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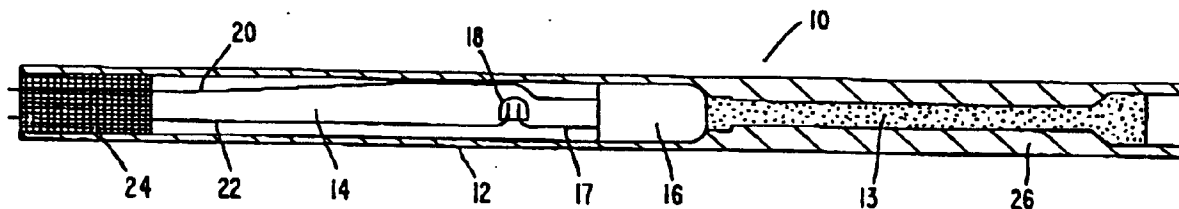
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(54) **Electrical detonator.**

(57) An electrical detonator has a case (12) containing an explosive charge (13), a semiconductor bridge (16) positioned adjacent one end of the explosive charge (13) and electrically connected to a spark gap (18) and, in some embodiments, a capacitor and a bleeder resistor. A pair of electrically conductive wires (20,22) are connected to the spark gap (18) and semiconductor bridge (16) to provide a means for passing an electrical charge to the semiconductor bridge (16). The detonator also may include an rf attenuator (24), such as a ferrite bead, through which the electrically conductive wires (20,22) pass.

FIG. 2



The present invention relates to an electrical detonator.

It is well known to initiate secondary explosive compositions by means of primary explosives. This method however, involves the use of materials which are liable to accidental initiation by extraneous sources such as, for example, heat impact, friction, electrostatic discharge or the like.

The advent of the exploding bridge wire provided a method of introducing a large amount of energy into a detonator. Presently available exploding bridge wire detonators usually contain lead azide or pentaerythritol tetranitrate (PETN) as the explosive material. The use of PETN, however, has limited the use of such detonators to relatively low temperature environments. Some detonators have used cyclotrimethylene trinitramine (RDX) or hexanitrostilbene (HNS) as the explosive material. The detonators have still required the introduction of a relatively large electrical charge into the bridgewire to heat the wire to a temperature at which it will explode.

Recently, a device referred to as a semiconductor bridge has been developed for ignition of pyrotechnics and explosives. One example of a prior art semiconductor bridge is illustrated schematically in Figs. 1a and 1b of the accompanying drawings, Fig. 1a being a schematic plan view, and Fig. 1B being a vertical section. Referring to these drawings, the semiconductor bridge consists of an "H" shaped, doped silicon material 2 sandwiched between a substrate 4 and an aluminum land 6. The bridge area provides electrical connection between the lands and the electrical circuit. The semiconductor bridge is actuated by a short, low energy pulse which may be in the range of from about 3 to 5 mJ that vaporizes the bridge material creating a hot plasma that ignites a small quantity of an explosive or pyrotechnic that is placed in intimate contact with the bridge. The assembly of the electrical circuit and small quantity of explosive and/or pyrotechnic in a metal or plastic shell is referred to as an SCB. SCB's operate at much lower input energies than conventional exploding bridgewire devices. A study of the mechanism of SCB's was conducted by Sandia National Laboratories and reported in 1989 in report number SAND 89-2033. The model study was directed to the initiation of the granular explosive 2-(5-cyanotetrazolato)pentaaminecobalt (III) perchlorate (CP).

We have now devised a detonator having increased stability and shock resistance over prior known detonators.

According to the present invention, there is provided an electrical detonator which comprises a casing; an explosive charge contained within said casing; a semiconductor bridge positioned adjacent said explosive charge and in intimate contact with a pyrotechnic; a spark gap electrically connected to said semiconductor bridge; and a pair of electrically con-

ductive wires which penetrate said casing and connect to said spark gap and semiconductor bridge to provide a means of introducing an electrical charge into said semiconductor bridge.

In the detonators of the invention, we prefer to use 2-(5-cyanotetrazolato)pentaaminecobalt (III) perchlorate (CP) or titanium subhydride potassium perchlorate (THKP) as the pyrotechnic, in combination with a semiconductor bridge to form an ignition source (SCB). To make a detonator of the invention, the case or shell has an open end into which are inserted, in sequence, a quantity of granular cyclotetramethylene tetranitramine (HMX) or other explosive, an SCB positioned adjacent one end of the HMX which is electrically connected to a spark gap and, in some embodiments, a capacitor and bleeder resistor, and finally an rf attenuator. The electrical connections extend outward from the rf attenuator through the end of the case. The components are then sealed or otherwise bonded within the casing to form the detonator. In an optional embodiment, the detonator may include a flying plate initiator. In another optional embodiment, the detonator may be configured into a small block where the safety circuitry is contained in the circuitry tube, which is positioned parallel to the detonation tube which houses the explosive.

In order that the invention may be more fully understood, reference is made to the accompanying drawings, in which:

Figures 1a and 1b are as previously described.

Figure 2 is a schematic illustration of one embodiment of the detonator of the present invention.

Figure 3 is a schematic illustration of another embodiment of the present invention including a capacitor.

Figure 4 is yet another schematic illustration of the present invention utilizing a flying plate.

Figure 5 is a schematic illustration of a fluid disable device for use with the detonator of the present invention.

Figure 6 is a schematic illustration of another embodiment of the detonator of the present invention wherein the detonator is configured into a small compact block.

Figure 7 is a schematic illustration of the assembly of the embodiment of the detonator of the present invention shown in Figure 6 assembled within a perforating gun.

Referring to the drawings, Figures 2-4 provide a schematic illustration of three illustrative embodiments of detonator 10 of the present invention comprising a casing or shell 12, having a varying diameter bore therethrough containing a quantity of HMX or other explosive identified as 13, an SCB 16 and a spark gap 18 which are connected by a pair of electrically conductive wires 20 and 22 to a means for introducing an electrical charge into the SCB 16, and means for sealing the casing and various optional

constituents such as an rf attenuator 24, a bleeder resistor and a capacitor in the electrical circuit.

The casing or shell 12 of the detonator 10 of the present invention comprises a cylindrical tube having a bore 14 of varying diameter therethrough, the diameter being sufficient to permit inclusion of an SCB within the bore 14. Typically the wall thickness of the case will be in the range of from about 0.075 to about 0.125 inches. The casing 12 may be comprised of substantially any material of high acoustic impedance such as, for example, aluminum, steel and particularly stainless steel, brass, rigid plastics and the like capable of withstanding exposure to a temperature of about 400°F for a period of at least about one hour without structural failure.

The SCB 16 is positioned within the casing 12 such that it will be in intimate contact or at least close proximity to the explosive to be placed within the bore 14. Preferably, the SCB 16 is positioned such that it will be in contact with the surface of the explosive exposed in bore 14. The SCB 16 may be substantially any of those which are commercially available in a size capable of insertion within the casing. Suitable SCB's are available, for example, from Thikol Corporation, Elkton, Maryland, and SCB Technologies, Inc., Albuquerque, New Mexico. The SCB 16 preferably is of the type activated by an electrical charge of from about 18 to about 24 volts at an amperage of from about 3 to about 4 amps. It is to be understood however, that other SCB's also may be suitable if they result in initiation of the deflagration reaction with the explosive composition in the detonator. The design of the SCB 16 is generally of the type having the electrical circuit illustrated in Figures 1A and 1B, and which was previously described. If desired, the SCB may be prepared by compressing a quantity of from about 50 to about 100 milligrams of a pyrotechnic in a suitable size metal or plastic container into intimate contact with a semiconductor bridge. It is contemplated that the pyrotechnic would be either CP, BNCP or THKP, or any other pyrotechnic or explosive having the characteristic of being reliably initiated by the SCB. Typically the CP or THKP is compressed by application of from about 10,000 to 12,000 psi of force to the material. The open end of the container having the electrical connections extending therefrom may be sealed by, for example, epoxy or the like.

The THKP utilized in the present invention is defined by the formula $TiH_x/KClO_4$ wherein x is greater than 0.6 and less than 1.9. The THKP is available from, for example, SCB Technologies, Inc., Albuquerque, New Mexico. THKP may be produced by a number of commercially known methods. One successful method of synthesis involves a very carefully controlled vacuum heating cycle followed by a controlled air oxidation step to thermally dehydride commercially available titanium hydride. This product is then blended with potassium perchlorate to yield the THKP. Gen-

erally, the subhydride is blended with the perchlorate in a ratio of about 1:2 by weight, however, it is to be understood that other ratios known to those skilled in the art may be employed.

An explosive charge 13 is positioned within an end 26 of the case 12 to improve initiation of a detonating cord such as a "PRIMACORD"™ detonating cord manufactured by Ensign-Bickford Company or other secondary explosive. The explosive charge is introduced into the casing as a powder and thereafter is compressed by application of, for example, a ram to the explosive at end 26 of casing 12. The explosive charge may comprise HMX, hexanitrostilbene (HNS) bis(picrylamino) trinitropyridine (PYX), trinitrotrimethylenetriamine (RDX) and mixtures thereof, or the like. It is contemplated that the explosive charge would have a velocity of detonation of 5,000 meters per second or greater. The end 26 of casing 12 may be sealed by a thin metal or plastic disk which is pressed into place or by a thin layer of epoxy to provide a seal on the exposed end of the explosive in the bore 14 in detonator 10.

The HMX or other explosive is compressed to a density in the range of from about 1.4 to about 1.6 grams per cubic centimeter at the exposed end. This results in a variation in the density of the HMX or other explosive in the bore from approximately the bulk density of the explosive at one end to the full compressed density at the other end. The length of the bore is such that the quantity of HMX present will, upon initiation, effect a transition from deflagration-to-detonation prior to passage of the combustion front through the mass of compressed HMX present within the bore. Typically, the bore 14 will have a length of at least about 1 inch for a bore diameter of about 0.1 inches. The bore within the casing 12 generally is flared in a frustoconical manner at the end at which initiation is to occur to provide a larger surface area upon which to initiate deflagration.

The SCB 16 is connected by an electrically conductive wire 17 to a spark gap. The spark gap 18 is utilized to protect the detonator against accidental initiation by an electrostatic discharge. Suitable spark gaps are available from, for example, Reynolds Industries and Lumex Opto. Typically the spark gap will have a voltage threshold of from about 80 to about 200 volts before passage of an electrical charge to the SCB 16 occurs. Spark gaps are available with various ratings and detonators can be prepared having different known spark gaps to permit controlled initiation of individual or multiple explosive charges in response to different electrical charges transmitted from an electrical source.

To facilitate placement of the SCB 16 and spark gap 18 within the casing 12, the components are preferably potted in a plastic resin such as epoxy or other material, or affixed to a substrate to permit maintenance of a fixed position within the casing 12. While

not required or essential, potting of the electrical components assists in reducing detonator failures.

The SCB 16 and spark gap 18 are provided with electrically conductive wires 20 and 22 which provide an electrical connection which extends outside of the casing 12. The casing 12 can be sealed by insertion of, for example, an rf attenuator, comprising a ferrite bead having passageways therethrough for the wires passing from the end of the casing 12. The casing 12 then may be crimped to retain the bead in position. The rf attenuator reduces the strength of any radio signal present to a level whereby the signal is incapable of accidental initiation of the detonator. Suitable devices include the MN 68 ferrite device available from Attenuation Technologies, La Plata, Maryland. The casing 12 also may be sealed with plastic resins or the like which bond to the casing to seal the various components within the casing.

In an alternate embodiment of the present invention, illustrated schematically in Figure 3, a capacitor 32 and a bleeder resistor 33 may be included within the electrical circuit created by the SCB 16 and spark gap 18 within the detonator casing 12. The bleeder resistor 33 and the capacitor 32 are placed in parallel to one another, and then in series with the spark gap 18. The capacitor 32 is utilized to store electrical energy sufficient to pass the spark gap and initiate the SCB and the resistor is used to slowly drain the capacitor in the event the capacitor is partly charged during an interrupted firing of the detonator. Typically, the capacitor is selected to provide a capacitance of 3.5 mF and the resistor is chosen to have a 1,000,000 to 2,000,000 ohm resistance. Suitable capacitors and resistors are available from, for example, Carlton-Bates Co., Texarkana, Texas. The electrical circuitry includes the SCB 16, which in turn is positioned adjacent the explosive charge 13.

In yet another embodiment of the present invention, illustrated schematically in Figure 4, initiation of the explosive charge is effected with a flying plate. In this embodiment, the end 26 of bore 14 is divided into segments 34, 35 and 36 and one segment contains no explosive. A quantity of granular explosive is positioned within segment 34 of bore 14 and compressed adjacent the SCB 16. A disk 38 then is inserted into the casing 12. The disk 38 generally has a diameter substantially the same as the inner diameter of the casing 12. The disk 38 may be comprised of aluminum, plastic or the like in accordance with the known techniques of initiation using flying plates. The thickness of the plate may vary, with the specific thickness being dependant on the energy necessary to detonate the explosive charge. The flying plate material selection and size determinations are considered to be well within the knowledge and capabilities of those individuals skilled in the art. In one embodiment a retainer 39 then is inserted within segment 35 of the casing 12 adjacent to the disk 38 and a prepressed

pellet of explosive is positioned within segment 36 with the remainder of the detonator 10 being as previously described.

The detonator 10 of Figures 3A, and 4 can alternatively be assembled without an rf attenuator 24, as illustrated in FIG. 3B, and still operate safely. The rf attenuator 24 is generally added as a precaution to reduce the strength of any radio signals that are present and, thus, act to prevent accidental initiation of the detonator 10. Tests have shown that accidental initiation of the detonator 10 is highly unlikely, even when the rf attenuator 24 is not used, because the capacitor 32 and bleeder resistor 33 together act to attenuate and rf energy that may be encountered during assembly and use.

The detonator 10 of the present invention may be utilized in environs subject to fluid influx in which it is desired to disable an explosive charge in the presence of such fluids. One particular application wherein a fluid disable is desirable is in the operation of subterranean formation perforating guns. Typically, the guns comprise a number of perforating charges contained within a sealed metal housing. If fluids enter the interior of the housing the performance of the perforating charges is effected and it also may result in misfires of the charges. When used, for example, in a perforating gun to activate a detonating cord connected to the perforating charges, the detonator may be connected to the detonating cord with a coupler 50 of the type schematically illustrated in Figure 5. The coupler 50 comprises a body 52 having a bore 54 therethrough which may have differing diameters down its length. The bore 54 is of a diameter at one end sufficient to fit over the end, in preferably a compression fit, of the detonator 10. The other end of the bore 54 is such as to accept insertion of the end of a detonating cord 55 therein. The bore 54 is of sufficient length that a void remains between the opposed end faces of the detonator and detonating cord 55 when positioned within the coupler. The coupler also includes at least one port 56 through the side wall of the coupler 50 in the region of the void. The port 56 is of sufficient size that upon exposure of the coupler 50 to a fluid, the fluid can flow through the port 56 and into the void. Entry of a fluid into the void will, upon detonation of the detonator, result in energy absorption by the fluid so as to prevent activation of the detonating cord 55. While the coupler 50 has been described as a device separate from said detonator 10, it is to be understood that a detonator casing could be produced in which the features of the coupler 50 would be incorporated and whereby a direct connection of the detonator could be effected with a detonating cord.

Figures 6 and 7 show a further embodiment of the subject invention, referred to as a "block detonator" 60, whereby the casing 12, instead of being configured as a single tube (as shown in FIGS. 2, 3A, 3B,

and 4) is configured as a block. In a preferred embodiment, the block detonator comprises a plurality of chambers, such as a first chamber 61, a second chamber 62, and a third chamber 63. The first chamber 61, also referred to as a safety circuit tube, houses the circuitry of the detonator 60, namely a spark gap 18, a bleeder resistor 33, and a capacitor 32. The bleeder resistor 33 and the capacitor 32 are placed in parallel to one another, and then in series with the spark gap 18. The second chamber 62 houses the booster 65 and the deflagration-to-detonation (DTD) tube 67, which in turn houses the semiconductor bridge (SCB) 16 and the explosive charge 13. The electrical circuitry of the safety circuit tube is electrically connected to the SCB 16, which in turn is affixed to the DTD tube 67 and positioned adjacent the explosive charge 13. The explosive charge 13, housed within the DTD tube 67, is positioned adjacent the booster 65. The booster is a heavier explosive charge which provides side initiation or explosive transfer to the detonating cord (not shown), which passes through the third chamber 63 for alignment of the detonating cord adjacent to the booster 65. The block detonator 60 is used with bottom-fired hollow carrier perforating guns where a fluid-disabled feature is required. This embodiment of the present invention is similar in geometry to conventional block detonators that have been used in the oilfield for many years, but is preferred over the prior art block detonators because it does not contain primary explosives.

It is contemplated that the block detonator 60 can be configured to have varying geometries and different numbers of chambers, and that the embodiment shown in FIG. 6 is but one such arrangement.

The block detonator 60 will disable itself if the gun 70 has inadvertently flooded. Conventional block detonators rely on fluid to create a barrier between the donor charge of the detonator and the detonating cord. The block detonator 60 relies on the wetting action of fluid migrating into the casing 12 and DTD tube 67 to inert the explosive booster 65, thus providing fire/no-fire reliability and eliminating the critical geometry characteristic found in conventional block detonators.

Also, by configuring the safety circuitry of the block detonator 60 such that it is parallel to the DTD tube 67, the overall length of the detonator 60 can be shortened to where the detonator is compact enough to fit into the bottom of a standard perforating gun without any modification to the gun or the bull plug (See FIG. 7). Furthermore, this embodiment of the detonator 60 can side initiate standard 80 grain detonating cords commonly used in perforating guns, making for safe and simple arming of the gun.

The operation of the block detonator 60 is illustrated in FIG. 7. The negative lead 22 of the detonator 60 is attached to a scratcher-type grounding spring 76 outside of a perforating gun carrier 70

known in the art. The grounding spring 76 is then inserted into the gun 70 and pushed forward until it abuts the lowermost shaped charge 78. The positive lead 20 is then spliced to the lead wire 73 that runs through the gun 70, arming the detonator 60 electrically. An insulating sleeve 74 is placed over the splice. Thereafter, the detonating cord 75 is passed through the block detonator 60 to provide the ballistic connection. The detonator 60 is pushed into the lower portion of the gun 70 and the cord 75 is trimmed flush with the edge of the detonator 60. The wires 20, 22 are carefully tucked inside the gun 70 and a bull plug 72 is threadably engaged to the bottom of the gun 70 to complete the arming sequence.

To further illustrate the present invention and not by way of limitation, the following example is provided.

EXAMPLE

A detonator is prepared utilizing a casing comprising 303 Stainless Steel having a diameter of 0.312, a length of 4.3 inches, and a wall thickness of about 0.106. A quantity of HMX is pressed into the bore in the end of the casing having the cross-section as illustrated in Figure 2. An SCB is connected to a spark gap and potted in epoxy within the casing prior to addition of the HMX. The electrical connections for the SCB and spark gap are passed through a rubber washer which is crimped within the end of the casing, sealing the detonator. The detonator was secured in a test fixture and connected to an electrical power source. An electrical charge having a voltage of 80-200 volts and current of 2.0 amps which was then applied to the detonator. The detonator fired.

While that which is considered to comprise the preferred embodiments of the invention has been described herein, it is to be understood that changes and modifications may be made in the apparatus and chemical compositions by an individual skilled in the art

Claims

1. An electrical detonator (10) which comprises a casing (12); an explosive charge (13) contained within said casing (12); a semiconductor bridge (16) positioned adjacent said explosive charge (13) and in intimate contact with a pyrotechnic; a spark gap (18) electrically connected to said semiconductor bridge (16); and a pair of electrically conductive wires (20,22) which penetrate said casing (12) and connect to said spark gap (18) and semiconductor bridge (16) to provide a means of introducing an electrical charge into said semiconductor bridge (16).

2. A detonator according to claim 1, which further includes an rf attenuator (24) positioned at the end of said casing (12) having the electrically conductive wires (20,22) passing therethrough. 5
3. A detonator according to claim 1 or 2, further including a capacitor connected to said spark gap (18) whereby discharge of said capacitor transmits an electrical charge through said spark gap (18) to the semiconductor bridge (16). 10
4. A detonator according to claim 1,2 or 3, further including a bleeder resistor which is positioned across the electrically conductive wires (20,22) within said casing (12). 15
5. A detonator according to claim 1, wherein the pyrotechnic contains a subhydride of formula $TiH_x/KClO_4$ wherein x is greater than 0.6 and less than 1.9. 20
6. A detonator according to any of claims 1 to 5, wherein at least a portion of said explosive charge (13) is compressed in said casing (12) to a density of from 1.4 to 1.6 grams per cubic centimeter. 25
7. A detonator according to any of claims 1 to 6, wherein said explosive charge (13) has a velocity of detonation of approximately 5,000 meters per second. 30
8. A detonator according to any of claims 1 to 6, wherein said explosive charge (13) has a velocity of detonation of greater than 5,000 meters per second. 35
9. A detonator according to any of claims 1 to 6, wherein said explosive charge (13) includes at least one of hexanitrostilbene, cyclotetramethylene tetranitramine, bis(picrylamino) trinitropyridine and trinitrotrimethylenetriamine. 40
10. A detonator according to any of claims 1 to 9, wherein said semiconductor bridge (16) is in intimate contact with a pyrotechnic that is reliably initiated by the semiconductor bridge (16). 45

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FIG. 1a

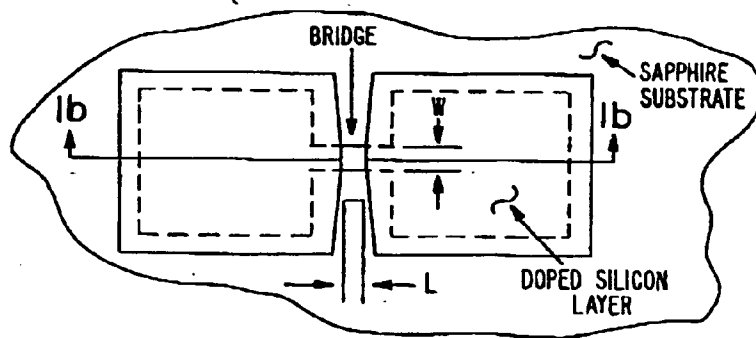


FIG. 1b

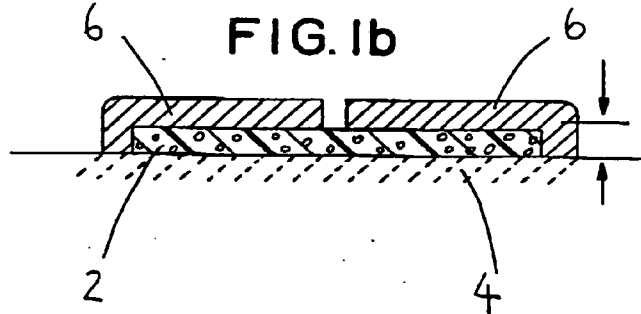


FIG. 2

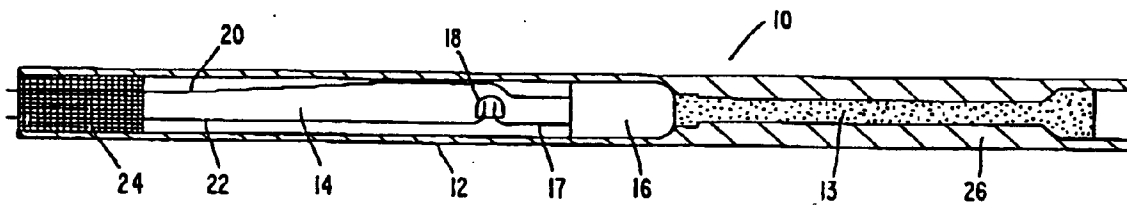


FIG.3A

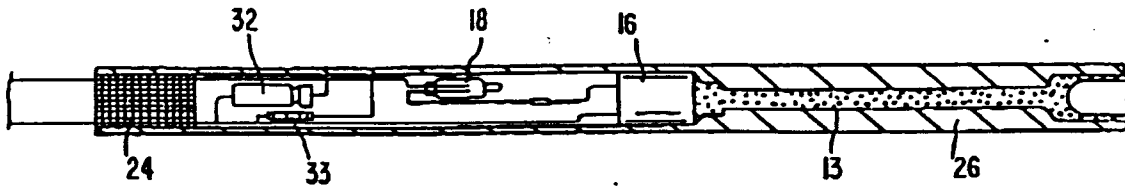


FIG. 4

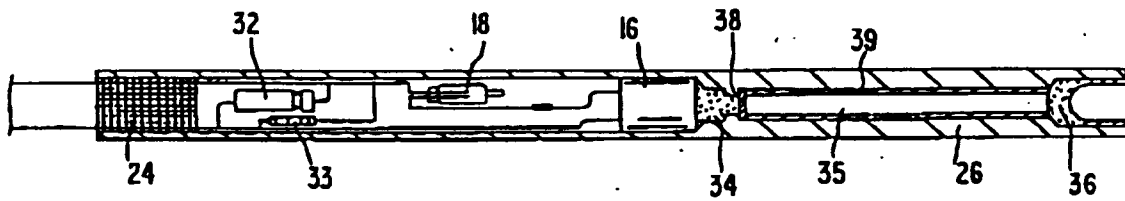


FIG. 5

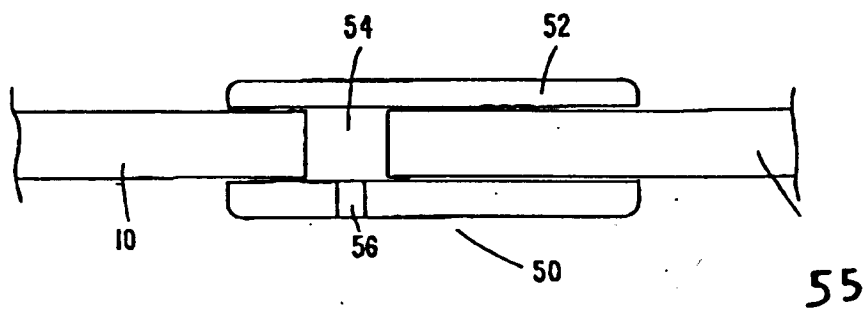


FIG. 6

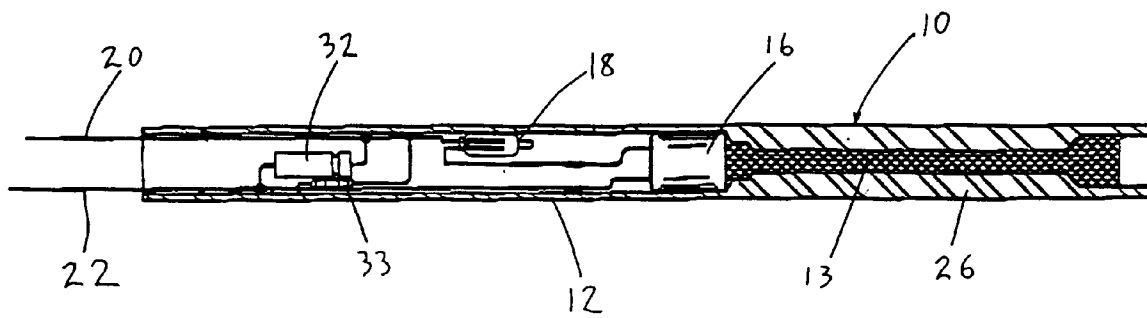
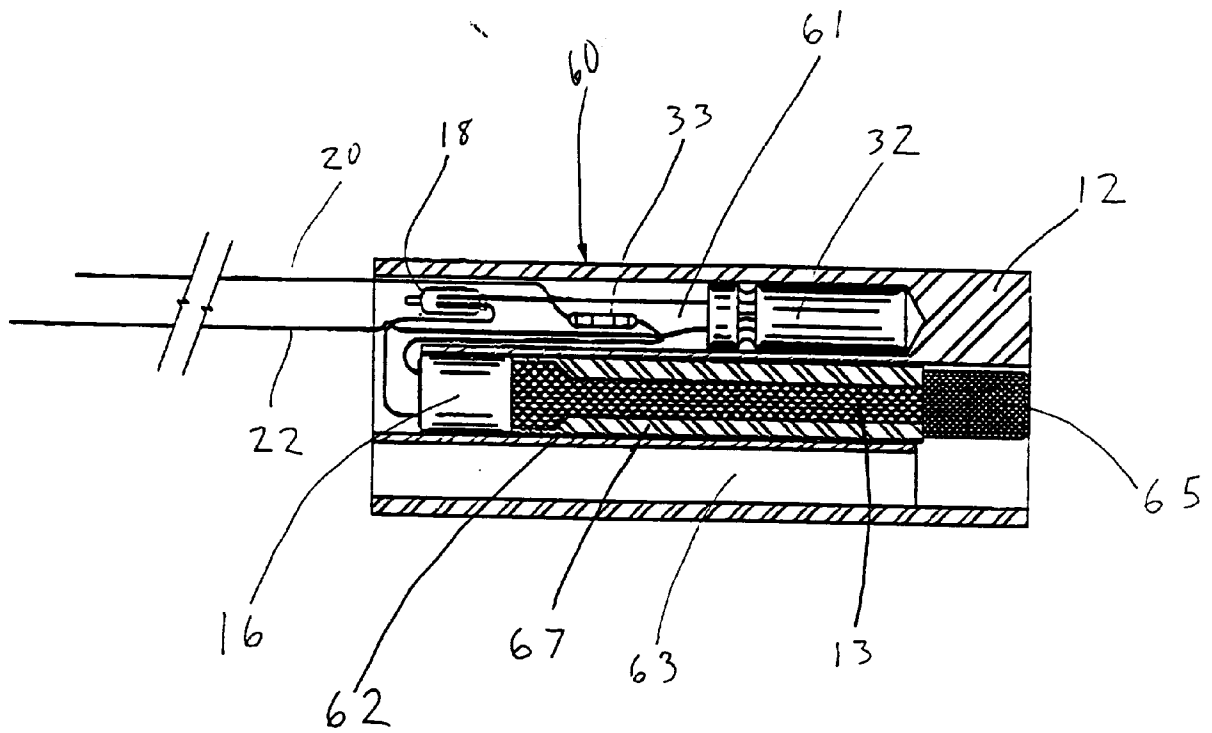


FIGURE 3B

FIG. 7

