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- [54] **DETONATOR WITH LOOSELY PACKED IGNITION CHARGE AND METHOD OF ASSEMBLY**
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- [51] **Int. Cl.<sup>6</sup>** ..... **C06C 5/00; F42B 3/10**
- [52] **U.S. Cl.** ..... **102/275.5; 102/202.5**
- [58] **Field of Search** ..... 102/202.14, 202.11, 102/202.12, 202.5, 202.7, 202.9, 275.5, 275.11, 215, 202, 331, 332; 86/1.1, 22, 50

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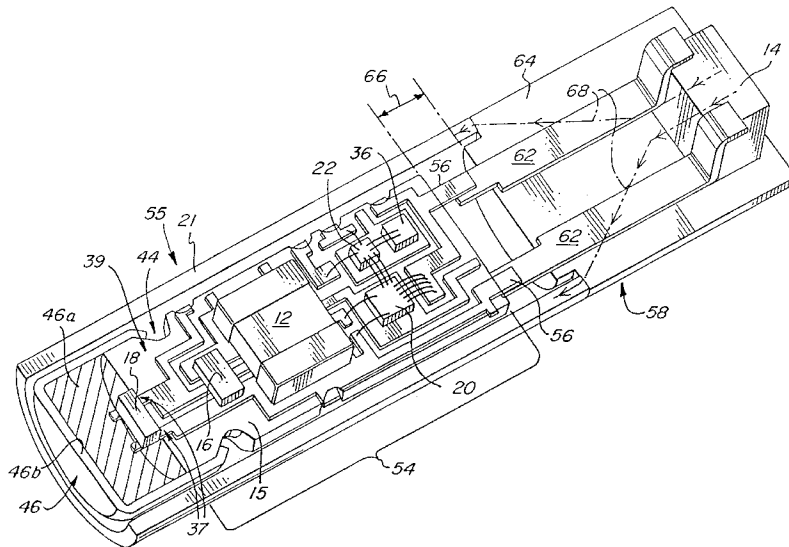
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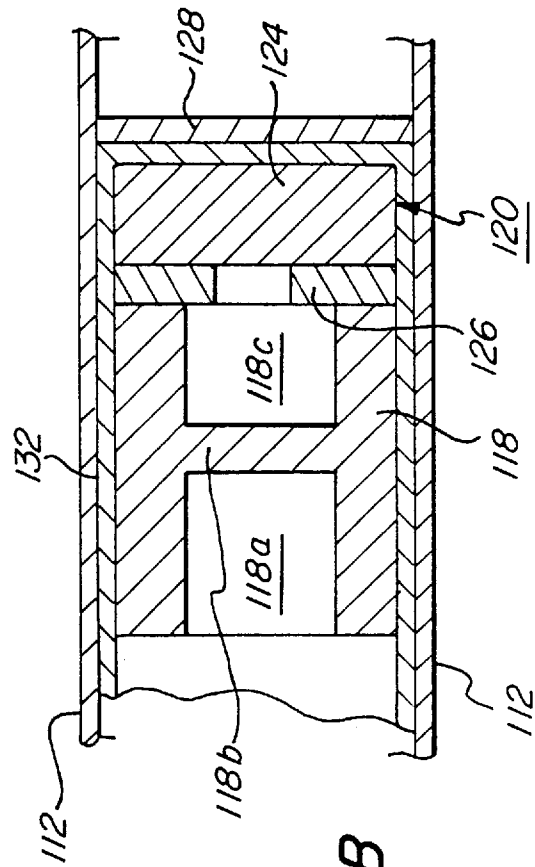
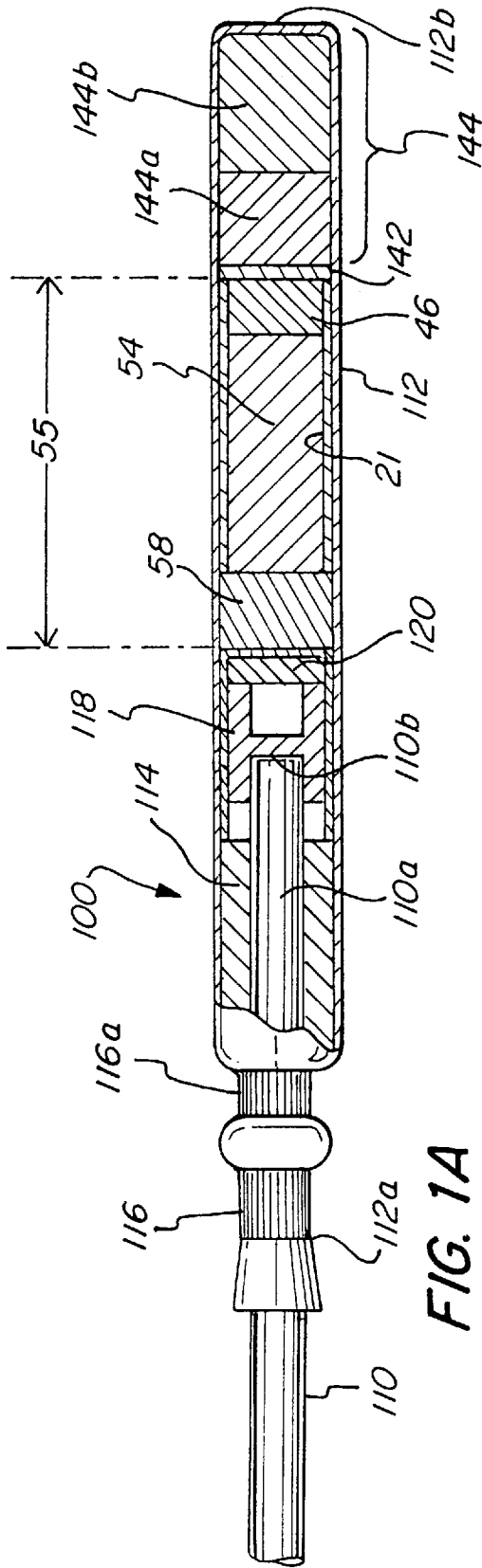
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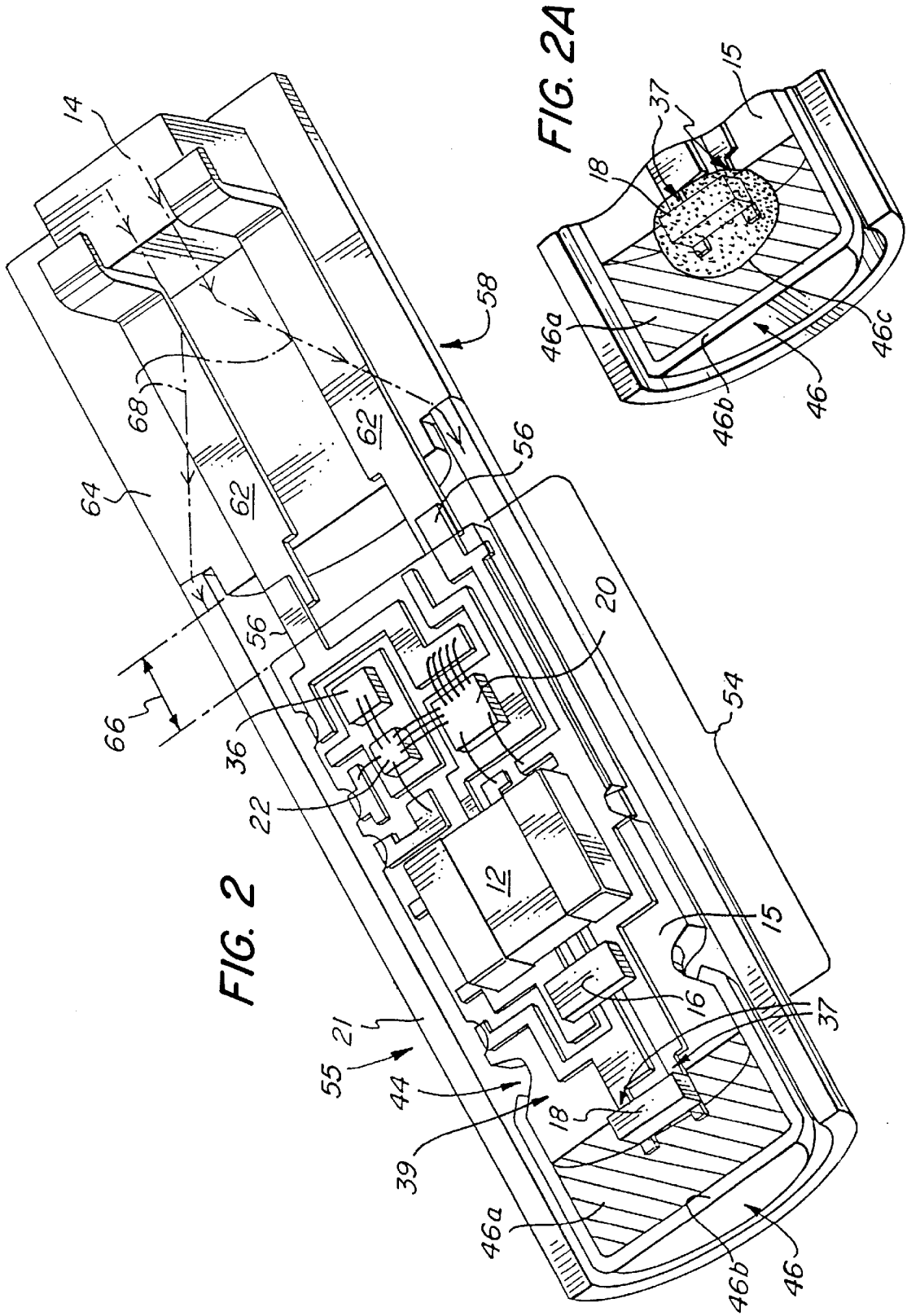
[57] **ABSTRACT**

A detonator (**100**) assembled from a housing (**112**), an output charge (**144**) and an initiation means (**110, 120, 58, 54**) includes a pulverulent ignition charge (**46a**) disposed in direct initiation relation to the initiation means, and an output charge (**144**) that may contain a pulverulent deflagration-to-detonation transition (DDT) charge (**144a**) and a base charge (**144b**). The ignition charge (**46a**) has an average particle size of less than 10 microns, or even less than 5 microns, e.g., 1 to 2 microns. The initiation means may include a semiconductor bridge (**18**) and the ignition charge (**46a**) may be compacted with a force of less than about 5880 psi, e.g., with a force of 1000 psi.

26 Claims, 2 Drawing Sheets







## DETONATOR WITH LOOSELY PACKED IGNITION CHARGE AND METHOD OF ASSEMBLY

### BACKGROUND OF THE INVENTION

#### 1. Field of the Invention

The present invention relates to detonators comprising ignition charges and a method for assembling such detonators.

#### 2. Related Art

U.S. Pat. No. 4,727,808, issued Mar. 1, 1988, to Wang et al, discloses an electrically-initiated detonator, an igniting means such as fuse head (9) or an electric resistance wire, low energy detonating cord, NONEL tube or safety fuse (see column 4, lines 41-44 and column 7, lines 21-28) and an initiating charge in initiation relation thereto. The initiating charge comprises a secondary explosive, such as PETN (pentaerythritol tetranitrate), RDX (cyclo-1,3,5-trimethylene-2,4,6-trinitramine), or a mixture thereof, with a particle size that may be below 30 micrometers ( $\mu\text{m}$ ) and which may be pressed to a density in the range of 1.2 to 1.6 grams per cubic centimeter (g/cc) (see column 5, lines 11-32). The initiating charge is used to initiate the base charge of the detonator. An intermediate charge may be disposed between the initiating charge and the base charge and may have an even lower density, e.g., to 0.8 to 1.4 g/cc (see column 5, lines 33-45). Example 7 shows a test employing PETN at 5 to 15  $\mu\text{m}$  particle size and a tamping of 133 kg (about 8660 psi) for a containment shell having an outer diameter of 6.5 millimeters (mm) and a wall thickness of 0.6 mm.

The "igniting means" mentioned in the Wang et al Patent draw or emit large amounts of energy relative to low energy initiation elements such as SCBs. Further, given the types of igniting means contemplated by Wang et al, the function time for the detonators disclosed therein will be on the order of about 50 microseconds. Because of this prolonged function time, the Wang et al detonators need to provide the confinement and empty chamber in the detonator to prevent the detonator shell from being destroyed by the gaseous products of the ignition charge before the detonation reaction is initiated in the base charge. In the embodiment of FIG. 13, the hollow interior of safety fuse 16 provides the empty chamber for this device.

Fyfe et al, in a paper entitled "BNCP Prototype Detonator Studies Using a Semiconductor Bridge Initiator", discloses the use of BNCP (tetraamine-cis-bis(5-nitro-2H-tetrazolato-N<sup>2</sup>) cobalt (III) perchlorate) for use in electric detonators incorporating a semiconductor bridge (SCB) in welded 304 stainless steel confinements. One test device comprised 25 milligrams of BNCP pressed to 10,000 pounds per square inch (psi); another comprised 49 milligrams of BNCP pressed to 20,000 psi. Ignition sensitivity tests for two different particle sizes of BNCP, 15 and 25 microns, performed with a rise time of 15 microseconds, showed that the larger particles took about twice as long to ignite as the smaller particles at 3.5 amps and, at 1.5 amps, the smaller particles ignited but the larger particles did not. In addition, at a fifty-microsecond rise time, the smaller particles were less temperature-sensitive than the larger particles.

The SCB employed by Fyfe et al measured  $90 \times 270 \times 2 \mu\text{m}$ , and consumed several millijoules of energy to ignite the BNCP. The reported 1 watt, 1 ampere no-fire of these detonators indicates that the BNCP charge was acting like a heat sink that quickly dissipated the ohmic heating of the SCB at the 1 watt, 1 amp no-fire current. Such heat absorp-

tion under no-fire conditions indicates that the BNCP was highly compacted.

A manufacturer of BNCP has published product literature suggesting the use of BNCP in place of lead azide as a primary explosive initiating charge and that BNCP is a DDT explosive with a theoretical maximum density of 2.03 g/cc.

U.S. Pat. No. 4,484,960 to Rucker, dated Nov. 27, 1984, discloses a bridgewire detonator comprising a boron/ferric oxide ignition composition. The ferric oxide particles are in the 0.2 to 1.2  $\mu\text{m}$  range. In the example, the ignition composition is loosely loaded into a blasting cap shell in contact with the bridgewire.

Conventional assembly methods for detonators generally comprise sequentially disposing various detonator elements within a metallic detonator shell. Some of the elements comprise pulverulent reactive materials, e.g., the base charge generally comprises a pulverulent secondary explosive, and such materials are typically tamped into the shell at pressures of 10,000 psi or greater. Other components in the detonator may comprise prefabricated units such as a delay unit or an electronic initiation unit which may be pressed into the detonator shell and which may contain compressed pulverulent material therein.

### SUMMARY OF THE INVENTION

In one broad aspect, the present invention relates to a detonator having a specifically configured ignition charge. Thus, the invention provides a detonator comprising a housing, a low-energy electronic initiation means in the housing, and an ignition charge disposed in the housing in direct initiation relation to the initiation means and in a state of compaction of less than 7000 psi. The ignition charge serves to produce a deflagration signal in the housing in response to a low-energy initiation signal from the initiation means, and it comprises particles having an average particle size of less than 10  $\mu\text{m}$ . There is also an output charge in the housing for producing a detonation output signal in response to the deflagration signal of the ignition charge.

According to one aspect of the invention, the ignition charge may be disposed in a pulverulent form and may be subjected to a compaction force of less than 5880 psi. For example, the ignition charge is subjected to a compaction force of less than 3000 psi, or less than 2000 psi.

Preferably, the ignition charge comprises BNCP.

In accordance with another broad aspect of this invention, there is a detonator comprising an initiation means for producing an initiation signal that releases less than about 850 microjoules into the housing. Optionally, the initiation means may release less than about 425 microjoules into the housing, or less than about 250 microjoules, or even less than about 100 microjoules into the housing.

It is generally preferred that the ignition charge comprise BNCP particles having an average size of less than 10  $\mu\text{m}$ , or less than 5  $\mu\text{m}$ , e.g., having an average diameter in the range of from about 0.5  $\mu\text{m}$  to 2  $\mu\text{m}$ .

Typically, the initiation means comprises a semiconductor bridge (SCB) initiation element.

According to still another broad aspect of this invention, the detonator comprises an ignition charge disposed in a state of compaction of less than 65.9 percent of its theoretical maximum density (TMD). For example, the ignition charge may be disposed in a pulverulent form and is in a state of compaction in the range of from about 49 to 65 percent of its TMD, or in the range of from about 49 to about 59 percent of its TMD.

In more specific embodiments, the invention provides a low-energy initiation unit in the housing comprising an SCB and an ignition charge disposed in the housing in direct initiation relation to the SCB. The ignition charge may comprise BNCP having a particle size of less than 10  $\mu\text{m}$  average diameter and in a state of compaction of less than 7000 psi.

Optionally, the ignition charge may comprise an adherent bead disposed on the SCB. The bead may comprise a mixture of BNCP and a binder.

In a particular embodiment, the detonator may comprise a containment shell secured to the initiation means in the housing, and the ignition charge may be disposed within the containment shell.

The invention also encompasses a method aspect, e.g., a method of assembling a detonator. One such method comprises pressing an output charge into a detonator housing, disposing a pulverulent ignition charge into the housing in signal transfer relation to the output charge, securing an electronic initiation means in the detonator housing in initiation relation with the ignition charge, and compacting the ignition charge with a force of less than about 5880 psi.

In another embodiment, the method may comprise pressing an electronic initiation means into an ignition charge with a force of less than about 5880 psi, securing the ignition charge to the initiation means, and then securing the ignition charge in the housing in signal transfer relation with the DDT charge, preferably without further compacting the ignition charge.

In yet another embodiment, the method may comprise depositing a bead of ignition charge on an electronic initiation means, and securing the electronic initiation means in the detonator housing with the ignition charge in initiation relation with the output charge in the housing.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1A is a schematic, partly cross-sectional view showing a delay detonator in accordance with one embodiment of the present invention;

FIG. 1B is a view, enlarged relative to Figure 1A, of the isolation cup and booster charge components of the detonator of FIG. 1A;

FIG. 2 is a partly cross-sectional perspective view of an initiation unit comprising an ignition charge in accordance with one embodiment of the invention; and FIG. 2A is a partial view similar to FIG. 2 of an initiation unit according to another embodiment of the invention.

#### DETAILED DESCRIPTION OF THE INVENTION AND PREFERRED EMBODIMENTS THEREOF

The present invention relates to an improvement in detonators, and a detonator in accordance with the present invention comprises a housing that contains an output charge, a low-energy initiation means and an ignition charge between the initiation means and the output charge. Broadly speaking, the initiation means provides a low-energy signal sufficient to initiate the ignition charge, which in turn initiates the output charge. The output charge provides the principal output signal of the detonator.

The initiation means of the present invention provides a low-energy initiation signal for the interior of the detonator housing such as may be provided by a 1-ohm semiconductor bridge initiating element measuring  $17 \times 36 \times 2$  micrometers (" $\mu\text{m}$ "), which can consume less than about 850 microjoules to produce an initiating plasma.

In a detonator according to the present invention, the ignition charge is disposed in the detonator housing in a manner that allows it to be initiated by a lower energy signal from the initiation means than would have been effective for prior art detonators. For example, a 1-ohm SCB measuring  $17 \times 36 \times 2 \mu\text{m}$  can initiate an ignition charge in accordance with the present invention with less than about 850 micro-Joules.

The ignition charge is sensitive to the initiation means and, upon initiation, it provides a rapid burn deflagration in the housing sufficient to initiate the output charge. The ignition charge of the present invention generally has an average particle size of less than 10 microns, and is preferably loosely packed in the detonator housing, e.g., at a compaction pressure of less than 7000 pounds per square inch ("psi"), as described below. The ignition charge is disposed in direct initiation relation to the initiation means, i.e., there is no intervening charge between the output of the initiation means and the ignition charge, and, preferably, no void space between them. Typically, the initiation means comprises a semiconductor bridge (SCB) that is in direct physical contact with the ignition charge.

The output charge must be sensitive to the ignition charge and it generally comprises a base charge of secondary explosive material. The output charge may comprise a deflagration-to-detonation transition (DDT) material which is sensitive to the pyrotechnical signal of the ignition charge and which can yield a detonation signal to initiate the base charge. In some embodiments, the base charge may comprise the same reactive material as the DDT charge but, in other embodiments, they may comprise different materials. For example, in one embodiment, the DDT charge may comprise BNCP and the base charge may comprise PETN (pentaerythritol tetranitrate), but in other embodiments, both the DDT charge and the base charge may comprise, e.g., BNCP.

As is known in the art, a DDT charge is preferably rendered in the form of larger particles than an ignition charge. Accordingly, the DDT charge of the present invention preferably comprises particles having an average size of 25  $\mu\text{m}$  or greater.

Referring now to FIG. 1A there is shown a digital delay detonator in accordance with one embodiment of the present invention. Delay detonator 100 comprises initiation means to provide a non-electric input signal to the interior of the detonator. The initiation means in the illustrated embodiment comprises a shock tube 110, a booster charge 120, a transducer module 58 and an electronics module 54. For manufacturing purposes, the transducer module 58 has been secured to one end of the electronics module 54 and a transition cap 46 comprising the ignition charge has been secured to the other end to form an electronic delay initiation unit 55, which is described more fully below.

As is well-known to those skilled in the art, shock tube comprises hollow plastic tubing, the inside wall of which is coated with an explosive material so that upon ignition, a low-energy shock wave is propagated through the tube. See, for example, Thureson et al, U.S. Pat. No. 4,607,573, issued Aug. 26, 1986. It is to be understood, however, that other non-electric signal transmission means such as a detonating cord, low-energy detonating cord, low velocity shock tube and the like may be used. Generally, any suitable non-electric, impulse signal transmission means may be employed in the illustrated embodiment.

Shock tube 110 is fitted to a detonator shell or housing 112 by means of an adapter bushing 114 about which housing

112 is crimped at crimps 116, 116a to secure shock tube 110 and form an environmentally protective seal between adapter bushing 114 and the outer surface of shock tube 110. Housing 112 has an open end 112a which receives bushing 114 and shock tube 110, and an opposite, closed end 112b. Housing 112 is made of an electrically conductive material, usually aluminum, and is preferably the size and shape of conventional blasting caps, i.e., detonators. A typical aluminum housing has an inner diameter of 0.26 inch and an outer diameter of 0.296 inch. A segment 110a of shock tube 110 extends within housing 112 and terminates at end 110b in close proximity to, or in abutting contact with, an anti-static isolation cup 118.

Isolation cup 118, as best seen in Figure 1B, is of a type well-known in the art and is made of a semiconductive material, e.g., a carbon-filled polymeric material, so that it forms a path to ground to dissipate any static electricity which may travel along shock tube 110. For example, see U.S. Pat. No. 3,981,240 to Gladden, issued Sep. 21, 1976. A low-energy booster charge 120 is positioned adjacent to, and in force communicating relationship with, isolation cup 118. As best seen in FIG. 1B, isolation cup 118 comprises, as is well-known in the art, a generally cylindrical body (which is usually in the form of a truncated cone, with the larger diameter positioned closer to the open end 112a of housing 112) which is divided by a thin, rupturable membrane 118b into an entry chamber 118a and an exit chamber 118c. The end 110b of shock tube 110 (FIG. 1A) is received within entry chamber 118a (shock tube 110 is not shown in FIG. 1B for clarity of illustration). Exit chamber 118c provides an air space or stand-off between the end 110b of shock tube 110 and booster charge 120. In operation, the shock wave traveling through shock tube 110 will rupture membrane 118b and traverse the stand-off provided by exit chamber 118c and impinge upon and detonate booster charge 120.

Booster charge 120 comprises a small quantity of a primary explosive 124 such as lead azide (or a suitable secondary explosive such as PETN or BNCP), upon which is disposed a first (non-explosive) cushion element 126. First cushion element 126, which is located between isolation cup 118 and primary explosive 124, protects primary explosive 124 from pressure imposed upon it during manufacture.

A non-conductive buffer 128 (not shown in FIG. 1A), which is typically 0.030 inch thick, is located between booster charge 120 and a transducer module 58 (described more fully below) to electrically isolate transducer module 58 from booster charge 120.

Isolation cup 118, first cushion element 126, and booster charge 120 may conveniently be fitted into an electrically conductive booster shell 132 as shown in FIG. 1B. The outer surface of isolation cup 118 is in conductive contact with the inner surface of booster shell 132 which in turn is in conductive contact with housing 112 to provide an electrical current path for any static electricity discharged from shock tube 110. Generally, booster shell 132 is inserted into housing 112 and housing 112 is crimped to retain booster shell 132 therein as well as to protect the contents of housing 112 from the environment.

As indicated above, the transducer module 58 is coupled with an electronics module 54 which in turn is connected to a transition cap 46 to form an electronic delay initiation unit 55. An optional open-ended steel sleeve 21 encircles electronics module 54 and transition cap 46 to protect them against lateral deformation of housing 112. Transition cap 46 comprises an ignition charge in accordance with the present invention, as will be described more fully below in relation

to FIG. 2. Adjacent to transition cap 46 is an optional second cushion element 142, which is similar to first cushion element 126. Second cushion element 142 separates transition cap 46 from output charge 144, which comprises a DDT charge 144a that is sensitive to the ignition charge of electronics module 54 and that is capable of converting the pyrotechnical signal of the ignition charge in transition cap 46 to a detonation shock wave signal. Output charge 144 preferably comprises a base charge 144b of secondary explosive, e.g., PETN, RDX (cyclo-1,3,5-trimethylene-2,4,6-trinitramine) or the like, which provides the principal explosive output of the detonator, which may be used to initiate a cast booster explosive, dynamite, etc.

FIG. 2 provides a partly cross-sectional perspective view of initiation unit 55. Electronics module 54 of initiation unit 55 includes various circuit components including an integrated timing circuit 22, a timing resistor 36, an integrated switching circuit 20, a storage capacitor 12, a bleed resistor 16 and output leads 37 that provide an output terminal. The various components are disposed within a protective encapsulation 15. There is also a semiconductor bridge (SCB) 18 measuring 17x36x2 μm, disposed across output leads 37, which provides the initiation signal to the interior of the detonator housing. Transition cap 46 comprises a containment shell 46b that is crimped onto neck region 44 of encapsulation 15. Containment shell 46b contains and holds an ignition charge 46a in direct initiation relation to SCB 18. In other words, there is no intervening charge of reactive material or empty space between ignition charge 46a and SCB 18. To dispose SCB 18 in direct initiation relation with ignition charge 46a in the illustrated detonator, SCB 18 may be embedded in ignition charge 46a, as shown. The ignition charge 46a may comprise, e.g., about 10 to 20 milligrams of a primary explosive material or a suitable substitute therefor such as BNCP. Preferably, ignition charge 46a consists essentially of BNCP, to the exclusion of materials that would prevent the initiation of BNCP under the conditions described herein, i.e., at low compaction, mild confinement and low energy initiation.

As indicated above, ignition charge 46a comprises small particles, e.g., with an average particle size of smaller than 10 μm. In addition, the charge is preferably in a state of low compaction. In the illustrated embodiment, before securing transition cap 46 to encapsulation 15, pulverulent ignition charge 46a is loosely disposed in shell 46b, which is dimensioned and configured to receive the end of encapsulation 15. For example, ignition charge 46a may be poured into shell 46b in powder form and remain there without being subjected to tamping or "pressing" or "compacting", except to the extent that the SCB 18 and the end of the electronics module cause compaction when the SCB is inserted into the ignition charge 46a, which can be reduced accordingly. This contrasts with prior art practice which taught compaction at, e.g., 10,000 psi. Optionally, mild compaction may be performed at less than 7000 psi, e.g., less than 4000 psi, less than 3000 psi or less than 2000 psi, e.g., 1000 psi. The output end 39 of electronics module 54 and encapsulation 15 is pressed into the ignition charge 46a. One advantage of the use of such low compaction pressures is that the chance of damaging the SCB 18 and the electronics module 54 as a whole is reduced because it becomes unnecessary to subject the electronics module 54 to high assembly forces. As a result, the ignition charge 46a is lightly compressed within containment shell 46b. Containment shell 46b is then crimped down onto neck region 44 to secure transition cap 46 onto encapsulation 15. The crimp and the structural strength of shell 46b are sufficient to

prevent subsequent assembly steps that involve moderate axial force from imposing additional pressure between ignition charge **46a** and electronics module **54**. Thus, the low compaction state of the ignition charge is preserved even if subsequent assembly steps involve the use of some pressure. Containment shell **46b** is made from 0.005 inch thick aluminum or a material of similar strength, and so does not provide the degree of containment evidently used by Fyfe et al in the disclosure discussed above, but it can withstand low axially-applied assembly forces. Sleeve **21** is helpful in sustaining axial assembly forces and thus shielding transition cap **46** from farther compaction. Since sleeve **21** is open-ended, however, it does not contribute significantly to the containment of ignition charge **46a**, so even with shell **46b**, sleeve **21** and housing **112**, ignition charge **46a** is not highly confined.

The Applicants have found that the sensitivity of BNCP particles is not only size dependent but is also affected by compaction pressure. This conclusion was drawn from the results of testing in which 10  $\mu\text{m}$  BNCP and 2  $\mu\text{m}$  BNCP ignition powders were compacted to various pressures for attempted initiation by 1-ohm SCBs. The SCBs measured 17x36x2  $\mu\text{m}$  on silicon substrate "chips" and were fired using energy from a 0.47 microfarad capacitor discharge unit. The SCB chips were mounted using a dielectric epoxy adhesive onto platforms comprised of Kovar, a registered trademark of CRS Holdings, Inc., having conductive leads extending therethrough, known in the art as a header unit. The BNCP was pressed with varying force into steel charge holders to which the header units were attached. The SCBs were fired at various voltages, with the results indicated in TABLE I.

TABLE I

Average BNCP Particle Size ( $\mu\text{m}$ )	Compaction Pressure (Kpsi)	Firing Voltage (volts)	Fire (Yes)/ Fail (No)
10	10	100	Yes
10	10	60	Yes
10	10	40	Yes
10	7	100	Yes
10	7	60	Yes
10	7	40	No
10	4	100	No
2	1	60	Yes
2	1	40	Yes
2	1	40	Yes
2	1	30	Yes
2	1	25	Yes

The data of TABLE I show that as BNCP compaction pressure decreases, 10  $\mu\text{m}$  BNCP becomes increasingly insensitive to low-energy initiation. At 7000 psi, a charge of 60 volts (corresponding to a stored energy level of about 850 microjoules, about half of which is estimated to have been consumed by the firing circuitry) was required to initiate the BNCP; 40 volts was inadequate. At 4000 psi, even 100 volts did not initiate the 10  $\mu\text{m}$  BNCP. However, the Applicants found that BNCP with average particle sizes of less than 10  $\mu\text{m}$ , e.g., about 2  $\mu\text{m}$ , sensitivity is increased to a degree that initiation could be achieved with less than 60 volts.

Similar tests were conducted by mixing 2  $\mu\text{m}$  BNCP with nitrocellulose and rendering the mixture as a slurry, as described below. Beads of the slurry were applied to SCBs as described above and were allowed to dry. The SCBs were fired using various voltage levels and ignition of the BNCP was achieved in the range of 100 to 30.5 volts; ignition did not occur at 30 volts. Further testing using 1  $\mu\text{m}$  BNCP

showed that initiation was attained down to 25 volts. Function times were all about 10 microseconds or less.

An unexpected result of preparing a detonator with an ignition charge in accordance with the present invention is that initiation occurs so rapidly that the need to confine the reactive materials in the detonator is reduced. For example, Fyfe et al found it necessary to provide a significant degree of confinement to assure proper initiation of a BNCP charge in a detonator, but they were examining highly compacted BNCP in a 15 to 25 micron size range. On the other hand, U.S. Pat. No. 4,727,808 to Wang et al, described above, teaches the need for a void space in the detonator. The void space allows for the dissipation of pressure from the ignition charge. Such dissipation is necessary because the ignition charge burns so slowly that the pressure build-up may damage the detonator before the explosive charge is initiated. In contrast, the ignition charge of the present invention achieves such a high rate of reaction that the ignition signal is transferred to the output charge before any deleterious damage to the detonator can occur. Accordingly, the need for either a high degree of confinement or a void space in the detonator has been obviated. The present invention may optionally be expressed as providing one or both of mild confinement and direct contact between the ignition charge and the initiation means, rather than strong confinement and void spaces for expansion of ignition charge product gases, respectively. The use of structures that provide strong confinement can be employed, however, if desired. Further, the ignition charge can be reliably initiated with less energy than was required in the prior art. For example, a loosely packed, small-particle ignition charge disposed in direct initiation communication with a semiconductor bridge can be initiated by the semiconductor bridge with less than about 0.25 milliJoule of energy. The initiation unit of a detonator for use with the present invention may be configured to provide less than 0.1 milliJoule (100 microjoules) of energy. In a particular embodiment, satisfactory initiation was attained with an initiation unit configured to provide about 0.068 milliJoule. In contrast, prior art detonators require that the SCB initiation element be provided with at least 0.25 milliJoule or greater. See, e.g., U.S. Pat. No. 5,309,841 to Hartman et al at column 7, lines 10-15 (0.25 milliJoule); U.S. Pat. No. 4,708,060 to Bickes, Jr. et al Example 1 and column 6, lines 7-11 (suggesting the use of a semiconductor bridge measuring 17x35x2 microns and fired with 1 to 5 milliJoules). Preferably, the particle size of the pulverulent ignition charge is such that the diameter of the average particle is not greater than the length of the semiconductor bridge of delay circuit **134**. In a particular embodiment comprising a semiconductor bridge measuring 17 microns ( $\mu\text{m}$ ) in length (measured in the output lead-to-output lead direction)x36  $\mu\text{m}$  in widthx2  $\mu\text{m}$  in depth, the average particle diameter is less than 10  $\mu\text{m}$ , preferably less than 5  $\mu\text{m}$  and may be, for example, in the range of 0.5 to 2  $\mu\text{m}$ . As suggested above, the encapsulated delay circuit may be pressed into ignition charge **46a** with little pressure relative to prior art detonators. The tamping pressure on the ignition charge may be less than about 4,000 psi, for example, or even less than 2,000 psi. In a particular assembly process, electronics module **54** may be pressed into ignition charge **46a** with a force of about 1,000 psi. The resulting density of the ignition charge **46a** will be significantly less than that of conventional ignition charges. In typical embodiments of this invention, ignition charge **46a** is pressed to less than 80 percent of its theoretical maximum density ("TMD"), for example, ignition charge **46a** may be pressed to less than 65.9 percent of its TMD. For example, an ignition charge

46a comprising BNCP may have a density in the range of from 1 to 1.32 grams per cubic centimeter (g/cc) (about 49 to 65 percent TMD) for example, the ignition charge 46a may have a density in the range of from about 1 to 1.2 g/cc (about 49 to about 59 percent TMD). With such low compaction, the structural elements of a detonator in accordance with the present invention, i.e., housing 112, transition cap 46, and sleeve 21, are not relied upon to provide confinement of the DDT charge, and can be made from thinner, less rigid material than would be required if pressures of 10,000 psi or 20,000 psi had to be withstood, as taught by Fyfe. Such structural elements would then provide mild confinement of the ignition charge instead of strong confinement as taught by Fyfe et al. The low tamping pressure between the encapsulation, the electronic delay circuit and the ignition charge is advantageous because it reduces the chance that the assembly process will cause damage to SCB 18 and/or to the electronic delay circuit.

In alternative embodiments, a bead comprising the pulverulent ignition charge may be applied or adhered directly onto SCB 18, as shown in FIG. 2A to assure good physical contact of ignition charge particles with the SCB. The bead, which is typically applied as a slurry of particles that is allowed to dry on the SCB and thus adhere thereto, typically provides about 5 milligrams (mg) or less of solid reactive material on the SCB, and the coated SCB may be pressed into the powdered remainder of the charge in transition cap 46. Such a slurry comprises the particulate ignition charge in a fluid medium such as water, volatile organic liquid, or the like and, optionally, a binder. Preferably, the binder comprises reactive material such as nitrocellulose. Optionally, the bead may entirely comprise the ignition charge of the detonator, and the coated SCB may be pressed into the output charge, e.g., into the DDT charge portion of an output charge. The bead-coated SCB may be pressed into a charge comprising additional ignition charge material or DDT-grade material, with a force of less than 7000 psi, as described above. Alternatively, cap 46 may be open-ended and may be filled with the slurry after it is secured onto encapsulation 15. The slurry is then dried before the electronics module is inserted into the detonator housing.

In all embodiments in which BNCP is deposited as a bead on the SCB, the material in the dried bead experiences only the compaction pressure with which the bead is pressed into a subsequent charge or other component in the detonator housing.

As indicated by FIG. 2, electronics module 54 may be dimensioned and configured to have electrical output leads 37 that protrude into the ignition charge 46a so that SCB 18 can be surrounded by, or embedded in, the ignition charge 46a. Such an arrangement improves the reliability with which SCB 18 initiates ignition charge 46a by allowing a high degree of surface area contact between them, as opposed to having an SCB mounted flat on a support substrate.

Electronics module 54 is designed so that output leads 37 and electrical input leads 56 protrude from respective opposite ends of electronics module 54. The transducer module 58, which comprises a piezoelectric transducer 14 and two transfer leads 62, is enclosed within a transducer encapsulation 64 that is dimensioned and configured to engage sleeve 21 so that transducer module 58 can be secured onto the end of sleeve 21 with transfer leads 62 in contact with input leads 56. Preferably, electronics module 54, sleeve 21 and transducer module 58 are dimensioned and configured so that when assembled, as shown in FIG. 2, an air gap indicated at 66 is established between electronics module 54

and transducer module 58. In this way, electronics module 54 is at least partially shielded from the initial pressure pulse that causes piezoelectric transducer 14 to create the electrical pulse that activates electronics module 54. The pressure imposed by such initial pulse is transferred through transducer module 58 onto sleeve 21, as indicated by force arrows 68, rather than onto electronics module 54.

Ignition charge 46a is disposed in the detonator housing in signal transfer relation to the DDT charge portion 144a of output charge 144. As indicated above, the function of DDT charge 144a is to convert the pyrotechnical signal of ignition charge 46a into a detonation signal sufficient to initiate a detonation output of the base charge 144b of output charge 144. Output charge 144 provides the explosive output for the detonator and generally comprises a secondary explosive material. In accordance with the present invention, DDT charge 144a is a pulverulent charge comprising larger particles than conventionally used in the prior art that may comprise, e.g., about 75 to 150 milligrams of material. The coarse DDT particles are generally at least about 25 microns in diameter, preferably at least 50 microns in diameter and, in a particular embodiment, they have an average diameter in the range of about 100 to 120 microns. In a preferred embodiment of the invention, DDT charge 144a comprises BNCP that may be pressed in the detonator housing with a tamping pressure of, e.g., about 10,000 psi. Such a DDT charge will typically have a depth of about ¼ inch in a detonator housing having an inner diameter of 0.26 inch and an outer diameter of 0.296 inch.

Base charge 144b comprises a secondary explosive material, e.g., PETN, that is initiated by the DDT charge 144a and which provides the output signal for the detonator. Optionally, base charge 144b may comprise the same explosive material as DDT charge 144a, e.g., both charges may comprise BNCP. However, BNCP is relatively expensive, so it is preferred to limit the BNCP to the ignition charge and the DDT charge, and to use PETN, which is less expensive than BNCP, for the base charge of the detonator. The use of BNCP in conjunction with the secondary base charge is advantageous relative to the use of lead azide because BNCP lacks lead and is therefore more acceptable from an environmental and health hazard standpoint. Further, BNCP has a stronger output force than lead azide, and so contributes to the explosive output of the detonator to a greater degree than lead azide. As a result, the quantity of secondary explosive of base charge 144b can be reduced proportionately. The secondary explosive of base charge 144b is provided in an amount suitable to yield (in combination with the output of the ignition charge) an output signal of the desired strength. A typical quantity of base charge material is about 500 to 1000 milligrams.

A detonator such as detonator 100 can be assembled by inserting various elements into a typically metallic detonator housing having one closed end and one open end. The elements are inserted into the housing sequentially with the first element being disposed against the closed end of the housing. In an assembly procedure suitable for detonator 100, output charge 144 may be pressed into the bottom, i.e., into the closed end of housing 112 under normal tamping pressure, e.g., a base charge 144b of PETN may be pressed to 10,000 psi in housing 112. A second cushion element 142 is disposed adjacent to output charge 144. Initiation unit 55 is then inserted into housing 112 adjacent to second cushion element 142. This disposes transition cap 46 in initiation relation to output charge 144 and disposes transducer module 58 towards the open end of the detonator housing. Booster charge 120 is thus situated in signal transfer relation



with transducer module 58. The end of shock tube 110, which is encased by adapter bushing 114, is inserted into the open end of detonator housing 112 so that the end 110b of shock tube 110 engages isolation cup 118 within booster shell 132. At that point, detonator housing 112 is crimped at crimps 116, 116a to secure the shock tube 110 and the initiation unit in the detonator housing. The ignition charge of initiation unit 55 is prepared as described above, so that in the finished detonator, the ignition charge remains loosely packed.

In operation, a signal emitted by shock tube 110 (Figure 1A) initiates booster charge 120, which produces a pressure pulse that activates piezoelectric transducer 14 (FIG. 2). The pulse of electrical energy produced by piezoelectric transducer 14 is received and stored by the electronics module 54 for a predetermined delay period. The electrical energy is then released to SCB 18 to provide the output signal of the initiation means of detonator 100. The ignition charge 46a, being in direct initiation relation to the initiation means, i.e., to SCB 18, is initiated thereby, and it initiates the DDT charge 144a, which provides a detonation shock wave to initiate base charge 144b (FIG. 1A).

While the invention has been described in detail with reference to particular embodiments thereof, it will be apparent that upon a reading and understanding of the foregoing, numerous alterations to the described embodiments will occur to those skilled in the art and it is intended to include such alterations within the scope of the appended claims. For example, while the illustrated embodiments all show detonators whose initiation means comprise delay elements, the invention encompasses so-called "instantaneous" detonators, which lack any significant delay. In addition, the invention is not limited to any particular material for the DDT charge, except where the claims so specify. Also, the initiation means may be entirely electronic instead of relying on a non-electric signal transmission line, e.g., shock tube, if desired.

What is claimed is:

1. A detonator comprising:
  - a housing;
  - a low-energy electronic initiation means in the housing;
  - an ignition charge disposed in the housing in direct initiation relation to the initiation means and in a state of compaction created by a compaction force of less than 7000 psi, for producing a deflagration signal in the housing in response to a low-energy initiation signal from the initiation means, the ignition charge comprising particles having an average particle size of less than 10  $\mu\text{m}$ ; and
  - an output charge in the housing for producing a detonation output signal in response to the deflagration signal of the ignition charge.
2. The detonator of claim 1 wherein the ignition charge is disposed in a pulverulent form and is subjected to a compaction force of less than 5880 psi.
3. The detonator of claim 2 wherein the ignition charge is subjected to a compaction force of less than 3000 psi.
4. The detonator of claim 3 wherein the ignition charge is subjected to a compaction force of less than 2000 psi.
5. The detonator of claim 1, claim 2, claim 3 or claim 4 wherein the ignition charge comprises BNCP.
6. A detonator comprising:
  - a housing;
  - an initiation means for producing an initiation signal that releases less than about 850 microjoules into the housing;

an ignition charge disposed in the housing in direct initiation relation to the initiation means, for producing a deflagration signal in the housing in response to a low-energy initiation signal from the initiation means; and

an output charge in the housing for producing a detonation output signal in response to the deflagration signal of the ignition charge.

7. The detonator of claim 6 comprising initiation means for releasing less than about 425 microjoules into the housing.

8. The detonator of claim 7 comprising initiation means for releasing less than about 250 microjoules into the housing.

9. The detonator of claim 8 comprising initiation means for releasing less than about 100 microjoules into the housing.

10. The detonator of claim 6, claim 7, claim 8 or claim 9 wherein the ignition charge comprises BNCP particles having an average size of less than 10  $\mu\text{m}$ .

11. The detonator of claim 10 wherein the ignition charge comprises particles having an average particle size of less than 5  $\mu\text{m}$ .

12. The detonator of claim 11 wherein the ignition charge comprises particles having an average diameter in the range of from about 0.5  $\mu\text{m}$  to 2  $\mu\text{m}$ .

13. The detonator of claim 6, claim 7, claim 8 or claim 9 wherein the initiation means comprises a semiconductor bridge (SCB) initiation element.

14. The detonator of claim 1, claim 3 or claim 6 wherein the low-energy electric initiation means comprises a semiconductor bridge element (SCB) and wherein the ignition charge comprises an adherent bead disposed on the SCB.

15. The detonator of claim 14 wherein the bead comprises a mixture of BNCP and a binder.

16. The detonator of claim 1 or claim 3 comprising a containment shell secured to the initiation means in the housing, wherein the ignition charge is disposed within the containment shell.

17. The detonator of claim 6 wherein the initiation means is disposed in the housing and wherein the detonator further comprises a containment shell secured to the initiation means in the housing, wherein the ignition charge is disposed within the containment shell.

18. A detonator comprising:
 

- a housing;
- a low-energy initiation unit in the housing comprising a semiconductor bridge (SCB);

an ignition charge disposed in the housing in direct initiation relation to the SCB and comprising BNCP having a particle size of less than 10  $\mu\text{m}$  average diameter and in a state of compaction created by a compaction force of less than 7000 psi and;

an output charge in the housing for producing an output signal in response to the initiation of the ignition charge.

19. The detonator of claim 1 or claim 18 wherein the ignition charge is subjected to a compaction force that ranges from about 1000 psi to about 7000 psi.

20. A method of assembling a detonator comprising:
 

- pressing an output charge into a detonator housing;
- disposing a pulverulent ignition charge into the housing in signal transfer relation to the output charge;
- securing a low-energy electronic initiation means in the detonator housing in initiation relation with the ignition charge; and

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compacting the ignition charge with a force of less than about 3000 psi.

21. A method for assembling a detonator, comprising:

pressing an output charge into a detonator housing, the output charge comprising a deflagration-to-detonation transition (DDT) charge;

pressing an electronic initiation means into an ignition charge with a force of less than about 5880 psi;

securing the ignition charge to the initiation means; and

securing the ignition charge in the housing in signal transfer relation with the DDT charge without further compacting the ignition charge.

22. The method of claim 21 comprising compacting the ignition charge with a force of less than about 3000 psi.

23. The method of claim 22 comprising compacting the ignition charge with a force of less than about 2000 psi.

24. The method of claim 21 comprising compacting the ignition charge with a force that ranges from about 1000 psi to about 5880 psi.

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25. A method of assembling a detonator comprising:

pressing an output charge into a detonator housing; depositing a bead of ignition charge on an electronic initiation means; and

securing the electronic initiation means in the detonator housing with the ignition charge in initiation relation with the output charge in the housing;

wherein the electronic initiation means and the ignition charge thereon is pressed against the output charge with a force of less than about 5880 psi.

26. A method of assembling a detonator comprising:

pressing an output charge into a detonator housing;

disposing a pulverulent ignition charge into the housing in signal transfer relation to the output charge;

securing an electronic initiation means in the detonator housing in initiation relation with the ignition charge; and

compacting the ignition charge with a force of less than about 3000 psi.

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