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Laser Technology Applications: A gift to Humanity

Devaryan Gupta

Abstract
LASER technology is something that we use almost every day in our lives, but don't even think about it. It has been used to make huge scientific findings and can help us in many ways. A LASER is a coherent and focused beam of photons. LASER stands for Light Amplification by Stimulated Emission of Radiations. This paper describes the LASER technology in details. This paper describes the history and extensibility of LASER. It also explains the concept of principles of LASER technology and how a LASER works? This paper also describes the different types of LASER and the application areas of LASER. Different types of LASER have different operation wavelengths and pump source. This paper also gives the knowledge on how the LASER beam is made and what components are required to make a LASER. The output of a LASER is a coherent electromagnetic field.

Keywords: Technology, Applications, electromagnetic

Introduction
A LASER is a device that emits light through a process of optical amplification based on the stimulated emission of electromagnetic radiation. A LASER is a coherent and focused beam of photons; coherent means that it is all one wavelength, unlike ordinary light which showers on us in many wavelengths. The acronym *LASER* stands for "Light Amplification by Stimulated Emission of Radiation". In modern usage, the term "light" includes electromagnetic radiation of any frequency, not only visible light, hence the terms *infrared LASER*, *ultraviolet LASER*, *X-ray LASER*, *gamma-ray LASER*, and so on. It is a device that creates a narrow and low-divergent beam of coherent light, while most other light sources emit incoherent light, which has a phase that varies randomly with time and position. Most LASERs emit nearly "monochromatic" light with a narrow wavelength spectrum.

History of LASER
The LASER would not have been possible without an understanding that light is a form of electromagnetic radiation. Max Planck received the Nobel Prize in physics in 1918 for his discovery of elementary energy quanta. Planck was working in thermodynamics, trying to explain why "blackbody" radiation, something that absorbs all wavelengths of light, didn't radiate all frequencies of light equally when heated.

Max Planck: In his most important work, published in 1900, Planck deduced the relationship between energy and the frequency of radiation, essentially saying that energy could be emitted or absorbed only in discrete chunks – which he called quanta – even if the chunks were very small. In 1905, Albert Einstein released his paper on the photoelectric effect, which proposed that light also delivers its energy in chunks, in this case discrete quantum particles now called photons

Physicists John L. Emmett and John H. Nuckolls were the key Lawrence Livermore National Laboratory pioneers in LASER and fusion science and technology. Emmett co-invented the multi-pass LASER architecture still in use today.

In 1917, Einstein proposed the process that makes LASERs possible, called stimulated emission. He theorized that, besides absorbing and emitting light spontaneously, electrons could be stimulated to emit light of a particular wavelength. But it would take nearly 40 years before scientists would be able to amplify those emissions, proving Einstein correct and putting LASERs on the path to becoming the powerful and ubiquitous tools they are today.

Fig 1(a)

In 1948, Gabor, D. invented holography. Holograms are widely used to check the originality of the products.
April 26, 1951: Charles Hard Townes of Columbia University in New York conceives his maser (microwave amplification by stimulated emission of radiation) idea while sitting on a park bench in Washington.
1954: Working with Herbert J. Zeiger and graduate student James P. Gordon, Townes demonstrates the first maser at Columbia University. The ammonia maser, the first device based on Einstein's predictions, obtains the first amplification and generation of electromagnetic waves by stimulated emission. The maser radiates at a wavelength of a little more than 1 cm and generates approximately 10 nW of power.
1955: At P.N. Lebedev Physical Institute in Moscow, Nikolai G. Basov and Alexander M. Prokhorov attempt to design and build oscillators. They propose a method for the production of a negative absorption that was called the pumping method.
1956: Nicolaas Bloembergen of Harvard University develops the microwave solid-state maser

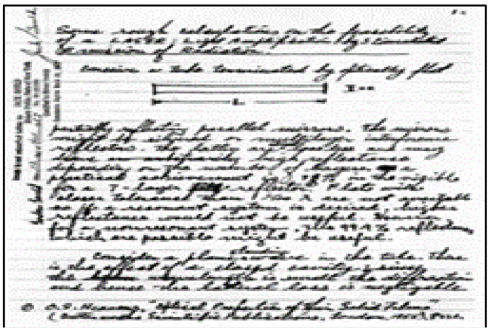


Fig 1(b)

This is the first page of Gordon Gould's famous notebook, in which he coined the acronym LASER and described the essential elements for constructing one. This notebook was the focus of a 30-year court battle for the patent rights to the LASER. Notable is the notary's stamp in the upper left corner of the page, dated Nov. 13, 1957. Sept. 14, 1957: Townes sketches an early optical maser in his lab notebook.
Nov.13, 1957: Columbia University graduate student Gordon Gould jots his ideas for building a LASER in his notebook and has it notarized at a candy store in the Bronx. It is considered the first use of the acronym LASER. Gould leaves the university a few months later to join private research company TRG (Technical Research Group).
1958: Townes, a consultant for Bell Labs, and his brother-in-law, Bell Labs researcher Arthur L. Schawlow, in a joint paper published in Physical Review Letters, show that masers could be made to operate in the optical and infrared regions and propose how it could be accomplished. At Lebedev Institute, Basov and Prokhorov also are exploring the possibilities of applying maser principles in the optical region.
April 1959: Gould and TRG apply for LASER-related patents stemming from Gould's ideas.
March 22, 1960: Townes and Schawlow, under Bell Labs, are granted US patent number 2,929,922 for the optical maser, now called a LASER. With their application denied, Gould and TRG launch what would become a 30-year patent dispute related to LASER invention.
May 16, 1960: Theodore H. Maiman, a physicist at Hughes Research Laboratories in Malibu, Calif., constructs the first LASER using a cylinder of synthetic ruby measuring 1 cm in diameter and 2 cm long, with the ends silver-coated to make them reflective and able to serve as a Fabry-Perot resonator. Maiman uses photographic flashlamps as the LASER's pump source.
July 7, 1960: Hughes holds a press conference to announce Maiman's achievement.
November 1960: Peter P. Sorokin and Mirek J. Stevenson of the IBM Thomas J. Watson Research Centre demonstrate the uranium LASER, a four-stage solid-state device.
December 1960: Ali Javan, William Bennett Jr. and Donald Herriott of Bell Labs develop the helium-neon (HeNe) LASER, the first to generate a continuous beam of light at 1.15 μm.
1961: LASERs begin appearing on the commercial market through companies such as Trion Instruments Inc., Perkin-Elmer and Spectra-Physics.
March 196: At the second International Quantum Electronics meeting, Robert W. Hellwarth presents theoretical work suggesting that a dramatic improvement in the ruby LASER could be made by making its pulse more predictable and controllable. He predicts that a single spike of great power could be created if the reflectivity of the LASER's end mirrors were suddenly switched from a value too low to permit lasing to a value that could.

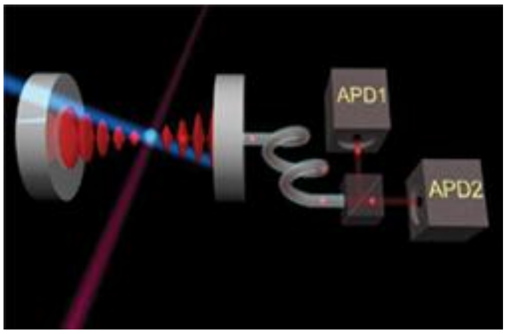


Fig 1(c).

A high-finesse optical cavity consisting of two mirrors traps and accumulates the photons emitted by the ion into a mode. The ion is excited cyclically by an external LASER and at each cycle a photon is added to the cavity mode, which amplifies the light.
October 1961: American Optical Co.'s Elias Snitzer reports the first operation of a neodymium glass LASER.
December 1961: The first medical treatment using a LASER on a human patient is performed by Dr. Charles J. Campbell of the Institute of Ophthalmology at Columbia-Presbyterian Medical Centre and Charles J. Koester of the American Optical Co. at Columbia-Presbyterian Hospital in Manhattan. An American Optical ruby LASER is used to destroy a retinal tumor.

1962: With Fred J. McClung, Hellwarth proves his LASER theory, generating peak powers 100 times that of ordinary ruby LASERs by using electrically switched Kerr cell shutters. The giant pulse formation technique is dubbed Q-switching. Important first applications include the welding of springs for watches.
1962: Groups at GE, IBM and MIT's Lincoln Laboratory simultaneously develop a gallium-arsenide LASER, a semiconductor device that converts electrical energy directly into infrared light but which must be cryogenically cooled, even for pulsed operation.

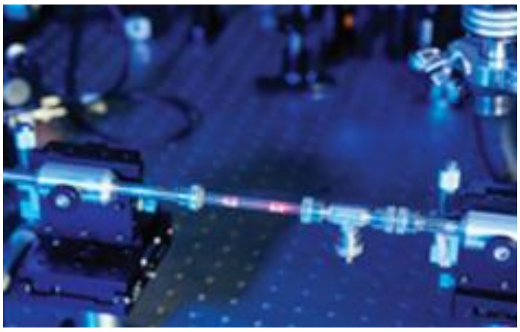


Fig 1(d)

October 1962: Nick Holonyak Jr., a consulting scientist at a General Electric Co. lab in Syracuse, N.Y., publishes his work on the "visible red" GaAsP (gallium arsenide phosphide) LASER diode, a compact, efficient source of visible coherent light that is the basis for today's red LEDs used in consumer products such as CDs, DVD players and cell phones.
June 1962: Bell Labs reports the first yttrium aluminium garnet (YAG) LASER.
Early 1963: Barron's magazine estimates annual sales for the commercial LASER market at $1 million.
1963: Logan E. Hargrove, Richard L. Fork and M.A. Pollack report the first demonstration of a mode-locked LASER; i.e., a helium-neon LASER with an acousto-optic modulator. Mode locking is fundamental for LASER communication and is the basis for femtosecond LASERs.
1963: Herbert Kroemer of the University of California, Santa Barbara, and the team of Rudolf Kazarinov and Zhores Alferov of A.F. Ioffe Physico-Technical Institute in St. Petersburg, Russia, independently propose ideas to build semiconductor LASERs from heterostructure devices. The work leads to Kroemer and Alferov winning the 2000 Nobel Prize in physics.
March 1964: After two years working on HeNe and xenon LASERs, William B. Bridges of Hughes Research Labs discovers the pulsed argon-ion LASER, which, although bulky and inefficient, could produce output at several visible and UV wavelengths.
1964: Townes, Basov and Prokhorov are awarded the Nobel Prize in physics for their "fundamental work in the field of quantum electronics, which has led to the construction of oscillators and amplifiers based on the maser-LASER-principle."
1964: The carbon dioxide LASER is invented by Kumar Patel at Bell Labs. The most powerful continuously operating LASER of its time, it is now used worldwide as a cutting tool in surgery and industry.
1964: The Nd:YAG (neodymium-doped YAG) LASER is invented by Joseph E. Geusic and Richard G. Smith at Bell Labs. The LASER later proves ideal for cosmetic applications, such as LASER-assisted in situ keratomileusis (lasik) vision correction and skin resurfacing.
1965: Two LASERs are phase-locked for the first time at Bell Labs, an important step toward optical communications.
1965: Jerome V.V. Kasper and George C. Pimentel demonstrate the first chemical LASER, a 3.7-µm hydrogen chloride instrument, at the University of California, Berkeley.
1966: Charles K. Kao, working with George Hockham at Standard Telecommunication Laboratories in Harlow, UK, makes a discovery that leads to a breakthrough in fibre optics. He calculates how to transmit light over long distances via optical glass fibres, deciding that, with a fibre of purest glass, it would be possible to transmit light signals over a distance of 100 km, compared with only 20 m for the fibres available in the 1960s. Kao receives a 2009 Nobel Prize in physics for his work.
1966: French physicist Alfred Kastler wins the Nobel Prize in physics for his method of stimulating atoms to higher energy states, which he developed between 1949 and 1951. The technique, known as optical pumping, was an important step toward the creation of the maser and the LASER.
March 1967: Bernard Soffer and Bill McFarland invent the tunable dye LASER at Korad Corp. in Calif.
February 1968: In California, Maiman and other LASER pioneers found the LASER advocacy group LASER Industry Association, which becomes the LASER Institute of America in 1972.
1970: Gould buys back his patent rights for $1 plus 10 percent of future profits when TRG is sold.1970: Basov, V.A. Danilychev and Yu. M. Popov develop the excimer LASER at P.N. Lebedev Physical Institute.
Spring 1970: Alferov's group at Ioffe Physico-Technical Institute and Mort Panish and Izuo Hayashi at Bell Labs produce the first continuous-wave room-temperature semiconductor LASERs, paving the way toward commercialization of fibre optic communications.
1970: At Corning Glass Works, Dr. Robert D. Maurer, Peter C. Schultz and Donald B. Keck report the first optical fibre with loss below 20 dB/km, demonstrating the feasibility of fibre optics for telecommunication.
A LASER in operation at the Electronics Resource Centres Space Optics Laboratory is checked by Lowell Rosen and Dr. Norman Knable. They investigated energy levels of atoms in very excited states as a step to improving the LASER's efficiency in space. The ERC opened in September 1964, taking over the administration of contracts, grants and other NASA business in New England from the antecedent North Eastern Operations Office (created in July 1962), and closed in June 1970. It served to develop the space agency's in-house expertise in electronics during the Apollo era. A second key function was to serve as a graduate and postgraduate training centre within the framework of a regional government-industry-university alliance. Research at the ERC was conducted in 10 different laboratories: space guidance, systems, computers, instrumentation research, space optics, power conditioning and distribution, microwave radiation, electronics components, qualifications and standards, and control and information systems. Researchers investigated such areas as microwave and LASER communications; the miniaturization and radiation resistance of electronic components; guidance and control systems; photovoltaic energy conversion; information display devices; instrumentation; and computers and data processing.

1970: Arthur Ashkin of Bell Labs invents optical trapping, the process by which atoms are trapped by LASER light. His work pioneers the field of optical tweezing & trapping and leads to significant advances in physics & biology.
1971: Izuo Hayashi &Morton B. Panish of Bell Labs design the first semiconductor LASER that operates continuously at room temperature.
1972: Charles H. Henry invents the quantum well LASER, which requires much less current to reach lasing threshold than conventional diode LASERs and which is exceedingly more efficient. Holonyak and students at the University of Illinois at Urbana-Champaign first demonstrate the quantum well LASER in 1977.
1972: A LASER beam is used at Bell Labs to form electronic circuit patterns on ceramic.
June 26, 1974: A pack of Wrigley's chewing gum is the 1st product read by a bar-code scanner in grocery store.
1975: Engineers at LASER Diode Labs Inc. in Metuchen, N.J., develop the first commercial continuous-wave semiconductor LASER operating at room temperature. Continuous-wave operation enables transmission of telephone conversations.
1975: First quantum-well LASER operation made by Jan P. Van der Ziel, R. Dingle, Robert C. Miller, William Wiegmann and W.A. Nordland Jr. The LASERs actually are developed in 1994.
1976: First demonstration, at Bell Labs, of a semiconductor LASER operating continuously at room temperature at a wavelength beyond 1 μm, the forerunner of sources for long-wavelength lightwave systems.
1976: John M.J. Madey and his group at Stanford University in California demonstrate the first free-electron LASER (FEL). Instead of a gain medium, FELs use a beam of electrons that are accelerated to near light speed, then passed through a periodic transverse magnetic field to produce coherent radiation. Because the lasing medium consists only of electrons in a vacuum, FELs do not have the material damage or thermal lensing problems that plague ordinary LASERs and can achieve very high peak powers.
1977: The first commercial installation of a Bell Labs fibre optic lightwave communications system is completed under the streets of Chicago.
Oct. 11, 1977: Gould is issued a patent for optical pumping, then used in about 80 percent of LASERs
1978: The LASER Disc hits the home video market, with little impact. The earliest players use HeNe LASER tubes to read the media, while later players use infrared LASER diodes.
1978: Following the failure of its videodisc technology, Philips announces the compact disc (CD) project.
1979: Gould receives a patent covering a broad range of LASER applications.
1981: Schawlow & Bloembergen receive the Nobel Prize in physics for their contributions to the development of LASER spectroscopy.
1982: Peter F. Moulton of MIT's Lincoln Laboratory develops the titanium-sapphire LASER, used to generate short pulses in the picosecond and femtosecond ranges. The Ti:sapphire LASER replaces the dye LASER for tuneable and ultrafast LASER applications.
October 1982: The audio CD, a spinoff of LASERDisc video technology, debuts. Billy Joel fans rejoice, as his 1978 album "52nd Street" is the first to be released on CD.
1985: Bell Labs' Steven Chu and his colleagues use LASER light to slow and manipulate atoms. Their LASER cooling technique, also called "optical molasses," is used to investigate the behaviour of atoms, providing an insight into quantum mechanics. Chu, Claude N. Cohen-Tannoudji and William D. Phillips win a Nobel Prize for this work in 1997.
1987: David Payne at the University of Southampton in the UK and his team introduce erbium-doped fibre amplifiers. These new optical amplifiers boost light signals without first having to convert them into electrical signals and then back into light, reducing the cost of long distance fibre optic systems.
1988: Gould begins receiving royalties from his patents.
This Electronics Research Centre study of the molecular properties of liquids was conducted using LASER technology. ERC opened in September 1964 and has the particular distinction of being the only NASA Centre to close, shutting down in June 1970. Its mission was to develop new electronics and training new graduates as well as NASA employees. The ERC actually grew while NASA eliminated major programs and cut staff in other areas. Between 1967 and 1970, NASA cut permanent civil service workers at all Centres with one exception, the ERC, whose personnel grew annually until its closure.
1994: The first semiconductor LASER that can simultaneously emit light at multiple widely separated wavelengths – the quantum cascade (QC) LASER – is invented at Bell Labs by Jérôme Faist, Federico Capasso, Deborah L. Sivco, Carlo Sirtori, Albert L. Hutchinson and Alfred Y. Cho. The LASER is unique in that its entire structure is manufactured a layer of atoms at a time by the crystal growth technique called molecular beam epitaxy. Simply changing the thickness of the semiconductor layers can change the LASER's wavelength. With its room-temperature operation and power and tuning ranges, the QC LASER is ideal for remote sensing of gases in the atmosphere.

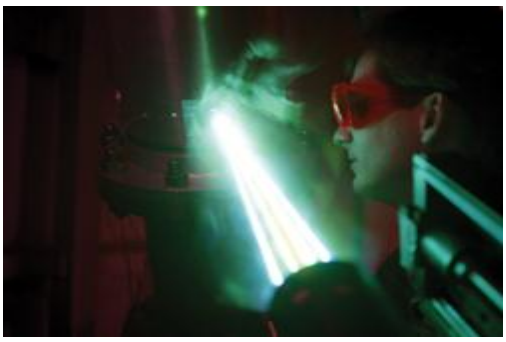


Fig 1(e)

In 1997, an engineer at the Marshall Space Flight Centre (MSFC) Wind Tunnel Facility uses LASERs to measure the velocity and gradient distortion across an 8-in. curved pipe with joints and turning valves during a cold-flow propulsion research test, simulating the conditions found in the X-33's hydrogen feedline. LASERs are used as they are nonintrusive & do not disturb the flow like a probe would. The feedline supplies propellants to the turbo pump. The purpose of this project was to design the feedline to provide uniform flow into the turbo pump.
1994: The first demonstration of a quantum dot LASER with high threshold density is reported by Nikolai N. Ledentsov of A.F. Ioffe Physico-Technical Institute.

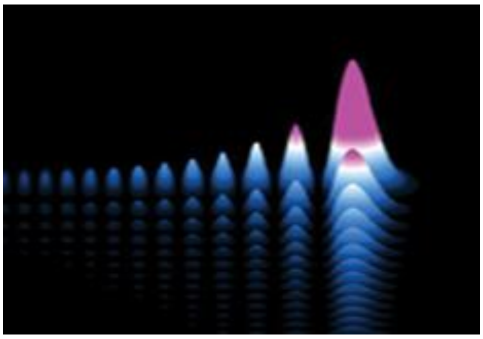


Fig 1(f).

An ideal finite-energy Airy Beam is a light beam that can bend and propagate without spreading. (Dr. Georgios Siviloglou, Centre for Research and Education in Optics and LASERs, University of Central Florida)

November 1996: The first pulsed atom LASER, which uses matter instead of light, is demonstrated at MIT by Wolfgang Ketterle.

January 1997: Shuji Nakamura, Steven P. DenBaars and James S. Speck at the University of California, announce the development of a gallium-nitride (GaN) LASER that emits brightblue-violet light in pulsed operation.

September 2003: A team of researchers from NASA's Marshall Space Flight Centre in Huntsville, Ala. successfully flies the first LASER-powered aircraft. The plane, its frame made of balsa wood, has a 1.5-m wingspan and weighs only 311g. Its power is delivered by an invisible ground-based LASER that tracks the aircraft in flight, directing its energy beam at specially designed photovoltaic cells carried onboard to power the plane' propeller.

The international inertial confinement fusion community, including LLNL researchers, uses the OMEGA LASER at the University of Rochester's Laboratory for LASER Energetics to conduct experiments and test target designs and diagnostics. The 60-beam OMEGA LASER at the University of Rochester has been operational since 1995.

2001: Lawrence Livermore at National Laboratory performed his experiments on Solid State Heat Capacity LASER (SSHCL).

2004: Electronic switching in a Raman LASER is demonstrated for the first time by Ozdal Boyraz and Bahram Jalali of the University of California, Los Angeles. The first silicon Raman LASER operates at room temperature with 2.5-W peak output power. In contrast to traditional Raman LASERs, the pure-silicon Raman LASER can be directly modulated to transmit data.

September 2006: John Bowers and colleagues at the University of California, Santa Barbara, and Mario Paniccia, announce that they have built the first electrically powered hybrid silicon LASER using standard silicon manufacturing processes. The breakthrough could lead to low-cost, terabit-level optical data pipes inside future computers.

August 2007: Bowers and his doctoral student Brian Koch announce that they have built the first mode-locked silicon evanescent LASER, providing a new way to integrate optical and electronic functions on a single chip and enabling new types of integrated circuits.

May 2009: At the University of Rochester in New York, Chunlei Guo announces a new process that uses femtosecond LASER pulses to make regular incandescent lightbulbs superefficient. The LASER pulse, trained on the bulb's filament, forces the surface of the metal to form nanostructures that make the tungsten become far more effective at radiating light. The process could make a 100-W bulb consume less electricity than a 60-W bulb

Fig 1(g)

A National Ignition Facility (NIF) hohlraum. The hohlraum cylinder, which contains the fusion fuel capsule, is just a few millimeters wide, about the size of a pencil eraser, with beam entrance holes at either end. The fuel capsule is the size of a small pea. Credit is given to Lawrence Livermore National Security LLC, Lawrence Livermore National Laboratory and the US Department of Energy, under whose auspices this work was performed.

May 29, 2009: The largest and highest-energy LASER in the world, the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory in Livermore, Calif., is dedicated. In a few weeks, the system begins firing all 192 of its LASER beams onto targets.

Fig 1(h).

June 2009: NASA launches the Lunar Reconnaissance Orbiter (LRO). The Lunar Orbiter LASER Altimeter on the LRO will use a LASER to gather data about the high and low points on the moon. NASA will use that information to create 3-D maps that could help determine lunar ice locations and safe landing sites for future spacecraft.

September 2009: LASERs enter household PCs with Intel's announcement of its Light Peak optical fibre technology at the Intel Developer Forum. Light Peak contains vertical-cavity surface-emitting LASERs (VCSELs) and can send and receive 10 billion bits of data per second.

December 2009: Industry analysts predict the LASER market globally for 2010 will grow about 11%, with total revenue hitting $5.9 billion.

January 2010: The National Nuclear Security Administration announces that NIF has successfully delivered a historic level of LASER energy – more than 1 MJ – to a target in a few billionths of a second and demonstrated the target drive conditions required to achieve fusion ignition, a project scheduled for the summer of 2010.

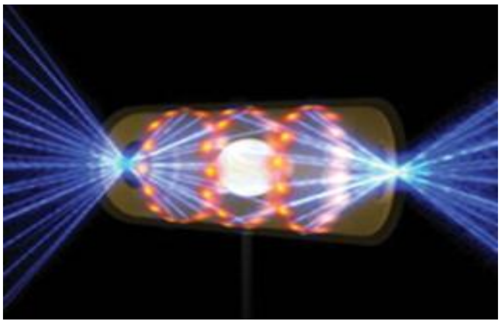


Fig 1(i)

This artist's rendering shows an NIF target pellet inside a hohlraum capsule with LASER beams entering through openings on either end. The beams compress and heat the target to the necessary conditions for nuclear fusion to occur. Ignition experiments on NIF will be the culmination of more than 30 years of inertial confinement fusion research and development, opening the door to exploration of previously inaccessible physical regimes. Credit is given to Lawrence Livermore National Security LLC, Lawrence Livermore National Laboratory and the US Department of Energy, under whose auspices this work was performed.
March 31, 2010: Rainer Blatt and Piet O. Schmidt and their team at the University of Innsbruck in Austria demonstrate a single-atom LASER with and without threshold behaviour by tuning the strength of atom/light field coupling.

Principle of LASERs: The principle of a LASER is based on three separate features:

- Stimulated emission within an amplifying medium,
- Population inversion of electronics and
- An optical resonator.

Spontaneous Emission and Stimulated Emission:
According to the quantum mechanics, an electron within an atom or lattice can have only certain values of energy, or energy levels. There are many energy levels that an electron can occupy, but here we will only consider two. If an electron is in the excited state with the energy E2 it may spontaneously decay to the ground state, with energy E1, releasing the difference in energy between the two states as a photon. [2] This process is called spontaneous emission, producing fluorescent light. The phase and direction of the photon in spontaneous emission are completely random due to Uncertainty Principle. The angular frequency ω and energy of the photon is: $E2-E1=h\nu$ ……………. (eq.1)
Here ħ is the reduced plank constant.
Conversely, a photon with a particular frequency satisfying eq.(1) would be absorbed by an electron in the ground state. The electron remains in this excited state for a period of time typically less than 10-6 second. Then it returns to the lower state spontaneously by a photon or a phonon. These common processes of absorption and spontaneous emission cannot give rise to the amplification of light. The best that can be achieved is that for every photon absorbed, another is emitted.

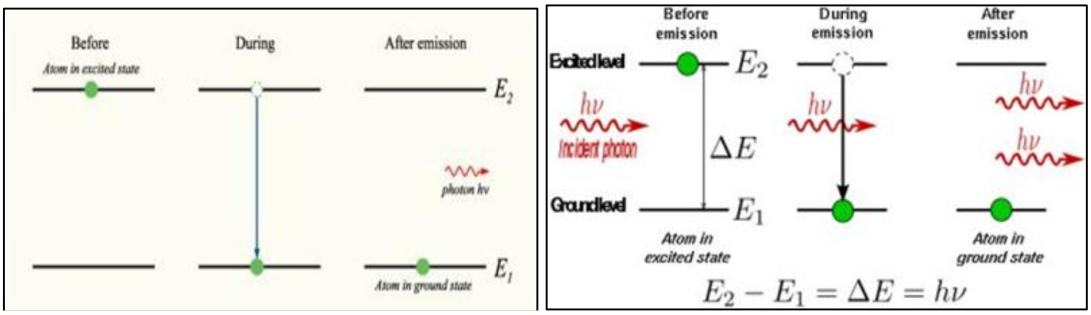


Fig 2: Diagram of (a) spontaneous Emission; (b) stimulated Emission

Alternatively, if the excited-state atom is perturbed by the electric field of a photon with frequency ω, it may release a second photon of the same frequency, in phase with the first photon. The atom will again decay into the ground state. This process is known as stimulated emission [3].
The emitted photon is identical to the stimulating photon with the same frequency, polarization, and direction of propagation. And there is a fixed phase relationship between light radiated from different atoms. The photons, as a result, are totally coherent. This is the critical property that allows optical amplification to take place.
All the three processes occur simultaneously within a medium. However, in thermal equilibrium, stimulated emission does not account to a significant extent. The reason is there are far more electrons in the ground state than in the excited states. And the rates of absorption and emission is proportional the number of electrons in ground state and excited states, respectively. So absorption process dominates.

Population Inversion of the Gain Medium
If the higher energy state has a greater population than the lower energy state, then the light in the system undergoes a net increase in intensity. And this is called population inversion. But this process cannot be achieved by only two states, because the electrons will eventually reach equilibrium with the de-exciting processes of spontaneous and stimulated emission [4].
Instead, an indirect way is adopted, with three energy levels (E1<E2<E3) and energy population N1, N2 and N3 respectively (see Fig.3a). Initially, the system is at thermal equilibrium, and the majority of electrons stay in the ground state. Then external energy is provided to excite them to level 3, referred as pumping. The source of pumping energy varies with different LASER medium, such as electrical discharge and chemical reaction, etc.
In a medium suitable for LASER operation, we require these excited atoms to quickly decay to level 2, transferring the energy to the phonons of the lattice of the host material. This wouldn't generate a photon, and labelled as R, meaning radiation less. Then electrons on level 2 will decay by spontaneous emission to level 1, labelled as L, meaning LASER. If the life time of L is much longer than that of R, the population of the E3 will be essentially zero and a population of excited state atoms will accumulate in level 2.

When level 2 hosts over half of the total electrons, a population inversion be achieved.

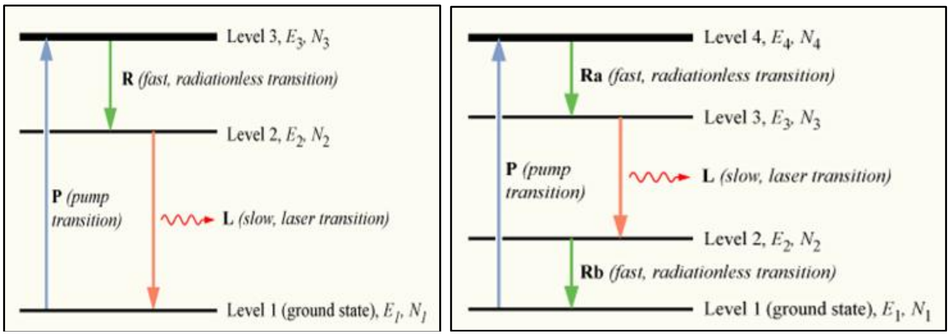


Fig 3: Electron Transitions within (a) 3-level gain medium; and (b) 4-level gain medium

Because half of the electrons must be excited, the pump system needs to be very strong. This makes three-level LASERs rather inefficient. Most of the present LASERs are 4-level LASERs, see Fig.3b [4]. The population of level 2 and 4 are 0 and electrons just accumulate in level 3. LASER transition takes place between level 3 and 2, so the population is easily inverted.

In semiconductor LASERs, where there are no discrete energy levels, a pump beam with energy slightly above the band gap energy can excite electrons into a higher state in the conduction band, from where they quickly decay to states near the bottom of the conduction band. At the same time, the holes generated in the valence band move to the top of the valence band.[5] Electrons in the conduction band can then recombine with these holes, emitting photons with an energy near the band gap energy.

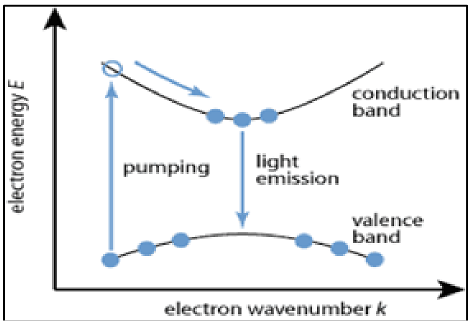


Fig 4: Diagram of electron transitions of semiconductor gain medium

Optical Resonator

Although with a population inversion we have the ability to amplify a signal via stimulated emission, the overall single-pass gain is quite small, and most of the excited atoms in the population emit spontaneously and do not contribute to the overall output [6]. Then the resonator is applied to make a positive feedback mechanism.

An optical resonator usually has two flat or concave mirrors, one on either end, that reflect lasing photons back and forth so that stimulated emission continues to build up more and more LASER light. Photons produced by spontaneous decay in other directions are off axis so that they won't be amplified to compete with stimulated emission on axis. The "back" mirror is made as close to 100% reflective as possible, while the "front" mirror typically is made only 95 - 99% reflective so that the rest of the light is transmitted by this mirror and leaks out to make up the actual LASER beam outside the LASER device [7].

Optical resonator also has a function of wavelength selector. It just makes a standing wave condition for the photons: $L=n\lambda/2$ ………….. (eq. 2). Here, L is the length of resonator, n is some integer and λ is the wavelength. Only wavelengths satisfying eq. (2) will get resonated and amplified.

Working of LASER

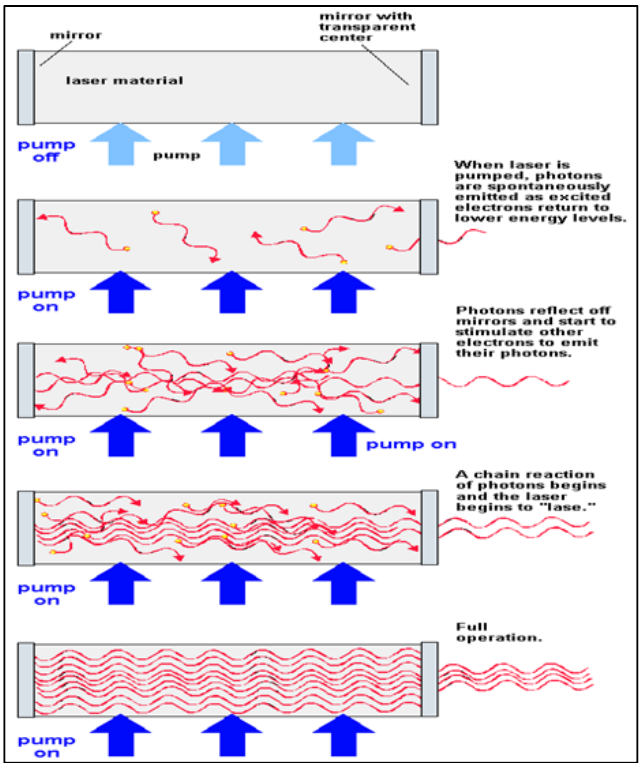


Fig 5: Schematic Diagram of LASER Operation

How LASERs work

A LASER is effectively a machine that makes billions of atoms pump out trillions of photons (light particles) all at once so they line up to form a really concentrated light beam. First, we should know how atom gives light.

What do weneed to make a LASER?

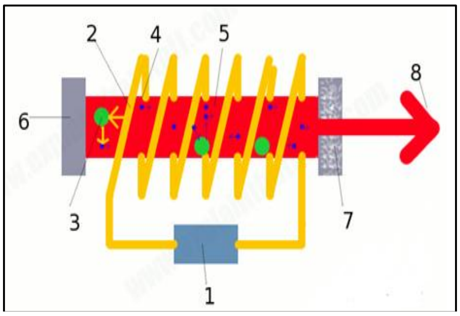
We need two basic parts:

- A load of atoms (a solid, liquid, or gas) with electrons in them that we can stimulate. This is known as the medium or, sometimes, the amplifying or "gain" medium (because gain is another word for amplification).

- Something to stimulate the atoms with, such as a flash tube (like the flash lamp in a camera) or another LASER.

A typical red LASER would contain a long crystal made of ruby (the medium, shown in the artwork below as a red bar) with a flash tube (yellow zig-zag lines) wrapped around it. The flash tube looks a bit like a fluorescent strip light, only it's coiled around the ruby crystal and it flashes every so often like a camera's flash lamp.

How do the flash tube and the crystal make a LASER beam?



1. A high-voltage electric supply makes the tube flash on and off.
2. Every time the tube flashes, it "pumps" energy into the ruby crystal. The flashes it makes inject energy into the crystal in the form of photons.
3. Atoms in the ruby crystal (large green blobs) soak up this energy in a process called absorption. Atoms absorb energy when their electrons jump to a higher energy level. After a few milliseconds, the electrons return to their original energy level (ground state) by giving off a photon of light (small blue blobs). This is called spontaneous emission.
4. The photons that atoms give off zoom up & down inside the ruby crystal, traveling at the speed of light.
5. Every so often, one of these photons stimulates an already excited atom. When this happens, the excited atom gives off a photon and we get our original photon back as well. This is called stimulated emission. Now one photon of light has produced two, so the light has been amplified. "Light amplification" has been caused by "stimulated emission of radiation" (hence the name "LASER", because that's exactly how a LASER works!)
6. A mirror at one end of the LASER tube keeps the photons bouncing back and forth inside the crystal.
7. A partial mirror at the other end of the tube bounces some photons back into the crystal but let some escape.
8. The escaping photons form a very concentrated beam of powerful LASER light.

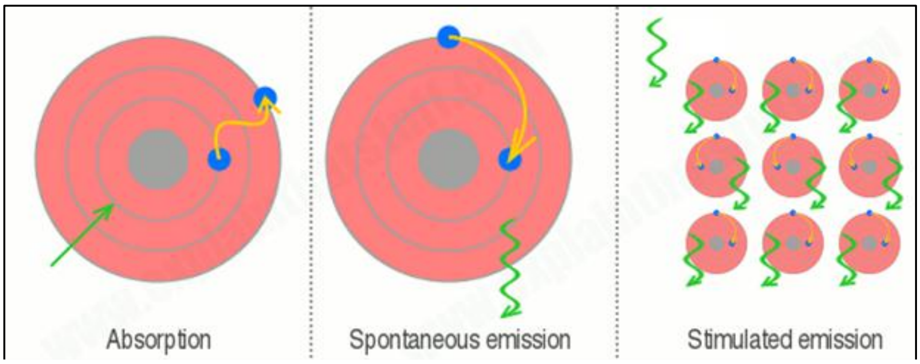
How do LASERs make light: Acronym of LASER is actually a very clear explanation of how LASERs make their super-powerful beams of light.

Spontaneous emission

"R" of LASER: radiation. The radiation LASERs make has nothing to do with dangerous radioactivity, the stuff that makes Geiger counters click, which atoms spew out when they smash together or fall apart. LASERs make electromagnetic radiation, just like ordinary light, radio waves, X rays, and infrared. Although it's still produced by atoms, they make ("emit") it in a totally different way, when electrons jump up and down inside them. We can think of electrons in atoms sitting on energy levels, which are a bit like rungs on a ladder. Normally, electrons sit at the lowest possible level, which is called the atom's ground state. If wefire in just the right amount of energy, wecan shift an electron up a level, onto the next rung of the ladder. That's called absorption and, in its new state, we say the atom is excited—but it's also unstable. It very quickly returns to the ground state by giving off the energy it absorbed as a photon. From candles to light bulbs and fireflies to flashlights, all the conventional forms of light works through the process of spontaneous emission. In a candle, combustion excites atoms and makes them unstable. They give off light when they return to their original (ground) states. Every photon produced by spontaneous emission inside this candle flame is different from every other photon, which is why there's a mixture of different wavelengths (and colours), making "white" light. The photons emerge in random directions, with waves that are out of step with one another ("out of phase"), which is why candlelight is much weaker than LASER light.

Stimulated emission:

Normally, a typical bunch of atoms would have more electrons in their ground states than their excited states, which is one reason why atoms don't spontaneously give off light. But what if we excited those atoms—pumped them full of energy—so their electrons were in excited states. In that case, the "population" of excited electrons would be bigger than the "population" in their ground states, so there would be plenty of electrons ready and willing to make photons of light. We call this situation a population inversion, because the usual state of affairs in the atoms is swapped around (inverted). Now suppose also that we could maintain our atoms in this state for a little while so they didn't automatically jump back down to their ground state. Then we'd find something really interesting. If we fired a photon with just the right energy through our bunch of atoms, we'd cause one of the excited electrons to jump back down to its ground state, giving off both the photon we fired in and the photon produced by the electron's change of state. Because we're stimulating atoms to get radiation out of them, this process is called stimulated emission. We get two photons out after putting one photon in, effectively doubling our light and amplifying it. These two photons can stimulate other atoms to give off more photons, so, pretty soon, we get a cascade of photons—a chain reaction—throwing out a brilliant beam of pure, coherent LASER light. What we've done here is amplify light using stimulated emission of radiation—and that's how a LASER gets its name.



How LASERs work in theory

Left: Absorption: Fire energy (green) into an atom and we can shift an electron (blue) from its ground state to an excited state, which usually means pushing it further from the nucleus (gray). Middle: Spontaneous emission: An excited electron will naturally jump back to its ground state, giving out a quantum (packet of energy) as a photon (green wiggle). Right: Stimulated emission: Fire a photon near a bunch of excited atoms and we can trigger a cascade of identical photons. One photon of light triggers many, so what we've got here is light amplification (making more light) by stimulated emission of (electromagnetic) radiation—LASER!

What makes LASER light so different?

If that's how LASERs make light, why do they make a single colour and a coherent beam? It boils down to the idea that energy can only exist in fixed packets, each of which is called a quantum.

The energy levels in atoms are in fixed places, with gaps in between them. We can only move electrons in atoms between the fixed energy levels. To make an electron jump from a lower to a higher level, we have to feed in a precise amount of energy, equal to the difference between the two energy levels. When electrons flip back down from their excited to their ground state, they give out the same, precise amount of energy, which takes the form of a photon of light of a particular colour. Stimulated emission in LASERs makes electrons produce a cascade of identical photons—identical in energy, frequency, wavelength—and that's why LASER light is monochromatic. The photons produced are equivalent to waves of light whose crests and troughs line up and that's what makes LASER light coherent.

Types of LASERs

According to the gain material, LASERs can be divided into the following types. Several common used LASERs are listed in each type [1].

Gas LASERs:

LASER Gain Medium	Operation Wavelength(s)	Pump Source	Applications and Notes
Helium-neon LASER	632.8nm	Electrical discharge	Interferometry, holography, spectroscopy, barcode scanning, alignment, optical demonstrations
Argon LASER	454.6 nm, 488.0 nm, 514.5 nm	Electrical discharge	Retinal phototherapy (for diabetes), lithography, confocal microscopy, spectroscopy pumping other LASERs
Carbon dioxide LASER	10.6 μm, (9.4 μm)	Electrical discharge	Material processing (cutting, welding, etc.), surgery
Excimer LASER	193 nm (ArF), 248 nm (KrF), 308 nm (XeCl), 353 nm (XeF)	Excimer recombination via electrical discharge	Ultraviolet lithography for semiconductor manufacturing, LASER surgery

Solid State LASERs

LASER Gain Medium	Operation Wavelength(s)	Pump Source	Applications and Notes
Ruby LASER	694.3nm	Flash Lamp	Holography, tattoo removal. The first type of visible light LASER invented; May 1960.
Nd:YAG LASER	1.064 μm, (1.32 μm)	Flash Lamp, LASER Diode	Material processing, LASER target designation, surgery, research, pumping other LASERs. One of the most common high power LASERs.
Erbium doped glass LASERs	1.53-1.56 μm	LASER diode	um doped fibres are commonly used as optical amplifiers for telecommunications.
F-centre LASER	Mid infrared to far infrared	Electrical current	Research

Metal-vapour LASERs:

LASER Gain Medium	Operation Wavelength(s)	Pump Source	Applications and Notes
Helium-cadmium (HeCd) metal-vapour LASER	441.563 nm, 325 nm	Electrical discharge in metal vapour mixed with helium buffer gas.	Printing and typesetting applications, fluorescence excitation examination (i.e. in U.S. paper currency printing)
Copper vapour LASER	510.6 nm, 578.2 nm	Electrical discharge	Dermatological uses, high speed photography, pump for dye LASERs

Other types of LASERs:

LASER Gain Medium	Operation Wavelength(s)	Pump Source	Applications and Notes
Dye LASERs	Depending on materials, usually a broad spectrum	Other LASER, flash lamp	Research, spectroscopy, birthmark removal, isotope separation.
Free electron LASER	A broad wavelength range (about 100 nm - several mm)	Relativistic electron beam	Atmospheric research, material science, medical applications

Application areas of LASER:
Scientific: In science, LASERs are used in many ways, including:

- Raman spectroscopy
- LASER induced breakdown spectroscopy
- Atmospheric remote sensing
- Investigating nonlinear optics phenomena
- Holographic techniques employing LASERs also contribute to a number of measurement techniques.
- LASER based lidar (LIght raDAR) technology has application in geology, seismology, remote sensing and atmospheric physics.
- LASERs have been used aboard spacecraft such as in the Cassini-Huygens mission.
- In astronomy, LASERs have been used to create artificial LASER guide stars, used as reference objects for adaptive optics telescopes.

Heat Treatment
Heat treating with LASERs allows selective surface hardening against wear with little or no distortion of the component. Because this eliminates much part reworking that is currently done, the LASER system's capital cost is recovered in a short time. An inert, absorbent coating for LASER heat treatment has also been developed that eliminates the fumes generated by conventional paint coatings during the heat-treating process with LASER beams.

Lunar LASER ranging
When the Apollo astronauts visited the moon, they planted retroreflector arrays to make possible the Lunar LASER Ranging Experiment. LASER beams are focused through large telescopes on Earth aimed toward the arrays, and the time taken for the beam to be reflected back to Earth measured to determine the distance between the Earth and Moon with high accuracy.

Photochemistry
Some LASER systems, through the process of mode locking, can produce extremely brief pulses of light - as short as picoseconds or femtoseconds (10^{-12} - 10^{-15} seconds). Such pulses can be used to initiate and analyse chemical reactions, a technique known as photochemistry. The short pulses can be used to probe the process of the reaction at a very high temporal resolution, allowing the detection of short-lived intermediate molecules. This method is particularly useful in biochemistry, where it is used to analyse details of protein folding and function.

LASER scanner
LASER barcode scanners are ideal for applications that require high speed reading of linear codes or stacked symbols.

LASER cooling
A technique that has recent success is LASER cooling. This involves atom trapping, a method where a number of atoms are confined in a specially shaped arrangement of electric and magnetic fields. Shining particular wavelengths of light at the ions or atoms slows them down, thus cooling them. As this process is continued, they all are slowed and have the same energy level, forming an unusual arrangement of matter known as a Bose–Einstein condensate.

Nuclear fusion
Some of the world's most powerful and complex arrangements of multiple LASERs and optical amplifiers are used to produce extremely high intensity pulses of light of extremely short duration, e.g. laboratory for LASER energetics, National Ignition Facility, GEKKO XII, Nike LASER, LASER Mégajoule, HiPER. These pulses are arranged such that they impact pellets of tritium–deuterium simultaneously from all directions, hoping that the squeezing effect of the impacts will induce atomic fusion in the pellets. This technique is known as "inertial confinement fusion”.

Microscopy
Confocal LASER scanning microscopy and Two-photon excitation microscopy make use of LASERs to obtain blur-free images of thick specimens at various depths. LASER capture microdissection use LASERs to procure specific cell populations from a tissue section under microscopic visualization.

Military
Military uses of LASERs include applications such as target designation and ranging, defensive countermeasures, communications and directed energy weapons.

Defensive countermeasures
Defensive countermeasure applications can range from compact, low power infrared countermeasures to high power, airborne LASER systems. IR countermeasure systems use LASERs to confuse the seeker heads on infrared homing missiles.

Tools
Cutting tools based on LASERs are widely used in industry: they're precise, easy-to-automate, and, unlike knives, never need sharpening. Where pieces of cloth were once cut by hand to make things like denim jeans, now fabrics are chopped by robot-guided LASERs. They're faster and more accurate than humans and can cut multiple thicknesses of fabric at once, which improves efficiency and productivity. The same precision is equally important in medicine: doctors routinely use LASERs on their patients' bodies for everything from blasting cancer tumors and cauterizing blood vessels to correcting problems with people's vision (LASER-eye surgery, fixing detached retinas, and cataract treatments all involve LASERs).

Communications
LASERs form the bedrock of all kinds of 21st-century digital technology. Every time we swipe shopping through a grocery

store barcode scanner, you're using a LASER to convert a printed barcode into a number that the checkout computer can understand. When we watch a DVD or listen to a CD, a semiconductor LASER beam bounces off the spinning disc to convert its printed pattern of data into numbers; a computer chip converts these numbers into movies, music, and sound. Along with fibre-optic cables, LASERs are widely used in a technology called photonics—using photons of light to communicate, for example, to send vast streams of data back and forth over the Internet.

Conclusion

The output of a LASER is a coherent electromagnetic field. In a coherent beam of electromagnetic energy, all the waves have the same frequency and phase. LASER technology is widely used in almost all the fields of science. It is quite safe technology.

Future Aspects

LASER technology can be widely used in the future. It will grow in the field of military and defence mechanism. It will be used in making weapons and missiles. This technology will be very promising in the field of medical science for the treatment of various diseases. LASER technology will have a bright future in communication. It will be growing in the field of spectroscopy and disorientation.

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