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A Paper on the Plasmas: A Short Experimental Study on the LASER-Triggered Photovoltaics

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Abstract:-This report presents the hands-on training experience and one of its kind at the Institute of Plasma Research relating to the plasmas in India. The training at the workshop was focused on learning various physical laboratory techniques, viz., soldering, arranging the diodes, triodes etc., up to the level of handling the LASER beam device etc. The coursework was a thorough orientation to the study of plasmas and nuclear fusion energy technology. separate practical session was given to observe the experiments and operation of the Indigenous Nuclear Fusion Reactor named 'Aditya', a Tokamak built in collaboration with the Russian nation at the Institute of Plasma Research, Gandhinagar, India. Incidentally, a full-fledged experimentation only started in 1989 and our batch was the second one at the Institute. Technologically speaking, this Tokamak was one of the kind in 1990s providing research support to almost all the plasma physicists in India. The LASERS is a plasma, in ordinary parlance, an excited state of physical matter. The plasmas are generated by triggering artificially the matter of gaseous nature. And they can be safely and precisely triggered using the lasers. During the workshop, the incumbent trainees were required to take up some research of their choice in plasma physics. The paper therefore, brings the importance about the Lasers and its applicability in the day-to-day life which was my studyat the Institute. If we have heard about the Plasma TVs, Laser printers, bar code scanners at the retail shops, mobile and android gadgets etc., we are making use of it without saying. The paper therefore, presents through the 1990s perspective of the author about plasma and the development of it sextensive usage in the present era.

I. INTRODUCTION

The Institute for Plasma Research (IPR)[1]is an autonomous plasma physics research institute in India and is mainly funded by the Department of Atomic Energy. The institute is basically, involved in research on confined hot plasmas and plasma technologies for industrial applications.

During the three months of my study at the Institute of Plasma Research, Bhat, Gandhinagar, Gujarat, India, I was introduced to a totally new dimension of physics which I could find ordinarily, in theory. To even think about participating in the experiments conducted with the nuclear power reactors was something new and amazing and there we were standing right in front of the huge Aditya built with Russian technology which was in thawing(cooling down)phase of the experiment. We were all awe-stricken to see the magnificent structure of Indian pride. Before, going further, it is essential to have a fair idea about plasma physics which is reviewed in the literature as given below.

II. REVIEW OF LITERATURE

Plasma[2]is one of the four fundamental states of matter. Plasma is an ionized gaseous substance that is highly electrically conductive, so that long-range electromagnetic fields dominate the behavior of the matter. Unlike the other three states, solid, liquid, and gas, plasma does not exist freely on the Earth's surface under normal conditions, and can only be artificially Induced by heating or subjecting a neutralinert gas to a strong electromagnetic field.

- *LASERS*

[1]https://en.m.wikipedia.org/wiki/Institute_for_Plasma_Research#cite_note-1

[2]from Ancient Greek πλάσμα, meaning "moldable substance".

The term "laser"is as an acronym for "light amplification by stimulated emission of radiation".

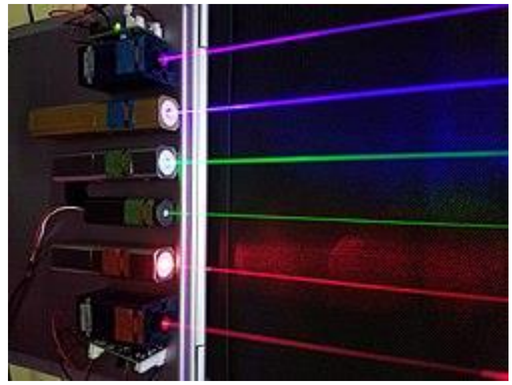
III. APPLICATIONS OF THE LASERS[3]

The New York Timeson the Nobel Prize award to the Laser Pioneer and Physicist Charles Townes reported, "a laser beam could, for example, carry all the radio and television programs in the world plus several hundred thousand telephone calls simultaneously. It is used extensively for range-finding and missile-tracking."

Over half a century later, applications like this— precision tools, digital communication, and defense— are among the most important uses of lasers.

Among their many applications, lasers are used in optical disk drives, laser printers, and barcode scanners; DNA sequencing instruments, fiber-optic and free-space optical communication; laser surgery and skin treatments; cutting and welding materials; military and law enforcement devices for marking targets and measuring range and speed; and laser lighting displays in entertainment etc.

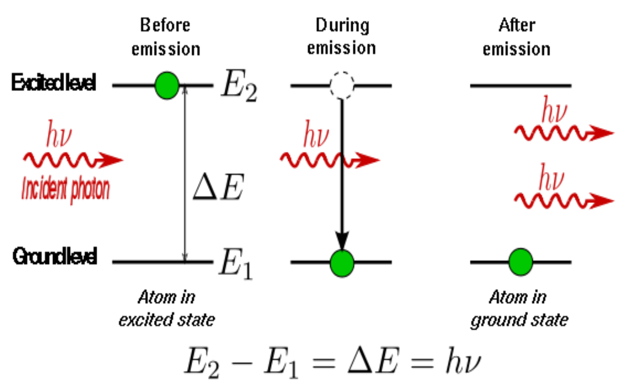
A laser beam used for welding(source: Wikipedia)



Red (660 & 635 nm), green (532 & 520 nm) and blue-violet (445 & 405 nm) lasers[4]

IV. STIMULATED EMISSION

In the classical view, the energy of an electron orbiting an atomic nucleus is larger for orbits farther away from it. However, quantum mechanical effects force electrons to take on discrete positions in orbital's. Thus, electrons are found in specific energy levels of an atom, two of which are shown below:



When an electron absorbs energy either from light, the photons or heat, the phonons, it receives that incident quantum of energy to jump to the higher level called the excited state of energy level. When an electron is excited from a lower to a higher energy level, it will not remain that way forever. It falls back to its state of equilibrium or in other words, it reaches its minimum level of energy.

An electron in an excited state may decay (fall)to a vacant lower energy state at a time constant characterizing that transition. Spontaneous emission is caused when an electron in an excited state decays without any external influence thereby,

[3]The New York Times, 1964.

[4]Wikipedia. Org visited 14[th]February, 2018 20:00 Hrs.

emitting a photon. And the phase of wavelength of such released photon is random. A matter or molecule consisting of many such atoms in an excited state thus, may result in a spectrally limited radiation, more or less centered around one wavelength of light however, the individual photons would have no common phase relationship and would emanate in random directions. This mechanism is called fluorescence or thermal emission.

An external electromagnetic field at a frequency associated with a transition usually affects the quantum mechanical state of the atom. When an electron in the atom makes such a transition a dipole field is created and this dipole oscillates at a characteristic frequency. In response to the external electric field at this frequency, the probability of the atoms entering this transition state is greatly increased. Thus, the rate of transitions is further enhanced due to thermal emissions. Such a transition to the higher state is called absorption, and it destroys an incident photon as it's energy goes into powering the increased energy of the higher state. A transition from the higher to a lower energy state, however, produces an additional photon and this process is called stimulated emission.

V. RESEARCH DESIGN

A simple experimentation was designed to understand the basics of Laser beams and its use in photovoltaic's. The theoretical part of it was explained and the practical session was carried thereafter, in the physical laboratory at the IPR, Gandhinagar, India.

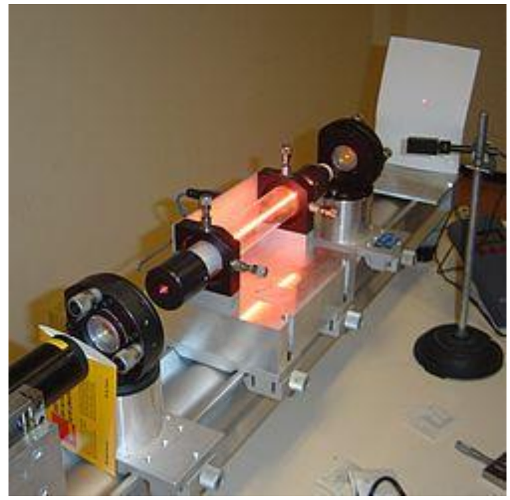
A. Scientific Experiment No. 1

Aim and Objectives

- A scientific experiment to check the alignment of optical equipment of helium – neon device using laser beams was performed.
- A scientific experiment to make laser beams follow precise paths in order to develop better Solar cells, i.e., employing microsecond pulses to form laser-fired contacts in photovoltaic devices was performed.

VI. OBSERVATIONSAND RESULTS

The basic mechanism of this device of laser is simple. It concentrates light over and over again through optimization until it emerges as a powerful coherent monochromatic beam of light.



VII. A HELIUM–NEONLASER DEMONSTRATION

The device supplies ordinary light to a neon tube. This glowing gas is excited and then acts as the gain medium through which the internal beam passes, as it is reflected thoroughly in the optical equipment. Laser output can be seen to produce a tiny intense spot on the screen of 1 mm in diameter. The gain medium is brought to an excited state by an external source of energy. This medium consists of gaseous atoms which are excited into such a state by means of an external light source, oran electrical field for atoms to absorb energy and to undergo a quantum leap in the energy level.

The gain medium of a laser used here, is a controlled gaseous matter of definite purity and concentration which amplifies the beam by the process of stimulated emission. This matter can be gaseous, liquid, solid, or plasma. The gain medium absorbs the external energy supplied which raises some electrons into higher energy levels or excited quantum states. The gaseous particles interact with light by either absorbing or emitting photons and the process is termed as a stimulated emission. The emitted photons of the gain medium travel in the same direction as the internal beam of light passing through it. When the number of particles in one excited state exceeds the number of particles in the lower-energy state, population inversion is achieved, asa result of which, the amount of stimulated emission becomes larger than the amount of absorption. Hence, the light is amplified. By itself, this becomes an optical amplifier in a resonant optical cavity toform a laser oscillator.

The resonator typically consists of two mirrors through which a coherent beam of light travels, reflecting back and forth so that an average photon will have to pass through the gain medium repeatedly before it is finally emitted from the output aperture or lost to diffraction or absorption. If the amplification of the gain medium is larger than the loss in the resonator, then the power of the reflected light rises exponentially. But each stimulated emission event returns an

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atom from its excited state to the ground state, reducing the gain of the medium. With increasing beam power the net gain becomes unity and the gain medium is said to be saturated in a continuous wave laser. The minimum supplied power needed to begin a laser action is called the lasing threshold. The gain medium will amplify those photons only that are in a spatial mode supported by the resonator which enables them to pass more than once through the medium and receive substantial amplification.

The light generated by stimulated emission is very similar to the input signal in terms of wavelength, phase, and polarization. This gives laser light its characteristic coherence, and allows to maintain a uniform polarization and monochromatic feature by the optical cavity design.

The beam in the cavity and the output beam of the laser travels though they are in a free space i.e., a homogeneous medium rather than through waveguides as in an optical fiber laser and can be approximated as a Gaussian beam in most lasers; such beams exhibit a minimum divergence for a given diameter. At the focal region, the beam is highly collimated, the wave fronts are planar without any beam divergence and normal to the direction of the wave propagation. The Gaussian beam of a single transverse mode laser eventually diverges at an angle which varies inversely with the beam diameter in accordance with the diffraction theory. Thus, the "pencil beam" directly generated by a common helium–neon laser would diverge at most perhaps 500 kilometers. On the other hand, the light from a semiconductor laser exits the tiny crystal with more divergence up to 50° of an angle which can be transformed into a uniformly collimated beam using a lens system. For instance, in a laser pointer, the light originates from a laser diode of a single spatial mode. The unique property of a laser light is therefore, its spatial coherence.

As understood differently, in the perspective of a social scientist who is working on a subject relating to pensions for the informal workers in a given social milieu, a flashlight very much resembles to the informal workers with no pension benefits and on the other hand, the laser beam is like the informal workers enrolled in work-place pensions of contributory nature. They work to gain a uniform pension benefit of a long focused range. Lasers are more than just powerful flashlights, the distinguishing features are[5]:

- Whereas, a flashlight is a "white" light, a laser is a monochromatic light of a precise frequency or the color may be invisible as inthe case of infrared or ultraviolet radiations.
- Whereas, a flashlight beam spreads out into a short and fairly fuzzy cone, a laser shoots a muchtighter, narrower beam over a much longer distance. It is said to be highly collimated.
- Whereas, the light waves in a flashlight beam are all mixed up with the crests of some beams running into the troughs of others, the waves in laser light are exactly in step with the crest of every wave lined up with the crest of every other wave. The laser light therefore is said to be highly coherent.

[5]Chris Woodford, Lasers, *Last updated: May 4, 2017, Wikipedia*

A laser thus, differs from other sources of light as it is spatially and temporally coherent. Spatial coherence allows a laser to be focused to a tight spot, enabling applications such as laser cutting and lithography. It also allows collimation i.e., to stay narrow over great distances mostly found in applications such as laser pointers. Lasers exhibit high temporal coherence, which allows them to emit light with a very narrow spectrum, i.e., they can emit a single color of light which is used to produce pulses of light as short as a femtosecond.[6]

From the viewpoint[7] oftoday, future solar cells will be tinier with higher efficiencyand durability.
Laser-fired contacts (LFCs) are typically fabricated with nanosecond pulse durations[8]that offer an advantage of reduced

[6] Ibid.
[7]Laser-fired rear contacts for crystalline silicon solar cells authored by E. Schneiderlöchner,R. Preu,R. Lüdemann,S. W. Glunz, TOC, Volume 10, Issue 1, January 2002, Pages 29–34. Copyright © 2002 John Wiley & Sons, Ltd.
[8]Ashwin S. Raghavan, Todd A. Palmer, Katherine C. Kragh-Buetow, Anna C. Domask, Edward W. Reutzel, Suzanne E. Mohney and Tarasankar DebRoy ,' Employing microsecond pulses to form laser-fired contacts in photovoltaic devices', TOC, Volume 23, Issue 8, August 2015, pp. 1025–1036. Copyright © 2014 John Wiley & Sons, Ltd.The paper states that, 'The simulated and experimental results indicate that contacts are hemispherical or half-ellipsoidal in shape. In addition, the resolidified contact region is composed of a two-phase aluminum–silicon microstructure that grows from the single-crystal silicon wafer during resolidification. As a result, the total contact resistance is governed by the interfacial contact area for a three-dimensional contact geometry rather than the planar contact area at the aluminum–silicon interface in the passivation layer opening. The results also suggest that for two LFCs with the same size top surface diameter, the contact produced with a smaller beam size will have a 25–37% lower contact resistance, depending on the LFC diameter, because of a larger contact area at the LFC/wafer interface'.

metal expulsion and can be implemented with diffractive optics to process multiple contacts simultaneously and meet the production demands for industrial and commercial applications.

B. Scientific Experiment No. 2

Aim and Objectives

To observe the phasein Thawing out of the nuclear fusion energy reactor, the Aditya Tokamak.

VIII. OBSERVATIONS

We were given metallic aprons to wear before entering the main chamber of Aditya Tokamak. We were informed that the nuclear fusion energy reactor is in the process of thawing out. It was almost one hour that the nuclear reactor was shut off and there is every likelihood of radiations being emitted from it. A strong graphite buffering may not be sufficient to stop the radiations completely, therefore, precautions must be taken before entering the chamber as we were informed. The radiations might affect the reproductive organs we were told, when some of us took it lightly to wear the safety aprons.

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A Tokamak (Russian: Токамáк) is a device that uses a powerful magnetic field to confine plasma in the shape of a torus. The characteristic torus-shaped reaction chamber is clad with graphite to help withstand the extreme heat and to contain hot plasma for producing controlled thermonuclear fusion power.

ADITYA[9], a medium sized Tokamakhas a major radius of 0.75m and minor radius of the plasma is 0.25m. Amaximum of 1.2 Toroidal magnetic field is generated with the help of 20 symmetrically spacedtoroidal field coils. ADITYA is regularly powered by the transformer-converter system. Pulses longer than 100 ms with 80-110 kA plasma current at toroidal field of about 0.9 T is being regularly produced for various experiments. From the time of original commissioning, ADITYA has been upgraded gradually in various ways. Vacuum system now has three discharge cleaning systems viz., Glow, Pulse and Microwave Discharge Cleaning. In addition a number of in-situ surface coating methods have been developed. Many more diagnostics have been integrated and made on-line. Some new designs are in the fabrication phase to increase the plasma energy content during discharge, an auxiliary-heating system based on Ion Cyclotron Resonance Heating, is used. For the purpose, a 20-40 MHz, 200 kW Ion Cyclotron Resonance Heating (ICRH) system has been integrated to ADITYA in addition to a 28 GHz, 200 KWgyrotron based Electron Cyclotron Resonance Heating (ECRH) system. To gain hands-on experience with Lower Hybrid Current Drive (LHCD) system which is a vital subsystem for the next machine SST-1, a plan to fully integrate it soon is in progress. The Government of India initiated the Plasma Physics Programme (PPP) for research on magnetically confined high temperature plasmas. The PPP evolved into the autonomous Institute for Plasma Research under the Department of Science and Technology in 1986. With the commissioning of ADITYA in 1989, full-fledged tokamak experiments started at IPR,Gandhinagar, Gujarat, India.

IX. CONCLUSION

The overall study at the Institute of Plasma Research was enlightening and thoroughly focused on plasma physics. The experience gained is beyond comparison with any other program. This research papers a humble attempt that presents the experiments done wayback in1990reviewingthe most recent contemporary authors on the subject. The advancement made in the usage of lasers in day-to-day life was envisaged long back and this is just a beginning of a plasma era.

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