Jan. 9, 1968 S. EPSTEIN 3,362,329

ELECTRO-EXPLOSIVE DEVICES

Filed Dec. 10, 1963 3 Sheets-Sheet 1

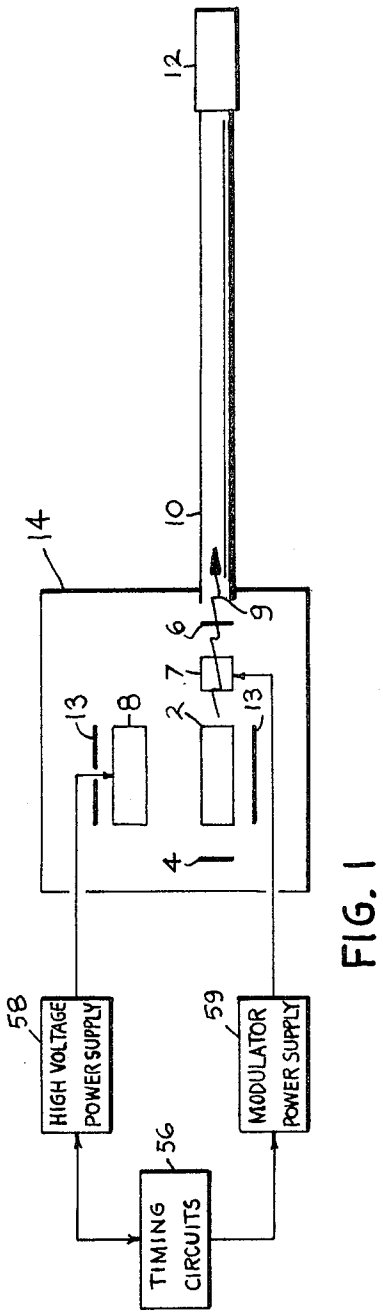


FIG. 1

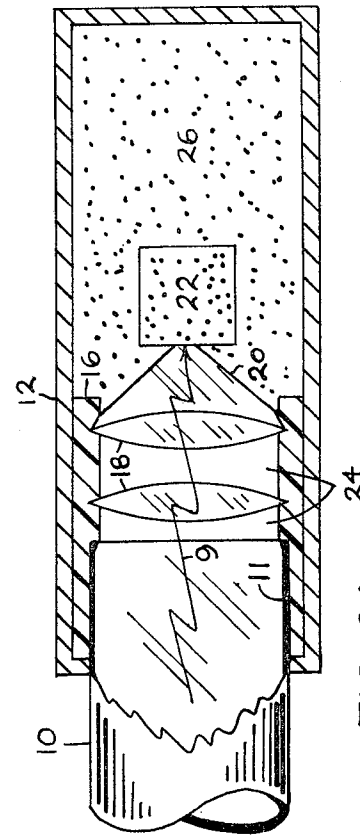


FIG. 2A

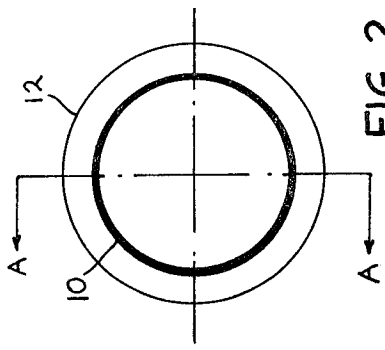


FIG. 2

ELECTRO-EXPLOSIVE DEVICES

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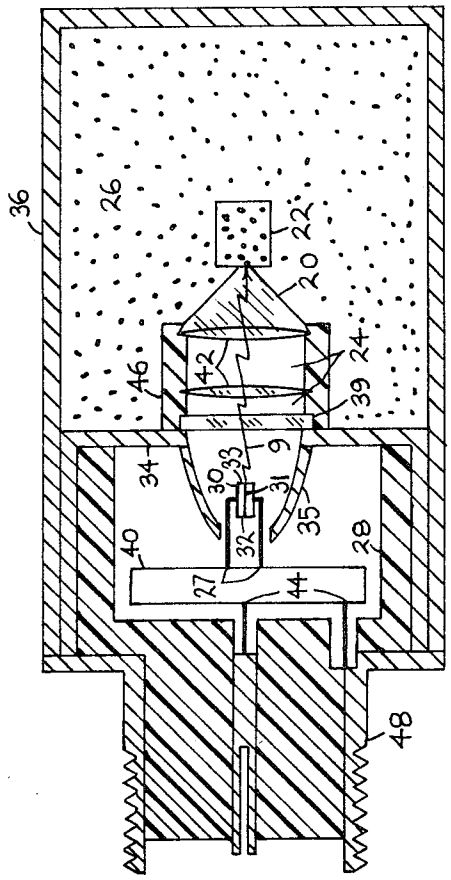


FIG. 3A

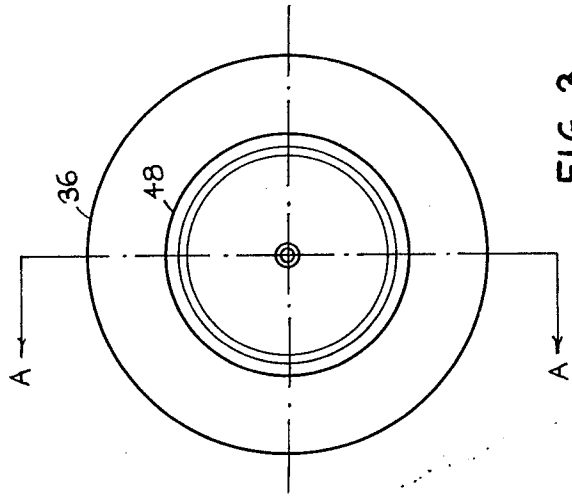


FIG. 3

ELECTRO-EXPLOSIVE DEVICES

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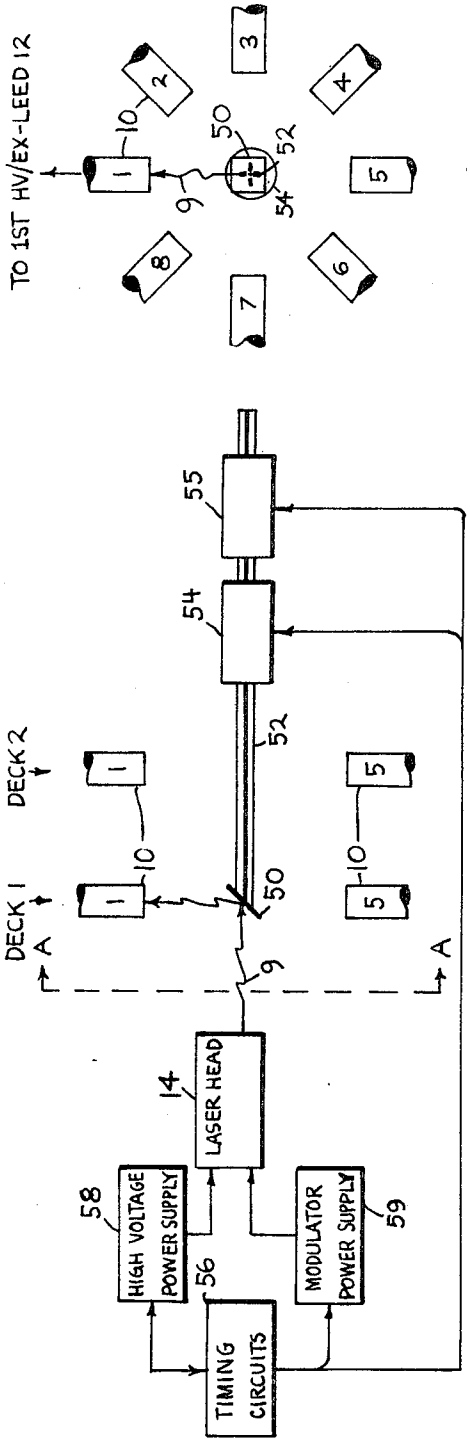


FIG. 4

FIG. 4A

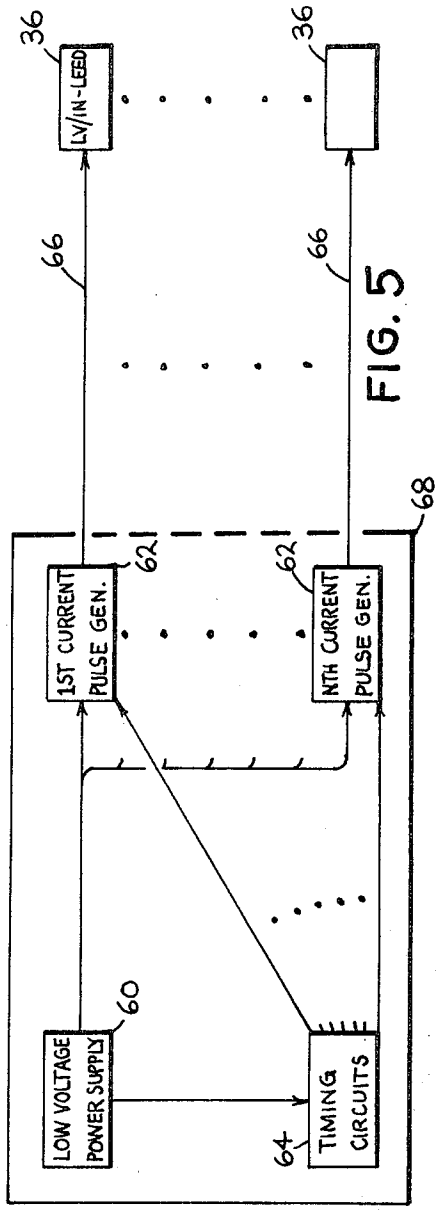


FIG. 5

United States Patent Office 3,362,329
Patented Jan. 9, 1968

3,362,329

ELECTRO-EXPLOSIVE DEVICES

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Filed Dec. 10, 1963, Ser. No. 329,477
6 Claims. (Cl. 102—70.2)

This invention generally relates to an electro-explosive device; a detonating cap or squib wherein the electrical energy that is used to initiate the explosion is coupled to the material used as the primer explosive via a laser beam.

Electro-Explosive Devices (EED's) are explosive devices which are initiated by electrical means. Such devices include squibs, detonating caps, blasting caps, explosive bolts, etc.; and amongst their usages are included detonation of explosive charges, ignition of rocket motors, closing switches, and the activation of thermal and mechanical devices.

At the present time there are two main generic families of EED's used to give rapid and controlled detonation of explosives: (1) The electric bridge wire cap exemplified by the figure shown on page B–22, dated April. 29, 1960, entitled E–94 E.B. Cap, from the catalog of E. I. du Pont de Nemours & Co., Inc., Wilmington, Del. This type of cap can be made to detonate within 5 milliseconds after a firing current of 5 amperes has been applied. (2) The arc firing cap exemplified by the figure shown on the data sheet for the Du Pont X–98AA Arc-fired E.B. Cap, dated August 1, 1963. The arc firing cap has a detonation delay of approximately 3 microseconds and will fire within ±0.3 microsecond of the mean delay period when energized with a 5000 volt pulse from a 3 microfarad capacitor.

Both types will operate when energized by an electrical pulse from an energy storage capacitor. The electric bridge wire type will detonate upon receipt of an electrical pulse from a voltage pulse source (less than 1000 volts) in the order of milliseconds and the arc firing cap will detonate upon the application of an electrical pulse from a high voltage pulse source (greater than 1000 volts) in the order of microseconds.

However, as stated in "Simultaneity of Explosion Times of Engineer's Special Detonators" by E. Bonner et al., BRL Technical Note 1470, August 1962, Aberdeen Proving Grounds, Md., it is possible to fire electric bridge wire caps in the microsecond range also if sufficient energy is used so as to explode the bridge wire. A high voltage pulse source is used to supply electrical energy several orders of magnitude above the minimum energy required to initiate detonation.

Therefore, it is possible to get EED's of the bridge wire (exploded) or arc firing types to detonate with mean delay times and variance of the mean delay in the order of microseconds. Typically, the power supply storage energy required is in the order of tens of joules and the voltage in the order of kilovolts or tens of kilovolts. Such power supplies are large and expensive; an example is given in "A Reliable 3-Channel Delayed Wire Exploder Unit," by E. E. Walbrecht, pp. 315–322, Exploding Wires vol. 1, Chace and Moore, Plenum Press, New York, 1959.

It is pointed out in "Safety Considerations with Electro-Explosive Devices," U.S. Army Missile Command Report RK–TR–62–10, Redstone Arsenal, Ala., that the level of energy required to cause EED functioning ranges from less than 100 ergs, for some types of carbon bridge wire caps, to more than 10^7 ergs. for some exploding bridge wire types. FIGURE 2, ibid., shows that the measured electrostatic energy on a human may be in the order of 10^5 ergs. and the suspected available

energy on a man may be in the order of 10^6 ergs, enough, apparently, to have caused the unintentional detonation of EED's. Other electrical hazards, causing unintentional detonation, are due to phenomena such as radio frequency waves and electromagnetic induction from power transmission lines, these effects are commonly referred to as Radio Frequency Interference (RFI). This spurious energy is usually picked-up and brought into the EED by the electrical leads of the EED. In spite of prior art safety designs for EED's, e.g., additives added to the explosive charges to reduce electrostatic sensitivity, Faraday screens, deliberately designing EED's to require an excessive amount of energy and/or power to initiate detonation, electronic filter and semiconductor circuits connected to the input leads of the EED etc., unintentional detonations traced to electrical causes still occur. This is due in large measure to the close proximity and subsequent intimate contact of the electrical initiating element, i.e., the bridge wire or the arc gap, with explosive material within the detonator cap; therefore, spurious energy can be easily coupled to the detonator cap charges, resulting in the prior art danger of unintentional detonation.

The objects of this invention are to provide:

(1) A novel detonation cap (EED) utilizing an external, non-expendable, pulse-type, solid-state laser as the initiating element, that can be used to give a precisely timed explosion. This embodiment of the Laser Electro-Explosive Device (LEED) typically requires a high voltage pulse source similar to those required by prior art EED's, but will give superior firing characteristics.

(2) A novel detonation cap (EED) utilizing an internal, expendable, pulse-type, injection laser as the initiating element, that can be used to give a precisely timed explosion when energized (pulsed) from a low voltage source, preferably a battery or a fuel cell with low internal impedance. This embodiment of the LEED will also give superior firing characteristics, e.g., lower mean time delay from instant of electrical energization to explosive detonation, lower variance about the mean delay (jitter) and better immunity from unintentional detonation (safer), than prior art EED's.

Other objects and advantages of the subject invention will be apparent from the following specifications and claims and from the accompanying drawings which illustrate the principles of the invention as incorporated in the presently preferred embodiments thereof.

The proposed EED's utilize a laser to provide the required detonating energy in the form of a high power electromagnetic pulse. Said electromagnetic energy can be focussed, by well known optical means, onto a material such as primer explosive constituting the primer charge. It is well known that such a concentration of electromagnetic power leads to unusually high values of electric field at the focus. Intense, localized, thermal and shock effects can be obtained in this way causing the detonation of the primer charge. Since the electromagnetic pulse can be transmitted from the laser to the primer charge via an isolating medium, e.g., air, vacuum, fiber optics, etc., the detonating initiator element is effectively decoupled from the primer charge; a desirable situation that has yet to be obtained by prior art EED safety design. Furthermore, because of the additional stage of energy conversion, i.e., from electrical energy input to laser electromagnetic radiation, well known shielding and filtering techniques, such as grounding screens, polarized filters, narrow frequency band-pass optical filters, etc., can be used with advantage to lower the probability of unintentional detonation due to spurious electromagnetic energy still further.

The electronic and laser states-of-the-art are such as to routinely allow laser electromagnetic radiation pulses

of time durations and the timing thereof in the order of milli-, micro-, or nano-seconds; LEED operation in the latter two areas will indeed give rapid and controlled initiation of detonation.

Two types of lasers, whose properties are well known to those conversant with the laser art, will be utilized to exemplify the LEED.

Referring to the diagrams:

FIGURE 1 is a schematic block diagram showing the principal elements of the "high voltage/external laser" EED (HV/EX–LEED).

FIGURE 2 is a schematic elevational view of the "cap" section of the unit illustrated in FIGURE 1.

FIGURE 2A is a sectional view as taken on the line A—A of FIGURE 2.

FIGURE 3 is an elevational view of an embodiment of the invention incorporating an internally disposed laser of the low voltage type.

FIGURE 3A is a sectional view as taken on the line A—A of FIGURE 3.

FIGURE 4 is a schematic block diagram type of presentation showing the principal elements of a sequentially detonatable multi-element high voltage external laser type of electro-explosive device incorporating the principles of this invention.

FIGURE 4A is a schematic vertical section as taken on the line A—A of FIGURE 4.

FIGURE 5 is a block diagram showing the principal elements of a multiple LV/IN–LEED (low voltage/internal laser) sequential, precision, firing system.

Referring to FIG. 1, this embodiment utilizes a pulsed solid-state laser **2** exemplified by the cylindrical ruby laser described in "Lasers, Principles and Uses," S. A. Collins, Electro-Technology, March 1963, pp. 64–70. A totally reflective surface **4** is placed at one end a partially reflecting surface **6** is placed at the other end of the laser rod **2**, thereby forming a Fabry-Perot interferometer; the stimulated electromagnetic radiation **9** is emitted through the partially reflective surface **6**, centered about the longitudinal axis of the laser rod **2**. A "giant" pulse can be obtained, if desired, if an electro-optical or magneto-optical "shutter" such as a Kerr Cell-polarizer combination **7** is used as a "Q spoiler"; this is discussed in "Giant Optical Pulsations from Ruby," F. J. McClung and R. W. Hellwarth, Proc. of the IEEE, January 1963, pp. 46–56, with FIG. 3 of said reference of particular interest. The "pumping" energy required to get the necessary atom population inversion in the laser material would typically come from a flash lamp **8** excited from a high voltage electrical pulse source as described in "Xenon Flash Tube Manual," bulletin SL–5–63–5M, Edgerton, Gemeshausen & Grier Inc., Boston, Mass. Typically, the flash lamp **8** is placed at one of the foci of an elliptical reflector **13** and the laser is placed at the other, see FIG. 1A, Collins, op cit. The laser output radiation **9** is transmitted via a hollow, straight, tube or flexible fiber optics **10** to the explosive detonator cap **12**. Note: As pointed out in Table 1 of "Laser Materials and Devices," R. D. Haun, Electro-Technology, September 1963, pp. 63–71, fiber optic glass can be made to lase at room temperature so that conceivably laser and transmission line could be made of the same material. In fact, elements **2**, **4**, **6**, **10**, and **12** could be fabricated into a single disposable unit to be inserted at the laser focus of the reflector **13** in lieu of the disposable unit, shown in FIG. 1, consisting of **10** and **12**. In either case, the non-expendable portion of the LEED, e.g., cryogenic equipment (if cooling is desired), pump and pump reflector, etc., are encased in a protective housing **14**, hereinafter referred to as the laser head.

Details of the explosive detonator cap part of the HV/EX–LEED are shown in FIGS. 2 and 2A. The energy guide **10** is covered with protective coatings **11** to prevent physical damage and to inhibit the transmission of leakage energy in or out of the system. For example, if fiber optics are used as the energy guide, in addition to the

usual "cladding," **11** could consist of a flexible, tightly woven Belden Braid type metallic screen sandwiched between two layers of an opaque, flexible, insulating, watertight material such as rubber; the metallic screen could then be grounded to the metallic cap case **12**, at one end of the guide **10**, and to the laser head housing **14** at the other end. The energy guide **10** seats into the insulating bushing **16** which also positions the focussing lens **18**. A solid, cone-like structure **20**, transparent to the laser frequency band, serves to position the primer charge **22** with respect to the focussing lens, transmit the energy to the primer charge, and helps confine the gaseous products of explosion. The air space **24** acts as the coupling medium between the end of the energy guide **10** and the focussing lens **18**. The main charge **26** surrounds the primer charge **22**, filling the remainder of the volume of cap **12**. The neck of the metal cap **12** is formed around the insulating bushing **16**, sealed and waterproofed, and grounded to the protective screen of **11**.

The second embodiment of the LEED, the LV/IN-LEED, is shown in FIGS. 3 and 3A. It utilizes a pulse-type, solid-state, injection-laser exemplified by the GaAs injection-laser described in "Infrared and Visible Light Emission From Forward-Biased P-N Junctions," R. H. Rediker, Solid State Design, August 1963, pp. 19–28. Note: Other materials may be used in the injection-laser, for example, silicon carbide, as reported in an item on page 11 of Electronic Industries, November 1963; and similar devices such as the InSb magneto-laser diode, as reported in an item on page 8 of Electronic Design, Nov. 22, 1963, may eventually be used in lieu of the injection-laser. Basically, this completely expendable version of the LEED can be energized from a low-voltage/high-current source. A high-current pulse, properly polarized and of magnitude above the coherent lase current density threshold, applied to the leads of an injection-laser, will create an essentially monochromatic electromagnetic pulse of coherent "light." Below this threshold, the radiation is broad-band and incoherent; said threshold represents the upper bound of the sub-lase region. If the radiation in the sub-lase region is intense enough and can be focussed, this region can be used for LEED operation also; such a device will hereinafter be referred to as the Sub-Laser EED (SLEED).

A high-current pulse is applied to the insulated electrical leads **27** with polarity such as to obtain forward biasing conditions at the injection-laser P-N junction **31**. The leads **27** are connected to the injection-laser **30**. The rear face **32** of the laser is ground optically flat and is coated to make it a totally reflecting surface; the front face **33** is ground optically flat and parallel to the rear face. The distance between said faces of the proper dimension forms a Fabry-Perot interferometer. Constructional details for a suitable high-power-pulse injection-laser package are shown in FIGS. 1A and 1B of an article entitled "Research in New England," Electronics, Nov. 1, 1963, pp. 23–24. Directionality effects of the electromagnetic beam **9** emanating from the front face **33**, in the vicinity of the P-N junction **31**, are discussed in detail in "Directionality Effects of GaAs Light Emitting Diodes," Parts 1 and 2, G. Burns et al., IBM Journal of R and D, January 1963, pp. 62–65. Typical characteristics for this type of laser at room temperature are given in "Room Temperature Stimulated Emission," G. Burns and M. I. Nathan, ibid., pp. 13–17. New geometries for raising the power output of gallium-arsenide infrared diodes and injection-lasers have been reported in the literature; for example, see FIGS. A, B, and C and the accompanying text on page 11 of Electronics, Nov. 8, 1963.

The metal shield **34**, containing an axial opening to allow the laser beam **9** to pass through, in conjunction with the metal case **36** effectively shields the primer charge **22** from spurious radiation. It should be pointed out at this time that the lower bound of the sub-lase region is represented by another rather ill-defined, electrical

current threshold. This is discussed on pp. 13 and 14 of "Semiconductor P-N Junction Lasers," R. N. Hall, IEEE Student Journal, May 1963. Roughly speaking, below the sub-lase region is the "spontaneous" region where weak radiation, incoherent and spread out over a wide frequency band obtains. If it is necessary to shield the charges from spontaneous emission radiation or even weak sub-lase radiation, due to thermal effects or spurious electrical signals, an optical filter **39** is placed over the opening in shield **34**; the optical filter having a frequency pass-band corresponding to the coherent lase wavelength of the laser. If one of the "new geometry injection lasers" mentioned above are used, an extension **35**, of shield **34**, is formed into a paraboloid-of-revolution reflector to help collimate the laser beam emanating from the injection-laser. The injection-laser **30** would then be placed at the focus of the reflector **35**. In either case, the laser beam **9** passes through the optical filter **39**, through the isolating air space or transparent filler material **24**, through the collimating and focussing lens system **42**, through the solid, transparent, cone-like member **20**, to the primer charge **22**. The lenses are positioned by the insulating tube **46**. The remaining volume of the LEED, surrounding the primer charge **22**, is filled with the main charge **26**. The leads **27** could now be brought out of the sealed and waterproofed neck of the LEED, i.e., as illustrated in the figures on the Du Pont data sheets, op cit.

If a pulse transformer **40** is incorporated into the LEED, electrical performance is improved, viz.; by utilizing the electrical current step-up capability to help attain the high-current-density required to obtain laser action from injection-laser **30**; by utilizing the impedance-transforming capabilities to help match the low impedance of the injection-laser **30** to the characteristic impedance of a transmission line **66** (see FIG. 5). Suitable pulse transformers are described in "Wide-Band Pulse Transformers for Matching Low Impedance Loads," S. Tansal and H. Sobol, Rev. Sci. Inst., October 1963, pp. 1075–1081. Leads **27** are now considered to be the output leads of the pulse transformer **40** and leads **44** are the input leads of **40** and the LEED. Complete shielding against RFI is possible if a shielded connector **48**, exemplified by the co-axial connector, well known to practitioners of the ultra-high-frequency art, is used to terminate the leads **44**. The female co-axial connector **48** is mated to a male co-axial connector which terminates an unbalanced transmission line; a shielded balanced transmission line and connectors could have been used instead. The connector **48** is mechanically and electrically bonded to the detonator cap case **36**. The remote end of the shielded transmission line **66** (at the current pulse generator **62**) would be grounded in accordance with well known techniques.

The LEED's may be detonated in any one of a number of possible modes:

(1) Single
(2) Multiple:
  A. Simultaneous
  B. Sequential

(1) Single: Referring to FIG. 1, the HV/EX–LEED is fired by having the timing unit **56** supply a single trigger pulse to the HV power supply **58** followed by a suitably delayed pulse to the electro-optical modulator power supply **59**. An electromagnetic laser pulse **9** will be generated within the laser head **14** and transmitted to the cap **12** by the energy guide **10**, thereby detonating the LEED **12**.

Referrign to FIG. 5, the LV/IN–LEED is fired by having the timing unit **64** trigger a single current-pulse generator **62**; the electrical energy required to generate said current-pulse is supplied by the LV power supply **60**. The current-pulse is transmitted to the LEED **36** by the transmission line **66**.

(2) Multiple–A. Simultaneous: Referring to FIG. 1, simultaneous firing of the HV/EX–LEED can be obtained by utilizing a plurality of single mode units, simultaneously triggered. This could be accomplished by having one of the timing units **56** act as the master timer and slaving the other timers to it. Alternately, simultaneous firing could be obtained from a single laser head **14**, large enough and powerful enough to accommodate and suitably energize a bundle of energy guides **10**.

Referring to FIG. 5, simultaneous firing of the LV/IN–LEED can be obtained by having the timing unit **64** supply simultaneous triggers to the plurality of current-pulse generators **62**. Alternately, simultaneous firing can be obtained from a single current-pulse generator **62** by hooking-up a plurality of caps **36** in series.

(2) Multiple–B. Sequential: Referring to FIG. 4, sequential firing of HV/EX-LEED's can be obtained from a single laser head **14** by the exemplary electro-optico-mechanical system shown. Operation is started by a trigger pulse from the precision, electronic, timing unit **56** which triggers the HV power supplies **58** and **59** as previously described. Since the stepping motor **54** is initially in the **1** position (see FIG. 4A), the ensuing laser pulse **9** from the laser head **14** is steered by the totally reflecting surface **50** to the 1st energy guide **10**, resulting in the detonation of the 1st LEED **12**. As soon as the 1st laser pulse **9** has been steered, the preprogrammed timing unit **56** sends an indexing pulse to the stepping motor **54** causing the motor **54**, the splined shaft **52** and attached reflector **50** to rotate or index to the 2nd position. This cycle is repeated until all the detonator caps **12** have been exploded in sequence. If more LEED's are to be detonated in sequence than the packing density of energy guides **10** on the periphery of the circle (formed by the abutting ends of the energy guides) permits, additional energy guide decks can be added. As soon as a laser pulse **9** has been steered to the last energy guide **10** on the 1st deck, the timing unit **56** sends an axial indexing pulse to the stepping linear actuator **55** and a rotary indexing pulse to the stepping motor **54** so that the next laser pulse is steered to the energy guide in the 1st position of deck **2** . . . and so on. This scheme is well suited for explosive trains with detonation separation periods in or above the millisecond range. For shorter detonation periods, i.e., the initiation of explosions separated in time of the order of microseconds, some sort of electro-optical steering system would be required.

Referring to FIG. 5, sequential detonation of the LV/IN-LEED's can be accomplished by having the preprogrammed precision electronic timing unit **64** trigger each one of the set of current-pulse generators **62** in sequence, thereby detonating the set of LEED's **36** in a precisely timed train. The requisite electrical energy is supplied by a Low Voltage power supply with low internal impedance **60**. By utilizing the state-of-the-art in microminiaturization techniques, solid-state techniques, and low-internal-impedance/high-current-density batteries or fuel cells, the system shown in FIG. 5 may be made compact and expendable. Preferably, units **60**, **62**, and **64** would be encased in an environmental protective housing **68**, i.e., explosionproof, shockproof, waterproof, radiation-free, etc., so that the lengths of the transmission lines **66** may be minimized; said minimization to be consistent with the ability of the aforementioned units, within the housing **68**, to operate properly in the shock environment and the desired spatial configuration of the set of LEED's **36**. A lower bound on the minimization of the transmission line **66** lengths is set by the well known phenomenon of sympathetic detonation of adjacent explosive charges; this is especially pertinent since EED's are frequently used to initiate the explosive or burning action of large explosive charges, rocket motors, etc. In spite of the expendable nature of this system, the equipment housed in **68** is salvageable.

All aforementioned systems are operable from points far remote from the physical embodiments previously described. For example, suitable transmitters can be lo-

cated at the remote points and a suitable receiver incorporated into the timing units 56 and 64. The transmission of appropriate signals could take place via well known wire or wireless techniques. To circumvent the everpresent hazard of unintentional detonation due to noise, RFI, tampering by unauthorized personnel, etc., error detecting and/or error-correcting digital codes could be used and associated encoders and decoders incorporated into said transmitters and receivers, respectively.

What I claim is:

1. An expendable ultra high speed detonating cap assembly comprising:
- a metallic housing having electromagnetic shielding properties,
- a priming charge of relatively sensitive detonatable material disposed within said housing,
- a laser assembly disposed within said housing and optically coupled in predetermined spaced relationship with said priming charge,
- and means for electromagnetically isolating said laser assembly from said charge and said housing to preclude premature detonation of said charge occasioned by environmental electromagnetic radiation.

2. A detonating cap assembly as set forth in claim 1 including:
- a main charge of relatively insensitive detonatable material disposed within said housing and in surrounding intimate interfacial relationship with said priming charge.

3. A detonating cap assembly as set forth in claim 1 including:
- means disposed intermediate said laser assembly and said priming charge to selectively concentrate a pulse of light energy emitted from said laser for directed application to said priming charge.

4. A detonating cap assembly as set forth in claim 1 including:
- means disposed within said housing and closely adjacent to said laser assembly to facilitate the supplying of a high amperage current pulse to said laser assembly.

5. An expendable ultra high speed detonating cap assembly comprising:
- a metallic housing having electromagnetic shielding properties,
- a charge of relatively sensitive detonatable material disposed within and partially filling said housing,
- a semi-conductor junction type laser assembly disposed within said housing and optically coupled in predetermined spaced relationship with said detonatable charge,
- means disposed intermediate said laser assembly and said charge to selectively concentrate a pulse of light energy emitted from said laser for directed application to said charge,
- means disposed within said housing and closely adjacent to said laser assembly to facilitate the supplying of a high amperage current pulse to said laser assembly,
- and fastening means having electromagnetic shielding properties closing one end of said housing and extending therefrom to isolate said charge, laser assembly and the electrical input leads thereto from environmental electromagnetic radiation.

6. The expendable ultra high speed detonating cap assembly as set forth in claim 5 including:
- a main charge of relatively insensitive detonatable material disposed within said housing and in surrounding intimate interfacial relationship with said first mentioned charge of relatively sensitive detonatable material.

References Cited

UNITED STATES PATENTS

3,177,651 4/1965 Lawrence.

BENJAMIN A. BORCHELT, *Primary Examiner.*

W. C. ROCH, *Assistant Examiner.*

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,362,329 January 9, 1968

Sidney Epstein

It is certified that error appears in the above identified patent and that said Letters Patent are hereby corrected as shown below:

Column 5, line 68, "Referrign" should read -- Referring --.
Column 8, after line 36, insert

3,228,337 1/1966 Grantham et al.

Signed and sealed this 12th day of August 1969.

(SEAL)
Attest:

Edward M. Fletcher, Jr.
Attesting Officer

WILLIAM E. SCHUYLER, JR.
Commissioner of Patents