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R. KARMANN ET AL

3,236,957

DEVICE FOR CONVERTING MECHANICAL INTO ELECTRICAL OSCILLATIONS

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Fig. 1

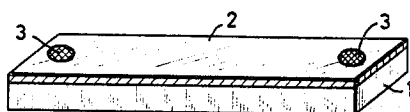


Fig. 2

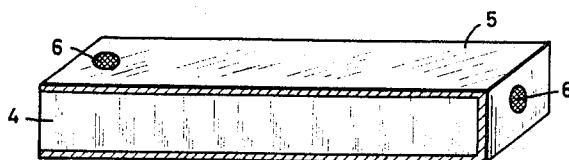


Fig. 3

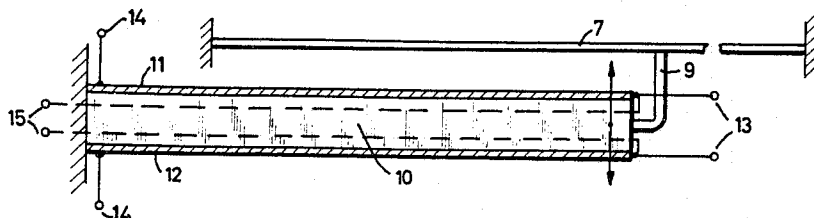


Fig. 4

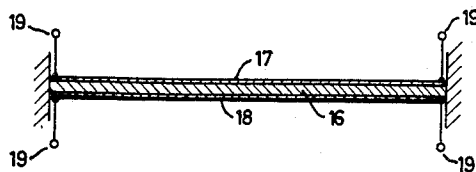


Fig. 6

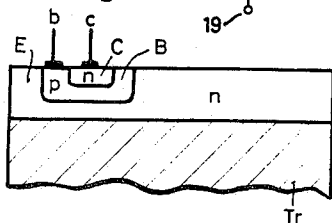
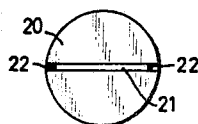


Fig. 5



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DEVICE FOR CONVERTING MECHANICAL INTO ELECTRICAL OSCILLATIONS

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23 Claims. (Cl. 179—110)

This invention is concerned with a device for converting mechanical oscillations into electrical oscillations.

As is known, semiconductors which exhibit the so called piezoresistive effect can be used for converting mechanical into electrical oscillations. This effect is due to the fact that the electrical conductivity of the semiconductor material changes depending upon the mechanical stress which acts on the semiconductor. This effect has been established until now, among others, in connection with silicon and germanium, whereby such effect is particularly great in given crystallographic directions, the so called preferential directions.

A microphone can be constructed by using a rod-shaped semiconductor of the above noted kind and subjecting it to mechanical stresses which are derived from sound oscillations. The semiconductor rod is for this purpose fixedly supported at one end while the other end thereof is provided with an oscillating membrane which receives the sound oscillations, whereby the conversion of such sound oscillations is effected by correspondingly straining the semiconductor rod. It was however found that while such a structure exhibits the microphone effect, its sensitivity is upon using semiconductor rods made of silicon or germanium, which materials are preferentially available on account of the use thereof in the transistor art, so low, that a microphone constructed in this manner is unsuitable for practical requirements.

The present invention may be employed in connection with microphones and sound pickups and generally in converting mechanical deflections into electrical signals. For example, its use is possible in connection with acceleration meters in which a static deflection of a relatively freely movable relatively heavy mass is transmitted to a conversion element.

The invention shows a way for considerably increasing the sensitivity of a device for converting mechanical into electrical oscillations with the aid of a plane body made of piezoresistive semiconductor material, for example, silicon or germanium. For this purpose, the body is made in the form of a plate or layer which is mechanically connected with a carrier having as compared with silicon or germanium a considerably lower modulus of elasticity and the thickness of which is considerably greater than that of the piezoresistive plate or layer, whereby the forces act upon the latter in perpendicular direction.

With such a structure are obtained advantageous mutually supporting effects which are operative in different direction. It is on the one hand possible to control the bending characteristic of the entire arrangement, by the selection of the material for the carrier, and on the other hand, to dispose the piezoresistive material, by the use of the carrier, in a zone in which the bending stresses are greatest, namely, to the outer plane or surface of the arrangement, so that bending deformations will produce maximum resistance changes. The effect of resistance change which is thus obtained can be fully utilized since the carrier, owing to its practically insulating action, does not permit a detrimental shunt formation over the zone which is not subjected to deformation in the region of the neutral fiber.

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It is in particular possible to make the piezoresistive material in the form of a foil and to unite it in this form with the carrier, whereby the otherwise disturbing great modulus of elasticity of the germanium or silicon, already employed for this purpose, becomes practically of no consequence. It was found that microphone sensitivities can be obtained, with carriers, having a modulus of elasticity such as noted before, which lie in the order of magnitude of the carbon microphone. It is moreover possible, by the selection of the carrier material, to obtain a favorable resonance frequency of such an arrangement, which is in the case of microphones of considerable importance.

The carrier is advantageously made of insulating material, especially synthetic material. The use of such material makes it possible to make an arrangement according to the invention which has a desired elasticity. However, it is also possible, upon using a semiconductor material with relatively low modulus of elasticity, especially an organic semiconductor material, to make the carrier as such of a material which is with respect to the piezoresistive layer weakly conductive, especially of intrinsically non-conductive semiconductor material, such material acting practically as insulator, to a thin surface layer which is imparted, for example, by diffusion, a conductivity so high that the action of the piezoresistive effect is substantially concentrated on this layer. Appropriately doped inorganic semiconductor material may likewise be used for producing the piezoresistive layer, which is of advantage since organic semiconductor material can be easily fastened together with inorganic semiconductor material. It is, in particular, possible to grow the inorganic semiconductor layer in single crystalline structure on the carrier of organic semiconductor material. An $A_{III}B_V$ -compound may also be used as a semiconductor material for the piezoresistive layer, in which A_{III} represents an element of main Group III of the periodic table, and B_V represents an element of main Group V.

The device or arrangement according to the invention may be made in different form depending upon the use thereof. It may be made in the form of a disk and may as such serve as a membrane, or it may be made rod-shaped. A structure in which a layer of piezoresistive material is provided on each side of a carrier is particularly advantageous. Such structure provides for two possibilities of action, namely, a piezoresistive action of the two layers each with the identical sign or with opposite signs, respectively. A bending will in the first case operate so that the resistance of one layer becomes high while the resistance of the other layer becomes low (extension and compression of identical material in both layers). In the second case, both layers will upon bending assume either higher or lower resistance (materials with opposite sign of the piezoresistive constant in both layers, for example, on one side oriented p-silicon and on the other side n-germanium). An arrangement of this kind, with two layers, can be in the case of either action advantageously combined with an electrical bridge circuit in which the two layers are disposed in appropriate arms thereof. In the case of action of the two layers respectively in opposite sense, such layers may also be electrically connected in series.

In case the arrangement according to the invention is to be circuited with amplifier elements, the latter may be one of the piezoresistive plates or layers. This may be done, on the one hand, by forming a part of a plate or layer by appropriate doping to act as an amplifying element, with terminals provided therefor, and on the other hand, by alloying to a plate or layer a transistor. The input impedance of connected electrical members, especially of amplifiers, can likewise be taken into account by imparting to each plate or layer by appropriate

doping, a conductivity which is effective to match such members.

Further details of the invention will appear from the description of embodiments which is rendered below with reference to the accompanying drawing.

FIG. 1 shows a rod- or bar-like body on which is provided a plate of piezoresistive material;

FIG. 2 represents a rod- or bar-like body on the surface of which is provided a layer of piezoresistive material, such layer extending U-shaped about the rod;

FIG. 3 indicates a rod which is provided with two piezoresistive layers, one end of the rod being fixedly supported and the free end thereof being mechanically connected with a membrane;

FIG. 4 illustrates in cross-sectional view a disk-like arrangement with two piezoresistive layers;

FIG. 5 is an elevational view of a disk provided with a strip of piezoresistive semiconductor material; and

FIG. 6 is an elevational view of a layer formed on a carrier, illustrated in section, and provided with layers forming a transistor.

Referring now to FIG. 1, numeral 1 indicates a rod made of synthetic material and serving as a carrier upon one side of which is provided a plate 2 of piezoresistive semiconductor material, such plate being mechanically connected with the carrier 1. The plate 2 is at each opposite end provided with a contact 3 which is made, for example, of gold or silver. Care must be taken to avoid upon contacting formation of barrier or blocking layers between the respective contact point and the piezoresistive material.

The embodiment according to FIG. 2 comprises a carrier 4, made of semiconductor material which is in weakly conductive, especially intrinsically non-conductive condition, thus serving practically as an insulator. Upon the surface of the carrier 4 is provided a thin layer 5 to which is imparted, for example by diffusion, a conductivity which is so high that the action of the piezoresistive effect is substantially concentrated on the layer 5. The layer 5 is drawn about one rod of the carrier 4, thus being cross-sectionally U-shaped, the carrier 4 lying between the legs thereof. This embodiment is particularly advantageous for operation in a circuit, for example, a bridge circuit, in which the two layers are to be interconnected at one side or end thereof. The configuration of the layers provides such interconnection automatically. Care must be taken in selecting the semiconductor material that such material has as compared with the germanium or silicon a considerably lower modulus of elasticity, an organic semiconductor being particularly adapted for this purpose. The piezoresistive layer 5 is likewise provided with contacts indicated at 6.

FIG. 3 gives an example for advantageously using the arrangement according to the invention in the construction of a microphone. Numeral 7 indicates the microphone diaphragm or membrane which is by means of a rigid link 9 fastened to one end of the rod-like carrier 10, such carrier being provided with two piezoresistive layers 11 and 12 which are connected therewith. The carrier 10 with its two layers 11 and 12 is at one end thereof fixedly supported and will therefore be bent, responsive to deflection of the membrane 7, in the directions indicated by the arrows. Accordingly, the sound oscillations acting on the membrane 7 are converted into corresponding bending deformation of the carrier 10, resulting respectively in stretching and compressing the layers 11 and 12. As is apparent, such operation requires a force component which acts on the respective layers 11 and 12 in perpendicular direction.

Assuming that the two layers 11 and 12 act respectively in the same piezoresistive sense, there will result an increase of resistance in one layer and a decrease of resistance in the other layer. Assuming, however, that the two layers 11 and 12 act respectively in opposite piezo-

resistive sense, either a resistance increase or a resistance decrease will occur in both layers responsive to the bending thereof.

Both actions are adapted for evaluation in an electrical bridge circuit. In the first assumed case, the two layers will be placed in two adjacent arms of the bridge circuit, and in the second case, the two layers will be placed in oppositely disposed bridge arms.

In the case of action in opposite piezoresistive sense, it is also possible to connect the two layers electrically in series circuit. The structure according to FIG. 2 is for this purpose particularly suitable since it includes the required series connection.

It may be noted at this point, that it is of course also possible to employ in the embodiment according to FIG. 3, the structure shown in FIG. 1, that is, a rod provided with only one piezoresistive layer.

In each of the above explained modes of operation there with result, responsive to bending of the piezoresistive layers, a conversion of the mechanical motions into electrical oscillations which can be obtained at the contacts of the piezoresistive layers, such layers being appropriately circuited with current sources. The change of resistance in the respective layer will be effective to control the flow of current supplied by the current source. Upon using a bridge circuit, the current source will have to be connected to a diagonal arm and the produced alternating voltage will then be obtained at the other diagonal arm.

FIG. 3 also shows terminals 13 and 14 extending from corresponding contacts disposed at the end of the respective layers 11 and 12. These terminals are to be connected in accordance with the requirements of the circuit in which the structure is to be used. The terminals 13 at the free end of the rod 10 may alternatively also be connected with lines extending through the carrier, as indicated by the dash lines, the latter ending in terminals 15. The advantage of such disposition is that the free end of the rod 10 is completely free of electrical leads. It must be considered in this connection that such leads could result in undesired damping of the system.

The structure according to FIG. 3 is for the sake of clarity drawn on a very much enlarged scale. The thickness of the rod 10 amounts in the case of practically well usable microphones to about 0.5 millimeter and the thickness of the layers 11 and 12 amounts to about 0.005 millimeter. The remaining structures shown in the drawing are likewise represented on an enlarged scale.

FIG. 4 shows a modified embodiment comprising a carrier made in the form of a disk 10 which is on each side provided with a thin layer of piezoresistive semiconductor material as indicated by numerals 17 and 18. The disk 16 with its layers 17 and 18 is supported at its rim so as to be advantageously freely rotatable. The respective layers 17 and 18 are, as in the previously described embodiments, provided with contacts to which are connected terminals 19. The arrangement may be employed as a sound-receiving membrane which flexes or bends responsive to the impact of sound waves, resulting respectively in corresponding stretching or compressing of the layers 17 and 18, such actions being as in the previously described embodiments converted into electric alternating voltages.

It is not necessary that the piezoresistive layers cover the entire area of the disk. As indicated in FIG. 5, the layers may extend in the form of strips which are, for greatest possible deformation, disposed diametrically. In case of the circular membrane of the embodiment shown in FIG. 5, the strip 21 is provided with a contact 22 at each end thereof.

As illustrated in FIG. 6, a piezoresistive layer E, corresponding to the layer 2, may be provided with additional layers operative to form a transistor. Thus, into the layer E, which for example, may be n-conductive,

is alloyed to a zone B of p-conductive, such zone embracing an n-conductive layer C. Letters *e*, *b* and *c* designate the terminals of the respective layers. The transistor so may be employed as an amplifier for use with the arrangement according to the invention.

Changes may be made within the scope and spirit of the appended claims which define what is believed to be new and desired to have protected by Letters Patent.

We claim:

1. A device for converting mechanical oscillations into electrical oscillations, comprising a plane body made of piezoresistive semiconductor material, said body being made in layer form which is bendable responsive to forces acting thereon derived from mechanical oscillations, a carrier for said body which is mechanically connected therewith, said carrier having a modulus of elasticity which is considerably lower than that of the piezoresistive material and being of a thickness which is considerably greater than that of the piezoresistive layer, means for supporting said carrier for subjection to such forces, acting upon said layer in a direction which extends perpendicularly thereto, and means for operatively connecting said body in an electrical circuit.

2. A device according to claim 1, wherein said carrier is made of a synthetic insulating material.

3. A device according to claim 1, wherein an $A_{III}B_V$ compound is used as a semiconductor material for said piezoresistive layer, in which A_{III} represents an element of main Group III of the periodic table, and B_V represents an element of main Group V.

4. A device according to claim 1, wherein a piezoresistive layer is provided upon each side of said carrier.

5. A device according to claim 1, wherein said carrier is of rod-shaped configuration.

6. A device according to claim 1, wherein said carrier is of disk-shaped configuration.

7. A device according to claim 1, wherein a part of said layer is doped to form an amplifying element.

8. A device according to claim 1, comprising a transistor alloyed to said layer.

9. A device according to claim 1, wherein said carrier is made of a semiconductor material which is with respect to said piezoresistive layer weakly conductive, especially intrinsically conductive semiconductor material, a thin strata extending along the surface of said carrier being of a conductivity so high that the action of said piezoresistive effect is concentrated on said strata.

10. A device according to claim 1, wherein a piezoresistive layer is provided on each side of said carrier, said layers acting in identical piezoresistive sense.

11. A device according to claim 1, wherein a piezoresistive layer is provided on each side of said carrier, said layers acting respectively in opposite piezoresistive sense.

12. A device according to claim 1, wherein a piezoresistive layer is provided on each side of said carrier, said layers acting respectively in opposite piezoresistive sense and being connected in serial relationship.

13. A device according to claim 1, wherein said carrier is of rod-shaped configuration, said layer extending along both sides of said carrier and being drawn over one edge

thereof to form a generally U-shaped structure with said carrier extending between the legs thereof.

14. A device according to claim 1, wherein said carrier is of rod-shaped configuration, comprising means for mechanically connecting at least one end of said rod with a membrane which is subjected to the action of sound waves.

15. A device according to claim 1, wherein said carrier is of rod-shaped configuration, said layer extending along both sides of said carrier and being drawn over one edge thereof to form a generally U-shaped structure with said carrier extending between the legs thereof, comprising means for mechanically connecting at least one end of said rod with a membrane which is subjected to the action of sound waves.

16. A device according to claim 1, wherein said carrier is of rod-shaped configuration, comprising leads forming an electrical connection extending through said rod.

17. A device according to claim 1, wherein said carrier is of rod-shaped configuration, comprising means for mechanically connecting at least one end of said rod with a membrane which is subjected to the action of sound waves, and comprising leads forming an electrical connection extending through said rod.

18. A device according to claim 1, wherein said carrier is of disk-shaped configuration and forming with the piezoresistive layer provided thereon a membrane which is subjected to the action of sound waves.

19. A device according to claim 1, wherein said carrier is of disk-shaped configuration, said carrier disk having a piezoresistive layer provided on each side thereof, at least one of said layers being formed as a diametric strip.

20. A device according to claim 1, wherein said carrier is of rod-shaped configuration having a piezoresistive layer provided upon each side thereof, said layers being formed from an inorganic semiconductor material and acting in identical piezoresistive sense.

21. A device according to claim 1, wherein said layer is doped to exhibit a predetermined conductivity.

22. A device according to claim 21, wherein an organic semiconductor is employed as semiconductor material.

23. A device according to claim 22, comprising a layer of inorganic piezoresistive semiconductor material provided upon a carrier of organic semiconductor material.

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ROBERT H. ROSE, *Primary Examiner*.