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Author
Mistry, Hemma

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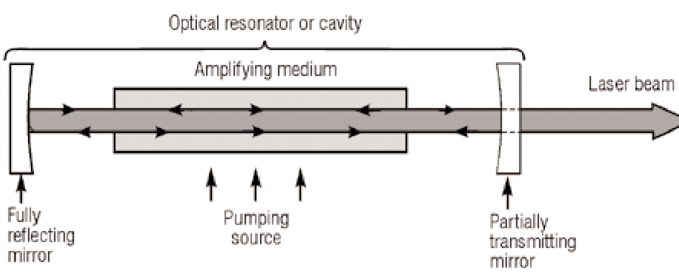
Light Wars: The Bright Future of Laser Weapons

by Hemma Mistry

Lasers as directed energy weapons: this idea may sound like the ray guns and light sabers of a science fiction writer's dreams, but the idea of incorporating lasers into military technology has been pursued since lasers were first invented. The U.S. government has spent millions of dollars attempting to make laser weaponry a reality. In 1983, the Reagan administration initiated an ambitious effort to create missile defense systems using lasers in space, nicknamed "Star Wars." Although these systems were never realized, the "Star Wars" program paved the way for future laser research. The Clinton administration continued the effort for missile defense laser weaponry with an agreement with the Israeli government in 1996. Currently there are several U.S. military funded programs developing laser weapons.

What is a Laser?



http://cord.org/step_online/st1-5/images/Fig05-01.gif

The basic components of a laser

Lasers can serve as a valuable technology in warfare because the light they emit has important and useful qualities. Laser light is monochromatic and coherent, which means that not only does the light have a uniform wavelength, but also the light waves maintain the same phase relationships over time. The waves also propagate in a definite direction. These properties allow laser light to carry a large amount of energy that can be applied in a specific direction, which is highly advantageous for a weapon.

The word laser is actually an acronym for "Light Amplification by Stimulated Emission of Radiation," and as the name implies, lasers work by amplifying light through the process of stimulated emission. In 1916, Albert Einstein first theorized stimulated emission as one of the three processes by which light can interact with matter (Perram, et al. 2004). In this process, a photon of light hits an electron in an excited, high energy state, causing the electron to fall to a lower energy state which releases a photon of light with the same wavelength, phase, and direction as the incident light. Mirrors are then used to amplify the emitted light, resulting in a beam of monochromatic, coherent, directed laser light.

This diagram shows the basic components of a laser. The gain medium, or amplifying medium, contains atoms whose electrons are stimulated to emit light. Mirrors on either end of the optical cavity reflect the light back several times through the gain medium, amplifying the beam. An energy input is also required to excite the electrons in the gain medium into a high energy state so that stimulated emission can occur.

Military Interest in Lasers

The characteristics of laser light give lasers the potential to make effective weapons. Because a laser beam is focused in one direction, laser weapons have the potential to be extremely accurate in hitting targets. In combat, this accuracy would minimize the destruction of surrounding area that is caused by more imprecise weapons such as explosives. The precise aim of the weapon and the minimal destruction would also reduce the harm caused to civilians and other unintended targets. Lasers would also enable the military to attack targets from far away, provided that there is an unobstructed path for the laser's beam to travel between the weapon and target. Since the beam would travel at the speed of light, the weapon would be effective on these distant targets almost instantaneously. This long-range capability of lasers also means that a laser attack could be carried out covertly from

Lasers could be used to destroy satellites in space, or conversely, space-based lasers could attack targets on the ground.

a great distance.

Since its invention in 1960 by Arthur Shawlow and Charles Townes, the U.S. military has been interested in applying laser technology to military use (Perram et al. 2004). For defense purposes, lasers could be implemented in ships, planes, or in ground-based systems to destroy missiles or rockets. Lasers could also be used to destroy satellites in space, or conversely, space-based lasers could attack targets on the ground. Lasers could also be built into army vehicles or even planes as offensive weapons that could target large areas (Dunn 2005).

Progress with Chemical Lasers

http://www.afa.org/magazine/dec2002/1202attack6.jpg

The Tactical High Energy Laser (THEL) at the U.S. Army Missile Range at White Sands, New Mexico

The military has invested in the development of several different types of lasers, and the main differences between these lasers are the source of electrons and the source of power. The most advanced military lasers currently are chemical lasers, which were invented in 1965 by George C. Pimentel (Perram et al. 2004). Chemical lasers obtain energy from an exothermic chemical reaction. This energy excites the electrons in the gain medium, which is usually a low pressure gas. For example, the reaction of fluorine atoms with hydrogen molecules produces hydrogen fluoride molecules and releases excess energy. These molecules of hydrogen fluoride become the gain medium, and the excess energy is used to raise electrons into an excited state.

Chemical lasers are the most developed and most advanced lasers used for military application. They are also capable of generating the highest power of any kind of laser – over 1 megawatt. The most advanced chemical laser defense system currently is the Tactical High Energy Laser (THEL), which is a deuterium-fluoride laser. In 1996, Northrop Grumman, a corporation providing defense technology, received $89 million to design and build this system for the US and Israeli governments. The system shot down its first Katyusha rocket in 2000, and since then it has successfully shot down multiple test rockets, mortar shells, and other missiles (Hecht 2006).

Despite its operational successes, the THEL has serious drawbacks. The whole laser system is about the size of six buses placed side-by-side, and the developers have so far failed to reduce the system to a reasonable size, which means that its portability would be an issue for military use. Another concern is the THEL's enormous fuel requirement and furthermore, the storage and supply of this fuel. The performance of the THEL is also unsatisfactory, considering the time and money spent building it. After investing over $300 million in this program, the Pentagon decided to drop THEL in September 2005 because of these problems, as writer William J. Broad explains in an article on the program (*New York Times*, July 30, 2006).

A chemical laser program that is showing some promise, however, is the Airborne Laser (ABL), also developed by Northrop Grumman. The goal of ABL is to fit a Boeing 747 airplane with an oxygen iodine laser weapon so that it can detect and shoot down missiles soon after they are launched. However, like THEL, ABL is not progressing as hoped – the team has yet to install the laser in the aircraft. Operational setbacks mean that the proposed date for the first missile test, 2008, will probably be further postponed.

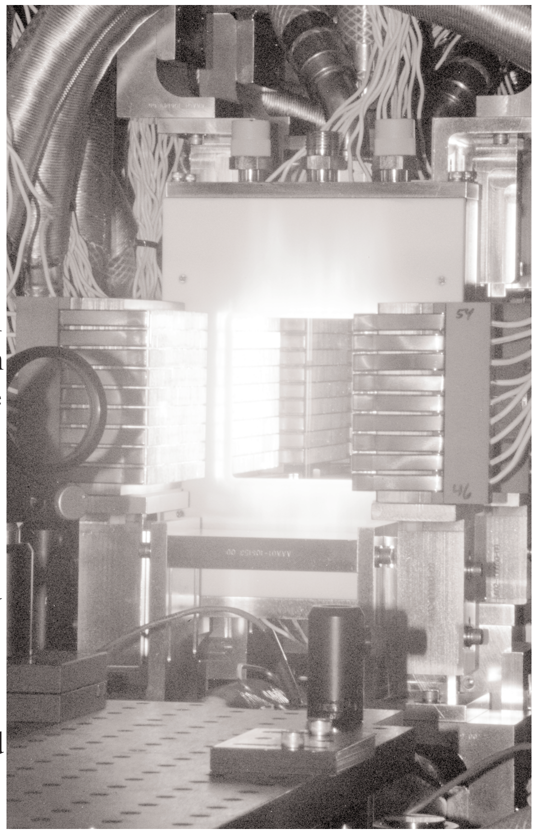
Solid-State Lasers Hold Promise

While scientists are struggling to successfully incorporate chemical lasers into missile defense systems, solid-state lasers are holding much more promise. Instead of chemicals, these lasers use a ruby or crystal to produce light. Most commonly, these lasers use crystal yttrium aluminum garnet (YAG). Ions of usually neodymium or ytterbium are dropped into the crystal, and the process of stimulated emission occurs on these atoms. The energy used to excite the electrons in these ions comes from electricity, specifically flashlamps or diodes.

The goal of ABL is to fit a Boeing 747 airplane with a laser weapon so that it can detect and shoot down missiles soon after they are launched.

Solid-state lasers hold several advantages over chemical lasers. Because they are powered by electricity, there is no need for expensive and bulky chemical fuels. They can also produce wavelengths of light that transmit well through the atmosphere, unperturbed by interference. However, solid-state lasers can only operate at a fraction of the power of chemical lasers. The military would like to see a 100kW solid-state laser because this is the energy required to destroy mortars and artillery rockets (Shachtman 2006).

The build-up of heat is a problem in solid-state lasers because the diodes produce a lot of heat but only perform well at room temperature. As the laser runs, heat builds up in the crystal which must be removed. This cooling problem places a limit on the power of the laser because as power output of the diodes increases, more heat is produced which must be removed. Most lasers are continuously cooled using a coolant such as water to remove waste heat. Continuous cooling, however, creates problems of its own. Because the inside of the laser is at a much higher temperature than the surface, a temperature gradient is created which causes stress damage to the equipment (Parker 2002).

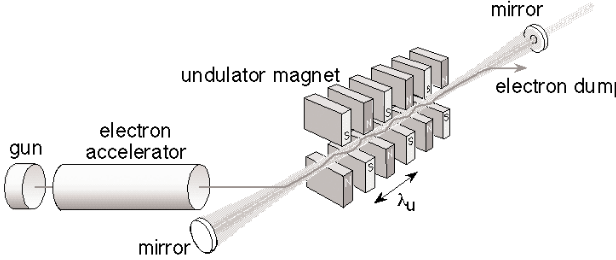


http://www.llnl.gov/PAO/news/news_images/bigpix/sshcl.jpg

The Solid-State Heat Capacity Laser at LLNL

Heat capacity lasers are solid-state lasers that separate the cooling process from lasing. These lasers operate in cycles: for about ten seconds the laser will fire, followed by a longer period of cooling (thirty seconds to a few minutes). Then, the laser will fire again. The laser can now be operated at higher power, meaning that a more powerful beam can be produced. This cooling process was a breakthrough in the development of solid state lasers made by the Solid-State Heat Capacity Laser (SSHCL) team at the Lawrence Livermore National Laboratory (LLNL) (Parker 2002). Their laser is currently the highest power solid-state laser in the world, and it reached this 67 kW energy level in February 2007, approaching the 100kw goal (Lawrence Livermore National Laboratory 2007).

The U.S. is currently funding the Joint High Power Solid-State Laser (JHPSSL) program, also under Northrop Grumman. In 2005, a 27kW beam was produced, and although it has not achieved the power level of LLNL's laser, progress is being made. JHPSSL also aims for a power level of 100kW, and this laser could be used in ships, aircraft, or ground-based systems for missile defense (Northrop Grumman 2007).



http://www.star.le.ac.uk/~rw/courses/lect4313_fig27.gif

A free electron laser. Electrons are accelerated in a linear accelerator, and then sent through the undulator, a series of alternating magnetic fields, in which laser light is created.

The Future of Free-Electron Lasers

Solid-state lasers and chemical lasers have certain limitations on the power and quality of beam that they can achieve. A laser that bypasses this problem and allows for increased tunability is the free-electron laser. Free-electron lasers work by sending a relativistic beam of electrons, or electrons moving close to the speed of light, through a series of alternating magnetic fields, called a wiggler or undulator. The wiggler causes the electrons to oscillate at a certain frequency depending on the strength and location of the magnets, and the electrons then emit light depending on their velocities. Free-electron lasers were first created in 1977 by John Madey at Stanford University (Dylla and Corneliussen 2005).

Unlike chemical and solid-state lasers, free-electron lasers can theoretically be tuned to any wavelength because they do not rely on the quantum structure of atoms to produce light. In chemical and solid-state lasers, the process of stimulated emission can only produce certain discrete wavelengths of light because electrons are bound to discrete energy levels. Since the transition between energy levels of the electron determines the wavelength of the emitted photon, these lasers can only operate at specific wavelengths. However, in a freeelectron laser there is no gain medium and the electrons are "free"; therefore, the emitted photons are not restricted by the discrete energy levels associated with atomic structure (Dylla and Corneliussen 2005). The absence of a gain medium also means that the laser will not generate a large amount of heat, so cooling is not an issue. The electrons in this laser do, however, need to be accelerated, and this requires an accelerator which can be large, heavy, and expensive.

The U.S. Navy has invested in the Free-Electron Laser (FEL) program at the Thomas Jefferson National Accelerator Facility. This laser has achieved 14.2kW of power, and progress is being made in improving this figure (Jefferson Lab 2007). Of the three lasers, freeelectron lasers have the most optimistic future as weapons because of their advantages over chemical and solid state lasers; however, their development is still in the early stages and it may be a decade or more before they are operational. While the most powerful and most advanced laser weapons systems involve chemical lasers, solidstate and free-electron laser programs promise much more exciting results. With the continued advancement of these military funded programs, the dream of futuristic laser weaponry could be a reality within the next decade.

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