

An article by M. Raymer, based on this section, also appeared on the web site for LASER FEST, the international celebration of the 50th anniversary of the invention of the laser. See <http://laserfest.org/lasers/how/extreme.cfm>

IN-DEPTH LOOK 14.2: EXTREME LASER FACTS

Scientists and engineers love lasers because they offer the possibility of extreme behavior. This allows scientists to probe nature on very fine scales and to burn holes through solid objects. To find out about extreme lasers—the X-GAMES™ of LASERS—I asked some experts¹ about the biggest, “baddest,” shortest, longest, slowest, fastest, and smallest lasers they knew of. These stats are from circa 2007 and are not necessarily the record holders but are important representatives of each category. The numbers in parentheses correspond to references given at the end of the chapter, where more information can be found.

Highest-energy laser pulse: 150 kilojoules (kJ) in a 10-nanosecond pulse. The National Ignition Facility (NIF) at the Lawrence Livermore National Laboratory in Livermore, California, achieved this result in 2005. The energy contained in the 150-kJ pulse is equivalent to a 1-ton automobile traveling at about 60 miles per hour. Soon, the NIF aims to achieve a pulse energy of a couple of megajoules. All of this energy will slam into a tiny pellet containing deuterium—a form of hydrogen—in an effort to induce nuclear fusion, which may serve as a futuristic source of power, as well as aiding in nuclear-weapons research [1].

Shortest laser pulse: Just under 1 femtosecond (fsec), or 10^{-15} sec. This subfemtosecond pulse was created at the Max Planck Institute for Quantum Optics in Garching, Germany, and is less than the time for a single oscillation cycle of a visible light wave. How short is this pulse? The duration of this pulse is to 10 sec as 10 sec is to the age of the Earth! To make such a short pulse, researchers have to generate light containing all colors from the visible region well into the ultraviolet region of the spectrum. Such a pulse of light looks white to the eye. This is very different from typical lasers, which emit a single color [2].

Highest instantaneous power: Just over 1 PW, or petawatt (i.e., 10^{15} W). This was first achieved at the Lawrence Livermore National Laboratory in 1996. This unimaginably high power exceeded the entire electrical generating capacity of the United States by more than 1,200 times, but was over in such a short time—440 fsec—that it produced “only” 680 J of energy. Because laser light can be focused to a very small spot, the focused energy density reached the equivalent of 30 billion J in a volume of 1 cubic centimeter, far larger than the energy density inside of stars. At such high energy densities, the electric field of the light is so strong that electrons become accelerated to almost the speed of light! [3]

Highest average power: More than 1 MW (megawatt) of continuous output power. This dangerously high level of power was first achieved by the Mid-Infrared Advanced Chemical Laser (MIRACL), at the High Energy Laser Systems Test Facility at White Sands Missile Range, New Mexico. Because the power is so high, it is operated only for seconds at a time, producing several megajoules of energy in an outburst [4].

“Baddest” laser: The U.S. Air Force’s airborne laser, a close relative of the MIRACL, described above, is mounted in a modified Boeing 747-400F freighter aircraft. It produces

¹ Thanks to Wayne Knox, the Director of The Institute of Optics at the University of Rochester; Philip H. Bucksbaum, Director of the Stanford PULSE Center at Stanford Linear Accelerator Center (SLAC); and Roger Falcone, Director of the Advanced Light Source, Lawrence Berkeley National Laboratory.

megawatt-power pulses with a duration of seconds and energies of megajoules, for shooting down enemy tactical nuclear-weapons ballistic missiles. That is one bad laser [5].

Longest laser: 1.3 kilometers (0.8 mi). This is the length of the Linac Coherent Light Source, a “free-electron” X-ray laser, which is being built as a component of the Stanford Linear Accelerator Center. The building is so long that scientists use golf carts to travel around in it [6].

Shortest laser: Several micrometers, or millionths of a meter in length. This is the length of the resonator in vertical-cavity surface-emitting lasers, or VCSELs. These special semiconductor lasers were invented at the Tokyo Institute of Technology and are becoming important in telecommunications and other applications [7].

Longest time of laser-cycle stability: 13 sec. This is the duration that a laser at the National Institute of Standards and Technology (NIST) was able to oscillate with precisely the same frequency. That is, the laser did not gain or lose even one wave cycle over a 13-sec time, during which it oscillated 1,064,721,609,899,145 times. That is one stable laser! Atomic clocks based on stable lasers such as this are used to synchronize the Global Positioning System (GPS), which is available to consumers via satellite [8].

Most precise length measurement using a laser: About 1 attometer (i.e., 10^{-18} m). This length-measuring sensitivity was achieved by the Laser Interferometer Gravitational Wave Observatory, or LIGO. This unbelievably small length is one hundred billionth of the diameter of an atom and is measured as the change of distance between two mirrors that are separated by 4 kilometers (2.5 mi)! The purpose of LIGO is to detect the passing by Earth of a gravitational wave created by two neutron stars colliding [9].

14.7 VARIABLE-COLOR SEMICONDUCTOR LASERS

One of the workhorses of the Internet Age is the semiconductor diode laser. Such lasers provide the light that “lights the fiber” and does the reading and writing of compact discs. Semiconductor lasers are made with the same types of crystals used to make LEDs; for example, gallium arsenide (GaAs), a crystal made of a pure mixture of gallium (Ga) and arsenic (As) atoms. This is a semiconductor crystal. Semiconductor lasers can be designed to emit different colors of light, including infrared. Similar to LEDs that emit different colors of light, these are made using different semiconductor crystals; for example GaAlAs, in which aluminum (Al) replaces some of the Ga atoms in a GaAs crystal.

A semiconductor laser can have the ability to vary the color that it emits. Because frequency changes with changing color, this is also called “tuning” the laser, analogous to tuning the frequency of a guitar string. Tuning a laser allows you to vary the laser beam’s frequency for use as a specific channel in a communication system. We will discuss this application in the next chapter.

To make a tunable laser, add a frequency-selective element inside of the resonator. **Figure 14.15** shows a laser with a prism placed inside of the resonator. The resonator is comprised of the 100% reflecting mirror on the bottom side of the semiconductor crystal and the partially reflecting mirror on the far side of the prism. The prism has the effect of filtering the optical feedback; that is, it restricts feedback to a narrow range of frequencies. Because the prism refracts light of different frequencies in different directions, a small range of light frequencies are sent back by the mirror into the center part of the crystal, where the gain is. Only light with the proper frequency is able to self-oscillate and create a strong coherent beam. The particular frequency that is allowed to self-oscillate is determined by the angle of the prism. Therefore, we can tune the frequency of the laser light by rotating the prism to change its angle.