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Types of Lasers and Its Applications in Various Fields

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Abstract
Since the occurrence of the first LASER (Light for Amplification by Stimulated Emission of Radiation) in the year 1960, there has been a steady increase in its Application. Different types have been found. There is rarely any scientific field which is not influenced by laser technology. As the capability of lasers increased, its applications became more and more diverse. Because of this laser, man work has become simple. Without any hard work, very fastly work can be finished. In this chapter, we enumerate a few types of lasers with its advantages and disadvantages and then go on to discuss more details about its applications in various fields.

Keywords: *Amplification, Stimulated Emission, Types, Advantages, Disadvantages and its Applications.*

INTRODUCTION:

Laser discharges the light through the amplification process depend upon the stimulated emission of electromagnetic radiation. The term "laser" is abbreviated as "light amplification by stimulated emission of radiation". The first laser was found in the year 1960 by Theodore H. Maiman at Hughes Research Laboratories.Now, term "light" constitutes electromagnetic radiation of any frequency, not only visible light, the frequency of the terms infrared laser, X-beam laser, and gamma-beam laser. Since the microwave foregoing of the laser, the maser, was first founded, gadgets of this sort operating at microwave and radio frequencies are known as "masers" but not "microwave lasers".

Lasers are distinguished from other light sources by their characteristics:

1.Monochromatic i.e. it consists of a single wavelength. This means the laser can be focused into a small area for long distances without any reduction in the intensity of the laser beam.

2. Collimated i.e. all parts will travel in the same direction. It means it follows a narrow path over greater distances.

3. Coherent i.e. they are in phase with each other. The laser emits coherent light. Hence laser is for cutting and lithography.

Spatial coherence is expressed through the output as a narrow beam.

Temporal coherence has a polarized wave at a particular frequency, whose phase is correlated over a great distance (the coherence length) along the beam. Lasers will have the high temporal coherence, which releases light with a narrow spectrum, i.e., they can emit a single color light. Also, temporal coherence is used to produce a light pulse with a broad spectrum but the duration is short as fem to second ("ultrashort pulses"). Spatial coherence allows a laser to be focused at a spot, which enables its applications such as cutting of laser and lithography. This also allows a laser beam to stay narrow over long distances, which enables applications such as laser pointers and lidar.

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March - April 2020
ISSN: 0193-4120 Page No. 2114 - 2122

A laser includes a gain medium; it is a mechanism for energizing it, also to implement optical feedback. The gain medium has the property to allow a laser to amplify light through stimulated emission. Light of a particular wavelength that is made to pass through the gain medium is amplified that is, its power is increased. For the light to get amplified, it needs some energy to be supplied in a process called pumping. The energy is generally provided as an electric current or as light with different wavelengths. Light for pumping may be obtained using a flash lamp or any other lasers.

The most common laser types gain feedback from an optical cavity— It has mirrors on either side of the gain medium. Light travels back and forth between these mirrors, by passing through the gain medium and get amplified every time. Generally, one mirror partially reflects and others completely reflect. Some of the light escapes through the partially reflective mirror. Based on the design of the cavity, the emergent light coming out from the laser spreads out or forms a narrow beam. These devices are sometimes called as a laser oscillator.

An electron in an atom can absorb energy from light (photons) or heat (phonons) only if there is a transition between energy levels that match the energy carried by the photon or phonon. For light, this means at any given transition will only absorb one particular wavelength of light. Photons with the correct wavelength allows an electron to jump from the lower to the higher energy level. The photon is consumed in this process. When an electron gets excited to a higher energy level, it does not stay there for a long time. The electrons return to their lower energy level which is not filled. When such an electron undergoes a transition to a lower energy level, without any external influence, a photon is emitted. This process is known as "Spontaneous Emission". The photon which is emitted has a random phase and direction, but its wavelength is equal to the wavelength of absorption of the transition. A photon with the same wavelength to get absorbed by a transition also causes an electron to drop from the higher level to the lower level, by emitting a new photon. The photon which is emitted perfectly matches the original photon with its wavelength, phase, and direction. This process is known as" Stimulated Emission".It can be represented as shown in the figure below.

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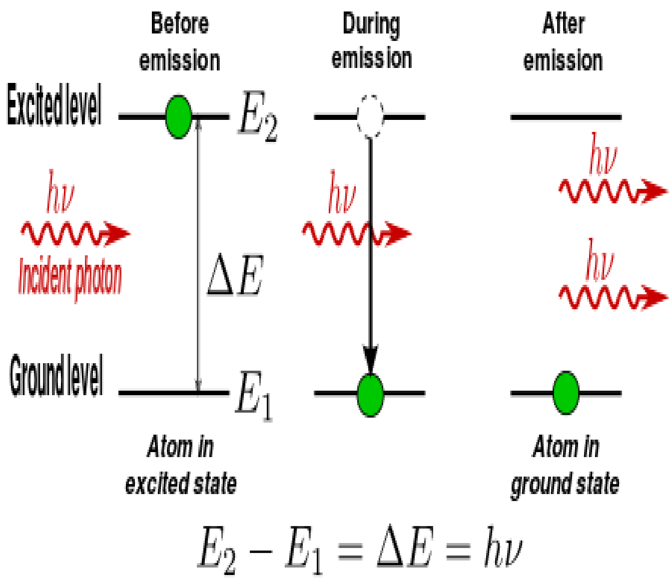

OBJECTIVES

Lasers are also used in optical disk drives, in bar-code scanning, DNA instruments, fiber-optics, photolithography, and optical communications, laser printers, for laser surgeries for skin treatments, welding materials, military and law enforcement gadgets for preparing targets and to measure range and speed as well. These are also used for car headlamps on luxury cars, using a blue laser and also phosphor to produce high directionality.

It is capable of cladding and cutting, through the use of three modular end-effectors

Includes intelligent sensor technologies for in-process monitoring

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It is linked to an intelligent system, to achieve adaptive process control, assurance of quality, and semi-automated process parameter configuration.

ADVANTAGES:

➨It has great information-carrying capacity and so it is used in the communication domain to transmit the information.

➨It is free from electromagnetic interference. This is used in optical wireless communication through free space for telecommunication and also in computer networking.

➨It has minimum signal leakage.

➨Fiber optic cables based on lasers are very light in weight hence used in fiber optical communication system.

➨It is less damaged when compared to X-rays and these are widely used in the medical field for curing cancers. Also used for burning small tumors on the eye surface and also on the tissue surface.

➨High intensity and low divergence of laser are used to knock down the enemy tank with accurate range determination. Neodymium and carbon dioxide laser types are used for this purpose. Laser range finder is also used in various defense areas for the medium-range up to 10 Km.

➨A single laser beam is focused in areas smaller than 1-micron diameter. One square micro area stores 1 bit of data. This helps to store 100 million data in one square cm.
Because of this reason, a laser is used in laser CDs and DVDs to store data in the form of audio, video, documents, etc.

DISADVANTAGES:

➨It is more expensive and so expenditure is high for the patients requiring laser-based treatments.

➨Costly to maintain them and hence more cost to doctors and hospital management.

➨Increases the complexity and duration of the treatment depending on laser devices.

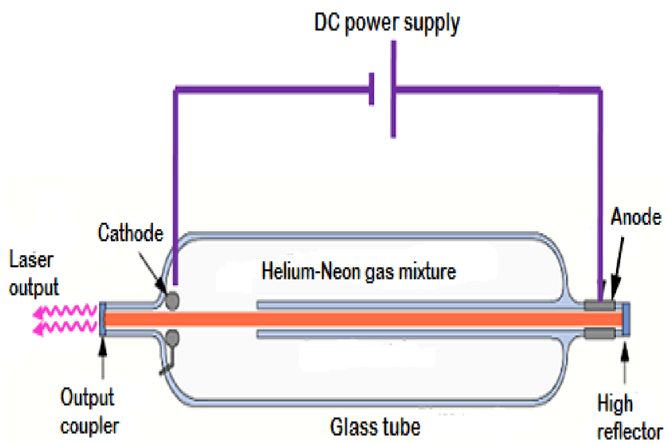
➨Lasers cannot be used in many commonly performed dental procedures such as to fill cavities between teeth etc.

➨The beam of the laser is very delicate to handle in the cutting process. If any slight mistake in adjusting distance and temperature, lead to burning or discoloring of the metals. Moreover, it requires high power during the cutting process.

➨It is harmful to human beings and may burn them during contact.

TYPES OF LASERS:

1**. HE-NE LASER**: First, a gas laser was invented in the 1960s when Iranian-American physicist Ali Javan and American physicist William R. Bennet invented Helium-Neon Laser. Mostly, He-Ne lasers due to their low cost and their high coherence, are used in optical research and educational laboratories. While it has the capability of emitting hundreds of watts in single spatial mode, carbon dioxide (CO_2) lasers are used in industries for cutting and welding purposes. A gas laser is a laser that discharges an electric current through a gas inside the laser medium, for the laser light to produce. In gas lasers, the laser medium is in gas form.



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He-Ne laser is the first laser that works on the principle of converting electrical energy into light energy. A laser light beam in the infrared region of the spectrum at 1.15 µm is produced. In this laser, the gain medium consists of a mixture of gases, which is packed up into a glass tube. The glass tube is filled with a mixture of gases which acts as an active medium or lasing medium. These lasers are used in applications that require laser light with very high beam quality and long coherence lengths.

ADVANTAGES:

1. These are small and compact.
2. These lasers have a longer life, usually 50,000 hours or more.
3. He-Ne laser is very simply constructed. It has good coherence property.

DISADVANTAGES:

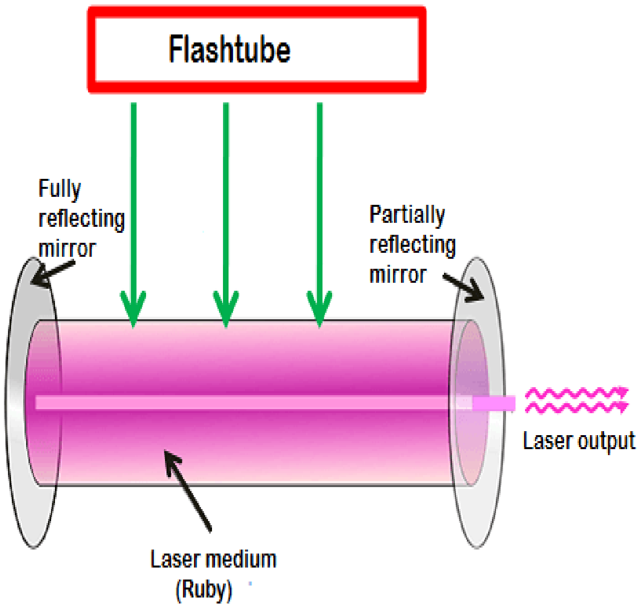
1. Output power is low.
2. It is a low gain device and requires high voltage for its operation.
3. Escaping gas from laser-plasma is its major drawback.

2. SOLID-STATE LASER :

In a solid-state, gain medium is of solid, like the liquid in dye lasers and gas in gas lasers. It uses a glass rod or crystalline rod which is "'Doped" with ions providing energy states. Solid-state lasers are mainly used in developing defense weapons.

A solid-state laser is a laser that uses solid as a lasing medium. Glass or crystalline materials are used in these lasers. Ions are introduced as impurities in the host material which may be a glass or crystalline. Adding up of impurities to the substance is known as Doping. Rare earth elements such as cerium (Ce), erbium (Eu), etc are commonly used as Dopants.

Materials like neodymium-doped yttrium aluminum garnet (Nd: YAG), Neodymium-doped glass (Nd: glass) and ytterbium-doped glass are used as host materials in laser mediums. Neodymium-doped yttrium aluminum garnet (Nd: YAG) is the commonly used one. Ruby laser is the first solid-state laser, where a ruby crystal is used as a laser medium.



In solid-state lasers, light energy is used for pumping. Light sources like flash tube, flash lamps, arc lamps, are used to achieve pumping.

Semiconductor lasers do not belong to this category because these lasers are electrically pumped and different physical processes are involved.

ADVANTAGES:

1. Material is not wasted in the active medium because, in this, a material used is in solid form not in gas form.
2 .Continuous and pulsed output is possible from a solid-state laser.
3. Construction of solid-state laser is simple & the cost of solid-state lasers is economical.

DISADVANTAGES:

1. The solid-state laser has very low efficiency when compared to CO_2 lasers.
2. Power is also not very high as in CO_2 lasers.
3. Due to thermal lasing in solid-state lasers, the power is lost when the rod gets too hot.

3. ND: YAG LASER:

Mostly used laser sources for moderate to high power will use a neodymium-doped crystal

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Yttrium Aluminum Garnet (YAG). Besides, other hosts with Nd, like calcium tungstate and glass can be used. The Nd: YAG laser is optically pumped using tungsten and has the capability of CW outputs approaching 2000 W at the 1.06 µm wavelength. edges of the crystal, in the form of a rod, are polished and coated to provide the cavity mirrors.

Nd: YAG belongs to the type of the solid-state laser. Solid-state lasers occupy a unique place in the development of lasers. The first laser medium used was a crystal of pink ruby (a sapphire crystal which is doped with chromium); from then the term "solid-state laser" is used to describe a laser whose active medium is a crystal doped with impurity ion. Solid-state lasers are rugged, easy to maintain, and has the capability of generating high powers. Even though solid-state lasers have some unique advantages over the gas lasers, crystals are not ideal cavities. Real crystals have refractive index variations that change the wavefront and mode structure of the laser. Due to high power operation crystal undergoes thermal expansion which varies the effective cavity dimensions and hence changes the modes. The laser crystals are made to cool down by forced air or liquids, particularly for high repetition rates. The most interesting aspect of solid-state lasers is that the output is not continuous usually, but it has a large number of separated power bursts. Normal mode and Q-Switched solid-state lasers are usually designed for the high repetition-rate operation. Generally, the specific parameters of operation are given by the application. For example, pulsed YAG lasers operating 1 Hz at 150 Joules per pulse may be used in metal removal applications. When the repetition rate increases, the allowable exit energy per pulse also decreases. Systems are in operation, for example can produce up to ten Joules per pulse at the repetition rate of 10 Hz. A similar laser, operated in the Q-Switched mode, can give a one megawatt per pulse at a rate up to ten pulses in a minute.

ADVANTAGES:

1. It is very useful for quick processing of thin materials.
2. It is very easy to gain the population inversion.
3. Easy to operate and maintain it and not very expensive.

DISADVANTAGES:

1. It is not optimal to be used for materials with moderate thickness.
2. It has low absorption of radiation of the lighter materials, very close to the visible spectrum.
3. Using this type of laser, slow production is possible, for thick materials and hence, it offers lower efficiency.

4. DYE LASERS:

Another type of lasers is dye lasers which have organic dye as the gain medium. The wavelength of these lasers can be altered. Although these lasers are solid-state lasers scientists have also explained emission in dispersive oscillator tenability incorporating solid-state dye gain media. These lasers are used in astronomy, spectroscopy and many more. Dye lasers are versatile. These lasers can offer very large pulsed energies, in addition to their recognized wavelength agility. Dye lasers pumped using flash lamps yield hundreds of Joules per pulse and copper-laser-pumped dye lasers are known to yield average powers in the kilowatt regime. A dye laser is a laser, with organic dye as its lasing medium, generally as a liquid solution. Compared to gases and most solid-state lasing media, a dye can usually be used for a wider range of wavelengths, often spanning 50 nanometers to 100 nanometers or more. Because of its wide bandwidth, it suits for tunable lasers and pulsed lasers. The dye rhodamine 6G, for example, can be tuned from 635 nm to 560 nm and can produce pulses as short as 16 fem to seconds. Moreover, the dye can be replaced by another type to produce an even much broader range of wavelengths, from the near-infrared to the near-ultraviolet, although it requires replacing other

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optical components in the laser, such as dielectric mirrors or pump lasers.

ADVANTAGES:

1. It is available in both the visible form and non-visible form.
2. The beam diameter is very low.
3. High output power is possible with dye lasers.

DISADVANTAGES:

1. Dye lasers are very expensive.
2. It is very difficult to determine the element that lases as it has a complex chemical formula.

5. SEMICONDUCTOR LASERS:

Semiconductor lasers are the lasers in which solid-state lasers are based upon gain media of semiconductor, in which optical gain is normally achieved through stimulated emission at an inter band transition by following the conditions of a high carrier density in its conduction band.

A pump beam with a photon energy just above the band gap energy excites the electrons to its higher state in the conduction band, from there they fatly decay to the lower states near to the conduction band. Same time, the holes which are generated in the valence band excite to the top of the valence band. Electrons present in the conduction band will then try to recombine with these holes, emitting the photons whose energy is near to the band gap energy. This can also be stimulated by the incoming photons with similar energy. A quantitative description can be based on the Fermi–Dirac distributions for electrons in both the bands. Most of the semiconductor lasers are laser diodes, which are pumped using electrical current in a region where n and p-doped semiconductor material meet. However, there are semiconductor lasers pumped optically, where carriers are generated through absorbed pump light, where interband transitions are utilized.

ADVANTAGES:

1. This employs a passive cooling technique.
2. It consumes low power.
3. Efficiency is very high with very high operation duration.
4. It can be easily operated.
5. Semiconductor lasers are not expensive and economical to afford.

DISADVANTAGES:

1. This laser is not suitable for many applications because of its low power production.
2. The output is affected by its temperature.
3. Beam divergence is greater compared to other laser types.
4. Sometimes it requires coolant.

APPLICATIONS:

MEDICAL APPLICATIONS:

A physical process that is the surgical removal of tissue with a laser is similar to that of industrial laser drilling. Carbon-dioxide lasers with 10.6 micrometers can burn away the tissue since the infrared beams are much strongly absorbed by the water that makes up the living cells. A laser beam cures the cuts, stop bleeding in blood-rich tissues such as gums. Similarly, Neodymium-YAG Laser with wavelength nearly one micrometer can penetrate the eye, welding a detached retina back into place, or cut the internal membranes which often grow cloudy after cataract surgery. Laser pulses with low intensity can destroy abnormal blood vessels that are spread across the retina in patients who are suffering from diabetes, delaying the blindness often associated with the disease. Ophthalmologists correct visual defects surgically by removing the tissue from the cornea, also reshaping the outer layer of the eye which is transparent with intense ultraviolet pulses from the excimer Lasers.

COSMIC SURGERY:

Removal of tattoos, scars, sunspots, wrinkles, birthmarks, and stretch marks. Eye surgery, also refractive surgery. General surgeries, gynecological issues, urology, and laparoscopic issues can be cleared. Laser therapy. Removal of the tumors, specifically in the brain and spinal cord too. Skin health assessments particularly regarding the damage caused through aging. In dentistry to remove caries, endodontic or periodontal procedures, tooth whitening, and also oral surgery.

OPTICAL COMMUNICATIN AND STORAGE:

The ability to focus laser beams to very small spots and for switching them on and off for billions of times per second makes lasers the important tools in the field of telecommunications and information processing. In supermarket laser scanners, it has a rotating mirror which scans a red beam while clerks will be moving the packages across the beam. Optical sensors detect light reflected from striped bar codes on packages, decode the symbol, then relay the information to a computer to add the price to the bill. Similarly, few semiconductor lasers read data from a variety of optical compact disc formats to play music, to display video recordings, and also can read computer software. Audio compact discs were introduced around 1980; using infrared lasers.

CD-ROMs for computer data soon followed. Optical drives use the most powerful lasers for recording the data on light-sensitive discs called CD-R (recordable)or CD-RW (read/write), which may be played in the ordinary CD-ROM drives. DVDs work in the same way, but it uses a short-wavelength red laser to read smaller spots so that the discs hold more information to play a digitized motion picture. A new generation of discs called Blu-ray uses blue-light lasers for reading and storing the data at a more higher density. Fiber-optic communication systems use semiconductor lasers to transmit signals more than a few kilometers. At infrared wavelengths of 1.3 to 1.6 micrometers, optical signals are sent, where silica glass fibers are most transparent. This technology has become the backbone of the global telecommunications network, and most telephone calls traveling beyond the confines of a single town go part of the way through optical fibers.

LASER MACHINING AND CUTTING:

Laser energy is focused on space and concentrated in time to get hot, burns away, and vaporizes the materials. Even though the total energy in a laser beam is small, the concentrated
power on small spots or during short intervals can be large. These lasers cost much
more than mechanical drills or blades, it has different properties that allow them to perform many other difficult tasks. A laser beam does not deform flexible materials as the mechanical drill so that it drills holes in materials like soft rubber nipples for baby bottles. The same way. Laser machining is not dependent on the hardness of the material, dependent on the optical properties of the laser and the optical and thermo-physical properties of the material. For example, lasers have drilled holes in diamond dies used for drawing wire. Several similar researches have shown that laser cutting is best achieved with ultrafast lasers, as the material evaporates and does not get a chance to melt under such ultrafast time scale interactions...

MILITARY AND DEFENCE APPLICATIONS:

Scientists proved that lasers can concentrate extremely high powers in either pulses or continuous beams. Fusion research, nuclear weapons testing and missile defense come under major applications for these high-power levels. High temperatures and high pressures are required to force atomic nuclei to fuse, releasing energy. Intense laser pulses could produce these conditions by heating and compressing tiny pellets that contain mixtures of hydrogen isotopes, which suggests using these "micro-implosions" to generate energy for civilian use and also to simulate the implosion of a hydrogen bomb, which involves the same processes. From then, a series of lasers have been built to test and refine these theories. High-energy lasers offer a method to deliver destructive energy to targets at the speed of light, which is very attractive for nuclear a missile that is the fast-moving targets. Military laser range finders were developed in the year 1970, to measure the distance to battlefield targets accurately. Military researchers have tested high energy lasers for use as weapons on land, at sea, in the air, and space, even though no high-energy lasers have been placed in orbit. Experiments prove that massive lasers can generate high powers; however, tests also showed that the atmosphere distorts such powerful beams, causing them to spread out and miss their targets. These problems have slowed research on laser weapons, even though interest continues in laser developments to defend against smaller-scale missile attacks.

METROLOGICAL AND GEOPHYSICAL APPLICATIONS:

Cartographer and construction workers use laser beams for drawing straight lines through the air. The beam itself is invisible in the air except were scattered by haze, but it projects a bright spot on a distant object. Assessor bounces the beam off a mirror to measure direction and angle. The beam can set an angle for grading irrigated land. Pulsed laser radar is used to measure distance in the same way as the microwave radar does, by timing how long it takes a laser pulse to bounce back from a distant object. For example, in 1969 laser radar accurately measured the distance between the Earth and the Moon. Laser range finding is more widely used for remote sensing. Instruments flown on aircraft can profile the layers of foliage in a forest. A laser altimeter is used by The Mars Global Surveyor to map elevations on the Martian surface. Mode-locked lasers emit tens and thousands of discrete laser lines with a frequency-spacing accurately given by the laser repetition rate free. Their output is generally referred to as a frequency comb where each tooth is an integer multiple of free. It is this simplicity by which a frequency comb directly links the optical and the radio frequency domains separated by several decades that are practically governed by very different technologies, which has made frequency combs very powerful and invaluable tools. The 2015 Physics Nobel Prize was awarded to Theodor Hänsch and John Hall for developing this idea.

LASER IMAGING AND HOLOGRAPHY:

The coherent light is more important for holography and interferometer also, which dependents on the interactions between light waves to make extremely precise measurements and for recording three-dimensional images. The result of adding light waves together is dependent on their relative phases. If the peaks of one align with the valleys of the other, they interfere destructively to cancel each other. If their peaks align, they interfere constructively to produce a bright spot. This effect is used to measure, by splitting a beam into two halves that will follow different paths. Changing one path just half a wavelength from the other will shift the two out of phase, producing a dark spot. This technique has proved invaluable for precise measurements of very small distances. By splitting a laser beam into two identical halves, holograms are made, using one beam to illuminate an object. Then this object beam is made to combine with the other half—the reference beam—in the plane of a photographic plate, producing a random-looking pattern of light and dark zones that records wave front of light. Later, when the light illuminates that pattern from the same angle as the reference beam, it is scattered to reconstruct an identical wave front of light, which appears to the viewer as a three-dimensional image of the object. Holograms now can be mass-produced by an embossing process, as used on credit cards, and do not have to be viewed in laser light.

BIOMEDICAL IMAGING AND SUPER-RESOLUTION:

Confocal microscopy is a ubiquitous imaging tool for imaging thick specimen in a wide range of investigations in biological, medical and material sciences. This uses UV or visible light for the single-photon excitation of the fluorophore from the ground to the excited state followed by deactivation through fluorescence emission which

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can be detected through high quantum efficiency Photo Multiplier Tube (PMT) in the range of near-ultraviolet, visible and near-infrared spectral region. The basic difference of confocal Light Scanning Microscope with the conventional optical microscope is the confocal aperture arranged in a plane conjugate to the intermediate image plane and the object plane of the microscope. The PMT can detect only the light that passed the pinhole. As the laser beam is focused to a diffraction spot, that gets illuminated only at a point of the object at a time, point observed is situated in conjugate planes, i.e. they are focused onto each other. The perfection of the focused beam which is connected to the resolution has always been a matter of concern in the far-field fluorescence microscopy. Optical microscopy remains the best choice for monitoring live specimens despite the resolution advantage of, electron microscopes since the energy which is deposited in electron microscopy adversely affects the viability of live specimens. This practical compromise implicitly sets resolution enhancement as one of the most important developments in optical microscopy. The resolution limit at the small excitation wavelength is approximately 150 nanometers in the lateral dimension and approaching 400 nanometers in the axial dimension. For imaging living cells, these values are approximately 200 and 500 nanometers, respectively. Thus, structures nearly having 200 to 250 nanometers cannot be resolved in the lateral plane by using a wide field or confocal fluorescence microscope and is known as the Abbe's resolution limit.

CONCLUSION:

The wavelength of Laser light is extremely pure while compared to other sources. In this paper has provided a glimpse of some of the many applications of lasers. We have deliberately provided more details on few of the recent applications. Applications of laser treatment have become highly accepted methods with advantages to general dental practitioners. Lasers has advantages such as a bloodless operative field, minimal to absent postoperative pain and high patient acceptance which makes laser a highly advantageous alternative to conventional treatment. We just hope that this would increase the interest of the reader to keep up with the many more laser applications that keep coming up with time.

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