LASER AND ITS APPLICATIONS

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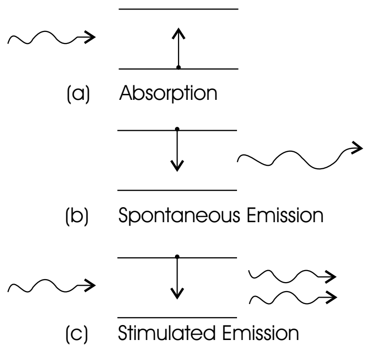
This article talks about laser, principle of laser action, different types of lasers and application of lasers.



Laser is undoubtedly one of the most significant inventions of the twentieth century which created a revolution in the world of science and technology. The laser has now permeated into almost all walks of life. It has been used for a number of applications in such important areas as communication, defence, space science, medicine, industry, etc.

T.H. Maiman of the Hughes Research Laboratory, California, U.S.A. developed the first ruby laser on 16 May 1960. Incidentally, this year the invention of laser has completed 50 years. It provides us an occasion to discuss about laser and its applications in some details.

What is Laser?

Laser is an acronym for Light Amplification by Stimulated Emission of Radiation. It is a powerful source of light having some unique characteristics which are not found in the normal light sources like tungsten bulbs, mercury lamp, etc.

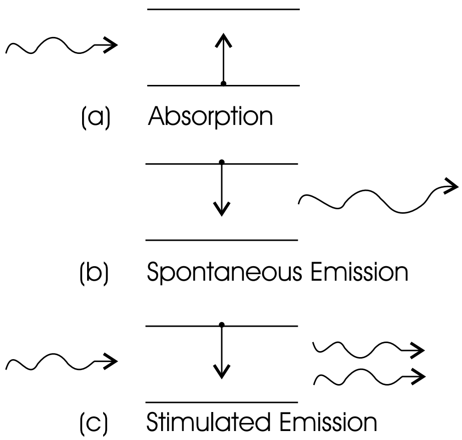


Fig.1: Phenomena of absorption, spontaneous emission and stimulated emission

The beam of ordinary light spreads out very quickly. It contains many colours or wavelengths and its waves are not in step with each other which means that the ordinary light is neither monochromatic (of a single wavelenght) nor coherent. On the other hand, laser light can travel very long distances with very little divergence. It is monochromatic and its waves are coherent, i.e., they are exactly in step with each other and thus have a fixed phase relationship.

Thus, laser light is coherent and monochromatic and has a high degree of directionality. Also, it has very high intensity. As a result, very high laser energy can be focused on to a very small spot. This property of laser has important applications in welding, cutting, laser fusion, etc.

It may be noted that both temporal and spatial coherence exist simultaneously in laser light. Temporal coherence means that the relative phase difference between two points in time (i.e., separated byΔt) remains fixed; while spatial coherence means that the relative phase difference between two points in space (i.e., separated by a transverse distance Δd) remains fixed. In fact, temporal coherence is related to monochromaticity (or the spectral purity) while spatial coherence is related to directionality and uniphase wavefronts. The properties of monochromacity and high degree of directionality exhibited by laser light make it a completely coherent light.

The basic principle of laser is based on the phenomenon of stimulated emission that was predicted by Einstein in 1917. However, this principle remained on paper for more than three- and- a- half decades; it could not be put to any practical applications.

In 1954, Charles Hard Townes from the University of Coulombia, U.S.A. succeeded in amplifying microwaves using this principle. This device was named Maser (acrony for Microwave Amplification by Stimulated Emission of Radiation).

Incidentally, the idea of maser struck Townes while sitting on a bench of the famous Franklin Park. It is a mere coincidence that simultaneously two scientists working at Labedev Laboratiories situated in Moscow of the erstwhile Soviet Union, Alexander Mikhailovich Prokhorov and Nicolai Gennediyevich Basov, were also thinking along the same lines. However, Townes was the first who succeeded to produce the first maser. Nonetheless, the two scientists shared the 1964 Nobel Prize in Physics with Townes.

Principle of Laser Action

In order to understand the principle of laser action, we first need to clearly understand the concepts of stimulated emission and population inversion.

According to quantum theory, every atom can have energies only in certain discrete states or energy levels. Normally, the atoms are in the lowest energy or the ground state. However, when light from a powerful source, like a flash lamp or a mercury are, falls on a substance, the atoms in the ground state can be excited to go to one of the higher energy stated. This process is called absorption.

After staying in the excited state for a very short duration, which is about 10 nanosecond (10^{-8}s), the atom returns to its initial ground state by emitting a photon. This process is called spontaneous emission.

It is also possible that an outside photon strikes an excited atom and stimulates it to emit a photon.

This process is called stimulated emission. However, a necessary condition for this to happen is that the outside photon should have energy that is equal to the difference between the energies of the atom in its excited and ground states.

The important characteristic of stimulated emission is that the emitted photon has exactly that same wavelength as the outside photon and that the two photons are in the same phase.

If this process is repeated, more and more atoms will be forced to give up photons thereby initiating a chain reaction. This results in rapid build up of energy of one particular wavelength travelling coherently in a precise, fixed direction. This process is called amplification by stimulated emission which is fundamental for laser action. However, one more condition, called population inversion, is also essential for laser action.

The number of atoms in any level at a given instant of time is defined as the population of that level. Normally, the population of the ground state is greater than that of the excited state. If somehow the situation could be reversed the population of the excited state will exceed that of the ground state. This would lead to the state of population inversion.

If between the ground and excited states, an intermediate state, called metastable state, having lifetime higher than that of the excited state be present then the atoms could pause at the metastable state for more time. This would result into a higher population of atoms in the upper energy (metastable) state relative to that in the ground state leading to population inversion which is an essential condition for laser action. The lifetime of the metastable state may be about a millisecond (10^{-3}s) which is fairly large compared to the lifetime of the excited state of the atom (10^{-8} s).

Main Components of a Laser

A laser generally requires three main components for its operation: (a) an active medium which may be in the form of solid, liquid, gas or semiconductor; (b) a pumping source to provide energy to the active medium for obtaining the state of population inversion; a xenon or krypton flash lamp or electrical energy is used as pumping source; and (c) an optical or cavity resonator for amplification action; two mirrors, one having cent per cent reflectivity while the other having 90 per cent or less reflectivity generally serve as cavity resonator.

The stimulated radiation resulting from population inversion multiplies by bouncing forth between the two mirrors and passing through the active medium. As a result, the radiation gets amplified and passes in the form of a narrow beam through the semi-transparent mirror.

Different Types of Lasers

T.H. Maiman, who demonstrated the first laser action in 1960, used a cylindrical rod ruby crystal to produce laser light in the visible red region. After ruby laser, attempts were made to produce different types of lasers. Although numerous types of lasers are available, depending on the production technique seven broad categories of laser have been identified. These are solid laser, gas laser, liquid (dye) laser, chemical laser, semiconductor laser, gas dynamic laser and free electron laser.

Besides producing light in the visible region, some of these lasers produce light in the ultraviolet and infrared regions too.

Scientists have also succeeded in producing X-ray that produce radiation in the X-ray region. Raman lasers, based on the Raman effect discovered by the celebrated Indian Nobel laureate C.V. Raman, have also been developed. It may be noted that Raman lasers are different from the conventional lasers as laser action is possible in them even without population inversion.

The scientists are currently busy in developing state-of-the-art lasers such as nano lasers, quantum dot lasers, etc. Some success in this direction has already been achieved.

Applications of Laser

Different types of lasers have been put to different kinds of applications. In the field of medicine, laser is used for performing cataract operation and surgery for correcting refractive errors of eyes; and for the welding of detached retina. Urinary stones in the kidney can be shattered with the help of laser. The blocked arteries can also be cleared using laser angioplasty. Laser is also being used for dental treatment and for the treatment of many different kinds of cancer.

Great strides have also been made in the area of communication by using laser as the carrier and optical fibre as the medium. Known as optical fibre communication, this has made communication of information or data very fast and reliable.

Laser has many applications in industry as well. It can be used for cutting of metals. Welding of even dissimilar metals is possible using laser. Holes can be drilled in such hard materials as diamond with the help of laser.

Another important application of laser is in the production of three-dimensional (3-D) images. This is done by using a technique called holography. To prevent counterfeiting, credit/ debit cards, mobile batteries, books, etc., carry plastic stickers on them called holograms. These are made with the help of holographic technique using laser.

Laser printers, another spin-off of laser technology, have virtually created revolution in the field of printing. Besides providing high printing speed and high degree of character flexibility, laser printers provide excellent print quality. They are being used worldwide for printing of books and other material.

Laser has many applications in the field of environmental pollution, seismology and metrology as well.

Applications of laser even extend to agriculture. Using laser, the rate of sprouting of seeds can be increased and even the crops can be reaped relatively early.

In our day-to-day life too, laser has many applications. Bar codes containing information about price and other details are printed on the food packets, consumer items, books, etc. Laser is used for scanning of these bar codes and all the information automatically come on the attached computer.

In scientific research too, laser has a variety of applications. In physics, it plays a significant role in the field of spectroscopy and thermonuclear fusion. In chemistry, laser is used for separation of isotopes, measurement of impurity present in materials and for the study of ultrafast chemical reactions.

In defence and warfare too, laser has important applications. Using laser systems, enemy missiles may be destroyed. Underwater ranging using laser makes possible detection of submerged submarines.

Besides, laser has plethora of applications in various other areas as well. Lasers are also being used for testing the validity of some basic scientific theories. The basic postulate of Einstein's special theory of relativity that the velocity of light in vacuum is constant was an outcome of the Michelsonn-Morley experiment that led to negative result regarding the existence of hypothetical medium called ether. After the invention of laser, this experiment was performed again using helium-neon laser source. However, this experiment also negated the existence of ether which lent support to the Einstein's special theory of relativity.

Scientists are hopeful that many more applications of laser would emerge in the near future. Today laser is greatly benefitting human society at large. However, for the sake of world peace and the welfare of humanity, laser should be used only for peaceful purposes and not as a weapon of destruction in wars.