Military Applications of the Laser

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Over the past fifty years, the laser has developed from a primitive apparatus to a ubiquitous tool in the world. Lasers are used in a wide range of devices including CD players and surgical instruments. Shortly after the laser was invented, the military saw great promise in the device and has been heavily involved in the research and development of better lasers. Currently, the military has uses for two main types of lasers, chemical lasers and solid state lasers. The lasers that the military has developed are used in a variety of weapons, the most important of which are laser-guidance systems, the "airborne laser", the tactical high energy laser, and the PHaSR. These four implementations of the laser are changing the way battles are fought both on the ground and in the sky.

In 1960, Theodore Maiman invented the world's first laser, a solid-state laser with ruby as its lasing media. Later that year, a group at Bell Laboratories created the first gas laser using helium and neon as its media. Although the laser was invented in 1960, the technology and knowledge to build one existed in 1917. It was in this year that Albert Einstein published his paper on stimulated emission, which is the principle involved in laser operation[1]. The basic physical device required to construct a laser is a gas discharge tube, which is used in neon signs and existed prior to the publication of Einstein's paper. With knowledge of stimulated emission and the availability of gas discharge tubes, the laser could have been created simply by adding a few mirrors and a power source, but this creative leap took upwards of forty years to finally occur.

The word laser is an acronym for "**l**ight **a**mplification by **s**timulated **e**mission of **r**adiation". The spelled out version of the word 'laser' gives the casual observer a very good idea of the mechanism of operation. Light is amplified inside of the laser due to repeated reflections off mirrors. The radiation emission of a laser comes from principles of quantum mechanics. When an atom is excited, its valence electrons move up to a higher energy shell. When the electron comes back down to its ground energy state, a photon of a single wavelength is emitted. The monochromatic nature of the emitted photon is due to the fact that the electron orbitals are precise distances apart. These so-called quantum leaps are responsible for the light emitted from a laser[1].

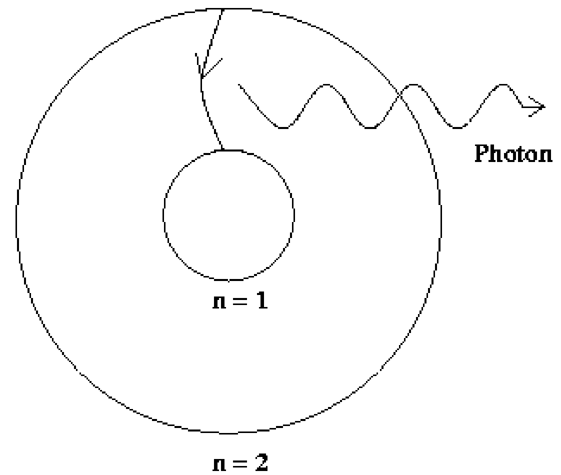

Figure 1: Photon emission by an atom[16]

Basic laser design is relatively simple and consists of only a few key elements. An excitable gain media, either gas or solid, is placed in a chamber between two mirrors, one of which is partially transparent. An optical or electrical energy source is used to excite the valence electrons of the gain media. During the energy pumping process, a point called population inversion is reached when more atoms exist in their excited state than in their ground state electron configuration. After population inversion, some atoms begin to drop back down to their ground configuration which results in the emission of a photon. These emitted photons then travel the length of the chamber, bouncing off the mirrors and stimulating other atoms to release photons of the exact same wavelength. This process is the "stimulated emission" part of the laser acronym that makes it different from other light sources. The stimulated emission continues until

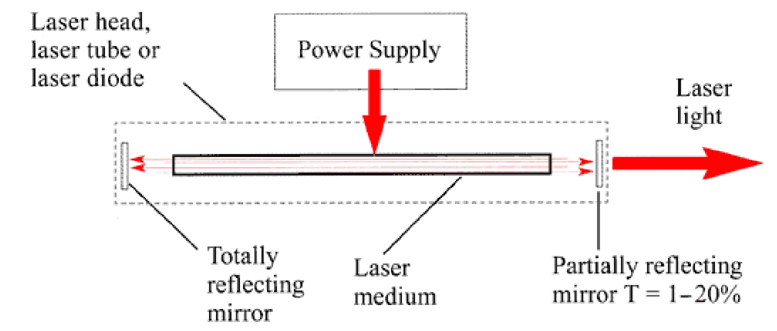

Figure 2: Laser Schematic[17]

the beam of photons inside the mirrored chamber reaches a certain intensity, at which point a monochromatic laser pulse is emitted from the partially transparent end of the chamber. This monochromatic pulse is unique to the laser and has characteristics that suit the device well for military use.

To date, the most useful laser for military purposes is the chemical laser, which is a class of gas laser. Chemical lasers use gas as their lasing media, and the most common gas media types are Hydrogen-Fluoride and Oxygen-Iodine. Power for these lasers is typically provided by electric pumping, but chemical reactions and optical means can also provide power[2]. Chemical lasers have several features that make them very useful for military applications including high beam quality, respectable energy efficiency, and the ability to produce more than 100 megawatts of power. Unfortunately, chemical lasers have two major faults that severely limit their future; they are incredibly bulky and their lasing media has a relatively brief shelf-life. Despite these drawbacks, chemical lasers have made their mark on military history and will continue to do so for years to come.

A mere eight years after the first laser came into being, the usefulness of the new invention was proven in the Vietnam War. In 1968, Raytheon developed and released the Paveway laser-guided bomb. This was a breakthrough munitions invention because it drastically improved the accuracy of bombs. Most laser-guided bombs are previously unguided bombs with a laser-guidance kit attached to them. This kit consists of a computer control group, guidance canards to enable proper steering, and a wing assembly attached to the back of the bomb which allows for maneuvering of the bomb toward the target. The target of the bomb is designated by a laser beam shone from the delivery plane, another aircraft, or a ground source[3]. The laser designator operates at infra-red frequencies and implements pulse-coding so that the enemy remains unaware of the imminent strike. Both the designator from the external source and the receiver on the bomb must be encoded properly to ensure that the correct target is hit. As long as the designator and the receiver share the same code, the bomb will travel towards its target.

Figure 2: Paveway II Laser-Guided Bomb[18]

Before the designator is turned on, the bomb is dropped from its carrier and begins its descent. The bomb's flight is divided into three stages, the first of which is the ballistic phase when the bomb free-falls without guidance towards its target. The second phase is the transition phase and is characterized by the receiver on the bomb picking up the laser signal on the ground target and utilizing its wings to hone in on the target. The third phase is the terminal guidance phase during which the laser-guided bomb makes a final adjustment to ensure that it is vectored in on the proper location, and as soon as this adjustment is made, the bomb returns to unguided free fall until impact[4].

Unfortunately, the laser-guided bomb is not without its drawbacks. If the laser is turned on too early, the bomb will pick up this signal and turn on its delivery path too early. This results in the bomb falling short of its target. The most physically relevant problem is that dust, fog, debris, and smoke all can cause the laser to diffract and scatter. Normally, lasers are incredibly focused beams of light with pin-point accuracy, but diffraction causes multiple beams to hit the ground, and the bomb will thus be delivered inaccurately[4]. Overall, laser-guided bombs have increased the effectiveness of airstrikes by reducing the amount of munitions used and time taken to eliminate targets.

Although Ronald Reagan's "Star Wars" system was never implemented, its main concept lives on in the belly of a Boeing 747-400[5]. The airborne laser (ABL), which is funded by the U.S. Missile Defense Agency, accomplishes the basic purpose of the system Reagan proposed in 1981[6]. The ABL is designed to locate launched enemy missiles, lock on to them, and eliminate them with a high powered laser pulse. The ability to do this provides a great means to ensure national security from ICBMs.

The ABL is housed in a Boeing 747-400 freight airplane that has been completely stripped and refitted with computers and batteries requisite for laser operation. The most striking modification of the plane is at the nose, where the traditional cone has been removed and replaced with a sphere that houses mirrors and serves as the aperture through which the laser pulses are fired. The 747 has been outfitted with infrared detectors and three different lasers. These devices are the functional components of the ABL system and work together to eliminate the target[7].

Figure 3: Airborne Laser[19]

The target of the ABL is a missile in its boost phase when it has a plume that is possible to track. Six infrared sensors initially detect the plume of the boosting missile[7]. Once the missile is detected, the track illuminator laser (TILL) is fired at the target to gather tracking information and determine a precise aiming point[8]. The TILL is a kilowatt class solid state laser that was developed by Northrop Grumman[7]. Next, the beacon illuminating laser (BILL) is fired and it detects atmospheric disturbances. These disturbances are then corrected for by an adaptive optics system, allowing for an accurate kill shot. With the target acquired and locked, the chemical oxygen-iodine laser (COIL) is fired. This laser is a chemical mega-watt class weapon that concentrates its energy on the missile's fuel casing. A few seconds after the COIL is fired the enemy rocket is completely destroyed[9].

In the summer of 2007 the ABL was tested at Edwards Air Force Base. The infrared trackers picked up a plume of exhaust from the test aircraft, at which point the TILL was fired and the tracking data was gathered. The test was successful and the target was locked and tracked by the solid-state laser. In upcoming tests, the BILL will also be fired to compensate for atmospheric irregularities. A full system test is scheduled to occur later in 2009 with the purpose of eliminating a launched test missile[8].

A missile defense system that is currently fully functional is the Nautilus tactical high energy laser (THEL), which was developed by the TRW Corporation for US and Israeli use. This system debuted in 2000 and successfully destroyed several Katyusha test rockets[10]. The THEL is a ground-based chemical laser that uses deuterium-fluoride as its media. An advantage this system has over traditional rolling airframe missile (RAM) defense is cost-effectiveness. A THEL kill costs about $3,000 compared to a very steep $444,000 for a RAM kill. It is not currently used by the U.S. but Israel plans to implement it in the near future[11]. The functionality of the THEL bodes very well for the ABL and laser systems that will be used by the U.S. in the future.

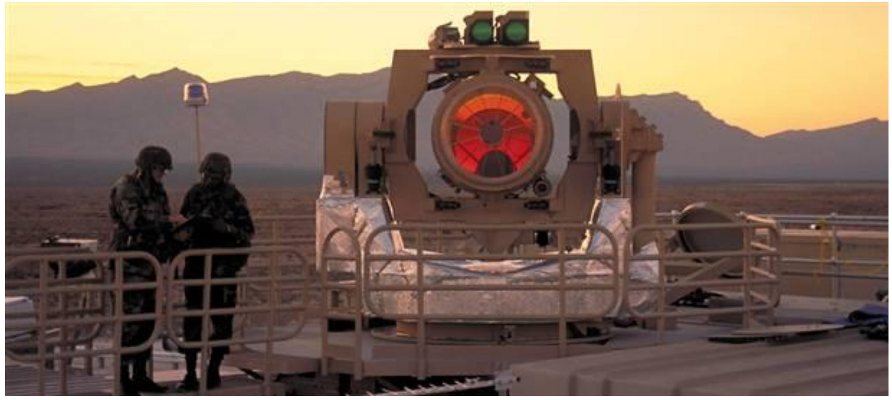
Figure 3: Nautilus tactical high energy laser[11]

While chemical based lasers have proven themselves capable of producing ample power, they have significant drawbacks such as bulk, longevity, and chemical hazards. However, solid state lasers are an up-and-coming technology that might address all of the problems of the chemical laser. Solid-state lasers (SSLs) operate in much the same manner as chemical lasers except that their lasing media is solid, not gaseous. Perks of solid-state lasers include much smaller size, infinite magazines, and long shelf life for the lasing media. These features make solid-state lasers very appealing for combat purposes and are why the military is spending great sums of money on SSL research[12]. The main drawback of this type of laser is that it lacks the power that chemical lasers have, but with more research and development, SSLs will be battle-ready in the near future.

One solid state weapon that has been developed is the PHaSR, which stands for Personnel Halting and Stimulation Response. The military has been trying to develop non-lethal long range weapons for a while, and the PHaSR is the first completed project without any significant drawbacks. The PHaSR is a portable weapon that fires two non-lethal lasers with the purpose of deterring incoming enemies. These lasers have an undisclosed solid-state gain media which uses low-power diode pumping as the energy source. One of the lasers emits a visible wavelength while the other operates in the mid-infrared range, and when fired, the weapon causes temporary disorientation of the target and impairs the enemy's ability to locate the laser source[13].

Figure 5: The PHaSR[13]

One of the problems with past systems like the PHaSR is that close-quarters use resulted in blinding, which is not allowed by the rules of war, and long-range use was generally ineffective. The system which preceded the PHaSR was the Saber 203, which was a simple laser that was loaded into the grenade launcher of an M-16 and emitted a single wavelength pulse. While convenient and easy to use, the Saber 203 was discontinued due to questions about its safety and efficacy. The developers of the PHaSR at Kirtland Air Force Base addressed these issues by incorporating a range finder that determines the maximum eye-safe energy that can be used. The ability to vary the energy of the pulses makes the PHaSR a viable battlefield weapon that can spare the lives of both forces on a battlefield[13].

While the PHaSR is an effective means to deter foes, the military is more interested in high-powered solid-state lasers capable of destroying targets. Currently, the U.S. Army is funding Northrop Grumman and Textron Systems to conduct the Joint High Power Solid-State Laser (JHPSSL) project. The aim of the project is to develop a high-energy laser system that can be incorporated in a variety of platforms including ships, manned aircraft, unmanned aerial vehicles (UAVs), and ground units[14]. Northrop Grumman has plans to use a solid-state laser in its TALON system which is a manned ground vehicle powered by hybrid electric motors. TALON's laser will be powered by the same type of motor as the drive-train and will be capable of eliminating mortars, rockets, and UAVs.

From its inception, the JHPSSL project has aimed to create a solid-state laser capable of producing 100 kilowatts, which is said to be the threshold of military-grade laser power. Roughly one month ago, Northrop Grumman announced that they had created a laser that produced 105.5 kilowatts. They accomplished this by linking seven 15 kilowatt lasers together, a method that until recently had only held true in theory. The laser is capable of maintaining 100+ kilowatts for over 85 minutes, a feat that is impossible for chemical lasers to accomplish. To provide perspective of the potential destructive power of a weapon like this, Boeing managed to down a UAV with a 1 kilowatt laser recently[15]. Boeing's weapon is much less useful because it takes a long time to eliminate the target, but a 100 kilowatt laser can eliminate a target in a matter of a fraction of a second. Northrop Grumman's laser is kept from overheating by pumping liquid coolant through the system, providing the laser with an unlimited magazine since powering a solid state laser is a non-issue and the gain media will not run out. The solid-state laser is still far from seeing the battlefields because it is underdeveloped and oversized. However, it does boast enormous potential and will surely be an asset to the military once it is scaled down and fully functional.

Figure 6: Northrop Grumman's TALON[20]

In the past fifty years, the laser has evolved from an interesting optical phenomenon with little use to an extremely advanced tool that has endless applications. The United States military realized the potential of the laser from the beginning and devoted resources to further the development process. It has taken quite some time to see the full capabilities of the laser, but battlefield ready weapons like the laser-guided bomb, PHaSR, and the THEL have altered what is now possible in combat. In the near future, the ABL and various solid state lasers will be fully functional and will further add to the United States' arsenal. All of these applications are made possible by the understanding of basic quantum mechanics and are now altering the way battles are fought.

References Cited

[1] Harbison, James P., and Robert E. Nahory. Lasers: Harnessing the Atom's Light. New York: Scientific American Library, 1998.

[2] "Gas Lasers." Encyclopedia of Laser Physics and Technology. 22 Nov. 2008. RP Photonics Consulting GmbH. 4 Apr. 2009 <http://www.rp-photonics.com/gas_lasers.html>.

[3] Sell, Christopher. "Deadly Accurate." Engineer 293.7708 (2006): 24-25. Academic Search Premier. EBSCO. U of Arkansas, Fayetteville, AR. 4 Apr. 2009 <http://search.ebscohost.com/>.

[4] "Laser Guided Bombs." Military Analysis Network. 12 Feb. 2000. Federation of American Scientists. 4 Apr. 2009 <http://www.fas.org/man/dod-101/sys/smart/lgb.htm>.

[5] Wilson, J. R. "Transforming the Battlefield: The Laser's Edge." Aerospace America Mar. 2007: 24-31. LexisNexis Academic. LexisNexis. U of Arkansas, Fayetteville, AR. 4 Apr. 2009 <http://web.lexis-nexis.com/universe>.

[6] Bloembergen, N. "Laser Technology in Peace and War." International Journal of Modern Physics B 18.26 (2004): 3373-3380. Academic Search Premier. EBSCO. U of Arkansas, Fayetteville, AR. 4 Apr. 2009 <http://search.ebscohost.com/>.

[7] Howard, Courtney E. "Weapons at the Speed of Light." Electro-Optics Supplement for Military & Aerospace Electronics Jan. 2008: 8-9. Academic Search Premier. EBSCO. U of Arkansas, Fayetteville, AR. 4 Apr. 2009 <http://search.ebscohost.com/>.

[8] McHale, John. "Laser Weapons: Moving from Promise to Performance." Military & Aerospace Electronics May 2007: 34-39. Academic Search Premier. EBSCO. U of Arkansas, Fayetteville, AR. 4 Apr. 2009 <http://search.ebscohost.com/>.

[9] Miller, John J. "Peace Through Light." National Review Aug. 2007: 22-24. Academic Search Premier. EBSCO. U of Arkansas, Fayetteville, AR. 4 Apr. 2009 <http://search.ebscohost.com/>.

[10] "Laser Gun Zaps Missile." BBC. 8 June 2000. 4 Apr. 2009 <http://news.bbc.co.uk/2/hi/science/ nature/782696.stm>.

[11] "Laser Weapon Passes Big Test." MSNBC. 7 May 2004. 4 Apr. 2009 <http://www.msnbc.msn.com/id/4926840>.

[12] "Solid-State Lasers." Encyclopedia of Laser Physics and Technology. 22 Nov. 2008. RP Photonics Consulting GmbH. 4 Apr. 2009 <http://www.rp-photonics.com/solid_state_lasers.html>.

[13] United States Air Force. Air Force Research Laboratory. Personnel Halting and Stimulation Response (PHaSR). 4 Apr. 2009 <http://www.kirtland.af.mil/shared/media/document/AFD-070404-043.pdf>.

[14] McHale, John. "Future Weapons: Solid-State Lasers." Military and Aerospace Electronics May 2006: 28-33. Academic Search Premier. EBSCO. U of Arkansas, Fayetteville, AR. 4 Apr. 2009 <http://search.iebscohost.com/>.

[15] "Miltary grade 100 Kilowatt Solid-State Laser produced." Gizmag. 4 Apr. 2009 <http://www.gizmag.com/miltary-grade-100-kilowatt-solid-state-laser demonstrated/11302/>.

[16] "Emission Spectrum." University of Winnipeg. 29 Sept. 1999. 16 Apr. 2009 <http://theory.uwinnipeg.ca/mod_tech/node151.html>.

[17] "How Lasers Work." Healing Light Associates. 2005. 16 Apr. 2009 <http://healinglightassociates.com/softlasers.how.shtml>.

[18] "Paveway II Laser Guided Bomb (LGB)." Lockheed Martin. 2009. 16 Apr. 2009 <http://www.lockheedmartin.com/products/PavewayIILaserGuidedBomb/>.

[19] "Airborne Laser (ABL)." Northrop Grumman. 2008. 16 Apr. 2009 <http://www.grumman.com/missiledefense/galleries/ABL.html>.

[20] "Talon." Northrop Grumman. 2009. 16 Apr. 2009 <http://www.aoainc.com/capabilities/ directed_energy_syst/laser_systems/solid_state_lasers/talon.html>.