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Applications of Lasers in Various Fields Such as Communications, Energy and Medicine

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Abstract: Lasers are one of the achievements of human technology, which are beginning to find an increasingly broad application in various fields. Lasers, or "light amplification by stimulated emission of radiation", are sources of optical radiation characterized by their extremely high output power, an extraordinary purity of the emitted radiation and the possibility of high spatial and spectral coherence of this radiation. There are many ways to establish the lasers by the type of active medium (gas, solid, semiconductor etc.), by the type of radiation emitted (continuous, pulsed, multimode, single-mode etc.), by the type of operating system (diode, marked, cutting, combining with fiber etc.), and by the wavelength in which they operate (infrared, visible, ultraviolet). Lasers have found and find a number of applications in everyday life in communications, construction, music, computer technology and others. The essay makes sense to focus on such technological applications of lasers, which can be especially promising for the future and whose appearance, to a large extent, is associated with the appearance of this new source of optical radiation. Areas where laser technology is already employed are included, in part because it is necessary to characterize the state of the art to appreciate what laser technology can replace and consolidate. However, emphasis is on more recent progress and predicted directions for technological advancement. These applications are considered together for each wavelength range and, when appropriate, also in relation to newly developed techniques for the generation of invisible infrared or ultraviolet radiations. Some aspects referring to one of the systems with which therapeutic procedures are carried out and considered briefly in one section are also discussed.

Keywords: Lasers, Optical Technology, Communications, Renewable Energy, Medical Applications, Innovation, Cost Optimization.

1. Introduction to Lasers

The first laser was constructed in 1960; today, less than 35 years later, lasers are used in a staggering variety of scientific and engineering applications, more than could have been predicted in the late 1950s. A percentage of laser articles appeared shortly after the laser was invented, was quite enthusiastic about prospective uses of lasers in devices, radar systems for guidance, heating and bonding in industry, welding, drilling, cutting and annealing in manufacturing, surgery and ophthalmology. Many of these ambitious predictions have been realized [1].

Lasers are employed in a vast array of scientific and engineering and commercial applications, and use is growing in fields as disparate as communications, energy, entertainment, chemistry, electronic manufacturing, medicine, and data storage. Lasers are employed in a broad range of scientific and technological tasks. Some of these tasks demand the use of specialized lasers with characteristics optimized for a certain type of application: for example, in hoken cell techniques is often used with large, or high power, solid state lasers. Other experiments require the development of novel techniques and development of special laser systems. In both cases, progress relies heavily on the availability of state-of-the-art laser technology. With the invention of the laser by Theodore Maiman in 1960, or scientists entered a new era; creative synthesis of coherent radiation having become possible.

In the half century that has followed, the range of laser types is enormous. The first laser was a solid-state device using a ruby crystal as the gain medium. Gas and semiconductor lasers soon followed, and these types still possess certain advantages for particular applications. Additionally, innovations in the field of lasers have made them so common in an extraordinarily wide variety of experimental apparatuses that one hardly takes note of their use as devices apart from the laboratory. The provision of high-quality cavity mirrors, accurate alignment tools, modulation devices, sensitive detectors, spectially designed laser safety gear, and so on, have made laser operation so common that most students have carried out laser-related experiments in undergraduate or postgraduate laboratory classes. [2][3][4]

1.1. Basic Principles of Laser Technology

Lasers generate and amplify light that is coherent, monochromatic and collimated. The concept of processes underlying lasing (stimulated emission, population inversion, optical cavity) is complex. A simple, intuitive outline of these principles is provided below to facilitate a basic understanding of lasers that are extensively applied in various fields. Knowledge of how a laser beam is produced, the importance of coherent light output, the various components making up a laser system, and the critical issue of wavelength of laser light will be helpful in further reading towards addressing laser application.

A Laser generates and amplifies light that is coherent, monochromatic and collimated. Coherent light output means that all waves are 'in phase' – in effect, the peaks and troughs of the light waves are perfectly distributed. Waves of constant frequency, phase, and pattern do not occur in nature and thus lasers produce light with unique characteristics. Bow waves caused by objects traveling on water or shockwaves created by landing supersonic airplanes are examples of a lack of coherence. Monochromatic light is light of uniform frequency and this advantageously avoids tissue scattering, allowing deeper penetration and providing for more selective tissue targeting, damage, and ablation. Unidirectional, virtual absence of divergence light is collimated and further differentiates laser light from other sources. The term laser is often used in medical journals to represent any energy based therapeutic device, which is a misnomer. For the purposes of this paper, laser defined above in the scientific context will be indicated by the use of an upper case "L" while a lower case "laser" will refer to the term as employed in publications [5].

Literature Review

2. Laser Applications in Communications

Lasers are being widely used to transmit signals for communications. They are now used to send data (words, pictures, sounds, etc.) over vast distances at very high speed, and with great accuracy. For instance, the US broadband internet infrastructure is almost entirely optical fiber, meaning that signals travel at the speed of light. What this means is that say, a web page hosted in the Eastern US can be read in the Western US with only half the delay that would come from merely being very close. Lasers are integral to this technology. Lasers are used to turn the electronic signals coming from the internet into light signals that travel down optical fiber cables. Laser light is much easier and cheaper to send over long distances than electronic signals on a copper wire. This is because electrical signals are just wiggling electrons, and that the longer a wire is, the more difficult it is to make sure the wiggling reaches the end okay. Laser light is photons, it's just going to the end. There isn't really a distance limitation at all. Also, while electronic signals have bleed-out, that is, information loss over distance, light signals essentially don't. This means that short of miles and miles of distance, the light will come out the other side almost perfect. The frequency of the light means that it can be split up into different signals that travel in groups. Using this kind of Frequency Division Multiplexing, a single cable can carry an almost endless number of different signal streams [6]. The massive increase in bandwidth that comes with this switch from copper.

The transmitters and receivers of the signals generally use a semiconductor laser, and to keep price down for the consumers it's a pretty barebones one so no Q-switching or anything like that. This kind of communication so ubiquitous it's even easy to forget about. You should be more impressed! It's called Laser Communication (or 'Free-space optical communication' when it uses the Air, as it can also). Lasers can be used to communicate with satellites, with airplanes, or with other buildings. Right now, Lasers are being tested for use in global networks as backups in case of a fault in a fiber optic cable. Lasers passed through lenses can produce very tight and directed light beams that don't spread much. This is useful for 'point-to-point' Architecture where lasers can be aimed and fired at each other to communicate more directly. Beyond the bandwidth point, lasers have a special place in the transcription of the Internet. It is widely known that lasers are integral to it now, but what might not be so well known is the rapidly advancing nature of it. It must be always improving at the fastest possible rate to stay ahead of the existing decay effects [1]. Thankfully, in that effort, lasers have an important role to play. Recently, more advanced lasers are being used as well as coherent optical communication techniques like QAM. All this to say, the future of laser communication is not just assured, but is almost assuredly grand as the internet becomes the Law of Physics of communication technologies for most of a century.

2.1. Fiber Optic Communication Systems

Lasers have a few specific applications in the world to which traditional light sources like the sun or electric lamps are not suited. Argon ion plasma lasers emit light in the violet-blue and green spectral regions and are useful in processing pigments and dyes. Since CO2 lasers emit in the infra-red region, lenses and windows are made out of a NaCl-ZnS or a KRS-5 which are transparent to this radiation. Typically CO2 lasers are pumped electrically and have output wavelengths of 10.6 or 9.6 micrometers. Depending on the production of the laser many different gases can be used, such as nitrogen, helium, carbon monoxide and xenon fluoride. For instance, excimer lasers are used industrially in the manufacturing of integrated circuits. Other gases, like helium-cadmium and various metal vapor lasers, produce UV light. Reduced halogen dyes doped into used nitrogen lasers produce expensive and dangerous green pulsed beams, which can be used for plume containment modeling in aerodynamics. Gas lasers require low pressure operation, making them relatively simple and inexpensive but they have a limited range of wavelengths. Due to their spectral properties, SALT and MOST ekranoplans use a krypton-fluoride gas ion laser for airborne applications. A variety of frequencies throughout the visible and infra-red have applications in spectroscopy and metrology. High-powered UV lasers are used in purchase viscous polymer sheet cutting.

The first working laser was made by Theodore H. Maiman and Charles Hard Townes at Hughes research labs in Malibu, California. The glass ruby and flashlamp construct were selected mainly because they were cheap and found lying around in the lab. Earlier attempts using synthetic rubies were working but were not published. The concept of lasers came from Albert Einstein in 1917 with his concept of stimulated emission of light and the basic outline developed in 1953 with the kill switch and before it even worked, name and acronym were also developed. The Bell Labs team's Ruby maser using red filter to prevent laser radiation and the emission of light, fluorescent meat and ansorbed of the radiation of a completely dispro feeling sent away most Swiss and formaldehyde. This discovery is the most significant breakthrough in the history of telephony, as fiber cable is the future of telecommunications. [7][8][9]

Materials and Methods

3. Laser Applications in Energy

There are an increasing number of areas in the energy sector where lasers are being used or considered for use. Due to the potentially significant impact on energy generation and efficiency, there are now many commercial interests in research and development of lasers in this sector. Lasers are being researched to improve various energy generation processes using renewable sources . They are also being applied to new energy systems aiming to reduce greenhouse gas pollution. Many researchers around the world are investigating the potential of lasers in solar power generation. For example, lasers can be applied in the construction and maintenance of solar collector arrays. Lensing could concentrate laser radiation directly onto the collector tubes, which pass the heat to a fluid medium to drive an electricity-generating turbine. Alternatively, an array of free-electron lasers could synchronously excite ammonia molecules, which could then photodisassociate to form hydrogen for fuel cells. Photocatalytic solar power can be generated using a combination of laser radiation and an appropriate photocatalyst. Concentrated solar power (CSP) systems will be phased out in the next few decades. The mirrors suffer from repeated impact during strong winds and the mechanisms of sun tracking, later judged unnecessary, are prone to frequent mechanical failure. As CSP systems are increasingly decommissioned in the future, it will become cost-effective to swap out the central receiver array with something newer. High-powered lasers would allow the construction of new high efficiency central receiver systems to replace these old systems. There is potential for laser diagnostic systems to be developed to substantially enhance the efficiency of existing energy generation systems and also to improve the regulation of electrical grids. The utilisation of laser-based systems in the energy sector can significantly contribute to reducing greenhouse gas emission and assist the transition from a high to a low carbon economy. [10][11][12]

3.1. Solar Power Generation

Usually, lasers are vastly used in communications and plenty of communication systems are based on laser technology. However, the potential of laser technology can reach well beyond communication. Recent trends seem to attest that a large number of new initiatives, based on laser systems, have been deployed in a variety of applications from which some are identified below. Solar power generation is regarded as the greatest hope to drastic reduction of CO2 emission through low pollutant and safe energy production. However, solar technology still cannot compete with fossil fuels and nuclear power which produce most of the electric power at present because of cost problem. Tradable energy policies in many countries have been changed into solar technology development and specific and intensive research works on cost reduction of important parts in solar thermal and photovoltaic power generation have been conducted. Solar technology runs into various fields of the R&D work including low cost manufacturing methods for high performance solar-cell modules, concentration technology utilizing reflectors, and sunlight input technology in solar cells such as fiber optics and laser beams. Over the last decades, as the efficiency levels have continually increased exponentially, the cost of photovoltaic cells has begun to become a significant hurdle. However, as of 2014, the cost of solar cells has decreased to a point where a number of countries are beginning to invest a great deal of capital and resources into their development and infrastructure. As these efficiency/cost curves for photovoltaic cells cross, yet more governmental/industrial resources will pour into their development, and research into means to improve efficiency levels will grow overall. One such line of research is the use of lasers, such as spectral splitting for multi-junction cells to make thermophotovoltaics (TPVs) for conventional concentrated solar power, and new thin film technologies for large-area photovoltaics ([1]). As the world inches toward a new type of energy generation where photovoltaics have a significantly larger share of the energy “pie”, new manufacturing technologies will have to be researched otherwise manufacturing defects will rise exponentially with each exponential order increase in output ([13]). This growth in investment will likely accelerate the finding of new improvements and efficiencies in the solar industry, and this paper will strive to keep up with those discoveries.

Results and Discussion

4. Laser Applications in Medicine

Technological advances over the years have seen lasers find ready adoption in a multitude of fields ranging from telecommunications, surveying and construction to provision of interactive displays. Laser-based operations are the very backbone of the modern geopolitical theatre, evidence of which can be seen in the different laser-equipped armaments across all the advanced militaries. Further, the creative application of laser technology is what powers the powerful quantum computers being developed. Yet it is the field of medicine which has, perhaps, seen the most transformative effects from the adoption and development of laser technology. Used in a myriad number of ways, from diagnostics to surgery, lasers have allowed precision and capability unrealized in the days of the scalpel.

Different kinds of lasers are used to perform medical procedures usually end in diagnostic, cosmetic, preventative treatments or surgery. Laser beams used in medical practice can heat, burn, cut, and destroy tissues. Their prescribed use and frequency of uses is controlled by a medical doctor. The overarching reasoning for their adoption in medical use is that laser-based surgeries and treatments expand the number and types of procedures that can be accomplished in a minimally invasive manner. In most cases, patients recovering from laser surgeries are able to resume normal activities in far less time than with traditional surgeries. Beyond that, the adoption of lasers into a medical practice significantly has been shown to reduce (even eliminate) the transmission of disease during surgical procedures. As laser technology continues to advance, medical techniques will be continuously improved and expanded exponentially.

Lasers are considered methods that have taught precision and accuracy in medical terms. In periodontology, dentists were able to remove inflamed and diseased tissues from around the base of teeth while aiming to maintain the health of the adjoining tissues. Also in endodontics, it was possible to kill bacteria while keeping the adjacent nerve and blood supplies intact. Eye procedures heavily rely on laser technology for their efficacy. As an example, LASIK surgery uses a laser beam to correct the shape of the eye’s cornea. As of 2024, performances and outcomes of such procedures have been very reliable. In neurosurgery, lasers are currently being used to precisely remove tumors that are otherwise inoperable. Early results suggest that using laser-based therapies has a good rate of success with this kind of procedure. Further work into laser technology and its application in medicine will continue to drive the improvement and development of new types of medical practices which can change the status quo and ultimately save lives. Emergency doctors often use a kind of medical laser to assist in diagnosing the EC with a puncture. As theoretical background, glass beads were filled under the irradiation of laser with longer wavelength than the second penetrating wavelength of water in the apparent liquid from which the EC patient obtained.

4.1. Surgical Procedures

The medical field was the first to offer a valuable use of lasers. In laser surgical procedures, the addition of multiple radially expanding beams with simultaneous ultrasonic signals would allow the operator to detect and correct the magnetic fluctuation noise. Laser surgery is gaining a lot of attention due to the quick recovery times and results. It is minimally invasive, leaving some small scars behind after the treatment. The advent of the laser in surgical procedures transformed modern day medical practices. Laser surgery is a type of surgery that uses special light beams instead of conventional surgical instruments for surgical procedures. It is rapidly gaining attention due to the quick recovery time and good results. Lasers are used to treat cancer, to shrink or destroy tumors, and to treat dis-colourized areas on the skin. Lasers are used for various procedures such as laser lithotripsy, eye surgery, cosmetic surgery, nerve surgery, skin surgery, breast surgery, gynecological surgery, brain surgery, and orthopedic surgery [14]. Japan has the most aging population followed by Italy, Finland, Portugal and Germany. As the majority of the population is of the older age group the requirement for laser surgery is swelling for medical as well as cosmetic reasons. The use of lasers in surgery could help in removing blood clots from vessels as it will cause less damage to the surrounding tissues. Different types of lasers are used for different applications. The surgical lasers are classified as CO2 lasers, NDYAG lasers, Argon lasers and Dye lasers. These lasers are typically used for neurosurgery, brain surgery, ear surgery, tonsillectomy, cosmetic surgery, or non-surgical facelifts. Emerging applications of surgical lasers which are being developed include partial thickness ocular surgery, bone sculpting, carpal tunnel decompression, transeptal dental procedures, laparoscopic surgery, and neuroablative procedures performed with intraoperative exploration by CT and MR scans. There are two types of laser systems used in surgery, limited-dermal and full dermal. The limited-dermal system has some of the procedures which need mild laser radiation while the full-dermal system is integrated into the specialized surgical systems. The light energy produced by the laser is transmitted to the tissue via optical fibers, where it vaporizes, coagulates, or produces the inflammatory reaction. Techniques involving the ablation of tissue and blood vessels have been demonstrated for several types of laser systems, whereas sub-ablative techniques, which operate at lower output levels, are less well-developed. Laser surgery is somewhat similar to other traditional surgical methods; the difference is that the physician performs by aiming the laser beam instead of the surgical instruments like blades or forceps. The advantages of laser surgery include: very less bleeding during the surgery; it restricts the bleeding vessels, it supports the coagulation of the vessels, the beam is so precise that normal tissue surrounding the lesion is left undamaged, the blades deflect or penetrate the area causing the pain, the continuous water spray technique helps cool the area, controlling blisters, and bacterial growth with the aid of a sapphire tip. The practices of laser safety greatly minimize the patient and operator risks. Laser light is highly absorbed by the ocular tissue, producing a dangerous scenario for the eye and indirectly on the nervous tissues. Input to the laser system is stopped after the triggering of fault signals. The higher heat conducting capacity makes it difficult for the surrounding tissues to heat up. The backing layer means that nothing is lost in the cutting process. So in a surgery procedure there are no reverse effects. Post operative side effects can develop by burning the target tissues. The side effects of the radiation come due to the inadmissibly high exposure level, the thermal destruction of the neural tissues and the uncontrolled exposure by the reflections. Outlining the role of lasers in surgery performance, the research was carried out to find out the trends of the utilization of this surgical method. In Korea, the research was carried out in three stages, the first research was to review all the available and the latest technologies and procedures. Five years analysis were performed. This market focused on the sales of the laser devices, the prime expenses and further cost of the tools. The second research was focusing the opinions of the medical professionals such as the expert surgeons, nurses, students and the manufacturers of these devices. 15 medical professionals were examined from three different categories. Tools and methods, possible Research and Development means of surgery were examined. 8 main aspects of the surgical procedures were observed. There were also given some suggestions, in particular to the newcomers about safety measures those are necessary to take before conducting these surgical procedures with the laser light. Analyses that one practice showed a trend toward less invasive procedures when this technology was used and resulted in faster patient recovery, potentially reducing the overall health care burden. The third research relates to analyze the pre-op and the pro-op safety requirements and the further actions to be made in order to prevent hazardous situations, causing the adverse consequences to the patient. Moreover the suggestions for the amendment and the improvement of the relevant laws and standards were given. In this context a new legislation and standards were prepared and came into practice. The main adverse effects of laser light were successfully prevented and now there are very few cases of the dangerous impact have been registered. The summary of those feasibilities and the importance of further research and investigation in this sphere of interest are described at the end. [10][15][16]

5. Conclusion

Rapid progress in laser technology has brought forth a plethora of new applications in diverse fields such as communications, energy, and medicine. This essay has discussed a range of those applications in energy sensing, electronic circuit etching for communication devices, neuroscience, and medicine's bioanalytical applications. It has examined these in terms of recent breakthroughs and the importance of the unique capabilities of lasers.

In conclusion, lasers have ascended to being undoubtedly one of the most significant technological tools of the 21st century. They are being routinely used in a diverse range of commercial applications. The main categories of advancements towards new applications were easily divided based on their resulting impacts that were on new developments in lasers underpinning applications, or applications of existing lasers. In tackling these issues, it was observed that the first case, the dramatic extension of fibre wavelength windows for lasers, had led to a multi-billion euro industry and was key in the internet age [17]. For electronics processing, consumer electronics have already benefitted from refined and adapted applications of lasers, whilst new applications were increasingly able to etch ever-finer electronic circuits. Finally, from a product perspective, cutting-edge analytical techniques were shown to rely upon new laser techniques in order to advance the understanding of complex systems, such as those in neuroscience. The significance of underpinning technological breakthroughs to the exploitation of scientists from different disciplines and the common provision of facilities was evident in all these cases.

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