

50th
Anniversary of
the Invention
of LASER

LASER AT 50

ON 21 July 1969, before leaving for Earth, astronauts Neil Armstrong and Edwin Aldrin had set up an array of small reflectors on the surface of the Moon. About ten days later, a team of astrophysicists at University of California's Lick Observatory pointed their telescope towards the precise location of human landing and sent a small pulse of power into the tiny instrument they had added to the telescope. The narrow beam of red light that emerged from it pierced the sky and disappeared into outer space. Slightly more than a second after the beam hit the reflectors, the Lick team detected its faint reflection. The time period between the launch of the pulse of light

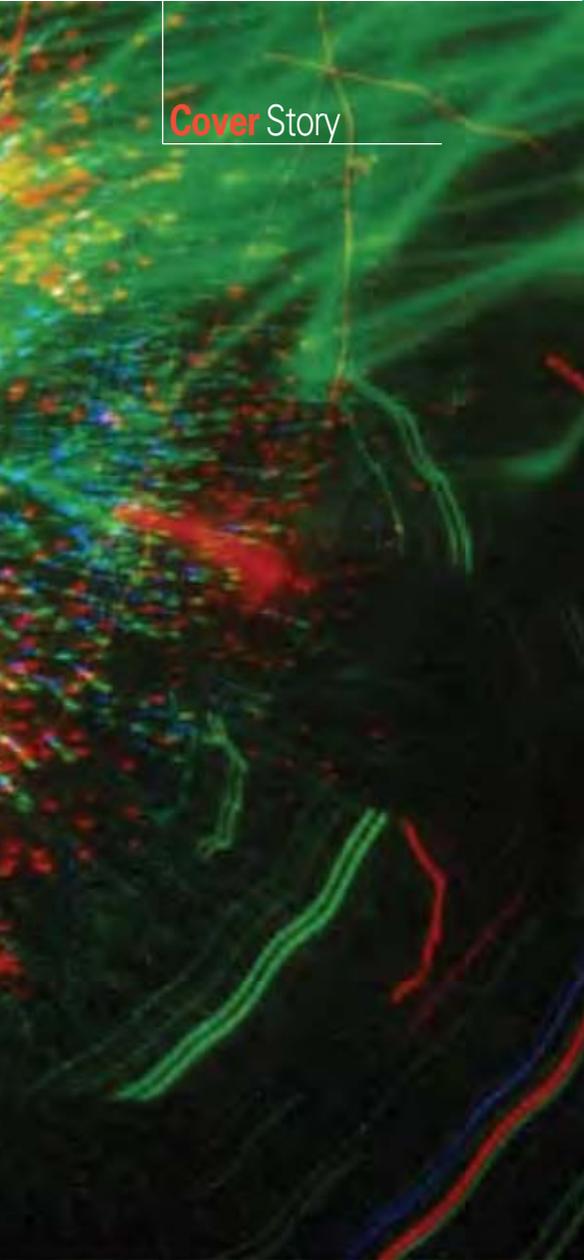
In the LASER we have a sort of Alladin's Lantern. All that we need is imagination to order it to perform tasks that we want done. Here's a look at this wonderful technology on the occasion of its 50th anniversary.

and its return permitted calculation of the distance between Earth and Moon with unprecedented precision, to the extent of correction within an inch.

The wonder ray that made this possible was LASER, a brand new invention that had been demonstrated just nine years before, in 1960. It was the brainchild of a 32-year-old engineer-turned-physicist at Hughes Research Laboratories, Malibu, California. His name was Theodore

Maiman, but at that time it was considered rather useless, upon which even his colleagues mocked him, saying, "Aha! Great solution! But what could be the problem?"

In fact, nobody could even imagine that Maiman's invention would become literally the workhorse of modern physics and so engraved on to everyday life. And today in its fiftieth birth anniversary, LASER is here to cool atoms, send data, mend eyes and trigger



Laser lights make for fascinating viewing



In 1918 itself Einstein had predicted the existence of gravitational waves produced by moving masses. But until today it has not been directly detected.

an atom to go on to high energy states, it can also force an atom to give up its energy and drop to lower states. While this “stimulated energy loss” happens, it will also lead to amplification of the emitted photon, a phenomenon called Coherent Amplification. In short, it is amplification stimulated by light creating a stronger emission (later abridged as LASER – Light Amplified by Stimulated Emission of Radiation).

The first brilliant success was by Charles Townes, who used this phenomenon to amplify the microwaves. The resultant device was called MASER, the acronym for ‘Microwave Amplification by Stimulated Emission of Radiation’. And in their historical paper published in *Physical Review*, Townes and his co-worker Arthur Schawlow hoped that the MASER concept could be extended to an “optical MASER”, in other words, the LASER.

Thus, it paved the way for a race to build a LASER, in which Bell Laboratories was destined to win as the research group led

by Charles Townes was there. Bell Lab, then called the Bell Telephone Laboratories, was a well-funded research institute with a backdrop of several high profile achievements. Even within Bell Lab there were other groups, well, outside also, who joined the race.

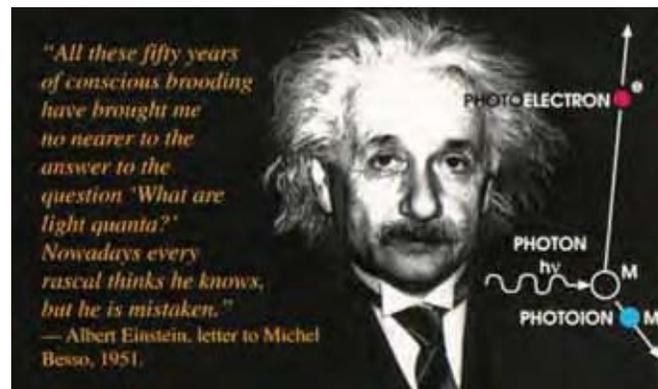
In US alone, there were more than six research labs including the famous General Electric and IBM. Townes’s former PhD student, Gordon Gould, was also among the rivals. He abandoned his thesis work and joined a private company engaged in LASER research. But, the dark horse was yet to join the race—Theodore Maiman, who was then at Hughes Research Laboratories, the research arm of Hughes Aircraft Company. Maiman’s engineering and physics experience was an added advantage, when the company wanted a MASER, as per the contract it signed with the US Army

fusion. While it is the “death ray” in military applications, it is forming part of high-life through spectacular “LASER shows” at stage concerts. It is there in our DVD’s, Bar-code scanners and latest mobile phones and so, simply but, it is unavoidable.

History of LASER

It goes to Einstein for a starting point in the history of LASER, who at the prime of his fame established the idea of stimulated emission, in 1917. It was a re-derivation of Max Planck’s Law of Radiation through conceptual advancement. However, till the end of the 1940s, the principle of stimulated emission was hardly sought, as the concept was largely considered a theoretical one.

Einstein based it in thermodynamics, that if light can force





Party Laser lights

Lasers are embedded in everyday life finding use in DVDs, bar code scanners, mobile phones, as military weapons, and even in surgery



Corps of Engineers. It was his efforts to make the MASER more compact and practical that led to the LASER.

Maiman's "Eureka"

The reason why light is usually absorbed in materials is simply that substances almost always have more atoms or molecules at lower states than at higher states so that more photons are absorbed than emitted. So, the trick in making a LASER is to produce a material in which the energies of the molecules or atoms are put in excited states than in ground states. A wave of electromagnetic energy moving through such a substance will pick up, rather than lose energy.

However, just one pass of the wave through the substance will not give

much amplification and so multiple reflections have to be there. This is achieved by placing two parallel mirrors on either side of the material, of which one mirror is partially transparent. When the internal reflections are enough to build up substantial amount of power, the ray will penetrate through the transparent mirror. This was the theoretical blueprint and next came the choke of the material.

Maiman was familiar with the properties of Ruby from his earlier works and so he selected it. Ruby is a crystal of Aluminum Oxide (Al_2O_3) in which a few Chromium atoms are dispersed as impurities. These Chromium atoms that exist as ions by losing three of their electrons can

absorb green light from the visible spectrum and go to excited states. When electrons fall back to the ground state from these high energy levels, they fluoresce in red. Maiman was thinking that he could use this red fluorescence to create LASER.

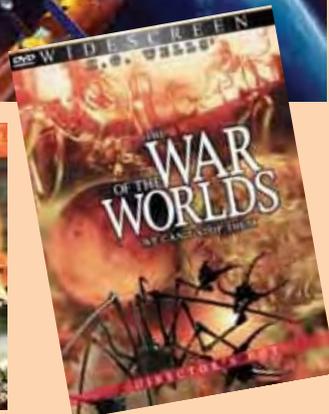
The path ahead was however not smooth as he thought. The first blow came from Arthur Schawlow who was his brother-in-law and work-mate. In September 1959, shortly after Maiman started his project, Schawlow publicly declared that Ruby couldn't be a candidate for stimulated emission. He argued, for that to happen, more electrons need to reside in the upper energy level than in the lower ones, a condition known as 'Population Inversion'. As per Schawlow, it was

Laser in Fiction

Invisible rays that could be used as weapon were always imagined in fiction stories even before the principle of LASER was thought of. The author who popularized it as a "death ray" was H.G. Wells, who in his 1898 tale *The War of the Worlds* described it as an "inevitable, invisible sword of heat" that Martians use against the Earthlings.

In 1927, Alexey Tolstoy depicted a LASER-like device in his science fiction novel *The Hyperboloid of Engineer Garin*. Through the 1930s these predictions were well played in celluloid also. In his novel *Fatal Eggs*, Mikhail Bulgakov used it to create some "biological effects" on the target though it was shown as a beam of red light that emerges from an advanced microscope.

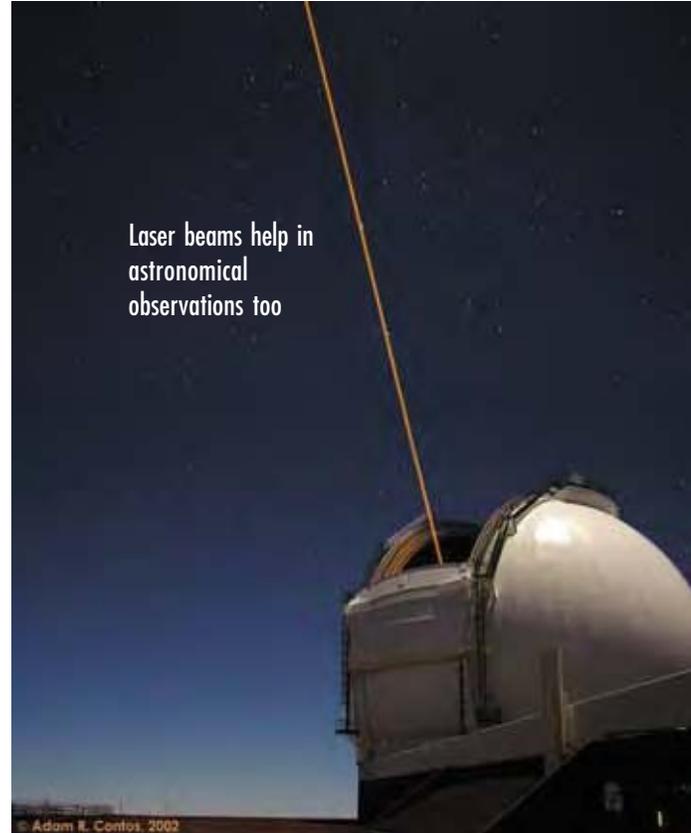
In the 1951 film *The Day the Earth Stood Still* LASER was the weapon the powerful robot uses. This was one of the reasons why newspapers first quoted Maiman's invention as "Death Ray" to his great dismay. In *Star Wars: Episode IV* also the doomsday fear was triggered using LASER. But, here it was not man but a distant star using LASER beams to destroy the Earth.





The laser also finds use in remote welding

In 1968, LASER proved to be a bloodless way to crush the kidney stone opening its potential towards guided surgeries. Now, it is routinely used to treat skin tumours as well as inaccessible brain tumours.



Laser beams help in astronomical observations too

impossible to achieve this for a three-level energy system such as Ruby, whereas it could be much easier for a “four-level energy system”.

Whether this was practically true or not was not the question but with repeated counseling against Ruby that came all along from respected scientists, Maiman’s employer stopped funding his research. For Maiman it was not a discouragement as he was willing to spend from his own pocket, but the next hurdle was not much far.

The problem was the ‘quantum efficiency’ of Ruby, that is, the number of fluorescence-photons emitted for each light photon absorbed. In a much discussed paper published in the *Review of Scientific Instruments* (30, 995), Irwin Wieder, a scientist personally trained by Maiman, claimed that the quantum efficiency of Ruby was just 1%, not enough to attain a stimulated emission. And as per the calculations of Maiman, for a successful emission it should be 75%, an ardent but

improbable objective!

However, there was a silver-line—if he could have a very bright pump of light source, it could work. And the ‘eureka’ moment came from reading an article about photographic-lamps that could achieve ‘brightness temperature’ of 8000 K. Everything that had to follow was more easy with the help of his technical assistant Irnee d’ Haenens and on 16 May 1960 they got the first evidence of a LASER in action, the lifetime achievement of Maiman!

In the Limelight? No!

In the euphoric days that followed, Maiman tried to refine his equipment and immediately prepared a report of his exciting results submitting it to *Physical Review Letters* on 24 June 1960. However, the journal editor did not accept the paper, stating that the MASER-physics had already reached a mature state and “yet another MASER-

paper” didn’t deserve rapid publication. (No wonder, Maiman’s invention was not ‘LASER’ then, it was only ‘optical-MASER’, as it was not Maiman but Gordon Gould, a graduate student at Columbia University who later named it as LASER.)

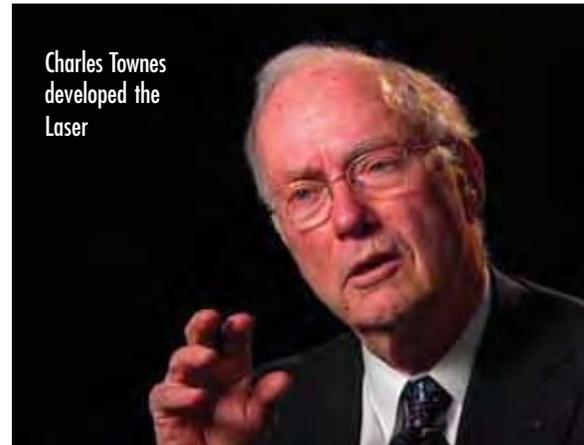
Anyway, Maiman had to pen a shorter version of his original article and send it to *Nature*, where it was accepted (187, 493). It was scheduled for the 6 August issue, but Hughes Lab was anxious to conduct a press conference before that—since Bell Labs was also involved in the race, there was no prize for a ‘runner up’! Thus the world came to know about it on 7 July 1960, which erased the long held conviction that LASER is not practically a possible thing. But many still continued to (or liked to!) disbelieve it.

National Ignition Facility

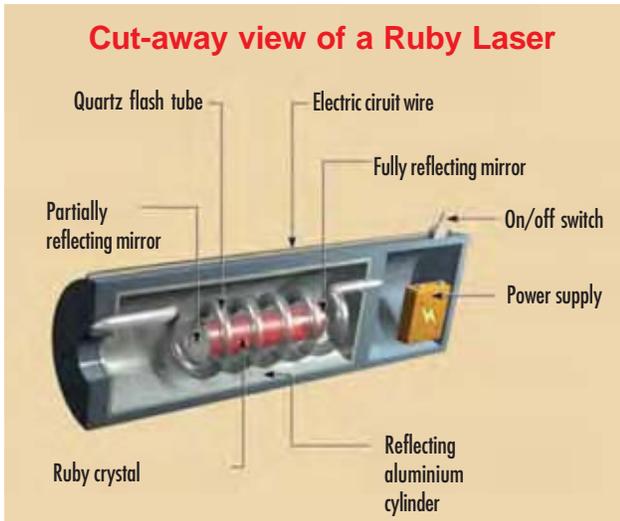
The National Ignition Facility (NIF) located at California’s Lawrence Livermore National Laboratory is the world’s largest LASER. It covers 70,000 m² and contains 8000 large optical units, each up to 1 metre in diameter. Together, the facility’s 192 LASER beams can provide 1.8 MJ of energy with a combined power of 500 TW (500 x 10¹² W). This



is about 40 times more than the power consumed by the entire world. Of course, this power only lasts for a few nano seconds, but it is enough to create pressures up to tens of millions of atmospheres, forcing atoms of Deuterium and Tritium to join together.



Charles Townes developed the Laser

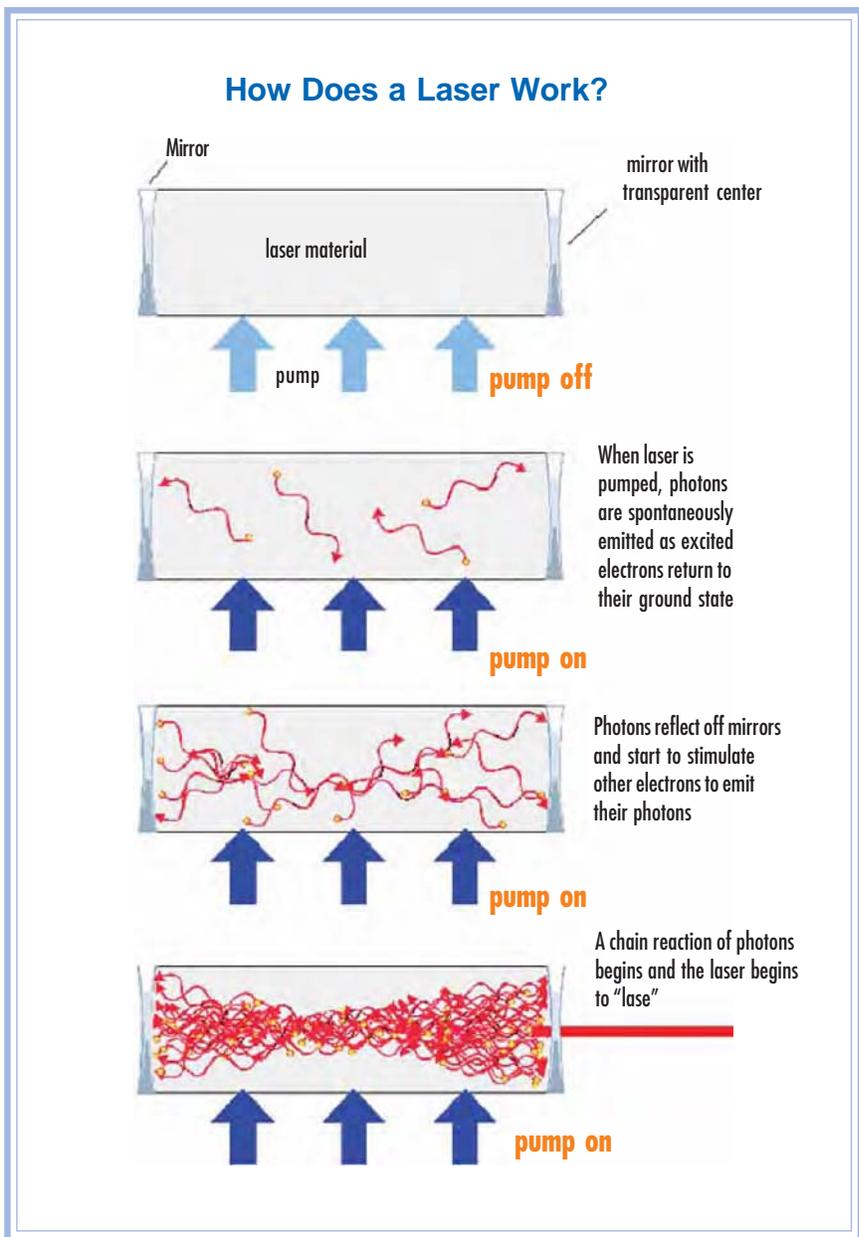


Though the potentialities of LASER were not known at that time, there was one more reason for Maiman not being in the limelight. On 1 August 1960, Shawlow and Townes at Bell Labs could reproduce Maiman's result and got it published also in the same journal that rejected Maiman's paper. It appeared in the October issue of *Physical Review Letters* and many who read it thought that Bell Laboratories was the first to build the LASER. For the American scientific circles as well as the public, Shawlow and Townes were familiar personalities and Bell Lab's trials on LASER implementation were rather well known also. So, even after 50 years, the invention of LASER still remains controversial, at least on the scoreboards of the rival fronts.

The LASER Revolution

The light of a LASER differs from that of an ordinary light source, just like music differs from noise. Moreover, a LASER beam can travel kilometers without much increase in its diameter. For example, when a Ruby-LASER was sent to Moon from Earth, the spot it created on the surface of Moon was only 9 km, even after travelling 2,40,000 miles.

Another quality of LASER is its immense luminous intensity. If we point our forefinger to sunlight, the power that falls on it is about one tenth of a watt. But, if light from LASER can be concentrated on it, it would be 10^9 watts. The size of a LASER device can be as big as a football field or as small as a pinhead. The light they emit can be invisible infrared, ultraviolet, X-ray



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or all the colours of the rainbow.

The wavelength of some LASERs is tunable and their intensity can be amplified through several orders of magnitude. Some LASERs can't even emit enough energy to cook an egg, whereas certain others can vapourize steel! The pulse of a LASER can be as short as to last for a second (10^{-15} s) while some others can create continuous beams that will remain for decades to come. However, many of these potentialities came through many years of research and in the beginning many entrepreneurs found that there were very few possibilities for commercial exploitation of LASERs. Many companies couldn't even pursue definite applications from this field.

The next type of LASER that immediately followed Maiman's Ruby-LASER was the Helium-Neon-LASER developed by Bell Laboratories in the same year, 1960. But the first LASER that became the most prevalent type was the Diode-LASER made up of the semiconductor Gallium Arsenide. It soon mushroomed into a wide variety of commercial versions that still

Maiman: The Man of Laser

Theodore Harold Maiman was born in Los Angeles in 1927. In his teens, he earned money for college by repairing electrical appliances and radio. After studying at University of Colorado, he went to do graduate work at Stanford University and got PhD in Physics from there in 1955.

He was employed in industry initially as a researcher in Lockheed Aircraft where he studied communication problems linked with guided missiles. He then went to Hughes Research Laboratories, California to work on the MASER. He left Hughes in 1961 to join a venture called Quanatron where he became the president of the newly formed Korad Corporation. He formed Maiman Associates in 1968.

He was twice nominated for Nobel Prize, but it was Charles Townes who shared it with two Russian theorists in 1964. Maiman always felt that his role in LASER discovery was downplayed and he was hurt by it. It prompted him to write "The Laser Odyssey" a memoir, in which he tried to present his side of the story. He died on 5 May 2007 in Vancouver, Canada at the age of 80.



hold sway in the global market.

The first automated LASER scanning machine was used in a supermarket checkout-counter in Ohio in 1974 paving the way for a Universal Product Code (UPC). Called simply the 'bar-code', it is used billions of times everyday by retailers and manufactures worldwide today. In the late 1970s, the first transatlantic fibre-optic cables were laid down, which operated through diode-LASERs. They could deliver light into fibres with a few micrometers of core diameter, thus, connecting the world in an integral manner. The effect was a revolution in communication that swept through Europe and the US in the late 1980s.

In industry, there was yet another wonder that enabled metal cutting as easy as slicing a cake. It was the carbon dioxide-LASER that became a

standardized cutting-tool even during the 1970s. In automobile industry, it introduced a new technique such as "remote welding" that made multiple spot welds possible through "optical steering".

This opened a new opportunity for LASER to be used as weapons though such fancies were already there with the development of Maiman's small LASER. But, rather than a "death ray", its first military application was for range finding. The first target LASER designators were used in the Vietnam War, in 1972. It made bombs intelligent rather than being stupid by falling anywhere. Ronald Reagan's 'Star Wars' programme envisaged LASERs as anti-missile weapons. Today these have become the norm for every country including India.

From the war-field the LASER directly entered into the music studio! In the 1970s, Sony and Philips began developing music digitally recorded on shiny plastic discs that were 12 cm in diameter, popularly known as "Compact Discs" (CDs). The first digitalized music album came out as a CD in 1982 with 74 minute of playback capacity - it was the album "52nd street" by Billy Joel. In the mid 1990s, came the Digital Video Discs (DVDs) that could store an entire feature length film. 'Blue-ray Discs' (BDs) were the next generation with 50-gigabyte capacity capable of holding more than five films in exceptionally high resolution.

Types of LASERs

There are many kinds of LASERs with different sub-types differing in their operational wavelength and applications.

- I. Gas LASERs: Helium-Neon LASER, Carbon dioxide LASER
- II. Chemical LASERs: Hydrogen Fluoride LASER
- III. Dye LASERs
- IV. Metal Vapour LASERs: Copper Vapour LASER, Gold Vapour LASER
- V. Solid state LASERs: Ruby LASER
- VI. Semiconductor LASERs: Hybrid silicon LASER, Diode LASER
- VII. Other types: Free Electron LASER, Raman LASER, Gas Dynamic LASER

TIMELINE OF LASER

1916	:	The theory of light emission by Albert Einstein—concept of stimulated emission
1951	:	Team led by Charles Townes builds the first MASER. Awarded Nobel Prize in 1964
1957	:	Gordon Gould coins the term 'LASER' in his lab notebook; basis for a 30-year patent dispute
1960	:	First working LASER invented by Theodore Maiman; Helium-Neon LASER comes from Bell Lab.
1961	:	First LASER surgery by Charles Campbell and Charles Koester
1962	:	Invention of diode-LASER by Robert Hall in General Electric Labs
1964	:	Kumar N. Patel at Bell Laboratories invents Carbondioxide LASER
1972	:	LASER target designators used for the first time in Vietnam War
1974	:	First trial of LASER barcode scanners in Supermarket
1978	:	First commercial LASER disc player in the market
1983	:	US President Ronald Reagan's Star War's speech reignites interest in LASER weapons
1988	:	TAT-8, the first transatlantic fibre-optic cable installed—dawn of LASER communications
1997	:	Creation of first "atom-LASER" by using Bose-Einstein condensate
2002	:	First LASER "guide star" used at the Keck 11 telescope in Hawaii
2006	:	Blue-ray discs in market
2009	:	Charles Kao shares Nobel Prize for his work on Fibre Optics
2010	:	World's largest LASER experiment at US National Ignition Facility aims to achieve "break-even point" for nuclear fusion

In fact, nobody could even imagine that Maiman's invention would become literally the workhorse of modern physics and so engraved on to everyday life. And today in its fiftieth birth anniversary, LASER is here to cool atoms, send data, mend eyes and trigger fusion.

Simultaneously, beam-scanning systems were invented which could dynamically follow music and trace intricate patterns in space. The first spectacular event was at the "Expo 70" World Fair in Osaka, Japan. Rock concerts by bands like Pink Floyd usually employed them to evoke awe and surprise until restrictions came up due to safety reasons.

In the field of medicine also, LASER heralded an authentic revolution. The first medical use of LASER was in 1961, when doctors at Columbia University of Medical Center in New York destroyed a retinal tumour using a Ruby-LASER. Ophthalmology was the most benefited field where LASER was

used for diagnosis as well as surgical cures. It enabled doctors to precisely vaporize a tissue or shape it as they wished. A classical example is LASIK (LASER-Assisted *in situ* Keratomileusis) Surgery where LASER is used to reshape the cornea. In 1968, LASER proved to be a bloodless way to crush the kidney stone opening its potential towards guided surgeries. Now, it is routinely used to treat skin tumours as well as inaccessible brain tumours.

New Dawns

In 1918 itself Einstein had predicted the existence of gravitational waves produced by moving masses. But until today it has not been directly detected. This is one of the research areas of future where LASER plays a part.

The equipment used for this is an Interferometer that was first built in 1978 though work on much powerful versions is still in progress. These are dubbed LIGO-LASER Interferometer Gravitationalwave Observatory of which one is in Hanford and the other in Livingston. Another is in Cascina in Italy officially known as VIRGO, which was opened in July 2003. Astrophysicists expect that LIGO and VIRGO may someday detect Einstein's dream waves.

LASERs also realized another of Einstein's predictions in 1924 about the existence of a special state of matter in which the so-called bosons may be forced to stay in a state with identical quantum properties. In 1995, that state was achieved which was called Bose-Einstein Condensation. With this, it was possible to explore certain aspects of quantum mechanics and superconductivity, the classical epitomes of modern physics.

Similar attempts have been made by the National Ignition Facility, California where conditions akin to the heart of a star have been created aiming to produce fusion power or the contrivances for it. The next generation telescopes also employ adaptive optics based on laser technology enabling astronomers to ascertain the position and movement of extrasolar planets.

Yes, in the LASER what we have is an 'Aladdin's Lantern'. What we need is only the imagination to order it tasks that we want done!

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