A COMPARATIVE STUDY OF X-RAY & γ-RAY LASERS AND ITS USES

Monika Khurana, **Dr. Rajeev Kumar Pandey

**Research Scholar CMJ University, Shillong*
***Department of Physics, Approved Guide of CMJ University,Shillong, Meghalaya*

INTRODUCTION

A laser is a device that amplifies light and produces a high directional, high intensity beam that has a very pure frequency or wavelength. It comes in sizes ranging from approximately one tenth the diameter of a human hair to the size of a very high powers ranging from 10^{-9} to 10^{20} Watt and in the wavelength ranging from the microwave to the x-ray spectral regions with corresponding frequencies from 10^{11} to 10^{-11} Hertz. Lasers have pulse energies as high as 10^4Joule and pulse durations as short as 6×10^{-15}sec.They can easily drill holes in the most of durable materials and can weld detached retinas within the human eye.

Almost everyone probably knows that the police use laser when they measure speed. At least many drivers that have exceeded the speed limit know about it, but how many know that you also use laser several times in a day? You will find its use in cd players and in laser printers. You 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 contained in laser is both fascinating and frightening.

There is nothing magical about a laser. It can be thought of as just another type of light source. It certainly has many unique properties that make it as a special source of light, but these properties can be understood without the knowledge of sophisticated mathematical techniques or complex ideas .The concepts, as they are developed, will be applied to all classes of laser frequencies and laser materials, so that we will develop a sense of broad field of lasers. Furthermore, we may also understand that how a laser light differs from ordinary light.

HOW DOES LASER LIGHT DIFFER FROM ORDINARY LIGHT?

Light is really an electromagnetic wave. Each wave has brightness and color and vibrates at a certain angle so called polarization. This is also true for laser light but it is more parallel than any other source of light. Every part of beam has the same direction and beam will therefore diverge very little.

With a good laser an object at a distance of 1 km can be illuminated with a dot about (2.3 inches) in radius.

As it is so parallel that it can also be focused to very small diameters where the concentration of light energy becomes so great that you can cut and drill with it. It also makes it possible to illuminate and examine very tiny details of a physical process. It is this property that is used in surgical appliances and in CD players.

It can also be made very monochromatic so that just one light wavelength is present. This is not the case with ordinary light sources. White light contains all the colors in its spectrum but even a colored light such as a LED (light emitting diode) contains a continuous interval of red wavelengths.

Furthermore, laser fields are very high as compared to the field strength of ordinary light. Because of its high field strength such properties of the matter can be understood which were not otherwise possible with the field strength of the ordinary light sources. As a laser field due to its high field strength can interact with inter-atomic fields.

Fundamental Ideas Initiated Laser

In early literature, particularly from researchers at Bell Telephone Laboratories, the laser was often called the optical maser. This usage has since become uncommon, and as of 1998 even Bell Labs uses the term laser [1]. In 1917, Albert Einstein in his paper on the quantum theory of radiations laid the foundation for the invention of the laser and its predecessor, the maser, in a ground breaking rederivation of Max Planck‟s Law of radiation based on the concept of probability coefficients later on to be termed as Einstein coefficients. In 1928, Rudolph W. Landenburg confirmed the existence of stimulated emission [2].

In 1939, Valentine A. Fabrikant (USSR) predicted the use of stimulated emission to amplify "short waves [3].

In 1947, Willis E Lamb and R.C Rutherford found apparent stimulated emission in hydrogen spectra and made the first demonstration of stimulated emission [2].

In 1950, Alfred Kastler (Nobel Prize For Physics 1966) proposed the method of optical pumping which was experimentally confirmed by Brossel, Kastler and winter two years later [4].

A LASER is a MASER that works with higher frequency photons in the ultraviolet or visible light or infra-red spectrum (photons are bundles of electromagnetic energy commonly thought as" rays of light" which travel in oscillating waves of various wavelengths) so far as radiation is treated as a wave.

As, MASER stands for Microwave Amplification by Stimulated Emission of Radiation.

Initial Concepts of Maser

In 1953, Charles H. Townes and graduate students James P. Gordon and Herbert J. Zeiger produced the first Maser, a device operating on similar principles to the laser, but producing microwave rather than infrared or visible radiation. Townes's MASER was incapable of continuous output. Nikolay Basov and Aleksandra Prokhorov of the Soviet Union worked independently on quantum oscillator and solved the problem of continuous output systems by using more than two energy levels. These systems could release stimulated emission without falling to ground state, thus maintaining population inversion. The first papers about the Maser were published in 1954 as a result of investigations carried out simultaneously and independently by Charles Townes and coworkers at Columbia University in New York and by Dr. Basov and Dr. Prokhorov at the Lebedev Institute in Moscow. These three gentlemen received the Nobel Prize of Physics in 1960 for their contribution in research and particularly in laser physics.

The fundamental physical principle motivating the MASER is the concept of stimulated emission. A maser beam is made up of entirely of stimulated emission. Finally, we can say that a MASER is a LASER of microwave region.

With stimulated emission, a photon of absorption wavelength λ is fired at an atom already in its higher energy state from prior absorption. The atoms absorb this photon, and quickly emit two photons to get back to its lower energy state. Both of these newly emitted photons are of wavelength λ.

The process of stimulated emission in a MASER may understood as follow:

(a) All of the molecules are in upper state and a photon of wavelength λ is incident from left. (b) The photon λ stimulated emission from the first molecule, so there are now two photons of wavelength λ ,in phase.(c)These photons stimulate emission from the next two molecules resulting in four photons of wavelengths λ .(d)The processes continues with another doubling of the number of photons.

Basically, a man-made maser is a device that sets up a series of atoms or molecules and excites them to generate chain reaction or amplification of photons. Metastable emission states make MASERS and LASERS possible. To get the proper wavelengths to generate the chain reaction, first electricity or another energy source is ”pumped” into a chamber filled with a particular atoms or molecules. Then this “pumping” radiation causes the transition of atoms from ground state to higher energy excited state. From this short-lived state the atoms come down through non-radiative transition to the long-lived metastable state. Once in metastable state many atoms can be accumulated in one place and in the same state. The LASER or MASER beam, stimulated emission, arises when all these accumulated atoms simultaneously make transition to the ground state, releasing their energy of wavelength λ, creating a beam of microwave radiation (or visible light in case of laser) which can be sent on the other atoms to cause the chain reaction. Since all the resulting photons have the same wavelength and the maser beams are extremely focused and coherent.

Initial Concepts of Laser Physics

In 1957, Charles Hard Townes and Arthur Leonard Schawlow, then at Bell Labs, began a serious study of the infrared MASER. The concept was originally known as "optical maser". Bell Labs filed a patent application for their proposed optical maser a year later. Schawlow and Townes sent a manuscript of their theoretical calculations to Physical Review, which published their paper in that year. (Volume 112, Issue 6)

At the same time Gordon Gould, a graduate student at Columbia University, was working on a doctoral thesis on the energy levels of excited thallium. Gould and Townes met and had conversations on the general subject of radiation emission. Afterward, Gould made notes about his ideas for a "laser" in November 1957, including suggestions using an open resonator, which became an important ingredient of future lasers.

In 1958, Prokhorov independently proposed an idea to use an open resonator. This idea was published for the first time. Schawlow and Townes also settled an open resonator design, apparently unaware of both the published work of Prokhorov and unpublished work of Gould.

REVIEW OF LITERATURE

The high rate of technology advancement in today‟s world is astounding. These technological advances are having an enormous impact on all aspects of life and their impact on the practice of medicine is not to be underestimated. One area of medicine that is undergoing extremely rapid development is the adaptation and integration of imaging into the process of cancer detection, diagnosis, and intervention. Radiation therapy is a prime example of this change. The role of the medical physicist in the radiation therapy process accelerates the development and introduction of these technologies into the clinical setting. As a result, imaging is now a pervasive component of radiation therapy with all major imaging modalities represented and numerous examples in which these modalities have been adapted to the treatment machine to allow increased accuracy and precision in the delivery of dose. While the objectives of these developments are clear, they raise numerous issues regarding the skills and resources that ensure these technologies are appropriately integrated and applied. Specifically, these developments place enormous pressure on the clinical staff to extend their knowledge base and their scope of responsibility.

In 2007, the IAEA assembled a team of medical physicists with experience in radiation therapy and imaging and charged them to examine the increasing role of imaging in the radiation therapy process and make recommendations related to their observations. A report was commissioned that should achieve the following objectives.

- *Review the status of mature imaging modalities currently employed in radiation therapy practice. These include pre-treatment imaging for target definition to in-room imaging for improved precision and accuracy of delivery.*

- *Review the availability and applicability of existing practice and quality assurance guidance documents related to the use of imaging information in the radiation therapy process.*

- *Identify of shortcomings in these documents while being cognizant of the broad range of needs found in the IAEA Member states.*

- *Develop a set of recommendations to the IAEA related to the needs and opportunities for further development with respect to imaging in radiation therapy. These recommendations may take the form of either detailed, prescriptive recommendations (e.g. formation of a CRP, preparation of a TECDOC) or broader recommendations regarding future directions.*

The resulting report was to be employed for internal use by the Agency, providing a perspective on the issues related to imaging in radiation therapy and assisting the Agency in accommodating these issues in the years ahead.

Imaging in the radiotherapy process

In the developed countries, radiation therapy is employed in over 50% of cancer patients at some point in the management of their disease. As a local therapy, radiation therapy seeks to exploit technology to conform the treatment to the targeted structure while avoiding surrounding critical normal tissue. Overall, the process of radiation therapy has become increasingly complex as the technology for its delivery advances. Recent developments in radiation collimation (e.g. multi-leaf collimators), computation (inverse planning), and imaging (target definition and targeting) have resulted in a far more complex radiation therapy process which promises higher quality of intervention, dose escalation, and/or reduced toxicity. The radiation therapy process contains many steps with imaging distributed throughout the process.

Imaging has become the primary source of information in the design of radiation therapy. As such, it is of critical importance that

(i) The signal contained in these images is well understood

(ii) The spatial distribution is precise and accurate. Failure in this aspect to do so can result in serious deleterious effects including failure to control the disease and/or induction of unforeseen toxicities.

Imaging for target determination

The use of imaging to define the cancer target is, in many ways, ideal, however, it is important to understand the limits of the imaging signal if it is to be appropriately applied. As with any measurement, it is useful to consider the precision and accuracy of the reported signal. The precision relates to the minimum quantity that can be detected by the system and the accuracy of its spatial resolution. In the context of cancer, this is highly relevant when considering the desire to treat not only the gross tumor volume (GTV) but also deliver a dose to the surrounding clinical target volume (CTV), which may contain microscopic extension of the disease and is by definition not visible on the available images. Incorrect interpretation of the imaging signal can result in either underestimating or overestimating the extent of these volumes. It can be anticipated that this problem will persist regardless of the specific imaging modality being employed. The complex nature of the disease makes complete characterization of the radiation target via imaging somewhat unlikely. As a result, the imaging systems effectively provide surrogate signals of the disease (e.g., a mass on a CT image). These surrogates are often referred to as „the target‟ although they are clearly not a <u>precise</u> or <u>accurate</u> representation. It is important to emphasize that the image signal is, therefore, only a surrogate of the target and must not be over-interpreted. In fact, the traditional practice of treating to bony anatomy recognizes that the bones are reasonable surrogates of the adjacent disease targets.

As in any measurement, there can be uncertainty in the quantities extracted from images. This is particularly the case in the determination of target location in treatment planning images (e.g., CT images for planning). Given that there are random uncertainties in any measurement, it is reasonable to expect that any image that is used to design the therapy will contain some geometric deviation from the mean. As a result, the use of such an image to design the therapy can introduce a systematic error that will persist over the course of therapy. The sources of this deviation are numerous and include, for example, momentary displacement of an internal structure at the time of planning image acquisition (e.g., rectal gas) or the random variations in the contouring of the structure by a busy clinician. In addition, there could also be systematic errors associated with a miscalibration of scale in an imaging system or sag in the level of the imaging couch.

As the field seeks dose escalation and reduced normal tissue complications, the need to reduce, manage and accommodate these uncertainties has been highlighted. The development of ICRU guidance documents on radiation prescription [1, 2] has created an important vehicle for development of image-based radiation therapy. The concept of the planning target volume (PTV) has allowed the radiation therapy field to relate the geometric uncertainties to a volume that can be included in the design of an appropriate dose distribution.

Imaging Modalities in Use in Radiation Therapy

COMPUTED TOMOGRAPHY

Current Issues and Future Developments

Computed tomography (CT) is and will be likely to remain the predominant volumetric imaging modality for radiotherapy. In common with other volumetric imaging modalities, CT is used to delineate tumour (Gross Tumour Volume, GTV), suspected tumour (Clinical Target Volume, CTV) and normal structures. Margins are assigned for geometric uncertainties, creating the Planning Target Volume (PTV) and Planning Organ-At-Risk Volumes (PRV).

Proposed Research Work

In the present course of investigation the laboratory status of x-ray lasers and γ-ray lasers will be studied. In recent years for lasers of x-ray regions many different schemes have been proposed. The most successful of the schemes has been the collisionally pumped x-ray lasers, which are produced in plasmas containing ions in a highly charged state. Within the ions, electrons move between the ground state and various higher energy levels so that the conditions are achieved for producing x-rays. Collisionally pumped x-ray lasers are highly useful because they can operate over a wide range of pump conditions and with a variety of targets.

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