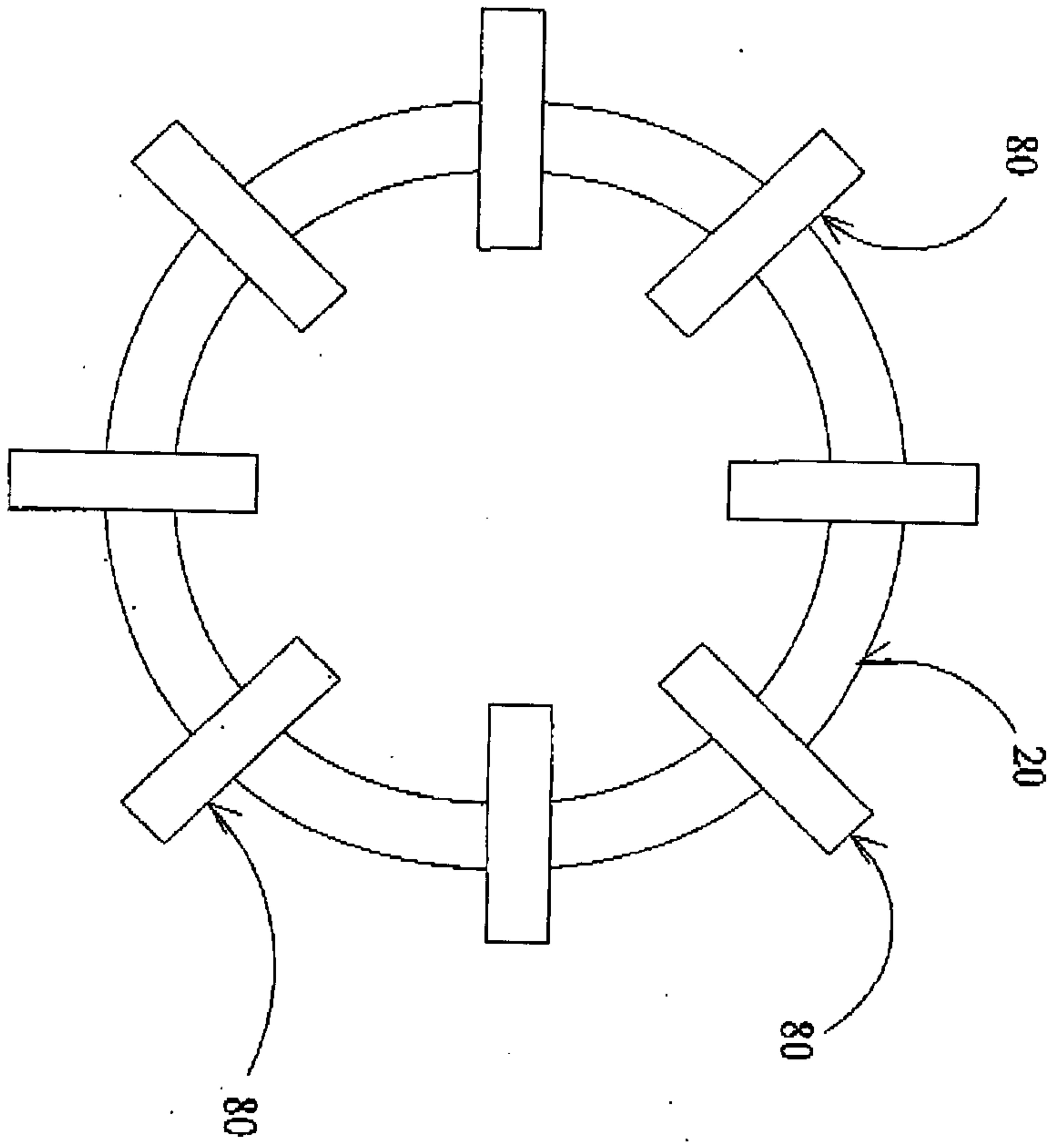


FIGURE 6B

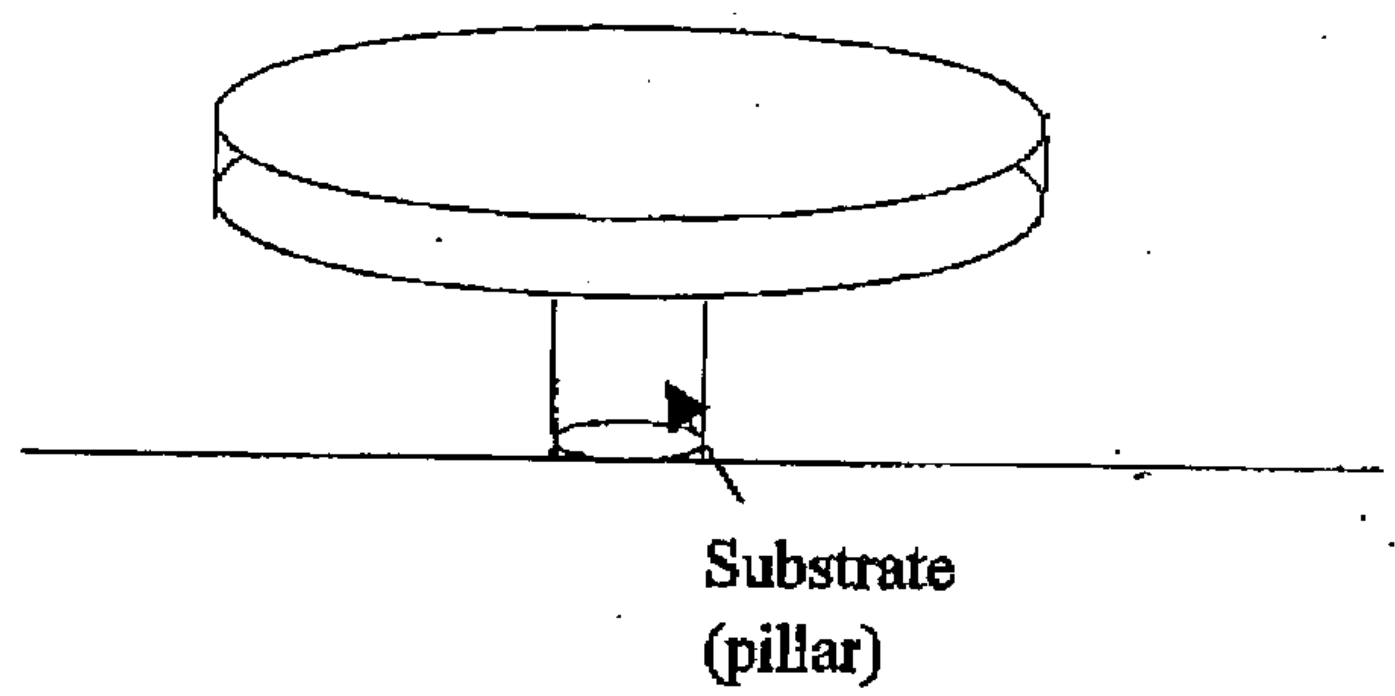
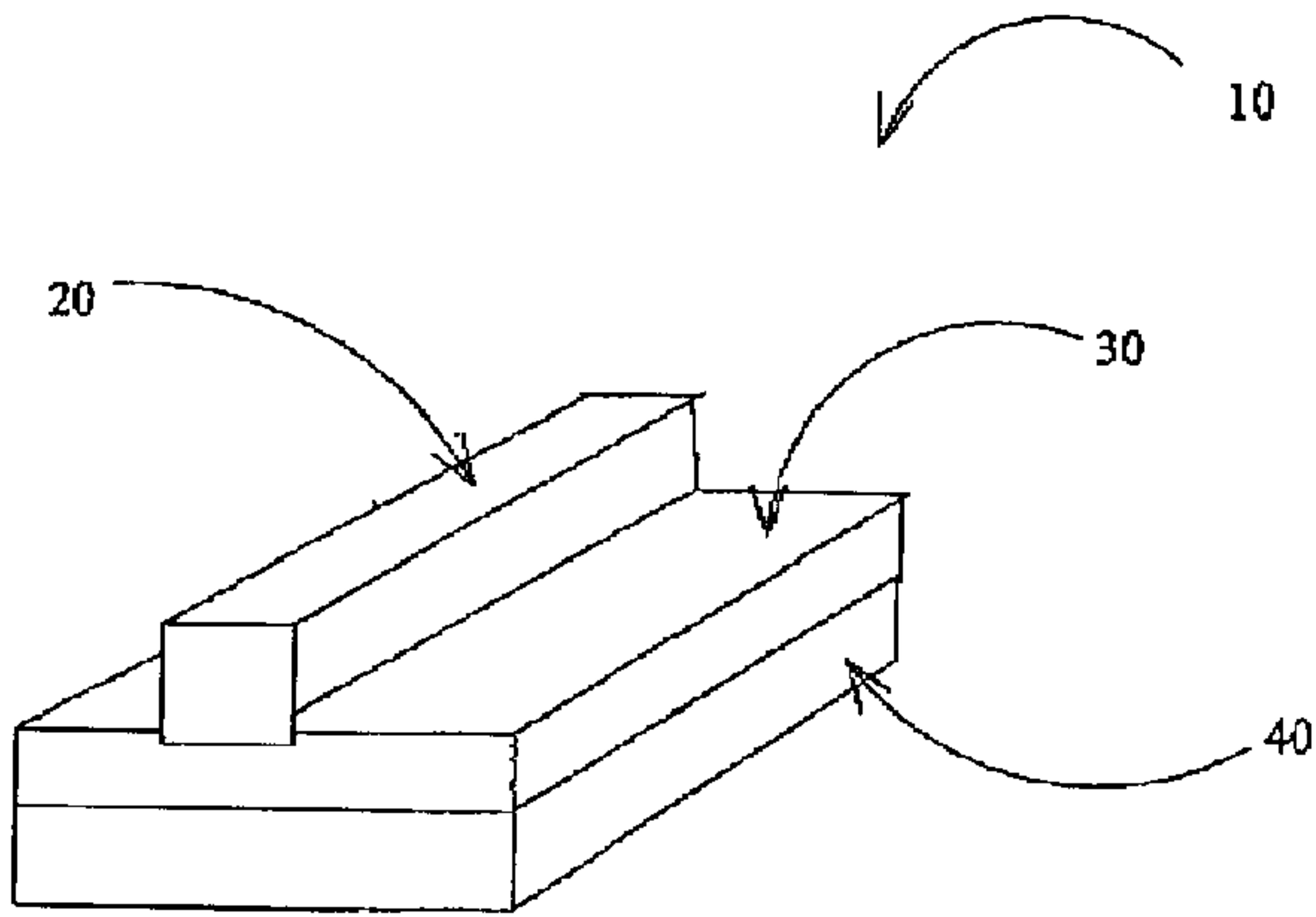


FIGURE 7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