Directed Energy Weapons

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Introduction

As we begin the 21st Century, the perceptions of military might and defence preparedness are changing significantly as compared to the years of the Cold War. The progress of defence technology can be closely linked to man's pursuit of electro-magnetic (EM) spectrum towards higher frequencies and efficiency as this has opened up new application potentials, and today the decisive impact of technology on warfare is more pronounced than ever before. Nuclear weapons, missile technology and surveillance technologies have emerged as the major factors that determine the power balance equations. The 21st Century, however, is likely to be dominated by technologies that can either defeat or reduce the strategic importance of these winner technologies of the 20th Century. Besides information technology (IT), directed energy weapon (DEW) is clearly emerging as the future technology to watch. Rapid advances, successful tests and deployable maturity of DEW within the next eight to 10 years may indeed influence the world power equations significantly.

Interest in use of EM energy as a weapon can be traced back to 1939 efforts at the TH Moray's laboratory in Salt Lake city, where promising work was established in 'Radiant Energy Amplifiers' and even to earlier experiments by Nikola Tesla on creation of very high flux of EM pulsed radiation that could produce atmospheric sparks. However, World War II and the arrival of nuclear weapons overshadowed further continued work in this field. References can be found to a lot of secret work both in the USA and erstwhile Soviet Union during the 1950s and 1960s on electro magnetic pulse (EMP) devices and their potential use as a weapon of mass disruption. Until the 1963 ban on atmospheric

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nuclear testing, many experiments were carried out to establish the effects of nuclear explosions in atmosphere as well as under sea. However, most of this knowledge and further work on EMP continues to be highly classified. 1970s and 1980s were witness to rapid advances in high power laser (HPL) technology as also some progress in high power microwave (HPM) technology. These have emerged as the main candidates for the DEW applications, with HPL having a clear lead over HPM in terms of range, accuracy and technological maturity.

A perception that erstwhile Soviet light amplification by stimulated emission of radiation (laser) work was edging ahead of the US efforts was one of the reasons for President Reagan's announcement of Strategic Defence Initiatives (SDI) in 1983. Although many perceive the SDI as too ambitious and some of the exotic space based laser weapon concepts of SDI have remained un-realised, in reality the SDI very much achieved its objective of spurring US Research and Development (R and D) in DEW and associated technologies and thereby ultimately defeating the Soviets in the technology race. The potential of HPL based DEW for tactical air defence, missile defence and anti-satellite applications is beyond doubt, as proved by several HPL tests in the past five to seven years. While advanced nations like the USA and Russia are already addressing engineering problems for effective deployment of such energy weapons, the technology levels needed for such systems appear to be within reach of several other progressive nations, such as Israel, Japan, Germany, UK, France, China and India. Laser technology progress has been quite phenomenal with demonstrated capabilities for hitherto impossible applications for defence and space. This paper, therefore, focuses primarily on HPL and their defence applications that are poised to make a major impact in the future.

HPL based DEW (HPL-DEW) have emerged as one of the most revolutionary class of weapons for the 21st Century. The existing technological maturity now allows confident anticipation for weapon applications. The ground based deployment of laser DEW for air defence against rockets and missiles has been already established by the joint US-Israel team and inter continental ballistic missile (ICBM) defence by use of air borne laser (ABL) is expected to be proved by the US Air Force in the next eight to 10 years. Pentagon planners envision a futuristic concept involving extensive use of ground based and space based laser weaponry as part of the National Missile Defence (NMD) programme. This will inevitably lead to space deployment of laser weapons with significant anti satellite (A-SAT) capabilities. Global influence of this new class of DEW will most likely rewrite the ground rules for the future warfare doctrines and world power equations.

While much has been written about the Revolution in Military Affairs (RMA) on account of the introduction of smart weapons and information technology in the networked centric warfare (NCW) techniques of the present day, the new dimensions of DEW and space based weapons are likely to bring about a yet another RMA, contours of which are yet to be clear.

In the last few years, the capability of laser weapons to destroy or disable soft targets was experimentally tested and some demonstrations of lethal effects have been confirmed. The technology required to implement such weapons in compact packages suitable for integration on combat platforms are now coming to maturity. Numerous advances, some of them even radical, have been made in the type of source devices, efficiency, power generation, thermal management, beam control, sensor, control electronics, optics, and control systems. Advanced air defence and defence against low flying rockets and missiles are now a battlefield reality and collectively these advances confirm the viability of HPL-DEW, which not only match the initial vision but in some cases far exceed it. While advanced countries like the USA and Russia are on the brink of introducing the DEW for revolutionary effects on future warfare, many other progressive nations see the technology well within reach in the next 10 years.

The function of a DEW class of weapon is to place on target, sufficient fluence (joules/cm^2) or irradiance (watts/cm^2) to inflict lethal damage or at least disable some critical component of the target. Laser DEW thus has two levels of applications, one for electro optic counter measures (EOCM) where relatively low energy laser is used to disable hostile sensors or damage front-end optics. The other level of application is the use of HPL for direct structural damage to attack enemy platform or weapon system. A typical tactical surface to air application of DEW will, however, have certain range limitations mainly due to atmospheric propagation losses. The effective 'radiation fluence' on the target is the critical lethal parameter for HPL weapons. Focusing on the vital small area of the target that will yield the most lethal effect, is the key to achieve DEW class of weapons that are energy efficient. For direct structural damage to military targets such as aerostat platform, unmanned air vehicles (UAVs), artillery rockets, cruise missiles, anti-ship missiles, or attack helicopters or aircraft, the typical effective atmospheric ranges may be limited to five to 10 km and for anti-sensor EOCM application corresponding operating ranges may be up to 10 to 20 km within the atmosphere. But if deployed outside the dense atmosphere, the lethal range can be extended to 1000s of km. HPL technology thus has the potential to add a new dimension to missile and space defence.

Special Features of Laser Weapons

Laser DEW have many unique features that make them a class by themselves. These can supplement the conventional defence in hitherto impossible areas. Some of the important characteristics of lasers for DEW applications are:-

(a) **Extremely High Speed.** Laser weapons fire laser beams that travel at the speed of light. Flight time to the target is thus negligible, achieving a hit as soon as fired, with no path corrections needed.

(b) **High Pointing Accuracy.** The coherent nature of laser beam causes very little divergence and with additional beam directing optics it is possible to achieve diffraction limited spot at far distances. Divergence values of 0.01 m-radian are easily achievable thus allowing 1cm accuracy at 1 km.

(c) **No Inertia and 'G' Effect.** Laser beam steering and pointing is practically without any inertia and the light bullet has no mass and hence no 'G' effects to correct for.

(d) **Deep Magazine.** For typical chemical laser large number of shots can be fired with a given charge of fuel. It is thus possible to fire bursts of HPL several times at an approaching target within the interaction window or the continuous wave HPL (CW-HPL) can be trained on to the target for several seconds to achieve disabling or destruction of the target.

(e) **Ultra Fast Response.** Current ship-borne missiles and guns are powerless against a dense saturation attack. However, laser weapons can quickly change the direction of fire by turning a control mirror, rapidly switching from one target to another in a fraction of a second.

(f) **High Probability of Intercept.** Unlike conventional weapons, laser weapons work in direct line of sight for instantaneous interaction. Hence they offer sure shot aiming and are more effective at closer ranges. But strong laser beams can be equally effective at tactical distances with near 100 per cent probability of intercept.

(g) **Highly Cost Effective.** It is estimated that the cost of launching a tactical rnissile can vary from about 50,000 to 2.5 million US Dollars. A single high power laser shot, according to estimates, after including hardware and infrastructure costs, is about 5000 to 10,000 US Dollars.

(h) **Simple Support Services.** Laser weapon systems employ energy, and not traditional shells or missiles and hence the fuel required such as gases or chemicals are relatively easy to handle or store with simpler support services.

(j) **Atmospheric Propagation Limitations.** One major limitation of laser weapon system is the adverse effect of the atmosphere on the beam quality, which effectively reduces the power density delivered on the target. One way to compensate is to have more source power, but this could also often aggravate the atmospheric effects. Innovative adaptive optical techniques are, therefore, used to correct the aberrations and beam degradations to restore the effectiveness of laser DEW systems.

HPL-DEW : International Scenario

The strategic value of HPL was recognised very early by both the US and the erstwhile Soviet Union and several secret and well funded R and D efforts over the past 20 to 30 years have resulted in the present significant level of technology capabilities. The US Air Force was one of the first to invest in HPL work and Project "8th Card" was initiated in 1970, for intensive laser development at the Kirtland Air Force base. One of the first efforts to develop a prototype laser weapon was the Mobile Test Unit (MTU) by the US Army in the mid-1970s. A 30-kilowatt (KW) electrically excited CO_2 laser was literally squeezed into a Marine Corps LVTP-7 tracked landing vehicle. The first success was in 1973, when a MQM-61A target drone, at a speed of 300 km/hr was shot down with a ground based CO_2-GDL (Gas Dynamic Laser) of 100 KW power. In 1975, at Redstone Arsenal in Alabama, apart from the US winged target drones the MTU also destroyed helicopter target drones. The combination of CO_2 and Nd: YAG lasers led to the Close-Combat Laser Weapon (C-CLAW) dubbed 'Roadrunner' by the US Army, which by 1985, successfully shot down a TITAN-I missile. In 1989, the same laser system was reported to have shot down a 'Vandal' missile flying at 2.2 mach. This was designed to attack enemy sensors, night vision equipment, and helicopter cockpits with a combination of relatively low-powered Nd: YAG and CO_2 lasers.

Yet another early success was the 1978 demonstration of destruction of tube launched optically controlled wire guided (TOW) missiles with a 400 KW deuterium flouride (DF) laser by the US Navy. In the late 1970s, a German company, Diehl, worked on a concept for a laser weapon carried by a 28-ton armoured tracked vehicle. It was based on a self contained electrically excited CO_2 laser. Meanwhile in 1983 five air to air Sidewinder missiles were destroyed by the Airborne Laser Lab (ALL) of US Air Force which used a 400 kw CO_2 GDL on board a KC-135 transport aircraft. This success was largely responsible for the SDI initiative of the US President announced in 1983. One very interesting high energy laser (HEL) development is the Mid Infra-Red Advanced Chemical Laser (MIRACL) coupled with the Sea Lite Beam Director (SLBD). MIRACL is a DF laser with a 2.2 megawatt (MW) output at 3,800 nanometers. Sea Lite is the beam steering device for the laser with 1.8 metre diameter directing optics. Some rather spectacular and thought provoking demonstrations have been made with this system at the High Energy Laser System Test Facility (HELSTF) at White Sands Missile Range, New Mexico. In 1987 the US Navy used the MIRACL at the missile test range to shoot down a BQM-34S target aircraft, flying at 256 m/s at altitude of over 800 metres. Reports of the various tests by Strategic Defence Initiative Organisation (SDIO) or Defence Advanced Research Project Agency (DARPA) funded US defence projects indicate varying levels of success and failures during these formative years for the HPL-DEW technology.

R and D of HEL weapon systems is proceeding in France also. The system named Laser Associe' A une Tourelle Experimentale (LATEX) consists of a laser in the 10 mw range coupled to an advanced aiming system developed by Laserdot. The programme was started by the General Delegation for Armament in 1986 and has advanced to a preliminary test carried out at Marcoussis in France over a range of about 200 metres against a missile head and an aircraft fuselage panel. It has been reported that trials will proceed in Landes, in southwest France, against a target flying at 300 yards per second at a range of 1.25 miles. China has also accelerated its HPL development programme and is believed to possess adequate capability for rudimentary missile defence and A-SAT applications.

One of the most interesting HEL weapon projects is the German air defence system called High Energy Laser Experimental (HELEX), which is a joint project between Diehl in Nuremberg and the German company MBB in Munich. The main component of the HELEX is a CO_2 GDL, which emits an average beam power of several megawatts over the specified time. To carry the laser and all of its accessories, the basic chassis from a German tank, Leopard 2, has been used. As laser weapons have a direct sight action, it is important to position the laser beam above the tops of surrounding trees and buildings. This problem is solved by using an elevator platform to carry a focusing mirror of about one metre in diameter along with the passive surveillance and target acquisition system. The area of coverage of the HELEX is also increased by the elevated platform.

The fact that so many papers on HEL and their effects have been published in erstwhile Soviet scientific journals is an indication of the amount of work done in this field and, thus, revealed their strong interest in this technology. The former Soviet Union (FSU) had developed Nd:YAG laser as a potent countermeasure to North Atlantic Treaty Organisation – Forward Looking Infrared (NATO – FLIR) sensors up to 20 km range. Unconfirmed reports of Soviet lasers blinding American spy satellites during the late 1980s did appear in the open media. It is estimated that at the time of Soviet collapse, there were more than 6000 battlefield lasers with the land forces alone. Kirov class battle cruisers are known to be fitted with MW level high power chemical lasers. The HEL weapon was said to be successfully used against the sensors of sea-skimming missiles out to a range of 10 miles. There have also been descriptions of the Soviet research facility at Sary Shagan in Kazakhstan following a visit by a delegation of US scientists in 1989. According to US analysts, a beam director with a diameter of approximately one metre was used in tests against both aircraft and satellite targets. The Royal Navy of UK is known to have deployed the Laser Dazzle Sight (LDS) on Type 22 frigate and Leander class frigates. The French Navy also successfully destroyed missile IR head with HPL gun in 1990. In 1995, China was first to market an anti-personal laser 'ZM-87' with a dual wavelength flash blinding capability up to 10 km. In 1978, the US Navy conducted a series of tests as part of the Unified Navy Field Test Programme at San Juan Capistrano in California, in which a chemical DF laser in the 400 KW range destroyed TOW antitank missiles in flight. To direct the laser to this target, which was comparatively small and fast, a Hughes aircraft aiming and tracking system was used. In 1980, a captive UH-1 helicopter was destroyed by this laser system.

Tactical High Energy Laser (THEL) is a short range, ground based air defence system under test and development by TRW Instruments for the US Army and the Israel Ministry of Defence. The device uses a high-energy, chemically generated DF laser beam to shoot down rockets. Israel has an urgent need to protect civilians and others living along its northern borders. In March 1995, Israel Defence Forces (IDF) signed up with the US Army the 'NAUTILUS' concept evaluation programme for use of HPL against possible rocket attacks. The THEL laser system is housed in several semi trailer-sized containers. The system has already demonstrated the capability to detect, acquire, track, and point the laser against operational Katyusha rockets in flight. The THEL demonstrator has destroyed more than 25 Katyusha rockets in flight during tests conducted in 2000 and 2001. Completion of the field testing of the THEL demonstrator at HELSTF is a crucial step before delivery of the system to Israel. In February 1996 the joint NAUTILUS team successfully destroyed a 122 mm artillery rocket in flight at the HELTF, using the MIRACL at fraction of the mw power capability to emulate the THEL application. In June 2000 the THEL system was tested successfully against Katyusha rockets and Israel is reported to have ordered 13 THEL systems from the company TRW Instruments for deployment on its vulnerable borders.

Today, the most important US-HPL programme is the Air-Borne Laser (ABL) project of the US Air Force that plans to have megawatt level high power Chemical Oxy-Iodine Lasers (COIL) on board a modified Boeing 747 aircraft. Flying at altitudes of over 12 km, the ABL system will be well above the dense layer of the atmosphere and hence capable of fairly large ranges of 600 km for possible anti ballistic missile (ABM) applications. Assisted by satellite early warning, and guided by the overall battle management system (BMS), a typical application scenario envisages acquisition and tracking of the ICBM by air-borne laser within 10 seconds of the rising missile breaking the cloud level of about 10 km. Within the next 30 to 40 seconds, the ABL is being designed to effectively shoot the ICBM with lethal laser energy, focused on the most vulnerable parts such as the fuel storage tanks of the missile. It is expected that a full one second exposure can rupture the missile body structure, causing the missile to explode in the atmosphere above the country that launched the ICBM, well before the multiple independent re-entry vehicles (MIRVs) could be discharged by the mother missile. The danger of any possible deadly fall out from any dirty warhead deployed, therefore, will be maximum for the country that launches the ICBM. The US Air Force programme envisages first ABL demonstrator in a year and deployment of a fleet of six ABL aircraft by 2007.

The Space Based Laser (SBL) programme has evolved based on a broad variety of technologies developed by SDIO of the US Government. Large Optics Demonstration Experiment (LODE), completed in 1987 provided the means to precisely control the HPL beams and the Large Advanced Mirror Program (LAMP) produced the 4 metre diameter space quality mirror. In 1991 the Alpha Laser (HF at 2.8 μ) developed by SDIO achieved megawatt power level at low-pressure environment similar to space. A number of Acquisition, Tracking, Pointing and Fire Control (ATP/FC) technologies have been developed for Rapid Retargeting and Precision Pointing (R2P2). In 1995, the Space Pointing Integrated Control Experiment (SPICE) demonstrated near weapon level results during testing.

In terms of HPL sources, the potential candidates include the GDL, the HF/DF Chemical Lasers, the COIL and the futuristic high average power Heat Capacity Solid State Laser (HCSSL). Presently, COIL looks very promising, although megawatt levels of power and high-pressure performance for tactical field deployment are yet to be reported by anybody. The HF-DF Chemical laser, which is more hazardous and expensive than COIL is, however, well established for megawatt level performance and hence the prime candidate for most near future applications. The GDL is the safest and least expensive HPL that has high potential in select application areas. However, in the complex high technology area of HPL systems, trade-off between reliability, safety, cost and efficiency is very common and all the HPL sources have their own plus points for different theatres of applications. For instance, while the optics aperture increases with longer wavelength, the complexity of adaptive optical components reduce as we use longer wavelengths. CO_2 GDL with its output at 10.6 mm is well suited for dry, clear weather, but is heavily absorbed by atmospheric moisture in adverse weather conditions. On the other hand, high toxicity of HF-DF chemical lasers may make them unsuited for deployment in terrestrial populated area, but somewhat better suited for ship based or space based applications.

The very promising supersonic COIL demands a very efficient high pressure singlet oxygen generator, the technology for which is very complex and still emerging. HEL weapons produce a huge internal amount of heat, and sustained operation at very high powers requires an effective system for the disposal of this wasted heat. In a gas laser, the high fuel flow serves to remove the excess heat, as the fuel is warmed by the laser reaction chamber and in the process cools the laser. As for the HCSSL, the technology for high power diode pumping and high heat capacity operation is yet to be achieved outside laboratory conditions and heat management and beam quality control for outdoor real deployment has many challenges to overcome.

HPL-DEW: The Indian Context

Given India's threat perceptions and the vital need for advance air defence and missile defence capability, it is extremely relevant that India should have robust indigenous capabilities in HPL technology. For a comparison, Israel which has to deal with similar threat of rockets and missiles from close ranges has already launched the 'NAUTILUS' HPL programme with US cooperation. It has already participated in successful tests of THEL-DEW system against artillery rockets. Similarly China which is now emerging as one of the future superpowers, has invested heavily in DEW technologies and is believed to have established substantial THEL capabilities as well as A-SAT technology potentials. Much like the nuclear and missile technology, the HPL technology is, therefore, already categorised as a sensitive strategic technology that is highly protected and of course denied to competing countries like India. Hence it is imperative that India should develop its own indigenous capabilities in this vital technology area of HPL and also the HPM, at the earliest.

While there is a general international consensus against the use of weapon in space, military and spy satellites of the advanced countries have been an integral part of defence apparatus for many years. Introduction of 'missile defence' will most certainly lead to weaponisation of space. The HPL technology by itself is multi-purpose and has potential space applications as well as important military applications for tactical, high precision air-defence, missile defence and even anti-satellite application potential. Like all technologies with far reaching strategic importance, the HPL-DEW technology has been first harnessed by the technology leaders who would like to maintain the technology advantage to themselves through tight export control regimes in the future and India must learn from the past experience and know that export control treaty to ban development and use of HPL-DEW by developing countries will be imposed sooner or later. Future is bound to see intense arms control measures on space technologies and only nations with established indigenous core competence will have the leverage to protect their legitimate interests in technologies for space control and space defence.

It is in this context that some preliminary R and D efforts in HPL were initiated by DRDO at the Laser Science and Technology Centre, (LASTEC), Delhi and significant progress has been achieved in the past six to seven years. Although started late, the work done under fast track projects has helped to establish a fair degree of indigenous know-how in all aspects of HPL-DEW technologies. Substantial expertise in GDL and beam control technologies has been acquired and technology demonstrations achieved with vehicle-mounted systems. Promising progress is also achieved in the futuristic supersonic COIL technology and work is in progress with large aperture optics and adaptive optics for outdoor testing and evaluation of atmospheric propagation effects and also for laser–target interaction studies. Promising results have also been achieved in the compact, high efficiency diode pumped solid state lasers (DPSSL).

Summary

DEW technologies are poised to make an important impact in the 21st Century. This is particularly so for HPL systems with potential space applications in the near future. HPL, although fairly large in terms of size and weight, are stand-alone systems capable of independent field deployment with very small demand of electric power. HPL systems demand integration of several key technologies but offer unprecedented flexibility, range, efficiency and accuracy for military applications. These are not area weapons and unsuited for any mass destruction. The technology will have a deep impact on space capabilities in future and hence is critical to national security. There is an urgent need to launch a major initiative to establish indigenous capability in HPL based DEW technology in the country. The main difficulties in India are lack of adequate trained manpower and non availability of critical materials and components from foreign sources due to strict export controls. Rapid build-up of indigenous capabilities will, however, require a national level programme with full co-operation between DRDO, Defence Services, Department of Atomic Energy (DAE), Indian Space Research Organisation (ISRO) and other relevant Science and Technology (S and T) institutions, universities and industry. Ambitious fast track projects backed by visionary leadership, adequate funding and robust manpower induction-training plan will be necessary to support such an initiative. All available inputs from friendly advanced countries must be availed at the earliest opportunity, because more and more restrictions on this strategic technology can be expected in the future. All this must be done at high priority, so that India has a fair chance to bridge the present technology gap of about 10 to 15 years in the foreseeable future.