(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 190 948 A2**

(12) **EUROPEAN PATENT APPLICATION**

(21) Application number: 86300880.1

(51) Int. Cl.⁴: **G 10 K 11/34**

(22) Date of filing: 10.02.86

(30) Priority: 08.02.85 JP 23875/85
08.02.85 JP 23876/85
08.02.85 JP 23877/85

(43) Date of publication of application:
13.08.86 Bulletin 86/33

(84) Designated Contracting States:
DE FR GB

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(54) **Ultrasonic probe.**

(57) An ultrasonic probe for an ultrasonic medical diagnostic apparatus which is composed of a plurality of piezoelectric vibrators (1) with electrodes (8, 9) attached onto both surfaces thereof and one or two acoustic matching layers (3, 6) which are provided on the surface of one electrode (8) of the piezoelectric vibrator. One of the acoustic matching layers is made of thermosetting resin such as epoxy resin mixed with carbonyl group material. A backing load member (2) which is made of epoxy resin or rubber material mixed with microspheres and metal or insulator powder is provided on the surface of the other electrode (9) of the piezoelectric vibrator. A filler material (5) which is made of rubber material or thermosetting resin is filled between each of said piezoelectric vibrators.

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ULTRASONIC PROBE

This invention relates to an ultrasonic probe which is used for an ultrasonic medical diagnostic apparatus and which serves as a transmitter and receiver of a sound wave.

There are various types of ultrasonic diagnostic apparatus, and hence, various types of ultrasonic probes for various purposes. As representative ultrasonic probes, there is an array-type ultrasonic probe in which multiple strips of micro piezoelectric vibrators are arrayed on a straight line.

The array-type ultrasonic probe is composed of multiplicity of strips of piezoelectric vibrators with electrodes attached onto both surfaces. Piezoelectric ceramic or the like is used for the piezoelectric vibrator and those piezoelectric vibrators with electrodes are set in array. On the electrode of the piezoelectric vibrator on the side of an object to be examined an acoustic matching layer is formed and, if necessary, an acoustic lens is disposed thereon. On the surface of the piezoelectric vibrator contrary to the object to be examined a backing load member is provided.

The acoustic matching layer consists of one or two layers made of glass or epoxy resin which is mixed with tungsten powder. When the acoustic matching layer made of these materials is attached to the piezoelectric vibrator, an adhesive should be made even and thin, and when the ultrasonic probe is operated with high-frequency waves, the matching layer should be made very thin to a degree of the order of several tens of microns, which is easy to damage and makes the manufacture of the ultrasonic probe very difficult.

The backing load member is generally made of epoxy resin mixed with tungsten powder, rubber material mixed with ferrite powder, or urethane rubber mixed with hollow microspheres of plastics having a diameter of several hundreds microns or below. The epoxy resin mixed with tungsten powder is superior in hardness characteristics, but has small acoustic propagation loss of sound wave. On the contrary, the rubber material mixed with ferrite powder is inferior in hardness characteristics. The urethane rubber mixed with the hollow microspheres of plastics has low acoustic impedance in comparison with said epoxy resin or rubber material, and wide dynamic range is obtained because of small deterioration of sensitivity for sound wave. However, the acoustic propagation loss for sound wave is small, approximately 2.5 dB/mm at 3.5 MHz.

SUMMARY OF THE INVENTION

It is therefore an object to provide an ultrasonic probe which has acoustic matching layer having high mechanical strength to prevent damage of the acoustic matching layer.

It is another object of the present invention to provide an ultrasonic probe for high frequency driving which is easy to manufacture.

It is a further object of the present invention to provide an ultrasonic probe which is small in size and light in weight.

It is a further object of the present invention to provide an ultrasonic probe which reproduces an image with high resolution by reducing crosstalks between the piezo-electric elements.

According to the present invention, an ultrasonic probe is provided which comprises a plurality of piezoelectric vibrators for transmitting and receiving ultrasound wave, a backing load member which is provided on one surface of said piezoelectric vibrators, an acoustic matching layer which is provided on another surfaces of said piezoelectric vibrators, and a plurality of fillers which are filled between said plurality of piezoelectric vibrators. The backing load member is composed of epoxy resin or rubber material which are essentially including metal or insulator powders and hollow microspheres of plastics. The acoustic matching layer consists of one or more layer, and the acoustic impedance layer on the side of an object to be examined is made of thermosetting resin mixed with carbonyl group material. The filler is made of epoxy resin which is mixed with powders as ocasion demands. The material of the filler is substitutable with rubber material or thermosetting resin which are mixed with metal powders or insulator powders and hollow microspheres of plastics.

BRIEF DESCRIPTION OF THE DRAWINGS

This and other objects as well as advantages of the p present invention will become clear by the following description of a preferred embodiment of the present invention with reference to the accompanying drawings, wherein:

Fig. 1 is a perspective view of a conventional ultrasonic probe;

Fig. 2 is a perspective view of an embodiment of an ultrasonic probe according to the present invention;

Fig. 3 is a cross-sectional view taken along the line A-A of Fig. 2;

Fig. 4 is a perspective view of another embodiment of an ultrasonic probe according to the present invention; and

Fig. 5 is a cross-sectional view taken along the line B-B of Fig. 4.

DETAILED DESCRIPTION OF THE INVENTION

Before description of the invention, a conventional ultrasonic probe will be explained with reference to the drawing for a better understanding of the invention.

Fig. 1 shows an example of a structure of an conventional ultrasonic probe. On the opposite side to an object to be examined of a piezoelectric vibrator 101 which is made of piezoelectric ceramic or the like, a backing load member 102 for expanding the frequency width of ultrasonic waves and obtaining the mechanical strength of the ultrasonic probe is provided through an electrode (not shown).

As the backing load member 102 a rubber material mixed with ferrite powder or a plastic material mixed with tungsten powder is used. On the side of the object to be examined of the piezoelectric vibrator 101, one or two acoustic matching layers 103, 106 for efficiently leading a sound wave to the object to be examined are provided on another electrode. Further, on these layers an acoustic lens 107 is provided. Numeral 105 represents a filler material which is filled in a gap between the piezoelectric vibrators 101. Numeral 108 represents a sound wave emanated from the ultrasonic probe. A material such as glass or epoxy resin mixed with tungsten powder is used as a material for the acoustic matching layer 103 on the side of the piezoelectric vibrator 101 and epoxy resin is used as a material for the acoustic matching layer 106 on the side of the object to be examined. The acoustic impedance of these materials is, generally, 8 - 15 x 10^5 g/cm^2.s in the acoustic matching layer 103 on the side of piezoelectric vibrator 101 (hereinunder "the first matching layer") and 2 - 4 x 10^5 g/cm^2·s in the acoustic matching layer 106 on the side of the object to be examined (hereinunder "the second acoustic matching layer"). The thickness of the first and the second acoustic matching layers 103, 106 is generally equal to a quarter wavelength of the sound wave which travels each acoustic matching layer.

If glass is used as a material for the first matching layer 103, the acoustic impedance is 11 - 15 x 10^5 g/cm^2·s, which is an appropriate value from the viewpoint of acoustic impedance matching, but the probe is mechanically weak. Therefore an ultrasonic probe in which glass is used for the first matching layer disadvantageously brings about a problem such as difficulty in manufacturing or decrease in the yield. On the other hand, when a epoxy resin mixed with tungsten powder is used for the first matching layer 3, the acoustic impedance can be freely selected (8 - 15 x 10^5 g/cm^2·s), and the probe is mechanically strong. However, since the velocity of sound of this material is as slow as 1600m/sec, the matching layer should be made very thin when the ultrasonic probe is operated with high-frequency waves, for example, 80 micron when the frequency is 5 MHz, which makes the manufacture of the ultrasonic probe very difficult.

The filler 105 is provided for acoustically coupling said piezoelectric vibrators 101 discontinuously to prevent acoustic crosstalk between the piezoelectric vibrators 101. For this purpose, adhesive of epoxy resin which has small acoustic impedance of about 3×10^5 g/cm^2·s is used. However, the adhesive 105 leaks the ultrasonic wave approximately 15 - 26% from one piezoelectric vibrator to neighbour piezoelectric vibrator. Furthermore, the adhesive 105 has small wave propagation loss of 1 dB/mm at 3.0 MHz. Therefore, the adhesive 105 of epoxy resin cannot prevent the crosstalk sufficiently.

Figs. 2 and 3 are a perspective view and cross-sectional view of an embodiment of an ultrasonic probe according to the invention.

An electrode terminals are bonded to an electrode 9 of a piezoelectric vibrator 1 by soldering or the like, and the backing load member 2 is bonded onto the surface of the electrode 9. Then, a material for the first matching layer 3 is provided by adhesive or pouring onto a common electrode 8 to form into the thickness of a quarter wavelength. This material for the first matching layer 3 is composed of essentially thermosetting resin mixed with powder of carbonyl group material. For instance, in the case of wave absorbing material of epoxy resin mixed with iron carbonyl produced by Emerson and Cumming Company (ECCOSORBCR-124), the acoustic impedance is 11×10^5 g/cm^2·s, the velocity of sound is 2500 m/sec and it cures in 12 hours at 60°C.

The piezoelectric vibrator 1 and the first matching layer 3 is divided into a plurality of portions by machining or laser-machining and gaps thus formed are filled with a filler material 5 the acoustic impedance of which is small, and the attenuation of sound wave of which is large.

Subsequently a second matching layer 6 of a thickness of a quarter wavelength is formed by the same adhesive or pouring method as in the first matching layer 3. The second matching layer 6 is made of a material having acoustic impedance of $2.5 \times 10^5 - 4 \times 10^5$ g/cm^2·s, such as epoxy resin. On the second matching layer 6 an acoustic lens 7 such as silicone rubber is provided.

The backing load member 2 is made of epoxy resin mixed with tungsten powder and hollow microsphere of plastics (hereafter called "microballoon"). For example the epoxy resin mixed with 250 wt % of tungsten powder and 3 wt % of microballon has the following advantageous properties.

Acoustic impedance	:	3×10^5 g/cm^2·s
Acoustic propagation loss	:	26 dB/mm at 3MHz.
Shore hardness D	:	more than 85

The filler material 5 is composed of a material such as epoxy resin, which may be adaptable of the adhesive for the second acoustic matching layer 6, or epoxy resin mixed with silicon carbide powder.

As described above, this invention introduces epoxy resin mixed with iron carbonyl, which can be poured and set at a temperature not higher than 100°C, as a material for the first matching layer 3, it is possible to easily obtain an ultrasonic probe of high efficiency and uniform properties. In addition, this material has the acoustic impedance of 11×10^5 g/cm^2·s, which satisfies the acoustic matching condition and increases efficiency. Furthermore, the high velocity of sound of 2500 m/sec allows the ultrasonic probe with a frequency of as high as 5 MHz to be made as thick as 125 micron, which is thick enough to be formed easily, and heightens reliability in mechanism.

To avoid unnecessary reflection of sound wave from the surface of the backing load member 2 and to obtain wide dynamic range, it is desirable to use a material having large acoustic propagation loss as the backing load member. The aforementioned material for the backing load member 2 has the acoustic propagation loss of 26 dB/mm at 3 MHz, which results to obtain the dynamic range of more than 150 dB. Furthermore, this material allows to lower the thickness of the backing load member 2 to 2.9 mm or more to avoid unnecessary reflection. As a result, remarkable miniaturization and light weighting of the ultrasonic probe are realized in comparison with the conventional one which utilize urethane rubber or rubber material with ferrite powder as the backing load member.

The filler material 5 of aforementioned epoxy resin or epoxy resin mixed with silicon carbide powder suppress unnecessary transverse vibration and attenuate acoustic crosstalk between the piezoelectric vibrators 1.

Figs. 4 and 5 are a perspective view and cross-sectional view of another embodiment of the present invention. In these figure, like reference numerals of those of Figs. 2 and 3 denote like elements. In this embodiment, the piezoelectric vibrator 1 is devided into a plurality of portions, but the first acoustic matching layer 3 is not devided which is different from the embodiment of Figs. 2 and 3.

The backing load member 2 is essentially composed of rubber material mixed with metal powder or insulator material and microballoon. For example, silicone rubber mixed with 200 wt % tungsten powder and 1.5 wt % of plastics microballoon has the acoustic impedance of 1.1×10^5 $g/cm^2 \cdot s$, and large acoustic propagation loss of approximately 40 dB/mm at 3 MHz. This material makes it possible to thin the backing load member to 1.5 mm or more, wherein dynamic range of signal is obtained by avoiding unnecessary reflection of sound waves from end surface of the backing load member.

The sensitivity for ultrasonic wave of the ultrasonic probe becomes large when the acoustic impedance of the backing load member 2 is small. By adjusting the amount of the mixed tungsten powder and the plastic microballoon in the silicone rubber material, the acoustic propagation loss thereof is adjustable between 35 - 50 dB/mm, and the acoustic impedance thereof is adjustable between 0.7×10^5 - 2×10^5 $g/cm^2 \cdot s$. The amount of the mixed tungsten and the plastic microballoon is also adjustable by changing the particle diameter thereof.

The backing load member 2 is manufactured by pouring the material or by sticking preformed block of the backing load member to the piezoelectric vibrator 1. The backing load material of the embodiment is also applicable to the structure shown in Figs 2 and 3.

It is also possible to use urethane rubber, butyl rubber, chloroprene rubber and so on as a mother material of the backing load member 2 in place of the silicone rubber.

Similarly, the tungsten powder mixed to the rubber material of the backing load material is also substitutable with molybdenum powder, lead powder, nickel powder, iron powder, zinc powder, ferrite powder, tungsten carbide powder, and silicon carbide powder. The metal powder and the insulator powder, such as tungsten powder and silicon carbide powder, are possible to be mixed together into the rubber material with the microballoon.

The backing load member 2 of this embodiment has small acoustic impedance so that little transmitted and received signals propagate to the backing load member 2. As a result, the sensitivity is prevented from deterioration and wide dynamic range can be obtained. In addition to this, large acoustic propagation attenuation of the backing load member 2 allows to form the backing load member 2 very thin, and therefore the ultrasonic probe can be miniaturized.

The filler material 5 may be substituted by a rubber material mixed with powders of metal or insulator and plastic microballoons. For example, silicone rubber containing 200 wt % of tungsten powders and 1.5 wt % of plastic microballoon represents the acoustic impedance of 1.06×10^5 g/cm^2·s and the acoustic propagation loss of approximately 40 dB/mm at 3 MHz. When this filler material 5 is inserted between piezoelectric vibrator 1 of PZT ceramics which has the acoustic impedance of $20 \times 10^5 - 35 \times 10^5$ g/cm^2·s, acoustic transmission coefficient between the piezoelectric vibrator 1 and the filler material 5 is approximately 6 - 10%, so that acoustic crosstalk is extremely reduced. Furthermore, the acoustic crosstalk resulted from the small acoustic transmission coefficient of 6 - 10% is practically attenuated in the filler material 5, because the filler material 5 of of the abovementioned material has acoustic propagation loss of 40 dB/mm at 3 MHz which is approximately 40 times larger than that of conventional filler of epoxy resin binder. As a result, no acoustic crosstalk is existed between the piezoelectric vibrator 1, and ultrasonic image with high azimuth resolution is obtained.

The acoustic impedance and acoustic propagation loss of the filler material 5 are adjustable by adjusting the amounts of the mixed tungsten powders and plastic microballoons. For example, the silicone rubber mixed with 100 wt % of tungsten powders and 2 wt % of plastic microballoons has acoustic impedance of 0.7 x 10^5 $g/cm^2 \cdot s$ and acoustic propagation loss of 50 dB/mm at 3 MHz. The silicone rubber mixed with 400 wt % of tungsten powders and 0.8 wt % of plastic microballoons has acoustic impedance of 2 x 10^5 $g/cm^2 \cdot s$ and acoustic propagation loss of 35 dB/mm at 3 MHz. As described above, acoustic impedance and acoustic propagation loss of the silicone rubber mixed with the tungsten powders and plastic microballoon are controlable by adjusting the mixing ratio of the tungsten powders and plastic microballoons.

The silicone rubber of the filler material 5 is substitutable with other rubber-such as urethane rubber, butyl rubber and chloroprene rubber, or thermosetting resin such as epoxy resin and urethane resin.

Furthermore, the tungsten powder is substituted by tantalum powder, ferrite powder, zinc powder, silicone carbide powder, tungsten carbide powder and iron powder. Metal powder and insulator powder, such as tungsten powder and silicon carbide powder, are possible to be mixed together. The filler material of the embodiment is also applicable to the structure shown in Figs. 2 and 3.

In the present invention, the piezoelectric vibrators 1 may be arranged not only in straight line but also in arc line or matrix figure.

CLAIMS:

1. An ultrasonic probe comprising:

a plurality of piezoelectric vibrators (1) arranged in sequence. each of which has electrodes (8,9) attached onto both surfaces thereof.

a backing load member (2) provided on the surface of one electrode (9) of said piezoelectric vibrator,

a first acoustic matching layer (3) provided on the surface of other electrode (8) of said piezoelectric vibrator,

a second acoustic matching layer (6) provided on said first matching layer (3), and

a filler material (5) filled between each of said piezoelectric vibrator,

said backing load member (2) being essentially composed of a material selected from a group of epoxy resin and rubber material which are mixed with microspheres and powders of metal or insulator, said first acoustic matching layer (3) being essentially composed of epoxy resin mixed with carbonyl group material, and said filler material (5) being essentially composed of a material selected from a group of rubber material and thermosetting resin.

2. An ultrasonic probe as claimed in claim 1, wherein said first acoustic matching layer (3) is divided into a plurality of components in correspondence to the plurality of piezoelectric vibrators, and said filler material (5) is filled between said divided first acoustic matching layer.

3. An ultrasonic probe as claimed in claim 1 or 2, wherein said backing load member (2) is epoxy resin mixed with tungsten powders and plastic microspheres.

4. An ultrasonic probe as claimed in claim 1, 2 or 3, wherein said filler material (5) is epoxy resin mixed with silicon carbide powders.

5. An ultrasonic probe as claimed in any one of the preceding claims, wherein said carbonyl group material is carbonyl iron.

6. An ultrasonic probe as claimed in any one of the preceding claims, wherein said plurality of piezoelectric vibrators (1) are arranged in straight line array.

7. An ultrasonic probe as claimed in any one of claims 1 to 5, wherein said plurality of piezoelectric vibrators (1) are arranged in arc line array.

8. An ultrasonic probe as claimed in any one of claims 1 to 5, wherein said plurality of piezoelectric vibrators are arranged in matrix.

9. An ultrasonic probe comprising:

a piezoelectric vibrator (1) with electrodes (8,9) attached onto both surfaces thereof,

a backing load member (2) provided on the surface of one electrode (9) of said piezoelectric vibrator, and

one or more layers(3,6) of acoustic matching material provided on the surface of other electrode (8) of said piezoelectric vibrator (1),

wherein said backing load member (2) is essentially composed of rubber material mixed with microspheres and powders of metal or insulator.

10. An ultrasonic probe as claimed in any one of the preceding claims, wherein said microspheres are plastics microspheres.

11. An ultrasonic probe as claimed in any one of the preceding claims, wherein said powder is one or more selected from a group of tungsten powder, molybdenum powder, lead powder, nickel powder, iron powder, zinc powder, ferrite powder, tungsten carbide powder and silicon carbide powder.

12. An ultrasonic probe comprising:

a piezoelectric vibrator (1) with electrodes (8,9) attached onto both surfaces thereof,

a backing load member (2) provided on the surface of one electrode (9) of said piezoelectric vibrator, and

one or more layers (3,6) of acoustic matching material provided on the surface of other electrode (8) of said piezoelectric vibrator,

wherein at least said piezoelectric vibrator is divided into a plurality of components and a filler material (5) being filled between said divided piezoelectric vibrator, said filler material being essentially composed of a material selected from a group of rubber material and thermosetting resin each of which is mixed with microspheres and powders of metal or insulator.

13. An ultrasonic probe as claimed in any one of the preceding claims, wherein said rubber material is one selected from a group of silicone rubber, urethane rubber butyl rubber and chloroprene rubber.

14. An ultrasonic probe as claimed in any one of the preceding claims, wherein said thermosetting resin is one selected from a group of epoxy resin and urethan resin.

15. An ultrasonic probe as claimed in claim 12, wherein said powder is one or more selected from a group of tungsten powder, tuntalum powder, ferrite powder, zinc powder, silicon carbide powder, and tungsten powder.

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Fig. 1

PRIOR ART

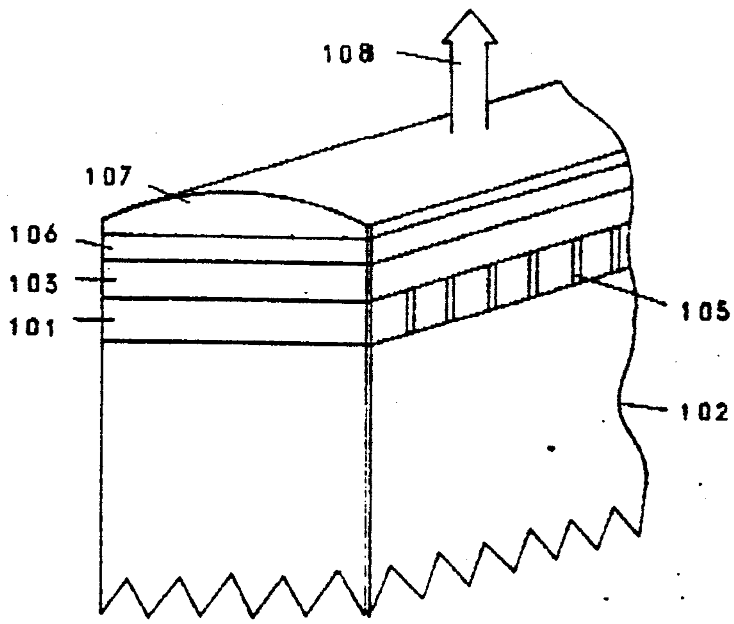

Fig. 2

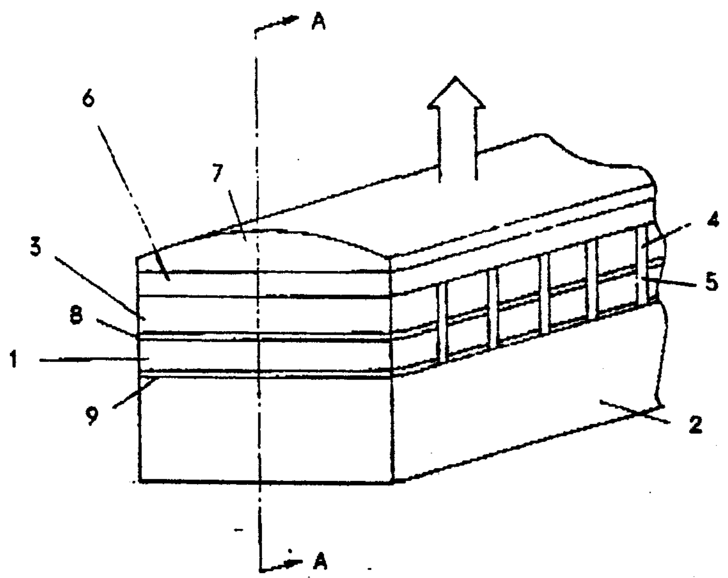

Fig. 3

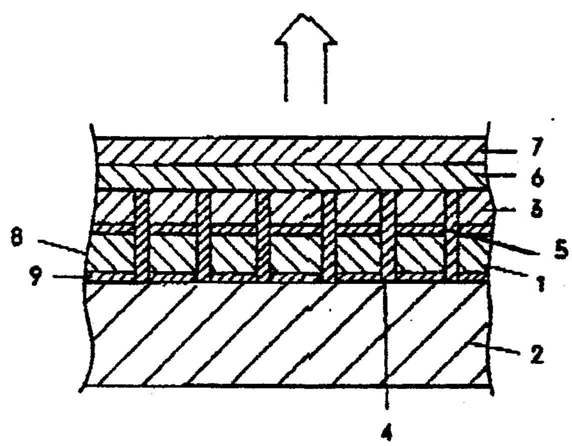

Fig. 4

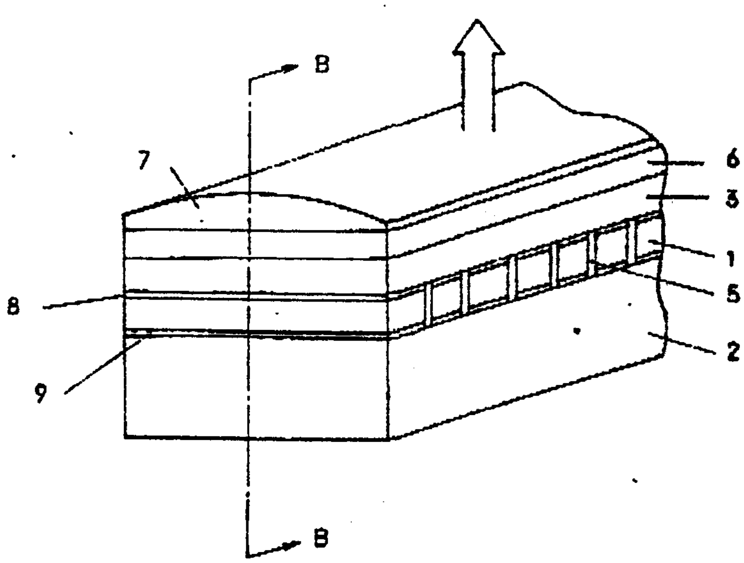

Fig. 5