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ABSTRACT

A reliable, cheap and simple pyrotechnic match head has been developed utilising a pyrotechnic slurry at the end of an optical fibre. A 1 W pulsed diode laser has been used to ignite the match head at pulse energies of about 2 mJ. The laser matchhead is a convenient means for ignition of pyrotechnic devices less prone to unintentional ignition from electromagnetic fields, radio frequency absorption, electromagnetic pulses, electrical discharge or stray electrical energy than conventional bridgewire match heads connected to electrical cables. The laser match head can also be coated with layers of different pyrotechnic slurry in order to make the match head less friction and impact sensitive, and to give the match head different thermal ignition properties.

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Laser Match Head for Pyrotechnic Ignition

Executive Summary

Laser fibre optic ignition of pyrotechnics offers a simple solution to the safety and reliability issues associated with the pick-up of spurious electromagnetic signals in conventional bridge wire pyrotechnic match heads. Bridge wire match heads located at the ends of two metal cables may be easily affected by stray electrical discharge or the reception of radio frequency energy. This may cause unintentional ignition of the match head, and makes the match head more susceptible to electromagnetic pulses.

It was the intent of this study to make laser ignition more simple, cheap and convenient than it has been up to now. This outcome has been achieved by placing pyrotechnic composition on the tip of the optical fibre, rather than making it part of an assembly separated from the optical fibre by a window or lens.

The laser match head reported here uses a slurry of boron/potassium nitrate/Viton® as the pyrotechnic ignition composition. It was found that the match head could be reliably ignited at single pulse energies of about 2 mJ (25 J/cm^2) with a 1 W diode laser emitting at 980 nm through a 100 μm diameter optical fibre core. In order to alter the thermal properties of the match head additional layers of different pyrotechnic composition can be applied. In addition, after firing the laser match head, the tip of the fibre optic can be cut off and the optical fibre reused by coating with pyrotechnic composition.

While several aspects of the DSTO laser match head are new, the concept has previously been patented (Refouvelet and Baldy, 1990) thereby inhibiting DSTO commercial exploitation.

Authors

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Augustine Lee is a graduate of the Flinders University of South Australia (BSc(Hons)) in Physical Chemistry and joined DSTO in 1990. Since then he has been involved in research in propellant combustion, rocket plume technology and novel ordnance systems technology. His current work is with pyrotechnics, emission spectrometry and radiometry.

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Michael Stringer completed his PhD in Chemistry at the University of Western Australia in 1982. Subsequently he spent three years as a post-doctoral research associate at the University of Adelaide. After nearly 12 years working in the both the private and public sectors, he joined DSTO in 1997. As a scientist in the Pyrotechnics Group, he is currently responsible for the development and testing of IR decoy flares for aircraft.

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Ken Smit joined DSTO in 1988 to work on energetic materials following postdoctoral work in the Netherlands and a PhD in Physical Chemistry at the University of Melbourne. In 1992/93 he undertook a 15 month attachment to the UK (Fort Halstead), and in 1997 relocated from Melbourne to Adelaide to continue research in pyrotechnics.

Contents

1. Introduction

Laser ignition of pyrotechnics has often been espoused as an important developing method for the safe and reliable ignition of pyrotechnic materials [1]. The main advantages of laser ignition through optical fibres, compared to transmission of electrical current through conductive wires, are that this process is immune from accidental ignition from electromagnetic fields, radio frequency absorption, electromagnetic pulses, electrostatic discharge or stray electrical energy [1]. These advantages are also recognised for the initiation of explosive detonation, and commercial devices have now been available for laser initiation of explosives for some time [1-4].

DSTO has had a long standing interest in the direct laser ignition of energetic materials, both through fundamental studies on the photochemistry and photophysics of explosives in the solid state [5,6] and solution [7,8], and in the direct and indirect laser ignition/initiation of pyrotechnic compositions [9-11] and high explosives [12,13]. The review by de Yong et al [1] provides good insight into the many facets of international research in this area.

It is generally accepted that direct laser induced ignition of pyrotechnic compositions, propellants and explosives occurs through the formation of hot spots, resulting in the onset of chemical reactions that cause further evolution of heat. Where heat energy is not dissipated soon enough, self-sustaining exothermic chemical reactions occur to cause ignition [1,9-11,14] and in high explosives they may ultimately result in detonation [1,15-18].

A wide range of laser sources have been employed to ignite pyrotechnic compositions, these have included Argon Ion, ruby, Nd/YAG, diode and carbon dioxide lasers. While the Nd/YAG and carbon dioxide lasers have provided many of the research results on ignition [1,9,19], increasingly the diode laser is becoming more important as a convenient and low cost method for reliable ignition [10,11,20-26]. The availability of diode lasers integrated with optical fibre output has encouraged development efforts in this area. Ignition of pyrotechnics using diode lasers generally utilises near infrared radiation in the region of 0.8 to 1.1 μm. While ignition occurs through absorption of this radiation by the pyrotechnic composition, the ignition energy threshold is not necessarily directly related to the absorption characteristics of the composition [1,10,11,20]. Other factors are involved, for instance the physical and chemical characteristics of the pyrotechnic powders that make up the composition [10,11]. This study makes use of a diode laser operating at 980 nm operating at 1 W power.

Past ignition studies have also involved a very wide range of pyrotechnic compositions, often with low ignition thresholds. The principal composition used in this study is based on the igniter composition boron/ potassium nitrate (SR 44), commonly employed for the ignition of pyrotechnics or propellants. Similar compositions have previous been shown to ignite using laser radiation from a ruby laser (694 nm, 14 J in 1 ms pulse) [27], a diode laser

(810 nm, 60 ms pulse at 39 W/cm^2) [10,11], zirconium pumped pyrolaser at 1050 nm (15 mJ in a 10 ms pulse) [21], and a CO_2 laser (10. 6 μm at 3.0 J/cm^2) [9]. Generally, pyrotechnic compositions are pressed into pellets in order to control the ignition geometry for laser ignition and to control combustion. A window or lens interface between the end of the optical fibre and the pyrotechnic pellet is also commonly employed [1,9-11,20,23]. The study reported here employs a slurry of pyrotechnic to cover the optical fibre end, as used by Refouvelet and Baldy [28] who employed nitrocellulose/acetone based composition.

2. Experimental

The 100/140 multimode optical fibre patchcord used in the present studies was comprised of core glass of 100 μm diameter in a 140 μm outer diameter Kevlar® optical fibre, surrounded by a protective jacket of Kevlar® and flame retarding polyurethane. An ignition paste was prepared in which 10.0 g of SR 44 ignition composition was slowly added while stirring to a solution of 0.5 g Viton A® (Dupont) dissolved in 5.0 g acetone (Lab Scan, AR Grade). A dark grey sticky slurry paste was formed, and the cleaved optical fibre tip was then inserted into the paste a number of times to build up layers of pyrotechnic material and form a match head that is illustrated in Figure 1. The match head was then allowed to cure for a minimum of 2 hours. Some match heads were also prepared using SR 252 composition instead of SR 44.

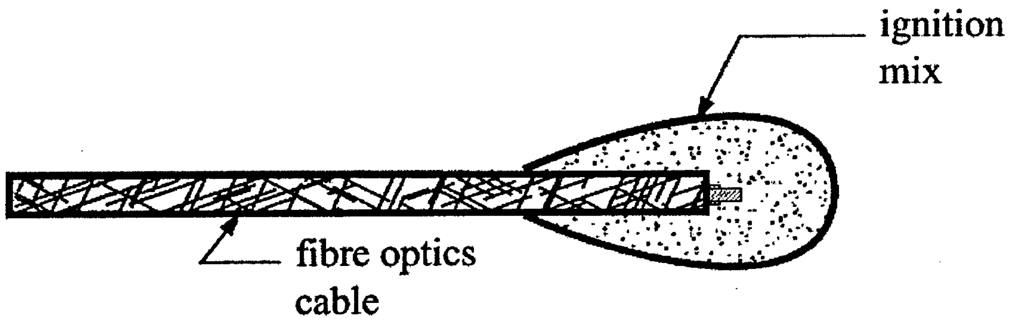

Figure 1. A mono-composition laser match head.

When a single type of pyrotechnic composition was employed the match head was mono-compositional. Some match heads were prepared as for a mono-composition, but then dipped into a second pyrotechnic slurry. The second slurry was prepared as above, but incorporated SR 252 composition instead of SR 44. This bi-composition match head is illustrated in Figure 2. The SR 44 based pyrotechnic on the bi-composition match head is the igniting composition, while the SR 252 based composition is the flashing composition.

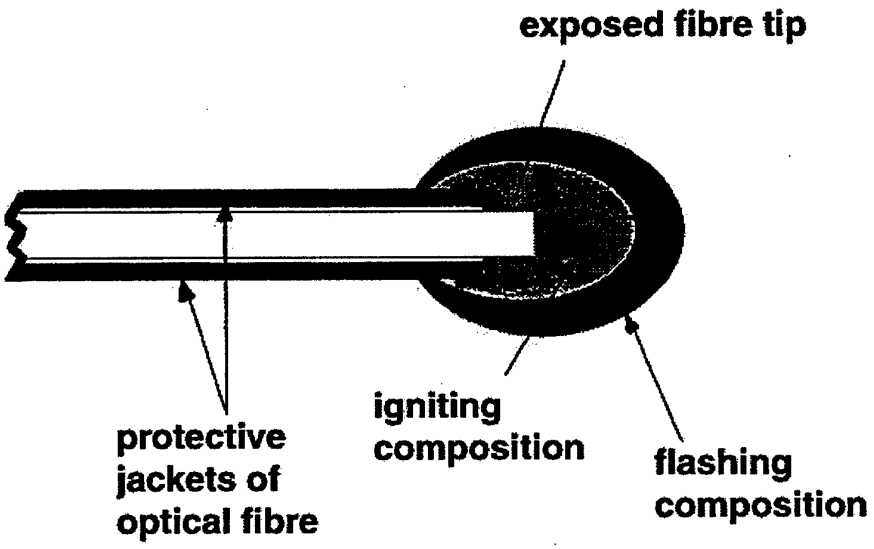

Figure 2. A laser bi-composition match head formed with two different pyrotechnic compositions.

One end of the optical fibre patchcord/match head was then coupled via a fibre connector to the 100/140 fibre optic cable leading out from the gradient index type optical fibre pigtail of a Class IV CW InGaAs semiconductor laser diode (EG&G Optoelectronics model C86155E-10). The laser diode had an emission wavelength at 980 nm, and 1.2 W power in single pulse mode. Monitored after transmission through the pigtail and optical fibre the power output was 1.0 W. Using an internal pulse generator quasi CW laser pulse length could be varied between 0.5 and 2 ms. A turn key laboratory laser diode driver power supply (Spectral Diode Labs model SDL-820) was used to control the laser output, using approximately 2.0 A of DC current. The current level was kept constant by the operator using the current control mode. A schematic of the experimental set up is shown in Figure 3.

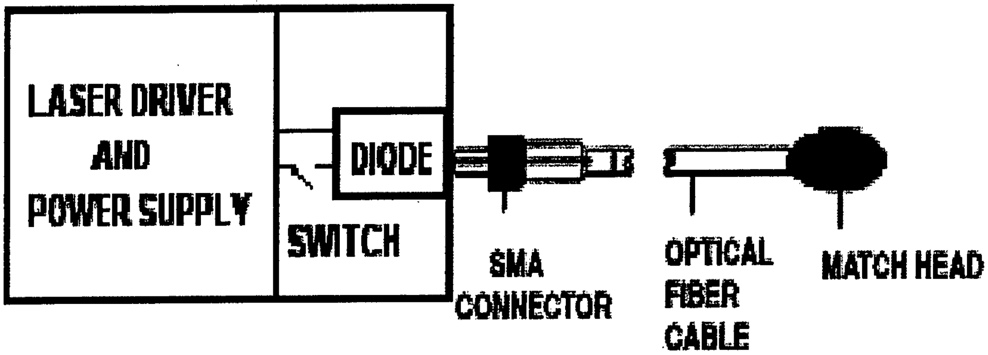

Figure 3. Schematic of the ignition system

After each firing the exposed patchcord optical fibre end was stripped and cleaved before re-deposition of the ignition paste. Initially, match heads were prepared using an optical fibre that had been cleaved with a razor blade; later match heads were prepared using a precision optical instrument to cleave the fibre. An optical microscope was then used for the later series of match heads to check the quality of the cleaved surface of the optical fibre before depositing pyrotechnic slurry.

The SR 44 composition was prepared by adding 6 g boron (Trona, BSS#120 sieved) to 14 g potassium nitrate (BSS#120 sieved), folding on Kraft paper and then sieve mixing with 3 passes through a BSS#120 sieve. The SR 252 composition was prepared by adding 8 g silicon (BSS#240 sieved) to 8 g potassium nitrate (BSS#240 sieved), and then adding 4 g sulphurless mealed powder. The mixture was then folded on Kraft paper and sieve mixed three times through a BSS#60 sieve. The composition was then granulated using water and passed through a BSS#18 sieve prior to oven drying.

3. Results and Discussion

Initial studies were undertaken on the match head containing only SR 44 based composition. A series of batches of match head slurry were prepared, and generally between 6 and 8 match heads were made from each batch, and tested for their ignition characteristics using the laser diode. It was observed that ignition could be effected at pulse lengths of only 0.35 ms, however this was not very reproducible and a value of 0.5 ms was generally used as the laser firing pulse length.

Using a laser pulse length of 0.5 ms, ignition was effected in about 63% of firings. When ignition was not achieved a second pulse of duration 1 ms was then fired about 2 minutes after the first into the same match head. This caused ignition of the remaining match heads with a probability of 58%. Match heads remaining after the first two pulses were ignited with a third consecutive pulse that was of 2 ms duration. The results are presented in Table 1.

Table 1. For mono-composition SR 44 based match heads, number of ignitions vs. pulse length

Mono-composition Batch Number, with no. of match heads in brackets	No. of Ignitions at 0.5 ms	No. of Ignitions at 1.0 ms	No. of Ignitions at 2.0 ms
1 (6)	3	1	2
2 (6)	4	2	
3 (8)	5	2	1
4 (8)	3	2	3
5 (8)	5	2	1
6 (8)	7	1	
7 (8)	6	1	1
Total (52)	33	11	8

When the match head was prepared using only SR 252 based slurry, no ignition was observed even at laser pulses of 10 ms duration. SR 252 composition is known to be significantly less sensitive to impact (FoI 30) and friction compared to SR 44 composition (FoI 120) [29]. However SR 252 is known to be more sensitive to temperature, igniting at more than 250 °C compared to 400 °C for SR 44. Since laser based ignition is known to occur through a thermal mechanism, the match head prepared with SR 44 would appear to be relatively more sensitive to thermal ignition compared to the SR 252 based match head. Previous results reported by de Yong and Lui using a 100 µm diameter optical fibre have also noted that SR 252 is much harder to ignite than SR 44 with a laser diode, as well as more difficult to ignite with the thermal output of a focussed xenon lamp [9,10].

It may be observed in Table 1 that the proportion of successful ignitions at 0.5 ms (ave. 81 %) increased significantly in match head Batches 6 and 7 compared to Batches 1 and 2 (ave. 58 %). Improvements in the preparation of the match heads were made during this series of experiments, particularly in the cleavage of the optical fibre and examination of the optical fibre tip prior to match head preparation. The better cleaved optical fibres enable increased concentration of the laser energy at the tip of the fibre. Some differences also resulted from the viscosity of the pyrotechnic slurry as this may affect intimate contact between the surface of the optical fibre and the pyrotechnic. The slurry viscosity depends on the amount of acetone present, since this solvent evaporates readily.

For a bi-composition match head, as shown in Figure 2, with SR 44 based ignition composition transferring ignition to a flashing composition based on SR 252, the following results were obtained (Table 2).

Table 2. Number of ignitions vs. pulse length for bi-composition match head

Bi-composition Batch Number, with no. of match heads in brackets	No. of Ignitions at 0.5 ms	No. of Ignitions at 1.0 ms	No. of Ignitions at 2.0 ms	No. of Ignitions at 4 ms
1 (7)	2	1	3	1
2 (8)	3	-	3	2
3 (8)	6	-	1	1
Total (23)	11	1	7	4

Initial ignition of the bi-composition match head was only achieved 48% of the time, compared to 63% of the time for the mono-composition match head. However variation in the results for the bi-composition match head is more marked than for the mono-composition match head. This variation is attributed to differences between the batches of composition, and to differences in both the preparation of the optical fibre and to the slurry coating deposition onto the fibre tip. Some improvement in the techniques for making the match heads were made, as for the mono-composition match head, and this is reflected in the third series of compositions in Table 2.

Where ignition was not achieved with the initial 0.5 ms pulse, it is possible that the match head has become altered so that the second pulse duration of 1 ms strikes either a sensitised or a de-sensitised less-receptive match head composition. Single pulses of 2 ms duration were however observed to ignite match heads without being exposed to prior laser pulses. Previous studies with these compositions have noted that when ignition is not achieved, cratering of the composition and deposition of partially reacted products may cause obscuration of a transmitting window [9,10]. Where the optical fibre tip is 0.5 mm from the bare face of the pyrotechnic composition the obscuration effect was no longer observed [9,10]. The relatively small size of the sample studied and the wide variation in match head response precludes a full statistical analysis of the effect of multiple firings in this study.

It has also been noted in the literature [1] that at short pulse durations pyrotechnic ignition may be characterised by a threshold ignition energy density, while at long pulse durations sensitivity may be characterised by a threshold ignition power. The current study uses the same laser power for all ignitions, varying only the pulse length. In order to observe this effect of energy or power density different laser power levels would be required, and greatly increased pulse lengths could then be used at lower power. The objective of the current study was restricted to illustrating the practicality of laser match head ignition, and to test their reliability with a 1 W laser diode.

While about 81% of mono-composition match heads (Batches 6 & 7) ignited using a 0.5 ms pulse length, all mono-composition laser match heads had ignited after the pulse length was increased to 2 ms, thus delivering 2 mJ from the 1 W laser output. The optical fibre tip has a cross sectional area of 0.785 x 10^{-4} cm^2, therefore a 2.0 mJ pulse is equivalent to 25 J/cm^2 and 12.7 kW/cm^2. These energy densities are very high compared to studies by de Yong et al on a similar boron/potassium nitrate composition, 3 J/cm^2 at 10.6 µm [9]. While at 810 nm (60 ms pulse) an ignition power of 39 W/cm^2 was used to ignite SR 44 pressed pellets [10,11]. Much higher ignition pulse energies of 50-100 J/cm^2 were however used by Ostrowski et al [27] for boron/potassium nitrate at 694 nm. The relatively high energy densities employed in this study are partly attributed to the very small size of the optical fibre cross-section, as the optical fibre tip is in direct contact with the match head composition, as well as the low pulse lengths used. A 0.5 ms pulse results in a pulse energy density of about 6 J/cm^2, just twice that determined at 10.6 µm [9]. The comparison is displayed in Table 3.

Table 3. Comparison of pulse and power energy density for laser ignition of pyrotechnics

Study	Laser Wavelength	Ignition Energy (J/cm^2)	Ignition Power (W/cm^2)	Comment
Laser match head Mono-comp.	980 nm	25	12700	2 ms pulse, 100% ignition
Laser match head Mono-comp.	980 nm	6	3175	0.5 ms 81% ignition
de Yong [9]	10.6 µm	3		Approx. 10 to 100 ms at 75 to 400 W/cm^2 respectively
de Yong [10,11]	810 nm		39	60 ms pulse
Ostrowski [27]	694 nm	50 - 100	50000 - 100000	1 ms

It may be noted that laser match head ignition may be affected by reproducibility in preparing the optical fibre, as well in depositing the slurry on the optical fibre tip. As standardisation of laser match head preparation is further improved, it is envisaged that reliable ignition will occur at 0.5 mJ. Match heads composed of SR 44 based composition can also be readily coated with a less sensitive composition, such as that based on SR 252 to give different thermal properties to the laser match head on ignition. The outer flashing composition assists in protecting the more sensitive composition from accidental ignition due to impact or friction.

The concept used in this study is the same as that reported by Refouvelet and Baldy [28], however their laser match head used nitrocellulose based ignition paste. The presence of their patent precludes patenting of the laser match heads developed in this study. Curiously no clear application of the French ignition match heads has been identified in the literature, despite the apparently convenient and reliable attributes. In particular the laser match head requires no assembly to attach a pyrotechnic pellet to the optical fibre. Assemblies reported in the literature generally use a window between the tip of the optical fibre and the pellet, or a lens [1,9-11,20,23]. These ignition assemblies can be critically dependent upon the exact positioning of the optical fibre with respect to the pyrotechnic pellet or window, a distance of 0.5 mm for instance has been recommended for the tip to front sample face distance [9,10].

As predicted by de Yong et al [1], there has been significant growth in applications for laser ignition and laser initiation in weapons systems. Applications include emergency egress from high-speed aircraft, ejection seats and canopy severance [30,31]. Some of these applications have only been demonstrated and are yet to see production, while others have completed flight worthiness. Laser diode systems have been undergoing qualification testing for the Evolved Sea Sparrow Missile (ESSM), and pyrolasers are in development for single event initiation in the Sparrow and Sea Sparrow programs [31]. As hardening of initiation systems to radio frequency interference becomes more widespread further applications of laser ignition are expected.

4. Conclusion

A laser match head has been developed that can produce reliable ignition of pyrotechnics while avoiding the effects of electromagnetic fields, radio frequency absorption, electromagnetic pulses, electrostatic discharge or stray electrical energy on ignition wires. The laser match head is readily and cheaply prepared from a slurry of pyrotechnic composition, avoiding complex and expensive pyrotechnic assemblies. Pulse lengths of 2 ms from a 1 W diode laser at 980 nm are required to reliably ignite the laser match heads. The pyrotechnic match heads can also be conveniently coated with alternative pyrotechnic composition to be made less sensitive to impact or friction and to produce different thermal properties upon ignition.

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19. ABSTRACT

A reliable, cheap and simple pyrotechnic match head has been developed utilising a pyrotechnic slurry at the end of an optical fibre. A 1 W pulsed diode laser has been used to ignite the match head at pulse energies of about 2 mJ. The laser matchhead is a convenient means for ignition of pyrotechnic devices less prone to unintentional ignition from electromagnetic fields, radio frequency absorption, electromagnetic pulses, electrical discharge or stray electrical energy than conventional bridgewire matchheads connected to electrical cables. The laser match head can also be coated with layers of different pyrotechnic slurry in order to make the match head less friction and impact sensitive, and to give the match head different thermal ignition properties.

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