Laser and its applications-a review

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Abstract:

Albert Einstein had described the theory of stimulated emission as early as 1917, but it would take three decades before engineers began to utilize this principle only after the invention of laser. Laser is used in communication, industry, medicine and environmental care and research. Laser has become one of the most powerful tools for scientists in physics, chemistry, biology and medicine throughout the world. One area that is considered to be very interesting is in the different methods to cool and capture atoms by using laser. We don't know yet what this knowledge and technology will be used for in the future, but we do know that future applications will be based on today's research in laser physics. Along with different applications of femto-second laser pulses, the recent discovery of atto-second laser pulses opens up new doors in laser technology. We have discussed some up-to-date developments in laser science and technology.

Key words: stimulated emission, principle of laser action, laser physics, laser cooling, laser comb, BEC, molecular dynamics, atto-second laser pulse.

Introduction:

If a sample absorbs some radiation, the sample can lose its excess energy by thermal collision or by re-emission of radiation. The second process leads to the very important topic of laser radiation. In this article, we have discussed the basic principles of the production of laser in detail. We also have discussed the special properties of laser which leads to different useful applications for the betterment of mankind. We have highlighted the important milestones in the development of laser technologies and important applications. We have mentioned 8(eight) Nobel Prizes [1-8] which are directly related to laser physics until 2018. Femto-second and nano-second laser-pulses give us lots of important applications in laser-induced molecular dynamics [6, 9-11]. We have also discussed about recent invention of attosecond laser pulses [12-14], which provides us new technologies to study dynamics of atomic electrons [15] and other sub-atomic particles.

Laser and Basic Principles:

What is Laser?

LASER stands for Light Amplification by Stimulated Emission of Radiation. Almost all of us probably know that the police use laser to measure the speed of speeding cars. At least car drivers who exceeded the speed limit know about it, but how many know that we also use laser several times during an ordinary day? We will find it in CD players, laser printers and much, much more. We often find laser in action movies where the hero has to escape the laser beams when he's trying to solve a thrilling problem. The power of a laser is both fascinating and frightening.

How Does Laser Light Differ from Other Light?

Light is an electromagnetic wave which has brightness and color and vibrates at a certain angle, so-called polarization. Laser light is more parallel than any other light source. Every part of the laser has (almost) the exact same direction and therefore almost do not diverge. Using a standard laser, an object at a distance of 1 km (0.6 mile) can be illuminated with a dot about 60 mm (2.3 inches) in radius. As it is parallel and it can be focused to very small diameters where the concentration of light energy becomes so high that you can cut, drill or turn with the beam. It can also illuminate and examine very tiny details. This property is being used in surgical appliances and in CD players. Laser light is very monochromic, i.e., just one light wavelength is present. Ordinary light is not monochromatic. White light contains all the colors in the spectrum, even a colored light, as for example, a red light-emitting-diode (i.e., LED) contains a continuous interval of red wavelengths. On the other hand, laser emissions are not usually very strong when we measure the energy content. A very powerful laser of the kind that is used in a laser show does not have more energy than an ordinary streetlight. The difference is in how parallel it is.

Stimulated Emission

Normally, atoms and molecules emit light naturally at more or less random times and in random directions and phases. All light sources, such as bulbs, candles, neon tubes and even the sun emit light in this way. Light is ordinarily emitted from the atoms or molecules that meet with two conditions: (i) they have stored energy originating from heat or previous absorption of light and (ii) some time has passed since the energy was stored. Now, if, energy is stored in the atoms or molecules and a photon of correct wavelength passes close-by, something else may happen. The atom or molecule emits light that is totally synchronous with the passing light. **Albert Einstein** predicted this way of emission of light early in the 1900s. This means that the passing light should be amplified. It can amplify a passing beam, provided three conditions are met: (i) energy is stored in the atom or molecule (same as above), (ii) light passes close enough to the atom or molecule before the atom or molecule emitted the light in the random fashion described above and (iii) the passing light has a suitable wavelength for the atom or molecule. The process is called stimulated emission (Fig.1). This stimulated emission, together with the feedback in a resonant cavity between two mirrors (Fig.2), forms the conditions for the production of laser.

Production of different Lasers and applications:

Nicolay Basov, Charlie Townes and Aleksandr Prokhorov shared the Nobel Prize [1-3] in physics in 1964 for their work which led to the successful construction of practical lasers. They founded the theory of lasers and studied how it could be built practically, originating from a similar appliance for microwaves called the MASER (Microwave Amplification by Stimulated Emission of Radiation) that was introduced during the '50s (which has not been so popular as laser).

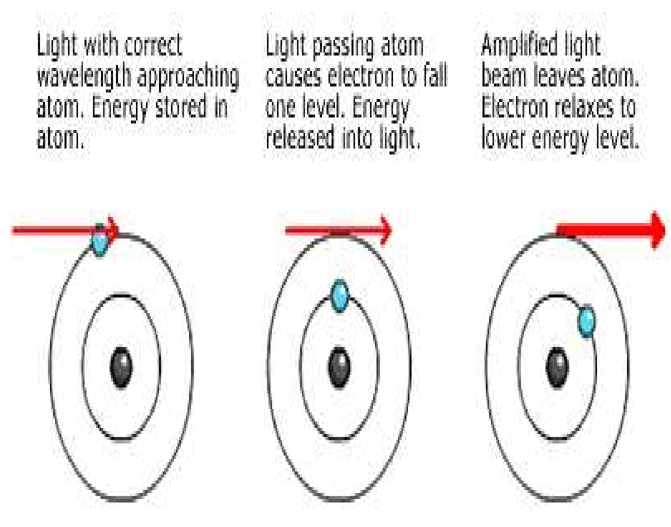

Fig.1: Stimulated Emission by an Atom

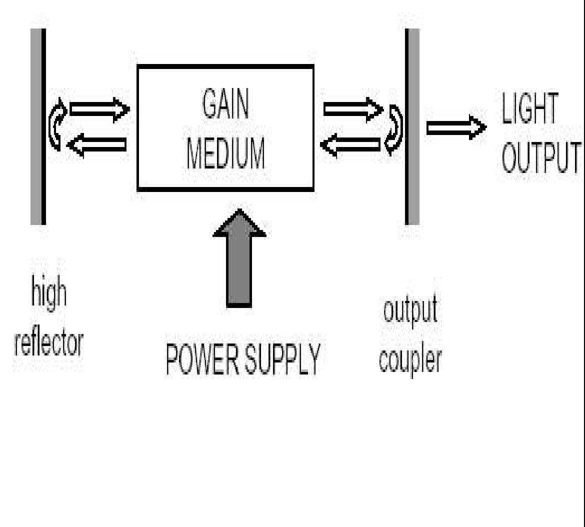

Fig.2: Principle of LASER action

However, the first functioning laser was built by **Maiman** [4] in 1960. This work resulted in a big and rather clumsy lasers built in the beginning of the '60s. Still, their theory for the laser describes fundamentally all lasers. Ruby lasers have historical importance because they were the first successful lasers. Ruby consists of Cr^{3+} ions doped into crystalline Al_2O_3 at a concentration of around 0.05% by weight. The host crystal, Al_2O_3, has no colour. The light is emitted by transitions of the Cr^{3+} impurities. Ruby is a ***three- level laser*** and the level diagram is shown below in Fig.3a. Ruby has strong absorption bands in the blue and green spectral regions. Electrons are excited to these bands by a powerful flash lamp. These electrons relax rapidly to the upper laser level by non-radiative transitions in which phonons are emitted. This leads to an increased population in the upper laser level. If the flash lamp is powerful enough, it will be possible to pump more than half of the atoms or molecules from the ground state (level 0) to the upper laser level (level 2). In this case, there will be population inversion between level 2 and level 0, and lasing action can occur if a suitable cavity is provided. The laser emission is of red colour at 694.3nm for Ruby lasers (the red colour: *ruber* means "red" in Latin). The diagram (Fig.3b) shows a typical arrangement for the construction of a ruby laser. The crystal is inserted inside a powerful flash lamp. We should cool the system by water-cooling arrangement to prevent damage to the crystal by the intense heat generated by the lamp. Mirrors at either end of the crystal fix the resonant cavity. Reflective coatings can be applied directly to the end of the rod (as shown in Fig.3b), or external mirrors can be used. The lamps are usually driven in pulsed mode by discharge from a series of capacitors. The laser pulse energy can be as high as 100 J per pulse. This is due to the fact that the upper laser level has long lifetime (~3 ms) to store a lot of energy and thus capable of producing population inversion. In this condition, a suitable resonant cavity, produced by two mirrors as shown in the figure Fig.3b, helps us to have production of laser.

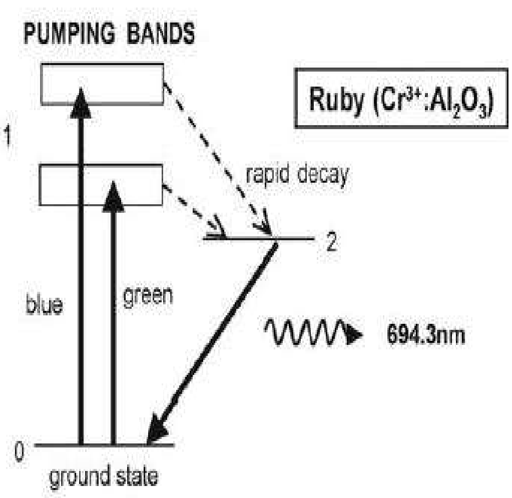

Fig.3a: Level Scheme of Ruby Laser

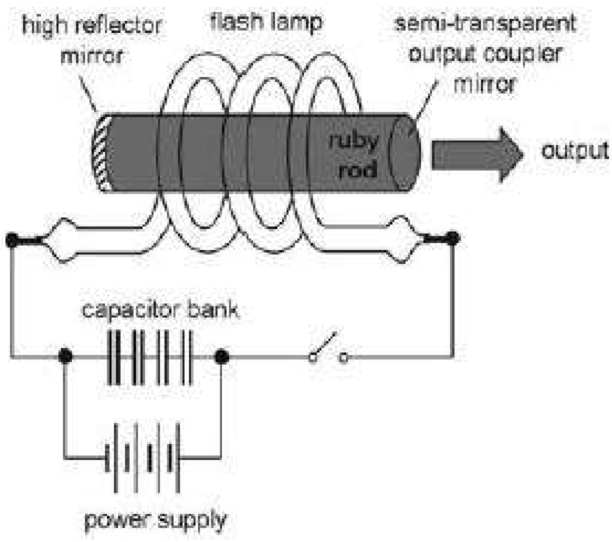

Fig.3b: Arrangement for a Ruby Laser

Gabor received the Nobel Prize in physics in 1971, having founded the basic ideas of the holographic method, which is indeed famous and spectacular application of laser technology. Initially, it was "just" a method of creating 3-D pictures. Subsequently, it has become a useful tool for the observation of moving objects. Much of what we know today about how musical instruments produce their tunes is due to the use of holograms. **Bloembergen** and **Schawlow** [5] received the Nobel Prize in physics in 1981 for their research to the development of laser spectroscopy. One typical application of this is nonlinear optics which means methods of influencing one light beam with another and permanently joining several laser beams (not just mixing them - compare the difference between mixing two substances and making them chemically react with one another). These phenomena mean that a light beam can in principle be steered by another light beam. If in the future someone intends to build an optical computer (that could be much faster and much more efficient in storing data- on which research is going on recently.), it would have to be based on a nonlinear optics. When using optical fibers, for example in broadband applications, several of the switches and amplifiers that are used require nonlinear optical effects. **Steven Chu, Claude Cohen-Tannoudji and William D. Phillips** [8] got the Nobel Prize in physics in 1997 for their developments of methods to cool and trap atoms with laser light which is a method for inducing atoms to relinquish their heat energy to laser light and thus reach lower and lower temperatures. When their temperature sinks very close to absolute zero, atoms form aggregates (Bose-Einstein condensation) in a way that reveals some of the innermost aspects of nature. This is the important application of laser cooling. After this discovery, very soon other scientists started to further develop closely related areas using this technique. When the laser was discovered in 1960, no one, except for a small group of physicists, knew anything about its applications. Laser technology was a solution looking for its problem.

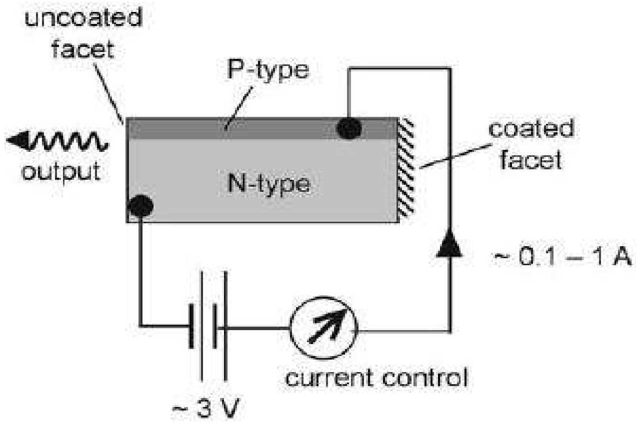

Fig.4: Semiconductor Laser

Alferov and **Kroemer** were given the Nobel Prize in physics in **2000** for their remarkable discoveries within the field of semiconductor physics (Fig.4). Their research leads to the development of semiconductor lasers. These are the kind of miniature lasers that today have become the cheapest, lightest and smallest.

This has become not only the basis for so many cheap and portable appliances, but also the foundation of optical information networks. The principle of operations of the CD player, laser writer, laser pointer and the barcode reader used by a cashier at a supermarket are all based on this discovery. **John Hall and Theodor Hänsch** received the Nobel Prize in physics in 2005 for "their contributions to the development of laser-based precision spectroscopy, including the optical frequency comb technique". The application of lasers to probe molecular dynamics was highly developed by **Ahmad Zewail** more than 20 years ago and was recognized by the award of Nobel Prize [6,7] in chemistry in 1999. The Nobel Prize in Physics for the year 2018 was for ground-breaking inventions in the field of laser physics. In this year, **Arthur Ashkin** was recognized for "the optical tweezers and their application to biological systems", while **G. Mourou** and **Donna Strickland** were recognized "for their method of generating high-intensity, ultra-short optical pulses" [8]. Lots of active research works are going on laser assisted chemical reactions and laser-matter [7] interaction dynamics. Atto-second pulses were produced in the year 2001 as a train of atto-second pulses from high harmonic generation [12-14]. Atto-second science arises from fundamental research into intense ultrashort-pulse atomic physics. This opened the door to real-time observation and time-domain control of atomic-scale electron dynamics [15].

Conclusions:

We have discussed the basic principles of inventions of different types of laser. We discussed different applications of lasers. We mentioned all the mile-stone inventions involving productions and applications of lasers which were recognized by the Nobel Prizes in Physics or Chemistry. Laser-atom atomic dynamics or laser-molecule molecular dynamics [7,9-11] are of extreme practical importance. Promotion from femto-second laser pulses [6,7] to atto-second science [12-15] is a revolution in technology. It integrates optical and collision science, greatly extending the reach of each. This is going to influence chemistry, biology and future technologies for mankind.

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