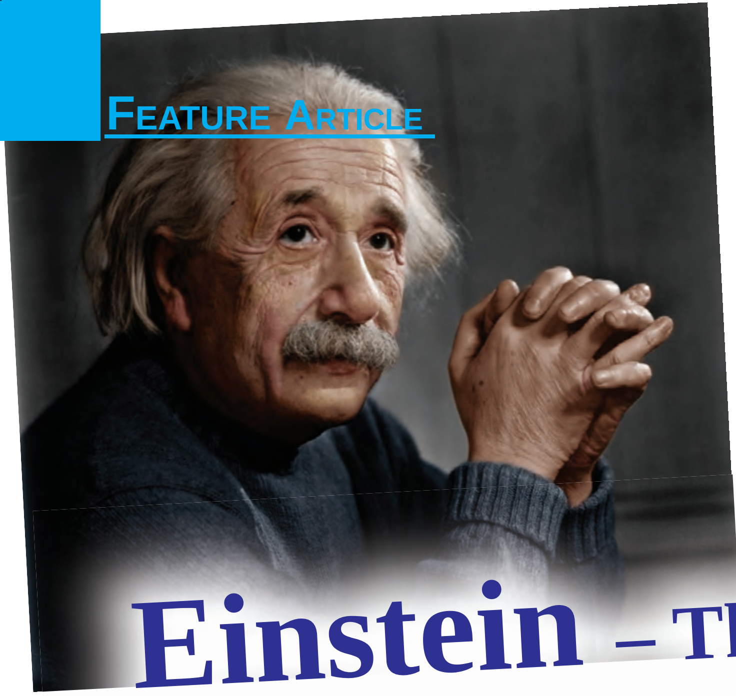
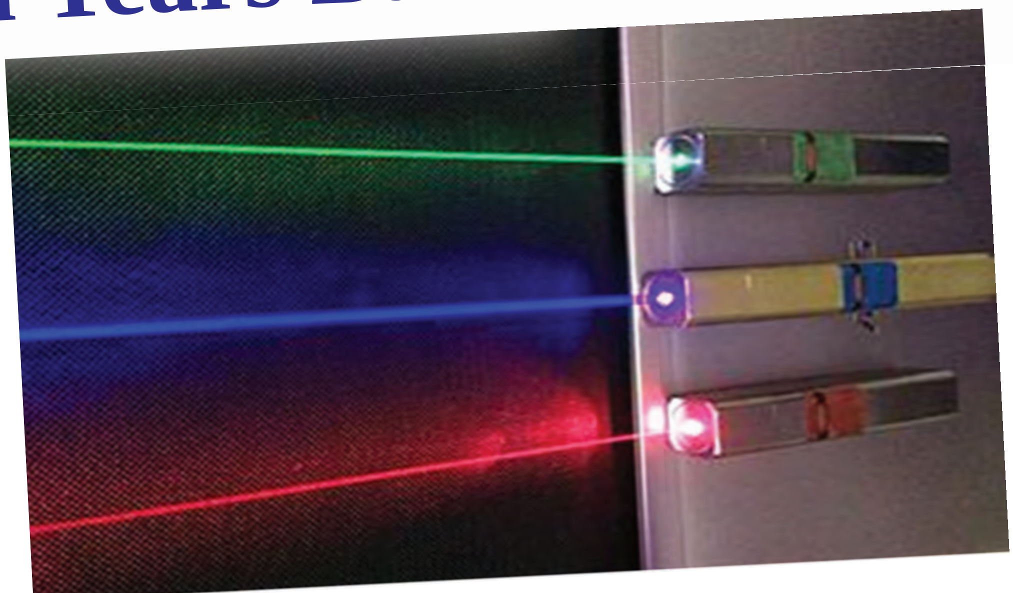


Sanjay D. Jain & Vivek M. Nanoti

The story of the birth of the LASER a hundred years back with Einstein's discovery of stimulated emission of radiation to the present day phenomenal progress achieved with LASERs is an interesting account of the connection between idea and fruition.

Einstein – The Man Who Laid the Foundation of LASERs Hundred Years Back



A hundred years back Albert Einstein laid the foundation of one of the most revolutionary inventions of the 20th century – LASER (Light Amplification by Stimulated Emission of Radiation). this would enable future scientists, engineers and doctors to provide sophistication to almost all walks of life.

His theory of stimulated emission of radiation, published in 1917, stimulated and guided research endeavours towards development of a working LASER for the next 43 years culminating in the invention of the first operational LASER by Theodore Maiman in 1960.

The term LASER conjures up images of incredible sources of light energy and magic light machines that can cut and drill metals, destroy satellites, read and send data, cool atoms, trigger fusion and perform complicated surgeries. This extraordinary application potential of LASERs was envisioned by Maiman.

However, like with all his other discoveries, Einstein was not aiming at any of these technological developments; he was just enjoying the fundamental challenges in physics by probing deeper and deeper to unearth the mysteries of nature; to fathom the unfathomable.

Einstein's Research

Einstein had a unique and peculiar style of research. He made many of his discoveries by the force of sheer thought. Instead of performing experiments in a laboratory he sat in a chair and performed 'thought' (gedanken) experiments. His 'apparatus' comprised fundamental principles and known facts of nature. He believed in the power of imagination and would often ask provocative questions that enabled him to reveal new truths of nature.

Max Planck and Niels Bohr

Though Einstein contributed substantially to almost all branches of physics he was more fascinated by light. He was aware of the work of Planck and Bohr about the quantum nature of light and had used the Planck's quantum hypothesis in explaining photoelectric effect in 1905.

During 1915-16, Einstein delved deeper into how light interacts with matter. He was quite deft at using thermodynamic arguments. He applied these arguments to figure out the processes involved in the thermodynamic equilibrium of radiation interacting with matter (gas of atoms) and published his research in three classic papers. The last of them, "Zur Quantentheorie der Strahlung" ("The Quantum Theory of Radiation") was published in the journal, *Physikalische Zeitschrift,* Vol. 18, pp. 121-128, 1917 (received on 3 March 1917).

Two of these processes, viz., absorption and spontaneous emission, were quite well known and Einstein included them as the first two postulates in his paper. Absorption (or stimulated absorption) is the process in which a photon of appropriate energy $h_\nu(= E_2 - E_1)$ is absorbed by the atom, raising it from a lower level E_1 to a higher level E_2. Spontaneous emission is a process in which an atom in the energy state E^2 makes a transition to the state E^1 of its own accord, i.e., without any external inducement resulting in the emission of a photon of energy h_ν.

These two processes cannot fully account for the thermodynamic equilibrium of matter-radiation interaction and Einstein intuitively predicted a third process – the process of *stimulated emission of radiation* – for a proper understanding of this equilibrium. He included it as a third postulate in his paper.

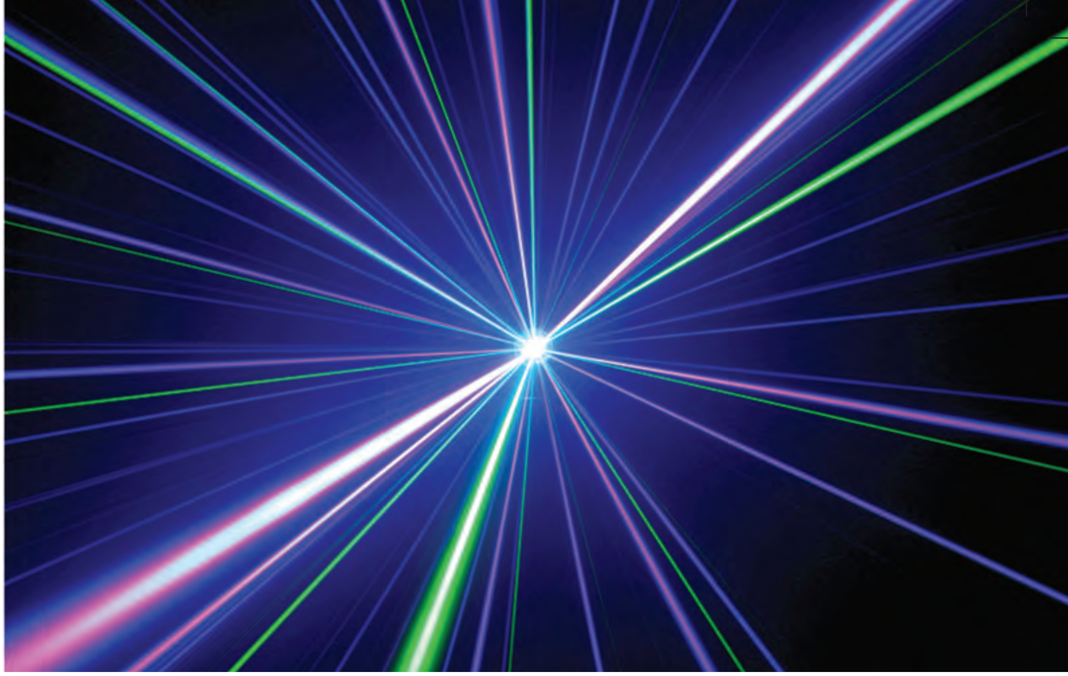
Stimulated Emission

The light output from the early incandescent sources and fluorescent lamps was incoherent, divergent, unpolarised and weak since it was produced through spontaneous emission, which is a random and uncontrolled process. Einstein's breakthrough discovery provided a new direction towards 'improving' light by 'purifying' and 'strengthening' it and promised coherent, polarised and strong light. This was because stimulated emission is a process that results in a photon that has exactly the same polarisation, same direction of propagation and same phase as the incident photon.

If this process could be achieved with large number of atoms in the higher energy state an avalanche of identical photons could be built and the process could be harnessed to produce light with

From Left to Right : N. Basov, A. Prokhorov, Charles Townes, Arthur Schawlow and Gordon Gould

Einstein's discovery of stimulated emission of radiation to the present day phenomenal progress achieved with LASERs is an apt and convincing reminder of the deep and strong connections between idea and fruition



all the desirable properties – the process of stimulated emission thus emerged as a key to laser operation.

Journey from Discovery to Development

Though the necessary theoretical foundation of laser was available in 1917 with Einstein's discovery, the journey from concept to reality was not an easy one due to enormous practical difficulties involved.

By 1954, the Soviet physicist N. Basov and A. Prokhorov and the American physicists Charles Townes and Arthur Schawlow could achieve amplification using stimulated emission in the microwave range (MASER: Microwave Amplification by Stimulated Emission of Radiation). By 1958, these physicists extended the maser concept to optical range and suggested the possibility of a *LASER as an optical MASER*. In 1959, Gordon Gould introduced the term LASER in a conference paper.

However, in the race towards development of the first LASER, Theodore Maiman proved to be a dark horse. After several setbacks his efforts bore fruits when he could demonstrate the first operational LASER, the Ruby Laser, on 16 May 1960 by shining a high-power flash lamp on a ruby rod. The historic paper by Theodore Maiman, in which he reported his discovery, was rejected by the journal, *Physical Review Letters*. He then sent it to the journal *Nature* where it was published on 6 August 1960.

Theodore Maiman

Though the development of the first operational LASER is credited to Maiman, he wasn't awarded the Nobel Prize though he was nominated for the Prize twice. Townes, Basov, and Prokhorov were awarded the 1964 Nobel Prize in Physics for their fundamental work, which led to the construction of LASERs.

LASERs have been employed since then in myriad research works for advancing scientific knowledge. These include the works of Nobel laureates Dennis Gabor (holography, 1971); Nicolaas Bloembergen, Schawlow and Kai Siegbahn (laser spectroscopy, 1981); Steven Chu, Claude Cohen-Tannoudji and William D. Phillips (development of methods to cool and trap atoms with laser, 1997) and Zhorev Alferov and Herbert Kroemer (semiconductor lasers, 2000).

LASER Types, Properties and Applications

Since the first LASER invented by Maiman in 1960, thousands of new LASERs have been developed so far. Schawlow even made a joking reference to the "edible" LASER (made of flavored gelatin) and the "drinkable" LASER (made of an alcoholic mixture).

LASERs are classified in several ways such as the choice of the active material used for LASER action, mode of operation (pulsed or continuous), power, efficiency and applications. Some well-known types of *lasers* are solid state lasers, gas lasers (further classified as atom lasers, molecular lasers and ion lasers), semiconductor lasers, liquid lasers, chemical lasers, dye lasers, Metal-vapour lasers, free electron lasers, and Raman lasers.

The properties that give LASER its extraordinary application potential are its high coherence, monochromaticity, convergence and intensity.

Coherence: Coherence time and coherence length of a wave are understood, respectively, as the time and the distance over which the wave remains coherent. LASERs have coherence lengths of the order of kilometres that are about 106 times that for ordinary light. Some fiber LASERS have coherence lengths exceeding 100 km.

Monochromaticity: LASERs have very narrow line width and hence a very high spectral purity or a high degree of monochromaticity compared to ordinary sources of light.

Convergence: LASER light spreads very little compared to ordinary sources of light, i.e., they have the minimum

Like with all his other discoveries, Einstein was not aiming at any of these technological developments; he was just enjoying the fundamental challenges in physics by probing deeper and deeper to unearth the mysteries of nature; to fathom the unfathomable. His theory of stimulated emission of radiation, stimulated and guided research endeavours towards development of a working laser.

divergence for a given diameter. For example, in the Apollo mission, the LASER beam shone on the Moon's surface diverged to only about 6.5 kilometres after travelling a distance of about 3,84,000 km!

Intensity: As the energy from an ordinary source of light spreads in all directions its intensity decreases away from the source in proportion to the square of the distance. However, due to very high directionality of a LASER beam the light energy is concentrated only in a very small region of space. This results in extremely high value of intensity even though the power of the laser may be small. For example, though the power of a 3.5 mW LASER is only about 1/105th fraction of the power of a 100 W bulb, its intensity is about 100 times greater! The intensity of a 1 mW laser beam is 3 x 106 times that of the Sun's radiation. Moreover, the intensity of a LASER remains undiminished over large distances.

Today LASER sources have been developed with such remarkable properties as high spectral purity (line width ≈ 10-6 Å), high directionality (divergence less than 10^{-5} radian leading to tight focusing to spots smaller than few square micrometers and thus to very high intensities), high power (≈ 10^5 W) leading to ultra-strong electric fields, short pulse widths (shorter than a femtosecond) and high monochromaticity (ultra-pure colours).

These remarkable properties of LASERs have made possible applications that were earlier considered impossible. LASERs helped to achieve the highest temperature on the Earth with NIF (National Ignition Facility) and to create the coldest objects to study new states of matter called BEC (Bose Einstein Condensate). The total number of LASER patents issued since its invention is well over 50,000. LASER is at the base of a fledgling revolution called photonics, just as the discovery of a transistor gave birth to a revolution called electronics.

Its industrial applications include cutting, drilling, welding, marking, alloying, heat treating, soldering, photolithography, industrial pollution monitoring, micro-machining and polishing. It has medical applications in dermatology, dentistry, cardiology, neurosurgery, eye surgery, spinal surgery, plastic surgery, cancer, endoscopy, physiotherapy and angioplasty. Its defence applications include target range finding, target designation, tracking and guidance. Lasers also have applications in information processing such as laser printers, CDs, DVDs, bar code scanners and fibre optic communication.

LASERs also have applications using Lidars (LIght Detection and Ranging) for measuring locations e.g., airborne bathymeters to measure the depth of water or the location of any submerged object, monitoring of volcanic aerosols that may affect global climate and monitoring of atmospheric pollution.

The story from the conceptual birth of the LASER a hundred years back with Einstein's discovery of stimulated emission of radiation to the present day phenomenal progress achieved with LASERs is an apt and convincing reminder of the deep and strong (but sometimes obscure) connections between idea and fruition, thought and reality, pure science and applied science, science & technology and research & development.

Dr. Sanjay D. Jain is Head, Knowledge Center, Priyadarshini Institute of Engineering and Technology, Hingna Road, Nagpur–19
Mr Vivek M. Nanoti is Principal, Priyadarshini Institute of Engineering and Technology, Hingna Road, Nagpur-19