Title: SYSTEM FOR PHOTONIC INITIATION OF NANOENERGETIC MATERIALS

Abstract: A self-propagating chemical reaction of a nanoenergetic material is initiated with a fluence of photons. The nanoenergetic material may contain a nanometal as a fuel and a solid oxidizing material.
SYSTEM FOR PHOTONIC INITIATION OF NANOENERGETIC MATERIALS

FIELD OF THE INVENTION

The invention relates to the initiation of energetic material such as propellants, explosives, and pyrotechniques.

BACKGROUND OF THE INVENTION

Detonators, igniters, air bag initiators or electric matches as shown in prior art Figures 1-4 are often used to ignite explosive materials. Most commercial igniters, detonators, and electric matches generally use lead-based material (such as lead thiocyanate, lead nitroresorcinate, lead stphnate, and lead tetroxide) or toxic materials (such as perchlorates) in their composition. One disadvantage of using such materials is that they constitute a health hazard to both users and the environment. However, these compounds continue to be used in ignitor formulations because a small diameter resistive bridgewire or semiconducting bridgewire can reliably initiate them. The practice of using an ignitor with a bridgewire to initiate these compounds is also disadvantageous in that it is susceptible to accidental or premature electrostatic discharge (ESD) or radio frequency (RF) initiation.

One method of overcoming the problem of accidental ESD or RF initiation is to use a shock tube to replace the electric detonators and blasting caps for many applications. Unlike copper wires, which transfer the electrical energy to the hot wire in a blasting cap (e.g., DC current, AC current or capacitive discharge pulse), the shock tube transmits a shock wave along with hot particles and gases to a pyrotechnic or explosive receptor in a blasting cap. The detonation is confined to the tube along its length and produces output only from the open end. In this way, the shock tube acts as a signal transmission device.

Shock tubes are becoming widely accepted in the field of commercial blasting, military demolition, seismic exploration and law enforcement as well as being adapted for use in fireworks under the trademark, NOMATCH™ (B&C Products). The primary reason for the popularity of the shock tubes in the energetics field has been their inherent safety and ease of use.

A widely used type of shock tube is the style based on a device described in United States Patent No. 3,590,739 ("the '739 Patent"). The '739 Patent describes a small diameter plastic tube with an explosive powder coated on the inside. The tube can be SURLYN®
material (Dupont) with an ID of about 1 mm and OD of about 3 mm, other plastics and multilayered plastics are also used to improve workability, durability, and abrasion resistance. The explosive can be 90% HMX plus 10% stearic acid coated flake aluminum. Other explosives such as PETN, RDX, and TNT are sometimes used.

The air in the tube provides part of the oxygen needed for combustion. The output is a high-pressure pulse (7 - 27 MPa for 20 - 50 μs at a temperature of 2000 - 2500 °K) composed primarily of gaseous CO₂, NOₓ, H₂O, and solid hot particles of Al₂O₃.

While it is possible to reduce the combustion wave speed from the nominal 6500 feet/second to as low as 100 feet per second by using alternative pyrotechnic mixtures (such as tungsten/potassium perchlorate) or introducing restrictions in the tube, it is often difficult to obtain precise, predictable timing when multiple detonators need to be fired.

The shock tubes are relatively electrostatically insensitive by virtue of their lack of electrical conductivity. While they are generally considered to have good mechanical stability, a sharp blow to the tubes, or a bend around too small a radius, can cause firing problems to the shock tubes.

An alternative method to bridge wire initiation of energetic material is described in United States Patent No. 3,408,937 ("the '937 Patent"). The '937 Patent discusses the use of light tubes and an extremely high-powered laser as a method to prevent accidental electrostatic ignition. In this prior art, conventional denoting materials are ignited using a high-powered, monochromatic laser, typically 5 megawatts per square centimeter, via a fiber optic cable. Because of the extremely high power required, this invention has not seen wide use. As fiber optics have become more readily available, further improvements to this invention have been developed. United States Patent No. 3,724,383 attempts to overcome some of the power requirements by using a spherical glass bead to focus the energy on Potassium Hexanitro Diphenylamine (KHND), which is loaded next to a gradient of increasing density of PETN. This combination lowered the activation energy slightly but still contains environmental hazardous chemicals and it is difficult to manufacture. United States Patent No. 5,179,247 eliminates the use of the KHND by recessing the area directly around the tip of the fiber optic. This recess reduces the heat transferred to the metal body and allows more heat to be transferred to the explosive. Hence, they are able to detonate a special blend of PETN or RDX directly. As before, this device still uses a high-powered laser and tries to minimize the energy required through modifications of the housing. Therefore, the
existing art does not provide an ignition system that uses environmentally benign chemicals, is resistant to accidental initiation, has precise timing, is mechanically robust and uses moderate energy.

United States Patent No. 4,898,095 describes a laser-detonatable blasting cap in which the energetic material is mixed with a laser beam-absorbing material such as carbon black in order increase the energy coupling between the laser and the energetic material. This enables the use of lower power lasers for the optical initiation of energetic material.

Until recently, few material alternatives were available to both reliably initiate a detonator and release low levels of toxic material. The development of high quality nanoaluminum powder in the late 1980s by Los Alamos National laboratory (LANL), and superthermites or Metastable Intermolecular Composites (MIC) in the 1990s, which are generally nanoaluminum based, also at LANL, has allowed the possibility of a new class of materials for the initiation of primary energetic compounds. Generally nanomaterials are considered to be materials which have at least one dimension that is nanoscale where nanoscale is considered to be less than 200nm and more preferably less than 100nm. MIC can comprise a mixture of a nanometal powder and a solid oxidizer with other possible additives depending on the application. Some of the examples of MIC materials may be a nanometal powder such as nanoaluminum powder mixed with MoO₃, Bi₂O₃, or CuO. Other nanoaluminum based energetic materials may use Polytetrafluorethylene (PTFE) as an oxidizer. A more generic name encompassing all energetic materials in which at least one component is nanoscale in at least one dimension is referred to as a “nanenergetic” material. Whereas the typical energetic material is organic, these new materials can be and generally are completely inorganic. The ingredients, as well as the products, of a MIC reaction are generally low in toxicity as compared to other primary ignition materials. Furthermore, MIC reactions are generally characterized as having high-energy content, high temperatures of reaction, minimal net gas generation (depending on choice of oxidizer and additives), and a tunable reaction rate.

Alternative designs of conventional electrical matches have also been developed to reduce health hazards. One design uses a specific MIC composition consisting of nanoscale aluminum and molybdenum trioxide to replace the lead-based composition. However, such a design is still similar to an existing electric match in that it has a bridgewire that is resistively heated to initiate a primary composition.
There is, therefore, a need for an ignition system that can be reliably ignited, is capable of precise timing, uses environmentally benign reactants and products, and is mechanically robust.

Prior Art Figure 1 is a typical electric match which includes the lacquer coating, high resistance bridgewire, pyrotechnic composition, non-conductive substrate, copperfoil, solder and leg wire. Prior Art Figure 2 is a typical detonator, which includes on the coaxial structure, an electrode, epoxy seal, ferrite bead, glass seal, crimp closure, bridgewire, first Pyro material and second-Pry material. Prior Art Figure 3 is a typical airbag initiator which includes leading wires, closure plug, anti-static spurs, protective sleeve, bridge-wire, fusehead, delay element, initiating charge and base charge. Prior Art Figure 4 is a typical ammunition round showing primer.

**SUMMARY OF THE INVENTION**

The current invention is a novel system and method to be used to initiate an energetic composition that may undergo combustion, deflagration or detonation and eliminates many of the problems associated with electrically-initiated devices such as electric bridge wires, impact-initiated devices such as percussion primers, and shock initiated devices such as shock tubes and laser operated devices. The initiation system can be used for ignitors, initiators, detonators or replacement for percussion ammunition primers.

An embodiment of the invention comprises a nanoenergetic material and a pulsed radiation (i.e., photonic) source that initiates the combustion of such material. A window, which is transparent to at least a portion of the emission from the photonic source, may separate the photonic source from the mixture.

Preferred embodiments of the invention have numerous advantages over the prior art. The present invention is generally insensitive to accidental or premature initiation by electrostatic discharge or RF pickup. Furthermore, the initiation can be precisely timed. Yet another advantage of the present invention is that very little energy and power are required to initiate it and the invention is mechanically robust. In addition, the byproducts of its combustion are low in toxicity. Finally, the invention can be fabricated inexpensively.
BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a diagram of a typical prior art electric match.
Figure 2 is a diagram of a prior art typical detonator.
Figure 3 is a diagram of a typical prior art airbag initiator.
Figure 4 is a diagram of a typical prior art ammunition round showing primer.
Figure 5 is a diagram of an embodiment of the invention.
Figure 6 is a diagram of another embodiment of the invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The current invention is in part enabled by a new class of materials referred to as nanoenergetic compositions or Metastable Intermolecular Composites (MIC). It has been found that the initiation of these self-reacting energetic materials and certain nanometals can be photonically initiated. That is, a brief, intense pulse of light can initiate the combustion of these materials. This attribute is enabled in part, by the unique physical attributes of nanoscale materials. Nanoscale materials, such as nanopowders, have a dramatically higher surface area to volume ratio than materials in bulk or micron form allowing them to absorb dramatically more energy per unit mass when irradiated. Furthermore, if the nanoscale material is a metal, it is generally very absorptive of light. For example, aluminum in bulk form is highly reflective, micron sized powered aluminum is light gray whereas nanometer sized aluminum appears dark gray or black and hence has a greater absorptivity. Furthermore, nanopowders intrinsically have a dramatically lower thermal conductivity and consequently cannot transfer absorbed energy very well. This means that if heated, the nanoscale material tends to stay hot for an extended period of time over larger scale materials. This increases the reactivity of the nanomaterial. In short, if a nanomaterial is absorbent and is irradiated with an intense, short pulse of light, it can be heated up to a very high temperature with very little energy. When it is heated up, it can react more readily.

Furthermore, nanocomposite mixtures of combustible materials, such as superthermites, have dramatically lower activation energies than micron-sized mixtures. This unique combination of properties allows the material to readily absorb photons, which consequently rapidly heats them causing them to react. Unlike conventional explosives, the
by-products are typically environmentally benign, such as alumina, and they can be tailored to have a significant or even little to no gas generation.

The combination of the above attributes makes a nanoenergetic material more amenable to photonic initiation than previous compositions. This is contrasted to placing a nanoscale unreactive material such as carbon black in a pyrotechnique composition in order to make it more sensitive to radiation. In this case, the heated unreactive material must transfer its energy to both reactants in intimate contact (e.g. both the oxidizer and the reducer) to initiate a pyrotechnique composition. Since it indiscriminately transfers its energy to all of its surroundings, more energy is required for initiation. In the present invention one of the reactants (fuel or/and oxidizer), not an inert material is the absorber of the radiation. In this case, it need only heat the other component of the reaction (oxidizer and/or fuel). This significantly lowers the power threshold for initiation by irradiation.

An embodiment of the invention is shown in Fig. 5. It comprises a nanoenergetic material 501 contained within a housing 505 and sealed on top by cap 504. The combustion of nanoenergetics material 501 is initiated by a photonic source 503. A window 502, is transparent to at least a portion of the emission from the photonic source separating it from the mixture. The nanoenergetic material may be electrically isolated from the radiation source and furthermore may be hermetically sealed. The radiation source may be ultraviolet, visible, infrared, or other wavelengths, or be a broad spectrum and may be emitted by a laser, LED, strobe flash, blackbody source, such as a bridgewire, or other means to generate photons. It may be coupled remotely to the nanoscale combustible mixture by a waveguide or/and focused by means of a lens, mirror, or other similar device. The transparent window may be composed of acrylic, polycarbonate, glass, or other material that passes radiation from the photonic source and also forms into a lens to focus the radiation onto the nanoenergetic material.

The current invention is further illustrated by the following example. In this example, the combustion of nanoaluminum powder in air was initiated from the flash of a common photographic camera (Studio 35 Single Use Camera [27 exposures], which is distributed by Walgreen Co, Deerfield, IL 60015-4681) at a distance of up to about 5 cm. Specifically, a self propagating combustion of passivated, 50 nm loose aluminum powder (manufactured and commercially available from Nanotechnologies, Inc., Austin, Texas) was initiated in air by radiating as little as 10 W from a Xenon flashlamp for about 100 microseconds and in the
process depositing about 1 mJ of energy through a 1 mm diameter glass ball lens placed on top of the powder. This corresponded to an area power density of about 500 w/cm² and an areal energy density of about 100 mJ/cm² required for initiation. Optical losses in the system were not accounted for, so the thresholds are somewhat lower. Note that the material can be photonically initiated without the use of the glass ball, but using it reduces the thresholds for initiation by about a factor of 4. Use of the glass ball also illustrates the low total energy threshold since the combustion can be seen initiating at the site of the ball and propagating outward.

This reflects a low energy and power threshold for the initiation of a self-propagating combustion for nanoaluminum in air and shows that both low power and low energy emissions offered by inexpensive photonic sources can be used to initiate a nanoenergetic material. Photoinitiation has been also demonstrated with 120 nm loose aluminum powder with the same disposable camera. Furthermore, photoinitiation with the same disposable camera has been demonstrated with a MIC (nanoaluminum and MoO₃) through a bundled fiber optic cable.

Another embodiment of the invention can be further illustrated by the following example. Copper oxide, 25 nm powder, produced by Nanotechnologies Inc. was stoichiometrically mixed with 2-micron aluminum powder (H-2 manufactured by Valimet) in an isopropanol dispersion. The dispersion was painted onto a porous cellulose substrate and dried with a heat gun. A 1 mm diameter glass ball was placed on top of the trace. The energetic material was initiated by the same disposable camera described above at a distance of about 1 cm. Here, the nano CuO, which is black, was the nanoscale reactant instead of the aluminum. By substituting the 2-micron aluminum with nanoscale aluminum, the energy threshold required to initiate the material can be further reduced.

Another embodiment of the invention is shown in Fig. 6. The invention may further comprise a pyrogen material 606, which is adjacent to the nanoenergetic material 601. The pyrogen material 606 may be a primary explosive such as lead azide, HMX, TNT, OCTOL; an energetic material such as aluminum, thermite; or combustible materials such as hydrocarbon liquid and fuels.

Unlike conventional primary or secondary explosives, the specific energy content of the nanoenergetic material utilized in the present invention is much higher and generates a much higher temperature. The result is that the nanoenergetic material can ignite a much
broader array of pyrogen materials. The nanoenergetic materials 601 may further be contained in a housing 605 or other similar device and is ignited by photonic source 603. The housing provides an environmental seal and protects the energetic materials from the surrounding environment. The housing further provides mechanical integrity to the device. It may further be a cylinder and composed of metal, plastic, glass, polymeric resin or other material than provides structural integrity. The housing may be capped at the top 604 to provide a seal for the energetic materials and on the bottom with a transparent window 602.

The nanoenergetic material 501 and 601 is comprised of at least a metal intermixed with a reaction agent, such as, but not limited to, an oxidizer or reducer. Additionally the metal and/or the reaction agent is nanometer in scale (at least in one direction) and highly absorptive. The nanometal may be, but is not limited to, one of the following materials: aluminum, zirconium, B, Mg, Si, Ti, Cr, Fe, Zn, Y, Sn, Ta, W, Bi, and combinations thereof. The reaction agent may be an oxidizer; such as molytrioxide, bismuth oxide, (tin-oxide, copper oxide, etc.) such that the combination with the nanomaterial forms a thermitic reaction. In the current invention the combination of material compositions and material size can be varied to adjust the specific energy output and the specific power output. For example, smaller nanoaluminum, 50nm, will react much faster than larger, 120nm aluminum. Alternatively, changing the size of the oxidizer will affect the reaction rate similarly. Hence the specific power output can be tailored to the application. Additionally, the burn rate of the nanoenergetics material can be varied by orders of magnitude from approximately 1 cm/s to 1 km/s. This allows precise timing of the delay such that the amount of delay required can be adjusted.

While the preferred embodiments use fiber optics to transfer the photons to initiate the nanoenergetics material, other devices such as a shock tube can also be used. One of the aspects of a shock tube is that they can become damaged which significantly reduces the pressure wave that propagates through the tube and hence causes problems initiating the detonator. A shock tube does produce a high amount of photons, even if the pressure wave is substantially reduced. Consequently, the current invention when used with a shock tube eliminates this problem.

The above descriptions have been made by way of preferred examples, and are not to be taken as limiting the scope of the present invention as defined by the following Claims. It should be appreciated by those of skill in the art that the methods and compositions disclosed
in the examples merely represent exemplary embodiments of the present invention. However, those of skill in the art should, in light of the present disclosure, appreciate that many changes can be made in the specific embodiments described and still obtain a like or similar result without departing from the spirit and scope of the present invention.

It will be understood that certain of the above-described structures, functions, and operations of the above-described embodiments are not necessary to practice the present invention and are included in the description simply for completeness of an exemplary embodiment or embodiments. In addition, it will be understood that specific structures, functions, and operations set forth in the above-described referenced patents and publications can be practiced in conjunction with the present invention, but they are not essential to its practice. It is therefore to be understood that the invention may be practiced otherwise than as specifically described without actually departing from the spirit and scope of the present invention as defined by the appended claims.
WHAT IS CLAIMED IS:

1. A process comprising the steps of:
   a) selecting an energetic material that comprises a metal and a reaction agent to
   yield an energetic material, wherein at least one of the metal or the reaction agent is nanoscale
   in at least one dimension and wherein the energetic material is operable to initiate when a
   photonic source is radiated upon it;
   b) activating the photonic source to initiate the energetic material.

2. A product comprising:
   a) a metal; and
   b) a reaction agent added with the metal to yield an energetic material, wherein at
   least one of the metal and the reaction agent is nanoscale in at least one dimension, and
   wherein the energetic material product is operable to initiate when a photonic source is
   radiated upon it.

3) A system comprising:
   a) an energetic material comprising a metal and a reaction agent added together
   to yield an energetic material, wherein the at least one of the metal and the reaction agent is
   nanoscale in at least one dimension, and wherein the energetic material is operable to initiate
   when a photonic source is radiated upon it; and
   b) a photonic initiation source for activating the energetic materials.

4. The process of claim 1, the product of claim 2, or the system of claim 3, wherein the
   metal is a nanoaluminum powder.

5. The process of claim 1, the product of claim 2, or the system of claim 3, wherein at
   least one of the metal and the reaction agent is nanoscale in at least two dimensions.

6. The process of claim 1, the product of claim 2, or the system of claim 3, wherein at
   least one of the metal and the reaction agent is nanoscale in at least three dimensions.
7. The process of claim 1, the product of claim 2, or the system of claim 3, wherein said photonic source is pulsed.

8. The process of claim 1, the product of claim 2, or the system of claim 3, wherein said photonic source has a pulse length at most about one millisecond.

9. The process of claim 1, the product of claim 2, or the system of claim 3, wherein said photonic source has a pulse length at most about 300 microseconds.

10. The process of claim 1, the product of claim 2, or the system of claim 3, wherein the metal is selected from the group consisting of aluminum, zirconium, B, Mg, Si, Ti, Cr, Fe, Zn, Y, Sn, Ta, W, Bi, and combinations thereof.

11. The process of claim 1, the product of claim 2, or the system of claim 3, wherein the spectrum emitted by the photonic source is broadband.

12. The process of claim 1, the product of claim 2, or the system of claim 3, wherein the photonic source is selected from the group consisting of a laser, an LED, a strobe flash, and a blackbody source.

13. The process of claim 1, the product of claim 2, or the system of claim 3, wherein the photonic source is coupled to a waveguide.

14. The process of claim 1, the product of claim 2, or the system of claim 3, wherein the photonic source is coupled to a focusing device selecting from the group consisting of a lens, mirror, microlens, microlens array, lenticular array, and combinations thereof.

15. The process of claim 1, the product of claim 2, or the system of claim 3, wherein the photonic source emits photons to the energetic material through a transparent material.
16. The process, product or system of claim 12, wherein said transparent material is selected from the group consisting of an acrylic, a polycarbonate, glass, and combinations thereof.

17. The process of claim 1, the product of claim 2, or the system of claim 3, wherein the reaction agent comprises an agent selected from the group consisting of molytrioxide, bismuth oxide, tin-oxide, copper oxide, iron oxide and combinations thereof.

18. The process, product or system of claim 14, wherein the metal is nanoaluminum.

19. The process of claim 1, the product of claim 2, or the system of claim 3, wherein the reaction agent is selected from the group consisting of at least one of an oxidizer and a reducer.

20. The process of claim 1, the product of claim 2, or the system of claim 3, wherein said photonic source has an energy at most about 100 mJ.

21. The process of claim 1, the product of claim 2, or the system of claim 3, wherein said photonic source has an energy at most about 10 mJ.

22. The process of claim 1, the product of claim 2, or the system of claim 3, wherein the metal has an average size of at most about 120 nm.

23. The process of claim 1, the product of claim 2, or the system of claim 3, wherein the metal has an average size of at most about 50 nm.

24. The process of claim 1, wherein the initiated energetic material ignites a pyrogen material.

25. The product of claim 2 and the system of claim 3, further comprising a pyrogen material operable for ignition by the energetic material.
26. An ignition device comprising a nanoenergetic material in an environmental enclosure, wherein environmental enclosure comprises a portion which is transmissive to an emission from a pulsed photonic source such that energetic material in the housing is operable to be initiated by the photonic source.

27. The ignition device of claim 25 further comprising a pyrogen material located adjacent to nanoenergetic material, wherein the nanoenergetic material is operable to ignite the pyrogen material.

28. The device of claims 25 or 26, wherein the transmissive portion of the environmental enclosure focuses photons from the pulsed photonic source on the energetic material.
Figure 1. Illustration of a typical electric match in cross-section (left) and viewed externally after rotating 90° (right).

Fig. 1

PRIOR ART

Fig. 2

PRIOR ART
Fig. 3
PRIOR ART

Fig. 4
PRIOR ART