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PIEZORESISTIVE TRANSDUCERS AND DEVICES WITH SEMICONDUCTING FILMS AND THEIR MANUFACTURING PROCESS

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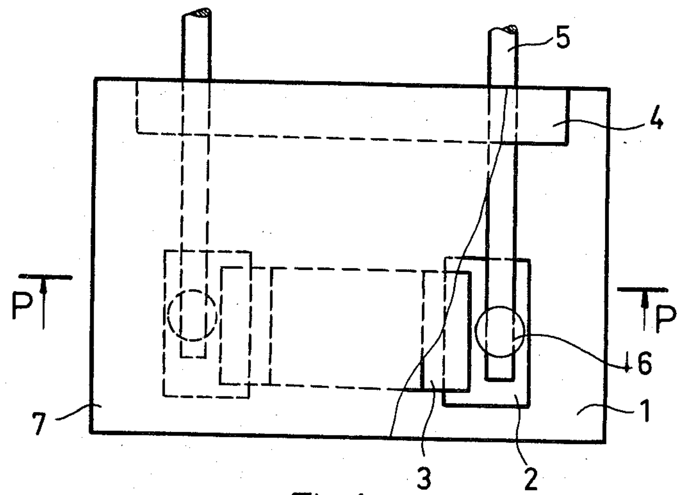

Fig.1

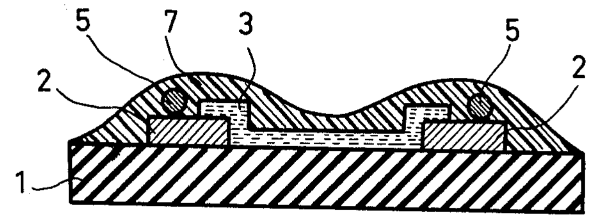

Fig.2

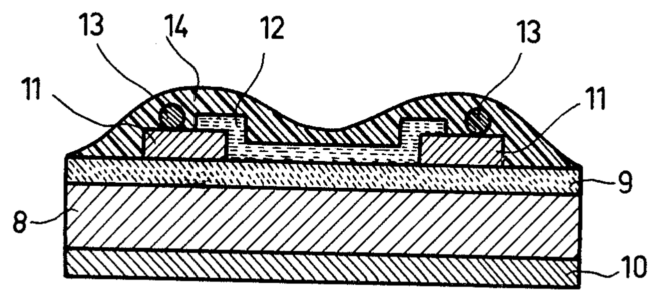

Fig.3

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U.S. Cl. 310—8.1 6 Claims

ABSTRACT OF THE DISCLOSURE

A method of making a piezoresistive device in which a mica, synthetic resin or metallic substrate (the latter coated with a layer of insulating enamel) is coated with strips of colloidal-silver paste, is fired to fuse the resulting conductive strips to the substrate, is provided with a layer of vapor-depositing germanium bridging the strips, is formed with wire terminals and is thereafter coated with a lacquer.

FIELD OF THE INVENTION

This application relates to piezoresistive transducers and devices with semiconducting films for measuring mechanical deformations by electrical means, and to the process for making such devices.

BACKGROUND OF THE INVENTION

There are known devices for measuring mechanical deformation based on the variation of the electric resistance of metal wires and of semiconductors. The chief drawbacv of metal-wire devices and transducers lies in the fact that their gauge factor G (defined as $G=dR/R\delta$, wherein R is the electric resistance of the transducer and δ its uniaxial deformation), has a maximum value of approx. 2.5. While this drawback disappears with single crystal semiconductor devices, their gauge factor G being approx. 100, the manufacture of such devices is hampered by the difficulty in cutting the transducer elements into such small dimensions as are necessary for such use. Besides, these devices are brittle and have a limited range of resistance values; they also have a temperature coefficient of the gauge factor or of the electric resistance some two orders of magnitude higher than those of metallic devices.

There have been produced, on a laboratory scale, transducers with semiconductor films with unoriented crystallites or with preferential surface orientation whose gauge factor G is ⅓ or ½ of the corresponding value for single crystal devices, but whose temperature coefficient of the gauge factor and of the electric resistance is by one order of magnitude lower than that of the single crystal devices. Such transducers are deposited on glass or mica, having on the latter a less satisfactory adhesion. Other disadvantages reside in the cumbersome process of making the electrodes and in the insufficient stability of the terminals due to the fact that the latter are fastened on the electrodes only by means of colloidal-silver paste.

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OBJECT OF THE INVENTION

The process according to this invention has as its object a method of making piezoresistive transducers and devices using same by means of vacuum deposition of polycrystalline germanium films, between metallic electrodes, on different insulating or conducting substrates, as for instance mica, kaptons, steel diaphragms, etc. whereby the disadvantages mentioned above are reduced.

SUMMARY OF THE INVENTION

According to this process there are deposited on the substrate metallic electrodes either of a colloidal-silver conductive paste, or of layers of Ag, Pt, Au, Al, Ni etc. The deposition of germanium is done under vacuum, preferably at a pressure $p<5\times10^{-5}$ torr, the substrate temperature being between 300° and 700° C., the deposition rate of the germanium film being less than 2000 A./minute. The terminals are fastened upon the substrate either by spot welding or by means of a colloidal-silver conductive paste, the mechanical stability being improved by gluing the terminals on the substrate with a polymer adhesive, for instance an epoxy-polymer, the operational stability being ensured by means of a heat-resistant protecting lacquer.

The substrate may be of any adequate insulating material, as for instance mica or kapton (the commercial name of a Teflon and Mylar based plastic which is utilized as a substrate in microelectronics) or of a conducting material, for instance plain carbon steel, or stainless steel, on which an insulating heat resistant enamel layer is applied by known technology.

DESCRIPTION OF THE DRAWING

In the drawing:

FIG. 1 is a top view of a device with transducer deposited on an insulating substrate;

FIG. 2 is a vertical section taken along line P–P′ of the device in FIG. 1; and

FIG. 3 is a vertical section of a device with a transducer applied on a metallic substrate with an insulating film thereon.

SPECIFIC DESCRIPTION AND EXAMPLES

Example 1

On a transparent mica substrate **1** (FIGS. 1 and 2) of a thickness between 10 and 1,000 microns, previously cleaned with detergents, absolute alcohol, water and distilled water, are applied by painting two conducting electrodes **2** of colloidal-silver paste following the outline of a pattern placed under the substrate. The surface of the electrodes and the distance between them are chosen in accordance with the desired electric resistance of the device, which may be between 1×10^2 and 1×10^6 ohms. The thickness of the polycrystalline germanium film must lie between 0.05 and 2 microns. The thus prepared substrate is heated with the side without electrodes of colloidal-silver conductive paste resting on the surface of a copper furnace to bond the assembly. On the same furnace may be glued a large number of substrates. Masks of aluminum foil strips of 20 microns in thickness are then applied over the inactive surface of each element, as well as over the outer halves of the electrodes. A plaited filament of 0.2–0.5 mm. diameter tungsten wire is made by pressing small pieces of polycrystalline germanium into the mesh. The substrates are degased at 500–600° C. for 10 to 40 minutes, in vacuum at a pressure $p<5\times10^{-5}$

torr. Thereafter the previously degased germanium is deposited by evaporation from the tungsten wire onto the mica substrate maintained at a temperature between 470° and 500° C., with a deposition rate less than 2,000 A./minute to form the polycrystalline film **3**.

After removing the substrate from the furnace, silver wire terminals **5** are fastened by gummed transparent tape **4** onto the substrate in the inactive region in such a way, that an electric contact between the electrodes and the terminals may be made by soldering with collodial-silver paste **6**. The whole surface of mica substrate is covered on that side on which the piezoresistive element is deposited, with a protecting lacquer **7**. Thereafter, the element thus obtained is cut along the outline of the mica substrate and the piezoresistive devices are then sorted and calibrated.

When kapton substrates are used, the operations are identical to those with mica substrates, with the only difference being the deposition temperature of the polycrystalline germanium. During the deposition operation the substrate is maintained at a temperature of 300°–375° C.

Example 2

On a metallic substrate **8** (FIG. 3) of carbon steel of at least 0.1 mm. thickness, degreased and etched by a detergent and sulphuric acid or hydrochloric acid, thereafter neutralized with sodium carbonate, borax and sodium nitrate and dried, a heat-resistant enamel film **9** of max. 0.4 mm. thickness is applied by pouring, simple spraying, by spraying in an electrostatic field, or by electrophoresis. After air-drying at up to 120° C., the substrate is placed in a furnace previously heated at 800–830° C., for 3–4 minutes, in the burning in zone. On the side of the substrate opposite that on which the transducer is to be deposited and which may come into contact with a corroding medium, the surface may be protected either by means of a stainless steel film **10**, or a heat-resistant acid- and alkali-proof enamel layer. The thus prepared substrate is placed with its side opposite to that on which the transducer is to be deposited on a copper furnace surface to bond colloidal-silver paste strips thereto as described. After the paste is dried the electrodes **11** are painted by means of a pattern with colloidal-silver paste or a paste of gold solution. Thereafter the inactive surfaces are masked with 20-microns-thick aluminum foil strips, the outer halves of the electrodes being similarly masked. On each electrode there are deposited according to requirements several transducers **12**.

A filament is made from 0.2–0.5 mm. diameter plaited wires, in to the meshes of which are fastened by pressing small pieces of polycrystalline germanium. The substrate is degased at 470°–550° C. over a period of 30–60 minutes, in vacuum, at a pressure $p<5\times10^{-5}$ torr. After that, the previously degased germanium is deposited by evaporation in vacuum on the enamel-covered metallic substrate, the temperature of the substrate during the deposition being between 470° and 530° C., the deposition rate being less than 2,000 A./minute.

After the substrate with the deposited transducer is removed, the terminals **13** out of 0.1 mm. diameter silver wire are fastened on the uncovered side of the electrodes by means of silver paste, after which the whole transducer element is covered by a heat-resistant lacquer **14**.

Example 3

According to Example 2, a maximum 0.1 mm. thick enamel film is applied on the surfaces of steel parallelopipeds of different sizes, as for instance 10 x 10 x 15 mm. On the enamel, employing a convenient pattern, are deposited an electrode of a gold solution by painting and thermal treatment at 700° C., during 5 minutes. The specimen thus obtained is correspondingly masked for instance by means of aluminum foil and is introduced into a small tantalum boat of adequate dimensions, with which the specimen is heated in vacuum to 350°–400° C. at a pressure $p<5\times10^{-5}$ torr. On the thus-prepared support is deposited the polycrystalline Ge film, as in Example 2. Thereafter the contacts are laid and the device is covered with heat-resistant lacquer, as in Example 2.

The thus-obtained device can be utilized for measuring stresses, signalling limit stresses, and for other tensometrical measurements.

This invention offers the advantages of a gauge factor $G=30$, a linear variation of dR/R with δ, as well as a temperature coefficient of the gauge factor and of the electric resistance of say -1×10^{-3} to -5×10^{-4}/degree C. in each case. The device also has a good time constancy, as well for R as for G; the stability of R is better than ±0.2% in 24 hours at 20° C. and that of G better than ±0.05% in 24 hours at 20° C. In addition better adherence is ensured between the polycrystalline film and the substrate, allowing measurements at large mechanical deformations, the maximum admissible deformation being 1×10^{-3}; the deviation from linearity at a maximum deformation δ between 6×10^{-4} and 10×10^{-4} being beneath 0.2%. The device utilizes as raw material polycrystalline germanium, which is much cheaper than the single crystals, allows the formation of well fastened terminals, which ensure a perfect electric contact and ruggedness, is protected against external agents, and ensures a more secure fastening of the transducer on the article whose deformation is to be measured in such way, that it forms practically a single body therewith. We are able to obtain an insulating film adherent to carbon steel, stainless steel or steel platings, without pin-holes, heat-resistant, and to use the device in corroding media.

We claim:

1. A method of making a piezoresistive mechanical-electrical transducer, comprising the steps of:

applying to a heat-resistant substrate at least two conductive strips in spaced-apart relationship;

vacuum-evaporating onto said substrate over a limited region thereof bridging said strips, polycrystalline germanium at a temperature between substantially 330° C. and 600° C. at a pressure less than substantially 5×10^{-5} torr at a rate up to about 2000 A. per minute to form a germanium layer;

soldering wire terminals to said strips; and

coating said substrate and said strips and the germanium layer with a layer of a heat-resistant lacquer.

2. The method defined in claim **1** wherein said substrate is selected from the group which consists of mica, kapton or enamel-coated metal, said strips are applied to said substrate at room temperature and said wires are bonded to said substrate by epoxy resin.

3. The method defined in claim **2** wherein said substrate is composed of steel coated with an enamel to a maximum thickness of 0.4 mm. and is fired at a temperature between substantially 800° C. and 900° C. for a period of 3 to 4 minutes.

4. The method defined in claim **1** wherein said strips consist of silver, gold or platinum paste fired to bond the strips to the substrate or are constituted of silver, platinum, aluminum, gold, nickel or molybdenum film.

5. The method defined in claim **4** wherein said strips are formed by applying colloidal-silver conductive paste to said substrate and heating said substrate with the colloidal-silver conductive paste thereon to form the strips and simultaneously bond the same to said substrate.

6. A piezoresistive mechanical-electrical transducer comprising:

a substrate selected from the group which consists of mica, capton or iron coated with enamel and baked at substantially 800° C. to 900° C. for a period of 3 to 4 minutes;

two spaced-apart conductive strips selected from the group which consist of silver, gold, platinum, aluminum, nickel or molybdenum on said substrate;

a polycrystalline germanium layer extending over a limited region of said substrate and bridging said strips;

a wire terminal soldered to each of said strips and bonded by epoxy resin to said substrate; and

a layer of heat-resistant lacquer coating said substrate, said strips and said layer.

References Cited

UNITED STATES PATENTS

3,137,834	6/1964	Pfann	73—88.5 X
3,290,569	12/1966	Weimer	307—308 X
3,492,513	1/1970	Hollander et al.	338—2 X
3,505,572	4/1970	Yamashita et al.	310—8.1 X
3,585,415	6/1971	Muller et al.	310—8
3,460,005	8/1969	Kandu et al.	310—8 UX

FOREIGN PATENTS

517,928	8/1953	Belgium	310—9.7

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