March 8, 1966 M. ZERBST ET AL 3,239,611

CONVERTING MECHANICAL INTO ELECTRICAL OSCILLATIONS

Filed March 7, 1962

Fig. 1

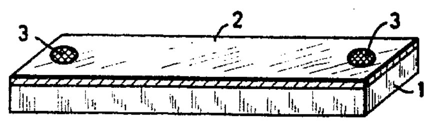


Fig. 2

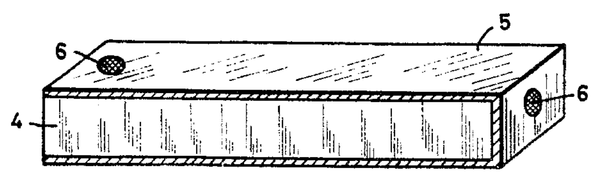


Fig. 3

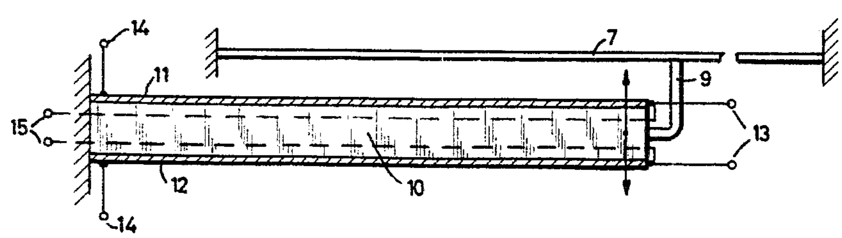


Fig. 4

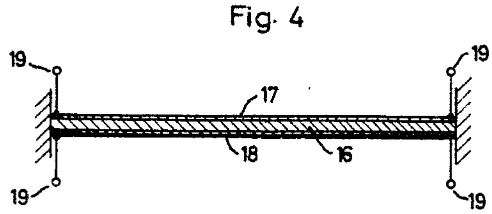
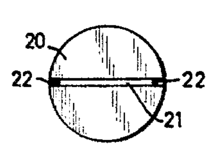


Fig. 5



3,239,611
CONVERTING MECHANICAL INTO ELECTRICAL OSCILLATIONS

Manfred Zerbst and Günther Winstel, Munich, Germany, assignors to Siemens & Halske Aktiengesellschaft, Berlin and Munich, Germany, a corporation of Germany
Filed Mar. 7, 1962, Ser. No. 178,785
Claims priority, application Germany, Mar. 9, 1961, S 72,898
9 Claims. (Cl. 179—110)

The invention disclosed herein is concerned with an arrangement for converting mechanical oscillations into electrical oscillations.

As is known semiconductors which exhibit the socalled piezo resistive 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 wave 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 wave oscillations, whereby the conversion of such sound wave 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 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 planar body made of piezo resistive semiconductor material, for example, silicon or germanium.

The invention proposes to use for this purpose a weakly doped or intrinsically non-conductive semiconductor, to a thin surface layer or stratum of which is imparted, for example by diffusion, a conductivity, so high, that the action of the piezo resistive effect is substantially concentrated on this layer.

The piezo resistive material is in such structure placed into a zone in which the bending stresses are greatest, namely, at the outer plane of the arrangement, so that bending deformations produce maximum resistance changes. The operative effect of the resistance change can be fully utilized, since the weakly doped or intrinsically non-conductive semiconductor material lying next to the piezo resistive stratum does not permit, due to its practically insulating effect, formation of a detrimental shunt in the region of the neutral fiber, over the zone which is not subject to deformation.

The semiconductor can be made of organic or inorganic material including, especially, an A_{III}–B_V-compound, wherein A_{III} represents elements of the third

group of the periodic table, and B_V represents elements of the fifth group.

The arrangement according to the invention may receive different form, depending upon the intended use thereof. It may be made in the form of a disk which can be directly employed as a membrane, or it may be made in the form of a rod. A structure in which a layer or stratum of piezo resistive material is provided upon each side of the semiconductor, is particular advantageous. Such structure may be suitably operated in an electrical bridge circuit, with the two layers disposed in appropriate arms thereof.

In the event that the arrangement according to the invention is to be circuited with amplifier elements, such elements can be combined with one or both of the piezo resistive layers. This may be done by forming a part of a layer, by appropriate doping, to perform as an amplifying element, provided with cooperating terminals, or by alloying a transistor to a layer. The input impedances of electrical members, which are to be connected to the arrangement, especially amplifiers, can likewise be considered, by imparting to each layer by appropriate doping, a conductivity such that the corresponding members are matched.

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

FIG. 1 shows a rod or bar provided with a layer of piezo-resistive semiconductor material;

FIG. 2 represents a rod or bar provided with a layer of piezo resistive material which is drawn about the rod in U-shaped manner;

FIG. 3 illustrates a rod which is supported at one end thereof and provided with two piezo resistive layers, the free end of the rod being mechanically linked with a membrane;

FIG. 4 is a cross-sectional view of a disk-shaped arrangement provided with two piezo resistive layers; and

FIG. 5 indicates in elevational view a disk provided with strips of piezo resistive semiconductor material.

Referring now to the embodiment shown in FIG. 1, numeral 1 indicates a semiconductor rod which is so weakly doped that it is practically in intrinsically non-conductive condition, so that it can in this connection be termed an insulator. To the upwardly facing surface of this rod is imparted, by diffusion, a conductivity which is so high that there results a piezo resistive layer or stratum 2 on which the piezo resistive effect is essentially concentrated. This layer 2 is at each end thereof provided with a contact 3 made, for example, of gold or silver. Care must be taken upon contacting that no blocking or barrier layers are produced between the respective contact points and the piezo resistive material. The piezo resistive layer may also be produced differently, for example, by alloying.

In the embodiment according to FIG. 2, the initial material is again a weakly doped or intrinsically non-conductive semiconductor 4 which operates practically as an insulator. To a thin surface layer 5 of the semiconductor body 4 is imparted a conductivity, so high that the piezo resistive effect is concentrated on the layer 5. The layer 5 is drawn about one end of the rod 4 so that the layer assumes a cross-sectionally U-shaped form, the respectively weakly doped or intrinsically non-conducting semiconductor material lying between the legs of the layer. This embodiment is particularly indicated for use in connection with a circuit in which the two layers are to be interconnected at one end thereof, for example, in connection with a bridge circuit. The required interconnection is in such embodiment automatically produced. The piezo resistive layer is again provided with contacts indicated by numeral 6.

FIG. 3 shows how the invention may be used in the construction of a microphone. The microphone has a membrane **7** which is by means of a rigid link **9** connected to one end of a semiconductor rod **10**, such rod acting as an insulator. The rod **10** is rigidly supported at one end thereof and is on its surface provided with two piezo resistive layers **11** and **12**. Upon deflection of the membrane **7**, the rod **10** will be bent in the directions indicated by the arrows. Accordingly, the sound wave oscillations impacting the membrane **7** will be converted into bending deformations of the rod **10**, with the result that the layers **11** and **12** are respectively stretched or compressed. As is apparent, this requires the operation of a force component acting upon the respective layers **11** and **12** in perpendicular direction.

An arrangement with two layers, as shown by way of example, in FIGS. 2 and 3, is particularly adapted for operation in connection with an electrical bridge circuit.

It may be noted at this point that it is of course possible to use in the construction according to FIG. 3, for example, the embodiment illustrated in FIG. 1, that is, a rod provided only with one piezo resistive layer.

In each of the above explained operating conditions will result a bending deformation of the piezo resistive layers, such deformations resulting in turn in electrical oscillations which may be obtained at the contacts of the piezo resistive layers which contacts may be connected to a current source. The current delivered by the current source will then be controlled by the longitudinal resistance changes in the respective piezo resistive layer. When using the arrangement in a bridge circuit, the current source will be connected to one diagonal while the produced alternating voltage is obtained at the other diagonal.

FIG. 3 also shows contacts **13** and **14** at the opposite ends of the layers **11** and **12**, which are to be connected as required in the circuit in which the arrangement is to be used.

In FIGS. 1 to 3, the parts are for convenient representation shown on a greatly enlarged scale. The thickness of the rod amounts in the case of practically well suitable microphones, to about 0.5 millimeter and the thickness of the piezo resistive layer to about 0.005 millimeter.

FIG. 4 shows an embodiment employing instead of a rod shaped semiconductor a semiconductor disk **16** which is on each side provided with a thin piezo resistive layer indicated by numerals **17** and **18**. The disk **16** with its layers **17** and **18** is supported at its rim so that it may suitably freely flex or oscillate. The layers **17** and **18** are, as in the previously described embodiments, provided with contacts indicated by numerals **19**. This arrangement can as such be used as a sound wave-receiving membrane, whereby the layers **17** and **18** are responsive to bending of the membrane respectively stretched or compressed, the corresponding deformations of the layers being as previously described connectible into electrical alternating voltages.

The piezo resistive layers need not cover the entire disk. As shown in FIG. 5, the layers may be in the form of strips which are in the case of a circular membrane, for maximum deformation, disposed diametrically. The circular membrane **20** indicated in FIG. 5 is provided with a strip **21** which is at its opposite ends provided with a contact **22**.

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. An arrangement for converting mechanical oscillations into electrical oscillations, comprising a planar body made of piezoresistive semi-conductor material which is relatively non-conductive, said body being provided thereon with at least one surface layer which is thin in comparison with the thickness of said body, and having a great conductivity as compared with the conductivity of said body so that the operative piezoresistive effect is concentrated substantially along said surface layer, and means contacting said surface layer at spaced points for operatively connecting said surface layer in an electrical circuit, whereby, responsive to the application of mechanical bending stresses to said body, longitudinal resistance alterations are produced in said layer, to accordingly vary the operation of such a circuit.

2. An arrangement according to claim **1**, wherein an A_{III}–B_V-compound, wherein A_{III} represents elements of the third group of the periodic table, and B_V represents elements of the fifth group, constitutes the semiconductor material.

3. An arrangement according to claim **1**, comprising a piezo resistive layer disposed on each side of said planar body.

4. An arrangement according to claim **1**, wherein said planar body is of rod shaped configuration.

5. An arrangement according to claim **1**, wherein said planar body is a disk shaped body.

6. An arrangement according to claim **1**, wherein said planar body is a disk shaped body, said body forming a membrane for impingement by sound waves.

7. An arrangement according to claim **6**, wherein at lease one piezo resistive layer is made in the form of a diametrically disposed strip.

8. An arrangement according to claim **1**, wherein said body is of rod shaped configuration and comprises organic semiconductor material, said rod shaped body having two of said surface layers disposed on opposite sides of said body.

9. An arrangement for converting mechanical oscillation into electrical oscillations, comprising a planar body made of piezoresistive semi-conductor material which is relatively non-conductive, said body being of rod shaped configuration and provided thereon with at least one surface layer which is thin in comparison with the thickness of said body, and having a great conductivity as compared with the conductivity of said body so that the operative piezoresistive effect is concentrated substantially along said surface layer, the latter extending on three sides of said rod shaped body in cross-sectionally U-shaped form with the legs thereof embracing said body on opposite sides thereof, and means for operatively connecting said surface layer in an electrical circuit, whereby current will be developed in said circuit responsive to the application of mechanical bending stresses to said body.

References Cited by the Examiner

UNITED STATES PATENTS

2,171,793	9/1939	Huth	179—122
2,798,989	7/1957	Welker	179—110
2,866,014	12/1958	Burns	179—122
2,898,477	8/1959	Hoesterey	179—110
2,907,672	10/1959	Irland	117—107
2,929,885	3/1960	Mueller	179—121
3,003,900	10/1961	Levi	148—1.5
3,031,634	4/1962	Vogt	338—2

FOREIGN PATENTS

1,006,169	4/1957	Germany.
678,766	9/1952	Great Britain.

OTHER REFERENCES

Mason: "Semiconductors in Strain Gages," Bell Labs. Record, vol. 37, No. 9, January 1959, pages 7–9.

ROBERT H. ROSE, *Primary Examiner.*