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REVIEW PAPER

Battlefield Lasers and Opto-electronics Systems

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ABSTRACT

During the last four decades or so, there has been an explosive growth in commercial, industrial, medical, scientific, technological, and above all, military usage of laser devices and systems. In fact, lasers have influenced every conceivable area of application during this period. While the expansion of non-military application spectrum of lasers is primarily driven by emergence of a large number of laser wavelengths followed by ever increasing power levels and reducing price tags at which those wavelengths could be generated, the military applications of lasers and related electro-optic devices have grown mainly because of technological maturity of the lasers that were born in the late 1960's and the early 1970's. Lasers have been used in various military applications since the early days of development that followed the invention of this magical device. There has been large scale proliferation of lasers and opto-electronic devices and systems for applications like range finding, target designation, target acquisition and tracking, precision guided munitions, etc. during 1970's and 1980's. These devices continue to improve in performance and find increased acceptance and usage in the contemporary battle-field scenario. Technological advances in optics, opto-electronics, and electronics, leading to more rugged, reliable, compact and efficient laser devices are largely responsible for making these indispensable in modern warfare. Past one decade or so has seen emergence of some new potential areas of usage. Some of these areas include rapid growth in the usage of lasers and opto-electronics devices and systems for electro-optic countermeasure (EOCM) applications, test and evaluation systems that can perform online functionality checks on military opto-electronics systems and also their interoperability. In this paper, an overview of the current and emerging military applications of lasers and opto-electronics systems has been given with an outline on the likely trends leading to performance enhancement of the existing systems and emergence of new application areas. Also, a brief on the developmental activity in the field of laser and opto-electronics devices and systems at Laser Science and Technology Centre (LASTEC), Delhi has been given.

Keywords: Laser, opto-electronic systems, laser devices, military usage, warfare, electro-optic countermeasures

1. INTRODUCTION

Laser though confined to premises of prominent research centres like Bell Laboratories, Hughes Research Laboratories and academic institutions like Columbia University in the early stages of its development and evolution, it is no longer so more than four-and-a-half decades after Theodore Maiman demonstrated the first laser in May 1960 at Hughes Research Laboratories. Laser, an acronym for light amplification by stimulated emission of radiation, as coined by Gould in his notebook, is a household name today. It is undoubtedly one of the greatest inventions of second half of twentieth century along with satellites, computers, and integrated circuits. Laser, which was called an invention in search of applications in 1960's, continues to be so even today due to the unlimited application potential it holds. Through there is an expanded use of lasers and laser technology in commercial, industrial, medical, scientific and military applications, the areas of its usage are multiplying and so are its applications in each one of those categories. There hardly has ever been an invention potent with such gigantic applications as the laser has proved to be in the past more than four decades of its existence.

1.1 Expanding Application Spectrum

The growth in the usage of laser devices has been phenomenal, particularly in the last fifteen to twenty years. During this period, we have not only seen the use of lasers in applications thought of in the early stages of lasers getting matured, we have also witnessed lasers making their presence effectively in many new areas. While on one hand, the systems meant for existing military applications continue to improve in terms of performance specifications and system engineering, lot of work is being done in technologically advanced countries to exploit the potential of lasers in a domain that is different from that of its existing usage.

The application spectrum of lasers is now not only limited to range finding, designation and direct energy weapons (DEW) applications. In fact the application spectrum of lasers for military applications is expanding at such a fast pace, beyond anyone's imagination. Many new concepts related to the use of lasers for military applications are being conceived that will attain maturity status in the next decade or so. Lasers are being used for satellite-to-submarine communication, for detection of tunnels and other underground objects on one hand to laser designation applications having

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global reach on the other. Non-lethal laser weapons at one corner of the globe can be used for dazzling troops at the other corner of the globe. In addition to gas dynamic and chemical lasers, solid state lasers are fast achieving higher power levels to be worthy of being used for directed energy weapons. An emerging concept in the field of directed energy weapons is to combine the laser and microwave technology to realise a more efficient and compact system.

2. DISTINGUISHING FEATURES OF LASERS

Unique properties of laser light that distinguish it from the conventional light sources include monochromaticity, directionality, coherence and intensity. Monochromaticity refers to single frequency or wavelength property of the radiation. Laser light is highly directional, which means that it spreads very little as it travels through the space. Coherence is indeed the most important of all properties that discriminates laser light from ordinary light from conventional sources. In a coherent light, all photons have the same phase and this phase relationship is preserved as a function of time. There is temporal coherence, which indicates coherence wrt time and spatial coherence, which is preservation of phase across the width of the beam. Extremely high intensity of laser light, which remains high even at long distances, is primarily due to low divergence associated with it.

3. TYPES OF LASERS

Looking at the present status of development of lasers, a large number of different types of lasers covering a wavelength spectra, from shorter than an Angstrom in vacuum ultraviolet to several millimeter in the far infrared, have been discovered by scientists the world over. Tens of thousands of laser wavelengths have been obtained in all kinds of laser media-in solids, liquids, gases, plastics, jet engine exhausts, flames, and so on. Of course, not all of them are potent enough to be generated cost effectively or matured in to useful laser devices for any meaningful application. But it does indicate the amount of interest being taken by researchers and also the quantum of funds being spent by various research and development organisations in the field of lasers. This is evident from their performance records in generating the highest powers, the shortest pulses, the greatest frequency stability, and the lowest noise figures, and so on.

Looking at the laser types that are particularly important for battlefield applications, vis-à- vis, the entire gamut of available laser devices, it is a clear tilt towards a specific class of lasers. Though there are a large variety of solid-state lasers, semiconductor lasers, gas lasers, dye lasers, ion lasers, free electron lasers, x-ray lasers, gas dynamic lasers, chemical lasers, and so on with majority of these categories further having a large number of different lasers, it is found that mainly the solid-state lasers, and to some extent that gas lasers, cover almost all military applications. And even amongst the solid-state lasers, it is the neodymium-doped lasers that rule the supreme as far as better known military applications are concerned. In the following paragraphs, at the current status of the battlefield use of lasers are covered and see how neodymium-doped lasers have dominated the scene as far as better known military applications are concerned.

In the field of high power lasers of DEW class, there are gas dynamic lasers (GDL) and the chemical lasers. Under chemical lasers, we have hydrogen fluoride/deuterium fluoride (HF/DF) lasers and also the upcoming chemical oxygen iodine laser (COIL). A gas dynamic laser achieves population inversion by rapid expansion of high-temperature, high-pressure laser gas mixture to a near vacuum in an adiabatic process through nozzles. Though the expansion reduces the gas temperature, a large number of excited molecules are still in the upper laser level. The cavity axis is transverse to the direction of gas flow. The high-temperature, high-pressure gas mixture is created in a combustion reaction and laser is called combustion driven gas dynamic laser (CD-GDL). This type of laser, which is capable of producing hundreds of kW of continuons wave power at 10.6 μm assumed importance as a potential HPL weapon but it has certain limitations due to heavy absorption of 10.6 μm wavelength by water vapour in the atmosphere. Interest in chemical lasers has assumed significance due to their potential as high power/energy laser weapons for battlefield applications. There are HF and DF lasers respectively emitting at 2.6–3.0 μ and 3.6–4 μ bands, respectively and the fast emerging COIL emitting at 1.3 μ.

3.1 Battlefield Lasers

Better known applications of battlefield lasers include range finding, target designation, target tracking, and guidance. There would hardly be any platform that is not equipped with some kind of laser device. For instance, one can not imagine a modern battlefield tank whose fire control system does not utilise the services of a laser range finder. It is true for other forms of armoured combat vehicles too. Interestingly enough, these devices are in use even in conjunction with squad weapons like assault rifles, light machine guns (LMG), and so on[1]. Small low-cost, low-power semiconductor diode laser modules with provision of precise X-Y movement are finding widespread use on squad weapons for target aiming and pointing, particularly during night operations. This increases weapon's effectiveness by improving the single shot, target hit probability, and reducing the collateral damage. LASTEC has also developed a laser aiming aid for a similar role, which is currently in production at Opto-electronics Factory, Dehradun, under the trade name of *INSA-LAKSHYA*.

3.1.1 Laser Range Finders and Target Designators

The laser range finders used on land-based platforms, either as a stand-alone system or as a part of the integrated fire control system are usually low-repetition rate systems producing laser pulses in the range of 5 pulses/min to 30 pulses/min. Due to advances in electronics and electro-optic technologies, these are available as compact hand-held devices similar in appearance to binoculars (Fig. 1).

Figure 1. Laser range finders.

Another class of range finders that combine the functions of target designation and range finding for munitions guidance, or those which form the sub-system of an overall laser tracker, has relatively much higher repetition rates in the range of 10 pulses/s to 50 pulses/s. Figure 2 shows one such portable ground-based laser designator. These lasers are not only becoming smaller in size, these are now available with additional features to give them in many built counter-countermeasure capability against similar systems developed by the adversary in an electro-optic countermeasure role.

Figure 2. Portable ground-based laser designator.

As the neodymium-doped YAG and glass range finders emit at 1064 nm, which has a serious eye hazard, the personnel using these always run the risk of being exposed to this hazardous radiation. The eye protection for the friendly troops comes in the form of safety goggles, which attenuate the harmful laser radiation to an absolutely safe level. This has also led to the development of eye-safe laser range finders and target designators. The low repetition rate class of range finders discussed earlier is being gradually replaced by eye-safe versions. Eye safe lasers emit at 1540 nm. Low repetition rate lasers usually employ erbium-doped glass as the active medium. However, erbium-doped glass is not suitable for high repetition rate lasers due to poor thermal conductivity of the glass host. Raman-shifted YAG and OPO-based YAG lasers have emerged as very strong contenders for building high repetition rate laser sources for target designation applications.

Diode-pumped solid state lasers, due to higher efficiency and consequent smaller size and lower weight have already found their place in the inventory of Armed Forces. It will not be long before the diode-pumped versions will completely replace the flash-pumped lasers for battlefield applications. Figure 3 shows a semiconductor diode-based laser range finder.

Figure 3. Semiconductor diode-based laser range finder.

4. EMERGING CONCEPTS

4.1 Laser Target Designators

An emerging concept, which will become a reality in the next decade or so, is the use of laser target designators to illuminate targets located few hundreds of kilometer from them. Such a system makes use of a space-based optical reflector. One such system is shown in Fig. 4. The system employs a optically flat reflector in MEO orbit and an image sensor on ground. The target area is identified and is imaged using the space reflector as mirror. When the exact target location is determined, the laser beam from the designator is reflected from the same reflector and placed on the target.

Another topology can be to have the image sensor also positioned in the space along with the reflector as shown in Fig. 5.

4.2 Detection of Mines, Tunnels, Facilities

One of the other potent uses of lasers can be for detection of buried mines, tunnels and other underground facilities and activities. The laser system in this case is deployed on an unmanned aircraft for aerial surveillance. The principle of operation of such a system will be that the laser beam reflected from a vibrating object will be frequency shifted due to Doppler’s effect. By measuring the frequency shift, the vibration frequency of the target can be determined, and hence, the target can be identified.

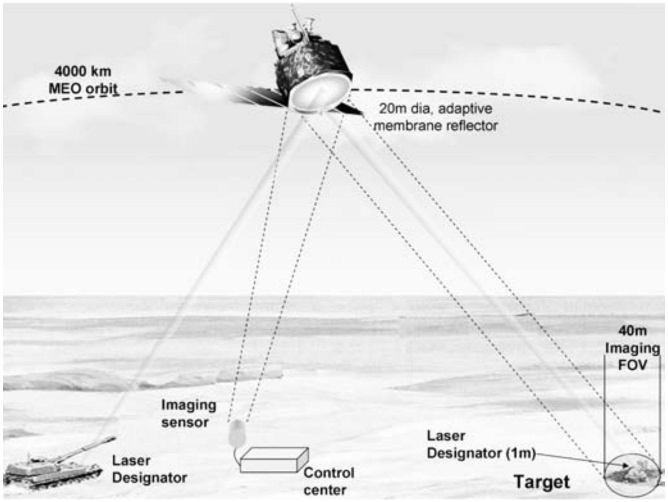

Figure 4. Long-range laser target designator with remote sensor on ground.

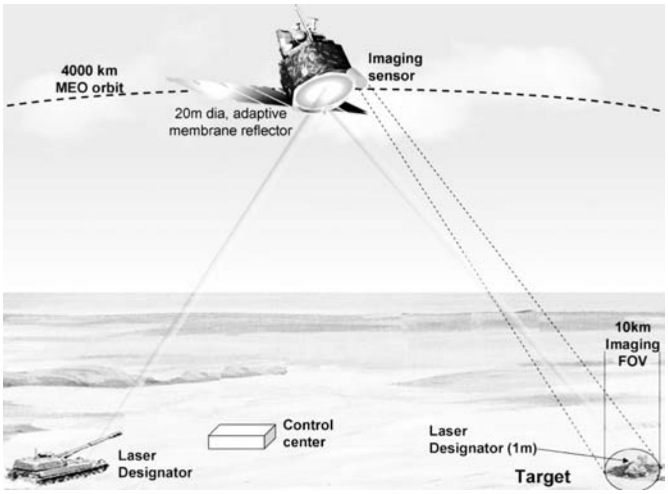

Figure 5. Long-range laser target designator with remote sensor in space.

4.3 Satellite-to-Submarine Communication

Yet another futuristic battlefield use of lasers can be for satellite-to-submarine communication applications (Fig. 6). The system uses blue-green laser systems placed on the satellite and large number of laser beams are directed at random places so as not to divulge the location of the ships. An optical sensor is placed on the ship, viewing in the upward direction which is used for receiving the signals from the satellite.

5. ELECTRO-OPTIC COUNTERMEASURES

One of the newer types of laser systems that have found recognition and wide acceptance by the Armed Forces in recent times is the laser systems that can offer effective countermeasures against those laser systems already in use. The relevance and importance of electro-optic countermeasure (EOCM) equipment in general and EOCM

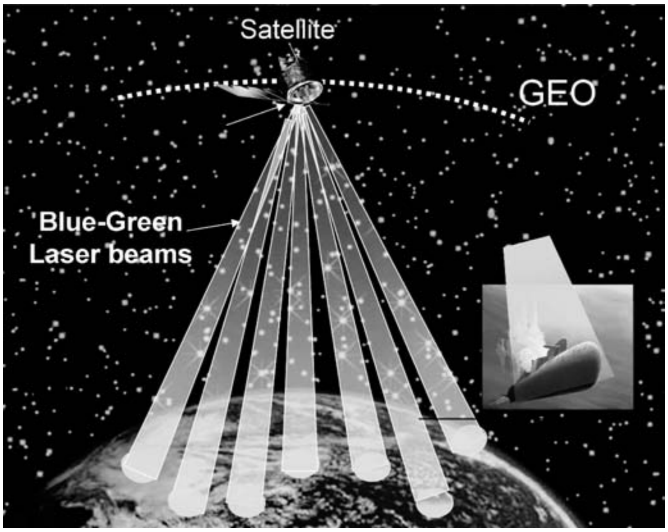

Figure 6. Satellite-to-submarine communication using lasers.

lasers of different types in particular stems form the fact that there is a large-scale use of electro-optic devices such as sighting and observation devices and laser systems such as those used for target range finding and designation in the contemporary battlefield today. Laser technology is quite mature today, which is leading to induction of laser devices in the Armed Forces for many new applications not thought of some time ago. This has led to a planned and concerted effort on the part of developed countries to develop and deploy EOCM systems to enhance the survivability quotient of the Armed Forces equipped with such a capability.

5.1 Types of EOCM Equipment

There are two broad categories of EOCM equipment including the EOCM class of lasers such as anti-sensor lasers and laser dazzlers, and the support devices such as laser threat detection systems. In the category of anti-sensor systems, the EOCM systems that are capable of causing only a temporary disability of electro-optic devices and opto-electronic sensors deployed by the adversary and also the systems that are capable of inflicting a permanent damage. In both cases, the target is the front-end optics and opto-electronic sensors. These are also sometimes referred to as soft-kill EOCM systems.

LASTEC has developed a dual role EOCM system capable of operating in anti-sensor and dazzling roles and having maximum operational range of 2.5 km. These systems by no means have the capability of inflicting a physical or structural damage to the platform carrying those systems. There are hard-kill EOCM systems that are capable of inflicting a physical damage to the front-end optics of any electrooptical system. These systems are usually vehicle-mounted and are much larger in size and weight than their soft-kill counterparts. The pulse energy levels in such lasers is of the order of several kilo-joules as compared to a few Joules in case of soft-kill systems.

5.1.1 Laser Dazzler

Laser dazzler is the other popular device that has been grouped under the EOCM lasers with the difference that a dazzler works on the biological sensor, i.e., human eye, rather than the opto-electronic sensors. These devices are non-lethal and eye-safe, which implies that such devices would cause only a temporary dazzling effect and not a lasting injury of any kind to the unaided eyes. Laser dazzler is very effective, both in the battlefield as well as for counter-insurgency operations due to its inherent surprise element and the least collateral damage associated with it. These features also make it the preferred choice when the Armed Forces are out on a peacekeeping or humanitarian mission. LASTEC has also developed a short-range hand-held laser dazzler with maximum operational range of 50 m (Fig. 7). The technology of the device has been transferred to production agency.

Figure 7. Hand-held short-range laser dazzler developed at LASTEC.

5.1.2 Laser Warning System

Laser warning system is invariably an integral part of any anti-sensor EOCM system. For example, knowledge of the type of laser threat and the angle-of-arrival of the laser beam may be used to trigger a cluster of aerosol/ smoke grenades to block laser radiation. This allows one to take an evasive action during those 50 s to 60 s for which smoke/aerosol screen remains effective. This type of defensive countermeasure action is particularly effective against laser-guided bombs (LGB). LASTEC has developed a precision laser warning sensor having a spectral coverage from 700 nm to 1600 nm and an angle-of-arrival accuracy of ± 3°, as shown in Fig. 8. In the case of active countermeasures system equipped with suitable laser emitters, the information on the incoming laser threat is fed to the servo control system, which in turn re-orients the EOCM laser in the precise direction of the incoming laser radiation. Such a system is usually deployed against incoming anti-tank guided missiles (ATGMs).

6. EMERGING CONCEPTS

A laser dazzler system having a global coverage can be designed based on the concept highlighted in Fig. 9. The system includes a reflecting sphere placed in MEO orbit and a laser dazzler on the ground. The laser beam from the dazzler strikes the reflecting sphere, which in turn directs it on to the enemy troops.

Figure 8. Precision laser warning sensor for AFVs developed at LASTEC.

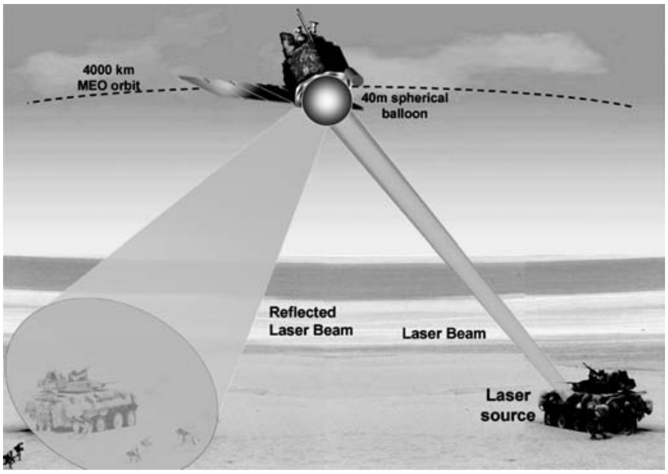

Figure 9. Laser dazzler with global reach.

7. ONLINE TESTING OF MILITARY OPTO-ELECTRONIC SYSTEMS

Another class of devices and systems that play a pivotal role in tactical warfare is the opto-electronic test systems that are used to perform serviceability check on critical electro-optical systems including precision guided munitions (PGM), laser warning systems, and other military opto-electronic systems[2]. Use of test devices that can perform online functionality checks on military opto-electronic systems is becoming increasingly important because of the tactical battlefield advantage these give to the user of these devices. These test systems provide functionality check on the vital parameters without removing the device-under-test (DUT) from the platform. Portable test systems, that can simulate the IR signatures of the target aircraft and the parameters of a laser target designators, are commercially available for online functionality check of IR-guided missiles and laser-guided munitions, respectively. LASTEC has done pioneering work in this field of battlefield opto-electronics by successfully developing a portable IR-guided missile tester and LGB tester. LASTEC has also developed a laser seeker evaluation system (Fig. 10) that can be used for comprehensive evaluation of known and unknown laser seeker units.

Opto-electronics sensors that allow interoperability of different EO systems on the inventory of different Armed Forces is another area that is drawing the attention of the user services. Future battles may see a laser target designator on the inventory of Army and a laser-guided bomb on the inventory of Air Force operating in tandem as one LGB delivery system. Laser spot detector fitted on the weapon-delivery platform could very easily achieve the intended objective.

Figure 10. Laser seeker evaluation system developed at LASTEC.

8. LASER-BASED DIRECTED ENERGY WEAPONS

One of the major areas of global interest for scientists, engineers, technologists, and war strategists today is that of DEWs. Two major categories of directed energy weapons include microwave-based DEWs and the laser-based DEWs. High power microwaves are high frequency pulses that require only a few ms to cause the damage. Laser-based DEWs on the other hand require a dwell time of typically few seconds. As DEW, the microwaves-based system is designed to produce the equivalent of electromagnetic interference to damage enemy's electronics. Due to concern about unintended side effects on the host platform, it is being considered to put such weapons only on unmanned combat air vehicles (UCAV). Also under consideration is use of high power microwaves as a weapon to attack underground and deeply buried targets that are resistant to high explosives.

Laser-based DEW is configured around a high power laser which has enough power, in the case of CW lasers, or sufficient energy per pulse in the case of pulsed lasers to cause the intended physical damage to the target. Countries like United States and Russia have already established feasibility of such weapons. Development of such laser systems, which can be used as weapons today is being pursued by not only the two above-mentioned countries but also many more including both developed as well as developing countries.

Though the lasers intended for already established applications, as outlined above in the preceding paragraph, will continue to improve as the newer technologies continue to evolve and develop, it is the use of lasers as a weapon called a directed energy weapon (DEW), a speed of light weapon that is going to rewrite the global military balance in the next 25 to 30 years from now. This new weapon is going to trigger a race amongst nations to develop different variance of laser weapons according to a report[3].

These weapons will play an increasingly dominant role in the first three decades of this century with the lasers rendering obsolete the traditional high tech weaponry and completely dominating battlefield. These laser weapons once matured and integrated on an aerial platform would have the capability to shoot down enemy aircraft and missiles over ranges in excess of 500 km. The power levels required in such applications are not enormous and are feasible to achieve in a practical size and weight. These lasers will give to the countries possessing them a capability to shoot down an intercontinental ballistic missile in its boost phase itself when it is highly vulnerable. Laser-based DEWs have generated a lot of interest amongst developed countries for anti-satellite applications. This is primarily due to the fact that satellites are particularly vulnerable to laser attack due to design criticality of thermal management system of a satellite. An anti-satellite laser weapon could afford to produce much lower target irradiance (of about 5 – 10 W/cm^2) for an extended time of 100 s to cause the damage.

Some of the prominent laser-based DEW systems include high energy laser (HEL) system for use as an air defence (AD) system against low-flying, high-performance battlefield aircraft, missiles and attack helicopters, TRW's general area defence integrated anti-missile laser system (GARDIAN), TRW's mid infrared advanced chemical laser (MIRACL) , which is a mega watt class CW deuterium fluoride laser, high energy laser weapon system (HELWEPS), which is again a chemical laser using ethylene, hydrogen and fluorinated nitrogen as the active medium, airborne laser (ABL) (Fig. 11) of the USA. configured around COIL, advanced tactical laser (ATL), which also uses COIL, tactical high energy laser (THEL) (Fig. 12), which is a tactical air defence system for use against short-range rockets and mobile version of THEL (M-THEL) system.

9. EMERGING CONCEPTS

An emerging concept in the field of high power lasers is to use solid state lasers with output power levels for few kWs for destroying the enemy targets at a range of 1-3 km. One such application is the use of lasers for mine diffusion. A typical high power solidstate laser-based mine

Figure 11. Airborne laser.

Figure 12. Tactical high energy laser.

neutralisation system mounted on a vehicular platform is shown in Fig. 13.

Another emerging concept in this field is to combine the high power laser and high power microwave technologies to design more powerful, yet smaller, electronic jammers for ballistic missile defence. The concept employs an ultra-short laser pulse propagating through the atmosphere. This laser pulse ionizes the air molecules, thereby creating an ionized channel in the air. This ionized channel is then used for transferring high voltage electrical pulses or intense microwave pulses to the target.

10. CONCLUSIONS

The 21st century is going to witness a large-scale proliferation of laser systems in the Armed Forces around the globe. There will be expansion in the already established military applications of lasers. Development and subsequent use of low-energy laser weapons, also called EOCM class laser systems will gain momentum. Different variants of these systems equipped with appropriate sighting or/and tracking mechanisms for day-night operation for anti-sensor and anti personnel applications will be inducted into Armed Forces on rifle tops battlefield tanks and fighting vehicles in large numbers.

Lasers are destined to become multi-functional to combine in one system the functions of range finding, target designation, target identification, and tracking. Individual sensors are going to be replaced by sensor suites that would offer multi-spectral sensing to provide reduced false alarm performance and long-range precision target detection and track[4]. Opto-electronic devices and systems that perform online functionality checks on military opto-electronic systems would assume importance and so would optoelectronic

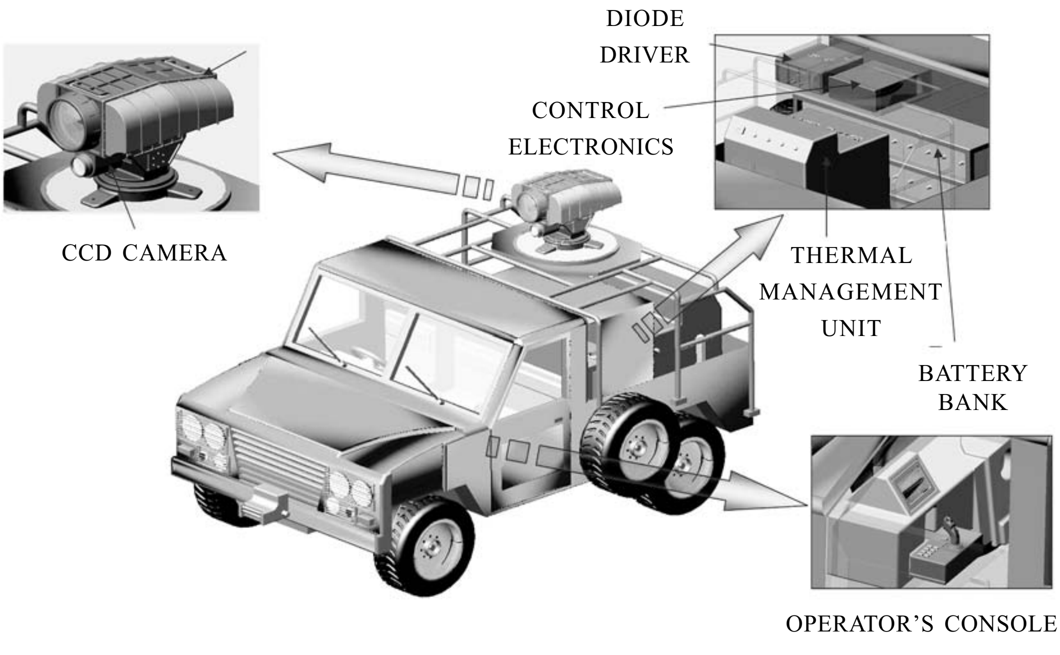

Figure 13. Laser for mine diffusion.

systems that facilitate interoperability of the three Armed Forces. Target signature measurement, modelling and management would facilitate denying the adversary acquisition of friendly force assets by threat sensors. Technologies will be developed to enable system capabilities for solid state, eye-safe lasers for long-range precision track and target identification.

Billions of dollars are being spent on development of high-energy laser weapons capable of shooting down aircraft, missiles from short ranges as well as from hundreds of kilometers away from the target. These airborne weapons of this class will be able to defend air bases, ports and aircraft carriers from ballistic missile attacks.

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