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3,284,679

SEMICONDUCTIVE STRESS SENSING DEVICES

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2 Sheets-Sheet 1

FIG. 1A

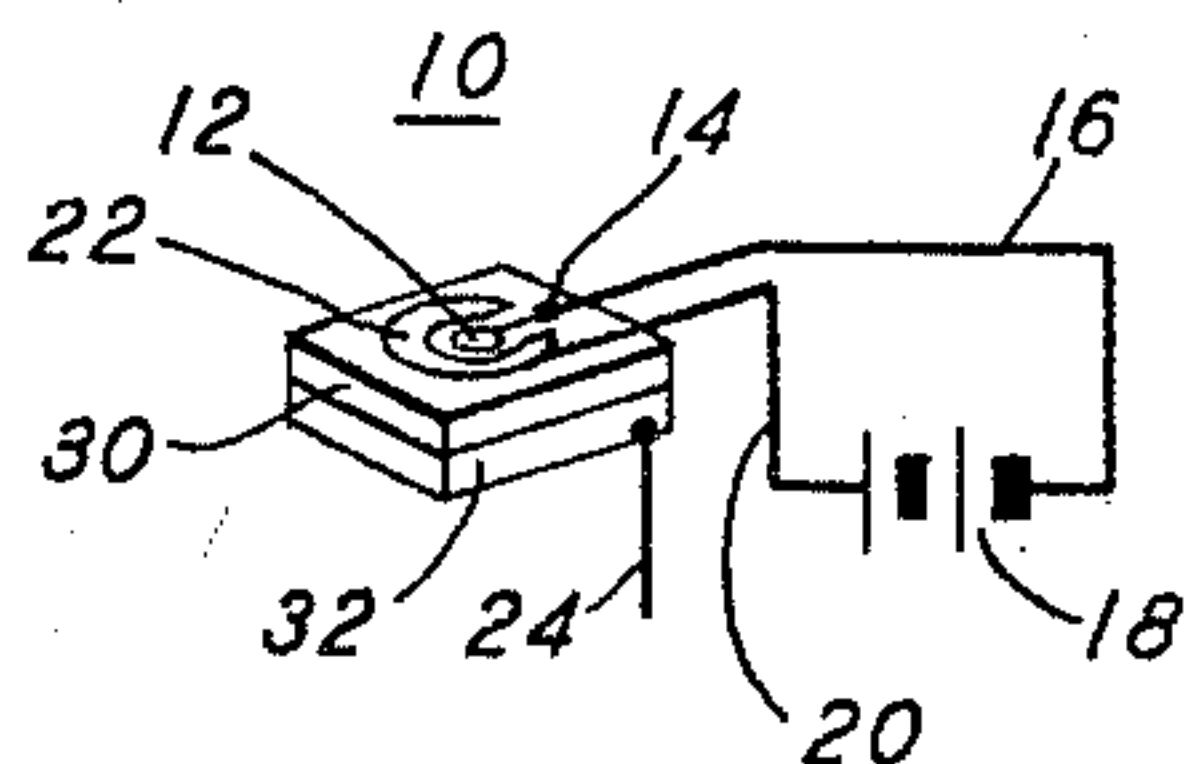


FIG. 1B

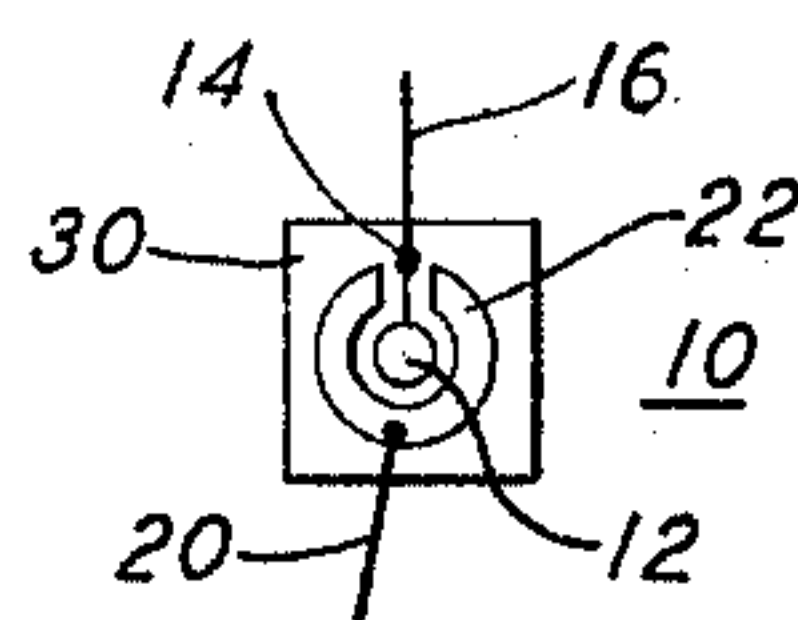


FIG. 2

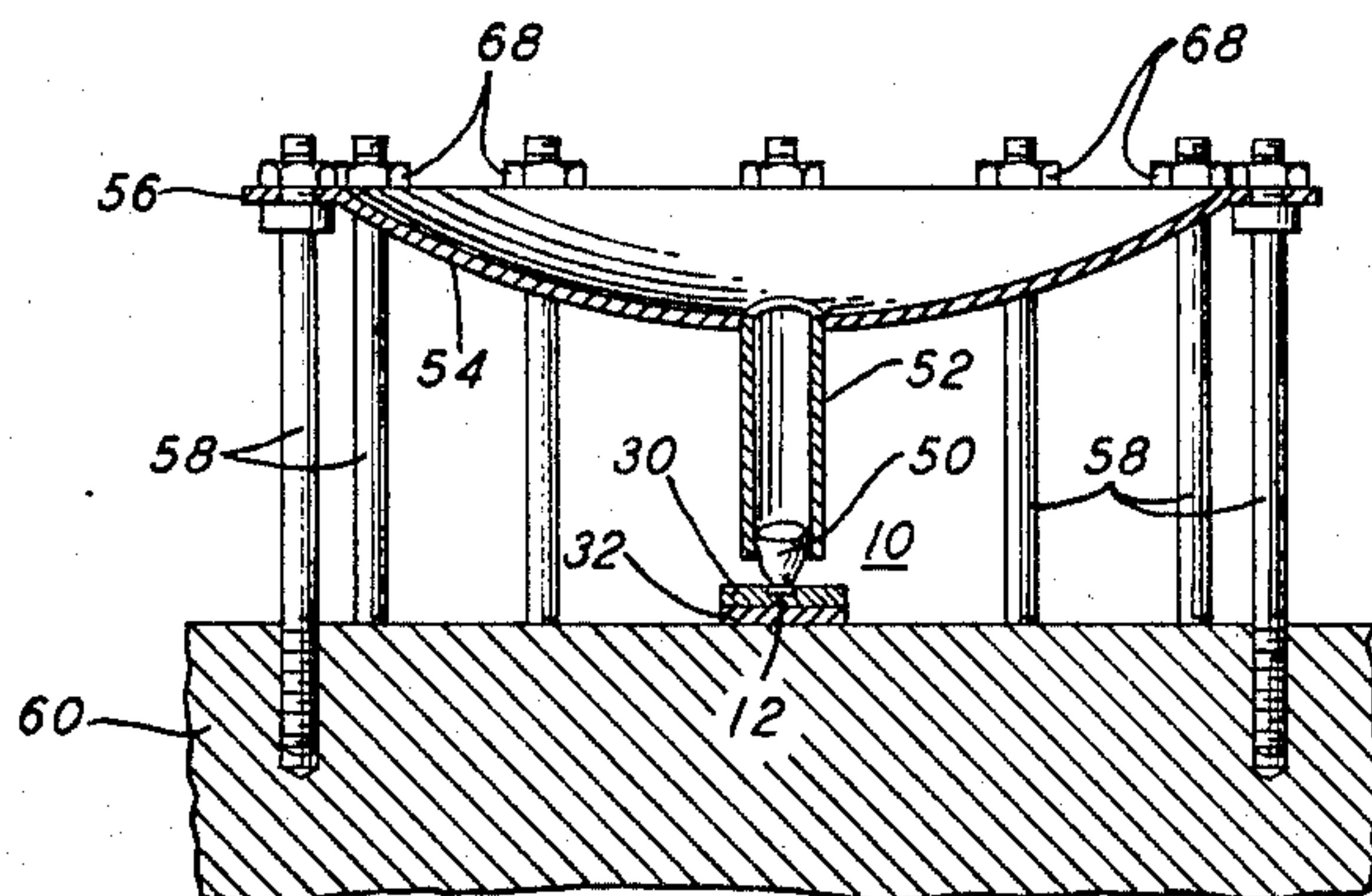
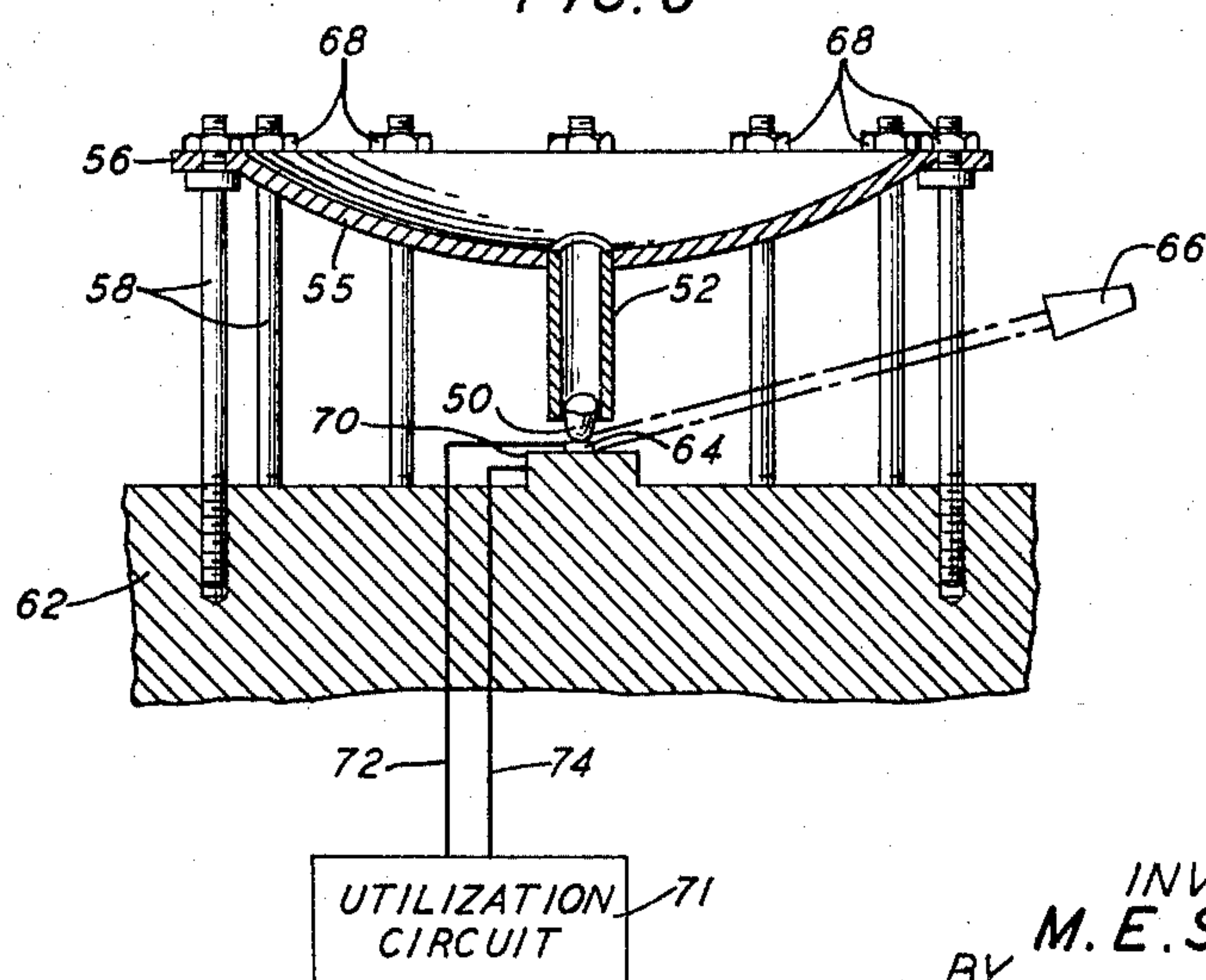


FIG. 3



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FIG. 4

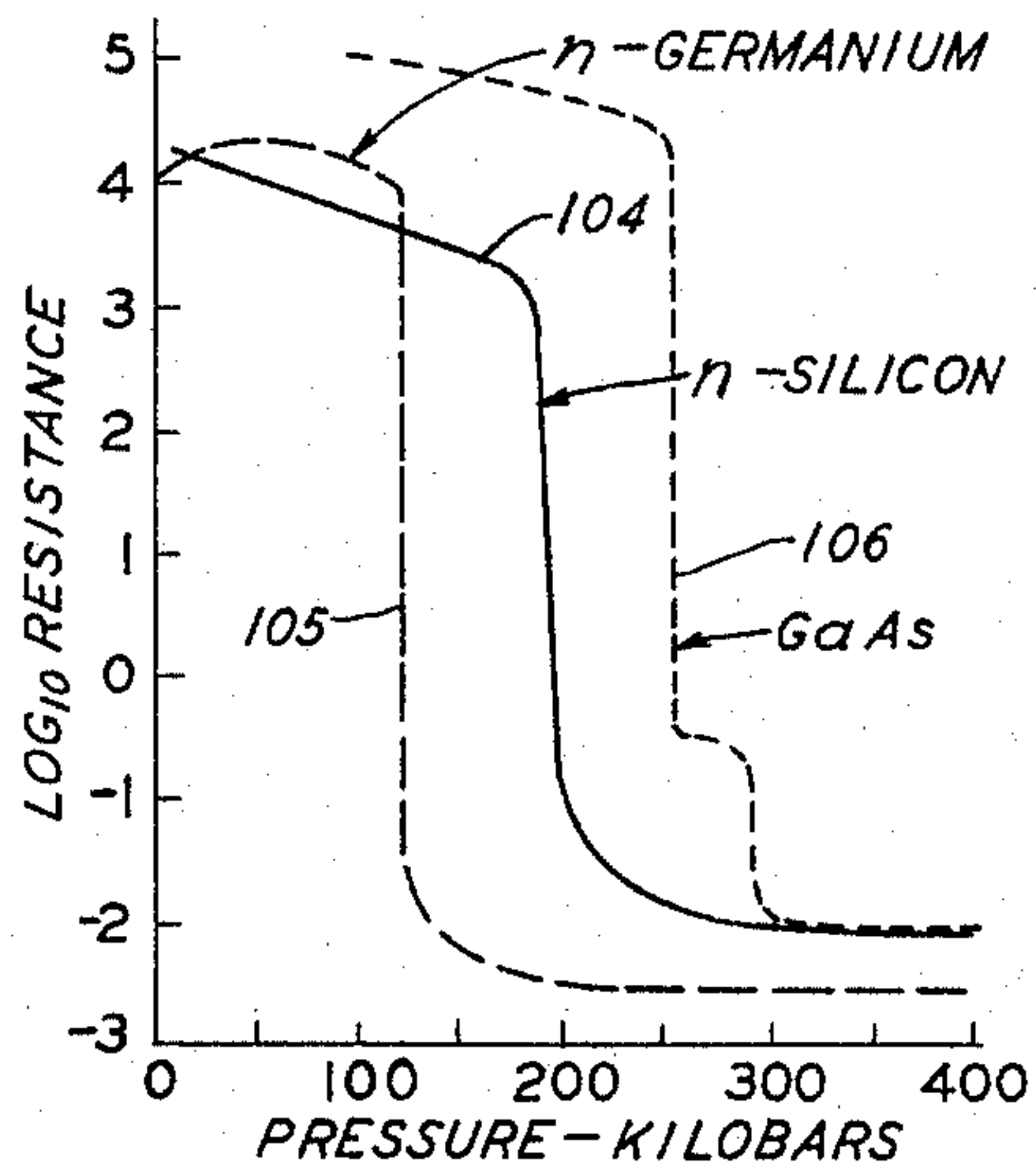


FIG. 5

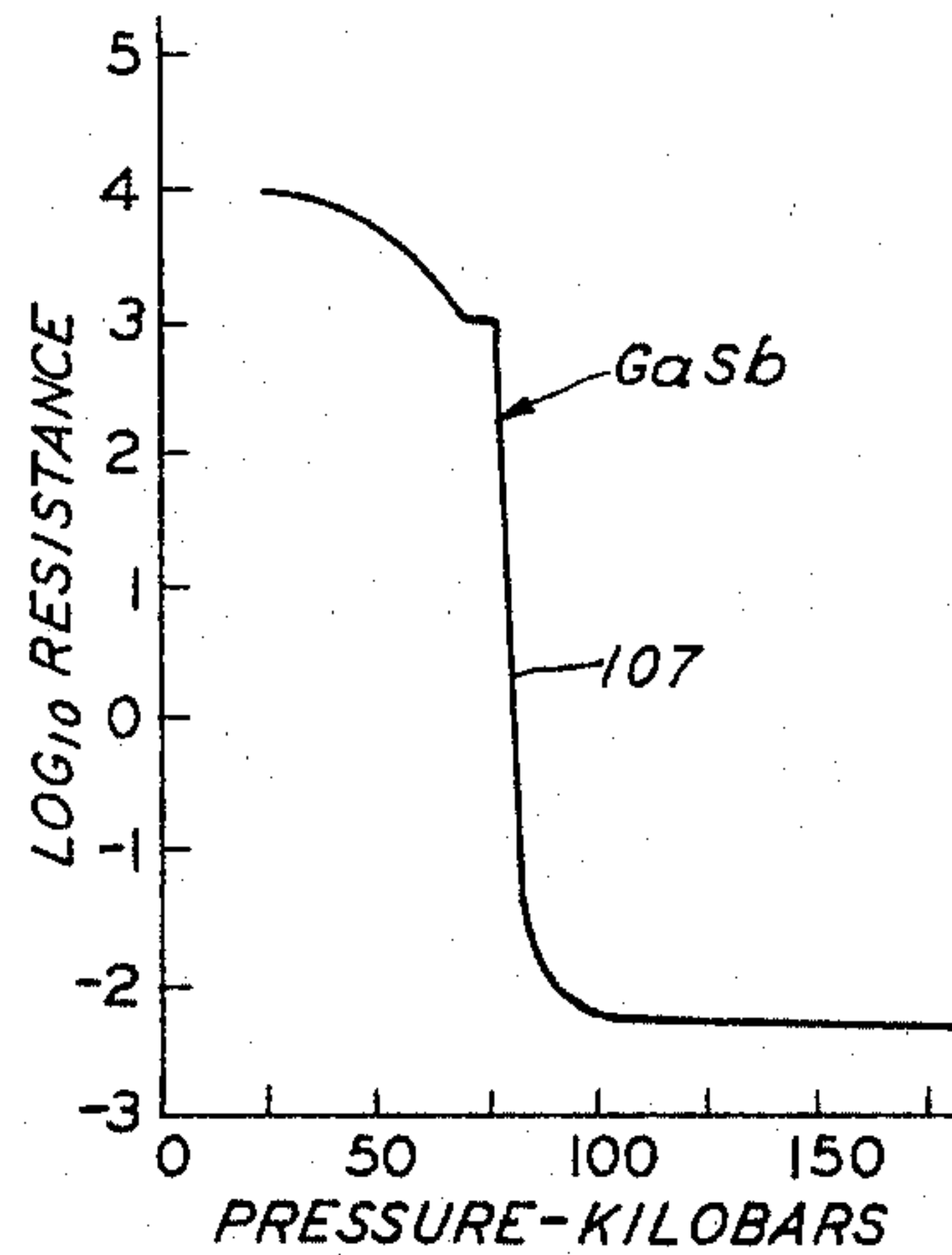


FIG. 6

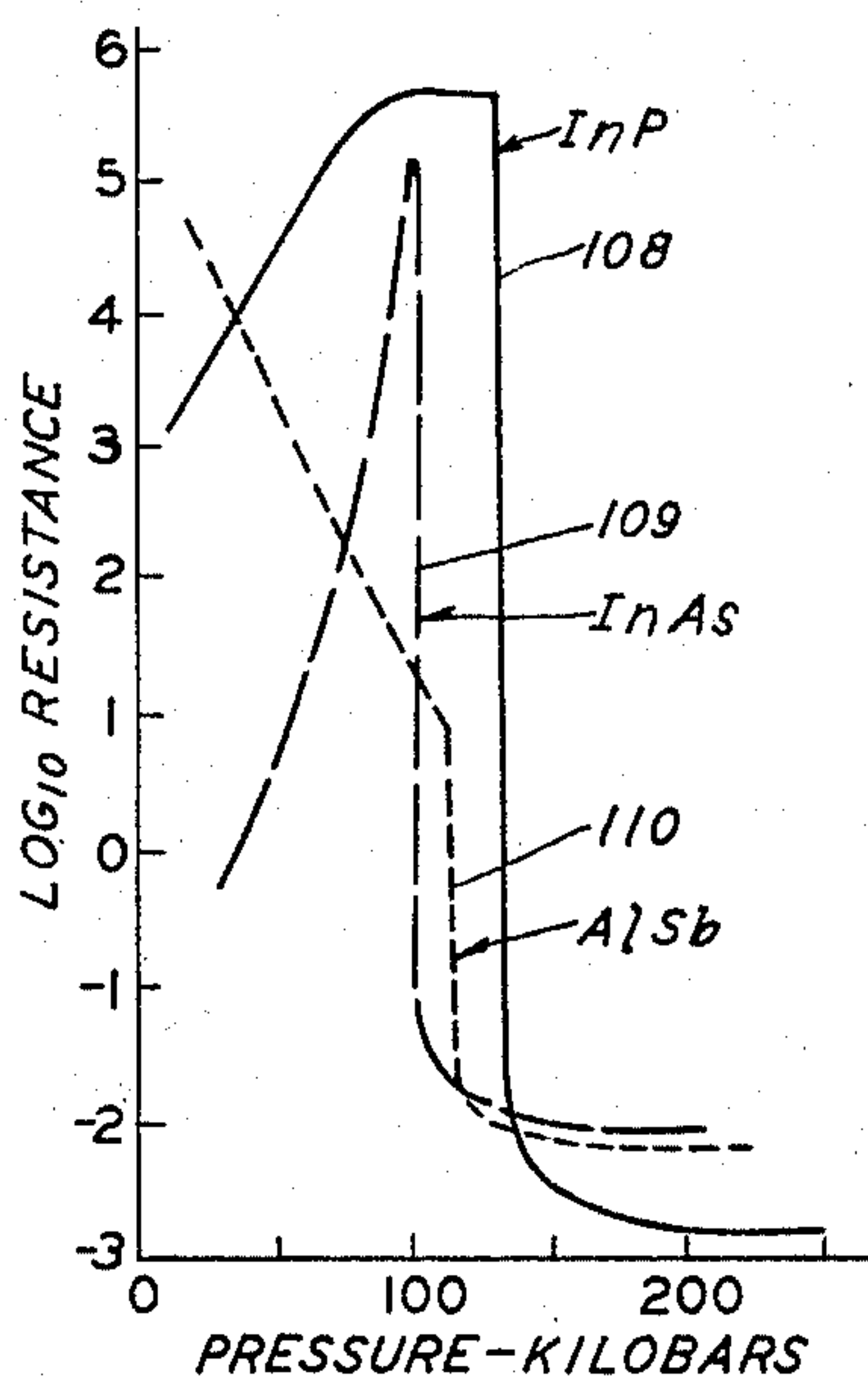
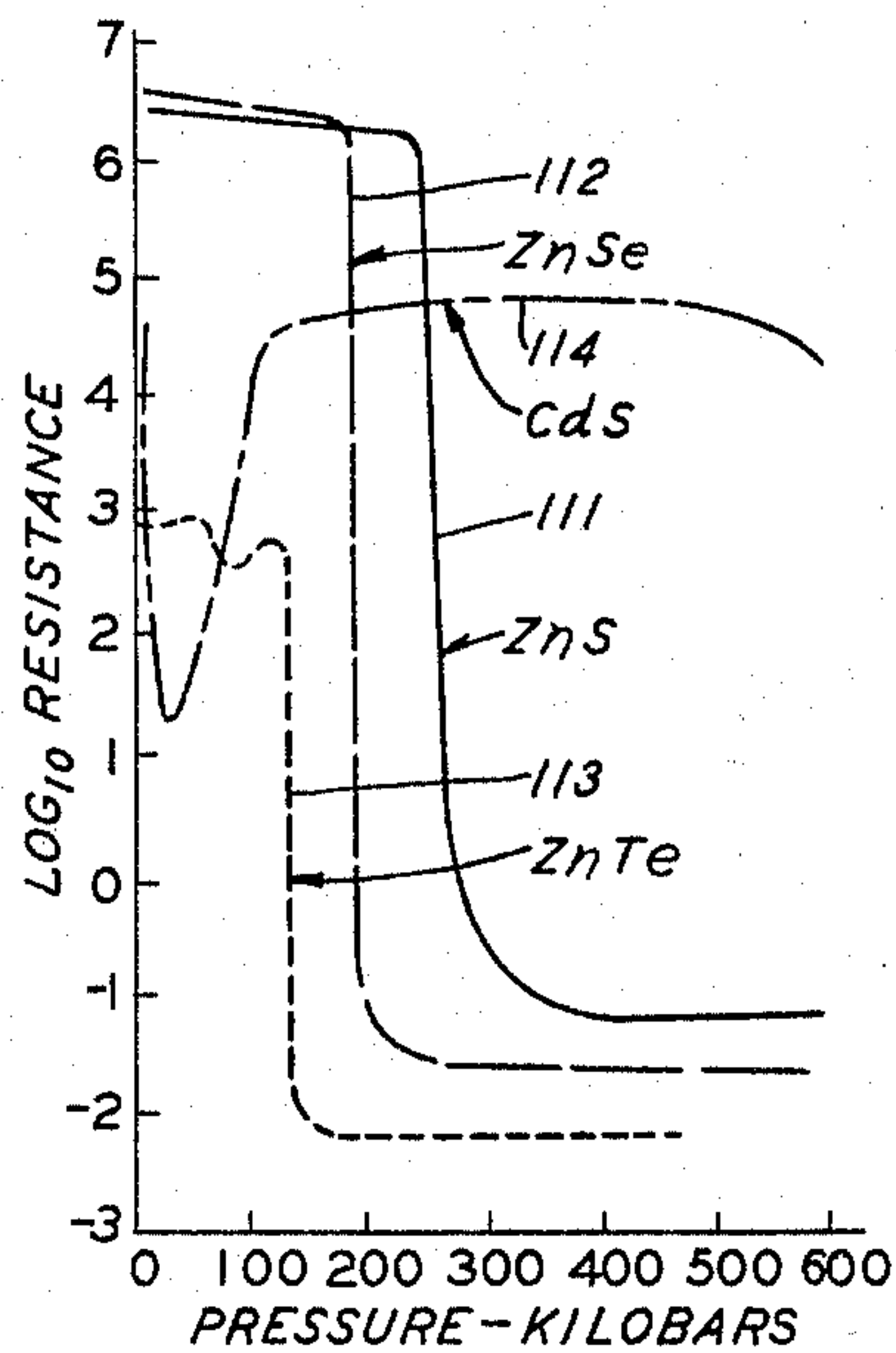


FIG. 7



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SEMICONDUCTIVE STRESS SENSING DEVICES

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17 Claims. (Cl. 317-235)

This invention relates to devices employing members of semiconductive material and to methods of making the devices. More particularly, it relates to devices which utilize specific sensitivities of various semiconductive materials to applied stress.

It has been demonstrated that semiconductive materials, including many specifically discussed hereinbelow, have resistance versus pressure characteristics which include limited portions, known as phase transitions, in which radical or abrupt changes in resistance with change in pressure occur. The pressures at which the respective materials undergo this "transition" in resistance are known as "transition pressures." The resistance changes are extremely large, for example, of 5 to 6 orders of magnitude. More specifically, in some instances a decrease in resistance of substantially 10,000 ohms may take place for a small increase in pressure as the transition pressure is realized.

Reference may be had, for example, to the consecutive articles by S. Minomura and H. G. Drickamer and G. A. Samara and H. G. Drickamer in the Journal of Physical Chemistry of Solids, 1962, volume 23, pages 451 through 461, inclusive, Pergamon Press (Great Britain), and to an article by A. Jayaraman, W. Klement, Jr., and G. C. Kennedy in the Physical Review for June 15, 1963, volume 130, No. 6. FIG. 4 on page 2280 of the last mentioned article presents a graphical summary of "transition pressures" for numerous semiconductive materials.

In order that pressures of the magnitudes required to invoke the above-mentioned radical changes or "transitions" can be readily achieved, it is usually convenient and practical that the members of semiconductive material be of extremely small physical dimensions. This in turn poses the problem, not infrequently encountered, as will be discussed hereinunder, with a number of other semiconductive devices, of accurately centering or positioning a small indenter or pressure applying member so that pressure may be applied squarely upon an extremely small member or area of semiconductive material.

In accordance with a further feature of the present invention, the indenter may take the form of a translucent point of very hard material such as diamond supported on a hollow shaft or the like, and the minute bit of semiconductive material is either illuminated by external means or in appropriate instances caused to become luminescent by application of a suitable voltage, whereupon the proper alignment of the indenter point on the bit of material can be determined by observation through the hollow shaft.

Accordingly, the present invention proposes the utilization of the extremely large resistance versus pressure transitions of semiconductive materials in the construction of devices such as microphones, strain gauges, seismographic detection devices, phonograph pickup devices, and the like, and further proposes a method of and structures for accurately positioning a small indenter or pressure applying member to bear squarely upon an extremely small member of semiconductive material or upon a specific extremely small area on a surface of a semiconductive device.

Objects of the invention are therefore to utilize the extremely large resistance versus pressure transitions of semiconductive materials and to facilitate the precise

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positioning of small indenters with respect to their associated minute semiconductive members or specific minute portions on the surfaces of semiconductive devices.

Other and further objects, features and advantages of the invention will become more clearly apparent from a perusal of the following detailed descriptions of specific illustrative embodiments and specific material characteristics in the following specification taken in conjunction with the accompanying drawing in which:

FIG. 1A illustrates a device of semiconductive material known as a "keyhole" transistor;

FIG. 1B is a top view of the transistor of FIG. 1A;

FIG. 2 illustrates a pressure applying arrangement of the invention by which accurate alignment of an indenter on the very small emitter region of a device such as that of FIG. 1 can be readily effected;

FIG. 3 illustrates a pressure applying arrangement similar to that of FIG. 2 for accurately aligning an indenter to bear squarely upon a small piece of semiconductive material;

FIG. 4 illustrates the resistance versus pressure transition characteristic of n-type silicon, n-type germanium and gallium arsenide;

FIG. 5 illustrates the resistance versus pressure transition characteristic of gallium antimonide;

FIG. 6 illustrates the resistance versus pressure transition characteristics of indium phosphide, indium arsenide and aluminum antimonide; and

FIG. 7 illustrates the resistance versus pressure transition characteristics of zinc sulphide, zinc selenide, zinc telluride and cadmium sulphide.

In more detail in FIGS. 1A and 1B, member 10 is a small transistor of the type which has been designated as the "keyhole" transistor because of the similarity in shape between the metal electrode 22 on the base 30 to the metal piece frequently employed as a facing for a keyhole. In actuality the over-all dimensions of transistor 10 may, for example, typically be 20 mil-inch by 20 mil-inch by 10 mil-inch but to make illustration feasible it is necessarily drawn to a substantially enlarged scale. (One mil-inch is, of course, one thousandth of one inch.)

The emitter region 12 is made very small, for example, it may comprise a circular portion having a diameter of 0.5 mil-inch and a laterally extending "tail" portion having a thickness 0.2 mil-inch and a length one mil-inch so that a very small metal electrode 14 at its outer end may serve, via a very thin lead 16, to make electrical contact to the emitter region 12. The emitter region 12 is induced in the surface of the base region 30 by diffusion in substantially conventional manner. The emitter region is of course of opposite type conductivity to that of the base region, that is, if the base is of n-type conductivity the emitter region should be of p-type conductivity, or vice versa.

The metal electrode 22 on the surface of the base region 30 surrounds the emitter region almost completely as shown, leaving a small clearance of, for example, 0.5 mil-inch between it and the emitter region periphery. Base lead 20 connecting to electrode 22 provides for electrical connection to base region 30.

Electrodes 14 and 22 may, for example, be applied by vapor deposition on the appropriate areas through suitable masking means in accordance with conventional practice in the art.

On the opposite or back major surface of base region 30 a collector region 32, remaining after the base region 30 has been induced in the wafer by diffusion, is of the same conductivity type as the emitter region, that is, of opposite conductivity type to that of the base region 30. Collector lead 24 makes an ohmic contact to the collector region 32 for the purpose of electrical connection thereto.

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For the specific purpose of locating an indenter squarely on the main circular portion of the emitter region, as will be described in detail in connection with FIG. 2, a battery 18 is connected between the emitter and base regions so as to suitably back-bias the emitter-base junction. As is well known to those skilled in the art, the periphery of the junction will then become luminescent, the utility of which property will become apparent hereinafter. After the indenter has been appropriately located, as will be described hereinafter, the battery 18 is, of course, replaced by a suitable bias for normal operation of the transistor.

In FIG. 2 transistor 10 comprising emitter region 12, base region 30, collector region 32 and appropriate electrodes as described above is supported on a member 60. An indenter is employed to apply pressure to emitter region 12 and comprises a hollow tube 52, in the lower end of which a small translucent point 50 of a hard material such as diamond is supported. The upper end of the indenter tube 52 is supported by the diaphragm 54 of resilient material such as steel which may be shaped to present a lower convex surface as shown.

A lip 56, also of steel, is integrally attached to and supports the outer periphery of diaphragm 54. Ring 56 is in turn supported in spaced relation to member 60 by a plurality of bolts 58 which pass through ring 56. The lower ends of bolts 58 may, for example, be threaded into member 60 and the upper ends of bolts 58 each are threaded for an appreciable distance from their respective ends and have two nuts 68, one above and one below ring 56, so that ring 56 may be locked in position between two nuts on each bolt.

The point 50 of the indenter should bear squarely on and substantially cover the surface of the emitter region 12 only. Since point 50 is translucent and tube 52 is hollow, if the periphery of the emitter region 12 is rendered luminescent by application of an appropriate back-bias voltage as discussed above in connection with FIG. 1 (battery 18), the position of transistor 10 on member 60 may be adjusted until region 12 is squarely positioned directly beneath the center of point 50, as indicated by visual observation through hollow tube 52. To facilitate accurate adjustment of the position of transistor 10, a micromanipulator (not shown) of conventional type may be employed.

In continuation of the basic research from which my copending application, Serial No. 282,792, filed May 23, 1963, evolved, it has been discovered that if a transistor having a very small emitter region (such as that described above for the structure of FIG. 1 of the drawing accompanying the present application) is employed and pressure is applied directly to the emitter region with no intervening metal electrode between the indenter and the surface of the emitter region, the transistor will be even more sensitive to stress, applied over substantially the entire periphery and surface of the emitter region, than transistors having larger emitter regions in which only a small portion near an edge of the emitter region is stressed, as taught in my above-mentioned copending application.

From the above, it is apparent that the "keyhole" transistor as illustrated in FIGS. 1A and 1B and described in detail above is particularly well suited for use in stress-sensing devices such as strain gauges, seismographs, microphones, phonograph pickup devices and the like.

By adjustment of the nuts 68 on bolts 58, diaphragm 54 can be utilized to prestress transistor 10, as taught in my above-mentioned copending application, so that it will be operating at optimum sensitivity.

Diaphragm 54 can also serve, in response to acoustic or ultrasonic waves impinging upon it, to superimpose information bearing pressure variations upon emitter region 12. Alternatively, information bearing pressure variations can be superimposed by appropriate mechani-

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cal linkage members (not shown) directly on the upper end of indenter tube 52.

The structure of FIG. 3 is similar to that of FIG. 2 in a number of details as indicated by the use of identical designation numbers on various parts of both figures.

The structure of FIG. 3 is, however, intended for use in stressing a small bit of semiconductive material, such as bit 64, to the point that its resistance versus pressure transition region is reached. It should be especially noted that bit 64 is of uniform character throughout and contains no so-called p-n junction.

Supporting member 62 has a small central pedestal 70 of electrically conductive material on which the bit 64 is supported. A number of sources of intense light such as 66 are provided at intervals around the assembly of FIG. 3 to brightly illuminate the surface of pedestal 70 and the periphery of bit 64 so that bit 64 can be squarely centered under point 50 of the indenter by visual observation through the hollow tube 52. Accurate alignment is essential since the bit 64 is to be subjected to a very considerable pressure and deleterious shear strains would be developed if the bit 64 were not squarely under the indenter. As suggested in connection with FIG. 3, a conventional micromanipulator (not shown) may be used to facilitate positioning bit 64. After the alignment is effected, the light source 66 may, of course, be removed or turned off.

The pressure on bit 64 can be increased by suitable adjustment of nuts 68 above and below ring 56 until the bit 64 is stressed to substantially the center of its resistance versus pressure transition region. A lead 72 is connected to the upper surface of the bit 64 and lead 74 is connected to pedestal 70 so that changes in the resistance of bit 64 can be introduced into an appropriate electrical utilization circuit 71 for measurement. The over-all device of FIG. 3 may then be employed as a strain gauge, seismographic instrument, microphone, phonograph pickup device, or the like, substantially as indicated hereinabove for the arrangement of FIG. 2.

As will become apparent in connection with the pressure versus resistance transition characteristics of numerous semiconductive substances, as illustrated in the curves of FIGS. 4 through 7, inclusive, to be described below, when bit 64 has been carried to substantially the center of its transition pressure region small changes in pressure will result in very substantial changes in the resistance of the bit. Thus a unique extreme of sensitivity to stress is readily obtained by use of the arrangement illustrated in FIG. 3. As mentioned hereinabove, bit 64 contains no p-n junction.

In FIG. 4 the resistance versus pressure transition characteristic 104 for n-type (conductivity) silicon is shown, the vertical scale being the logarithm to the base ten of the resistance, the horizontal scale being the pressure in kilobars (a pressure of one kilobar is 1,000 kilograms per square centimeter). The transition takes place at a pressure slightly less than 200 kilobars so that the resistance of a given sample of silicon, for example, drops from a maximum of about 1,000 ohms to a small fraction of an ohm for a small increase in pressure sufficient to carry the material through its phase transition.

In FIG. 4 the corresponding transition characteristics 105 for n-type (conductivity) germanium is shown. In this instance the transition takes place at a pressure of approximately 125 kilobars and drops in resistance from nearly 10,000 ohms to a fraction of an ohm for a small change in pressure at its transition.

Corresponding transition characteristics for a number of other semiconductive materials are the characteristics 106 of FIG. 4 for gallium arsenide, 107 of FIG. 5 for gallium antimonide, 108 of FIG. 6 for indium phosphide, 109 of FIG. 6 for indium arsenide, 110 of FIG. 6 for aluminum antimonide, 111 of FIG. 7 for zinc sulphide, 112 of FIG. 7 for zinc selenide, 113 of FIG. 7 for zinc

telluride and 114 of FIG. 7 for cadmium sulphide, respectively.

The choice of a material in any specific instance will obviously depend upon the pressure which can most conveniently be applied, though other conditions such as the physical characteristics of the material, the contaminants present in the adjacent atmosphere, and the like, may also require consideration in making a selection. The above described specific characteristics are substantially those given in the above-mentioned articles by S. Minomura et al. and G. A. Samara et al.

Numerous and varied modifications and rearrangements of the above disclosed illustrative embodiments clearly within the spirit and scope of the invention will readily occur to those skilled in the art. Accordingly, it should be understood that the arrangements disclosed are illustrative and not to be construed as limiting the invention described.

What is claimed is:

1. A member of semiconductive material having a known pressure versus resistance characteristic, the latter including a transition portion, means for subjecting the member to a fixed initial pressure corresponding substantially to the center of said transition portion, means for superimposing on the member information bearing pressure variations, and means for utilizing the resultant changes in the resistance of the member.

2. The arrangement of claim 1 in which the semiconductive material is selected from the class which consists of silicon, germanium, gallium arsenide, gallium antimonide, indium phosphide, indium arsenide, aluminum antimonide, zinc sulphide, zinc selenide, zinc telluride and cadmium sulphide.

3. The arrangement of claim 1 in which the semiconductive material is silicon.

4. The arrangement of claim 1 in which the semiconductive material is germanium.

5. The arrangement of claim 1 in which the semiconductive material is gallium arsenide.

6. The arrangement of claim 1 in which the semiconductive material is gallium antimonide.

7. The arrangement of claim 1 in which the semiconductive material is indium phosphide.

8. The arrangement of claim 1 in which the semiconductive material is indium arsenide.

9. The arrangement of claim 1 in which the semiconductive material is aluminum antimonide.

10. The arrangement of claim 1 in which the semiconductive material is zinc sulphide.

11. The arrangement of claim 1 in which the semiconductive material is zinc selenide.

12. The arrangement of claim 1 in which the semiconductive material is zinc telluride.

13. The arrangement of claim 1 in which the semiconductive material is cadmium sulphide.

14. Means for centering a small pressure applying indenter on an extremely small area of semiconductive material which comprises an indenter in the form of a hollow cylindrical shaft having a small point of translucent material, and means for illuminating the extremely small area of semiconductive material whereby the indenter point may be accurately aligned to impinge upon the said area by visual observation through the hollow indenter.

15. The arrangement of claim 14 in which the extremely small area is the surface of a portion of a semiconductive device which portion makes a p-n junction with surrounding portions of the device and the extremely small area is illuminated by the application of a back-bias voltage across said p-n junction.

16. A transducer comprising a member of semiconductive material, said material being of uniform character throughout and having a predetermined pressure-resistance characteristic, the latter including a transition region; means for subjecting the member to a fixed initial pressure corresponding substantially to the center of said transition portion; means for superimposing on the member information-bearing pressure variations of a magnitude sufficient to vary the resistance of the member within the limits defined by the bounds of said transition region; and means connected to the member for utilizing said variations in resistance.

17. The arrangement of claim 16 in which the semiconductive material is selected from the class which consists of silicon, germanium, gallium arsenide, gallium antimonide, indium phosphide, indium arsenide, aluminum antimonide, zinc sulphide, zinc selenide, zinc telluride and cadmium sulphide.

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