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Status Of Laser Technology In India

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Abstract: The facility for laser technology at institutions and laboratories in India provide enormous opportunity to the scientists and research scholars involved in the field of gas lasers, free electron lasers, solid state lasers, semiconductor lasers, laser related materials/crystal and components etc. The effort in the field of optical research using lasers comprises of holography, optical information/signal/data storage, processing, communication and computing, etc. by academic and R&D institutions shows remarkable progress. The laser spectroscopic activities develop laser culture in the laboratories. For the development of optical integrated circuit, and future optical communication systems with sophisticated facilities, it is essential to make indigenously produced lasers. Keeping in mind the importance of developing applications of laser, a linking up of institutions and industry is recommended. In this article, an attempt has been made to highlight the measures of success that has been achieved by academic and R&D institutions around the country.

I. INTRODUCTION

The laser (light amplification by stimulated emission of radiation) is a light source that exhibits unique properties of monochromaticity, directionality and coherence. The basic principles for laser science are the quantum nature of light and a process called stimulated emission. A laser basically consists of three parts: a resonant optical cavity (optical resonator), a laser gain medium (active laser medium) and a pump source to excite the particles in the gain medium. The optical resonator consists of at least two mirrors between which the light bounces up and down resonantly. One of the end mirrors is usually partially reflective called the output coupler. The laser operation requires a gain medium in the resonator, which amplifies light. Lasers are classified by the type of gain medium they employ (gas laser, solid-state laser, dye laser, semiconductor laser, etc.). The active particles in the laser gain medium need to be in a state of inversion for the laser to operate. To reach this state pumping process is required, which lifts them into the required energy state.

In fact, lasers are used in thousands of applications in every section of modern society, including consumer electronics, information and communications technology, entertainment, science and industry, the medical field and defence. Modern laser research involves fundamental laser physics, creative development of novel laser concepts and advanced experimental work and diagnosis. All this can lead to the development of new lasers, which will fulfill the requirements of current and future demands in science and industry.

II. LASER TECHNOLOGY

In last two decades laser technology has spread in its wavelength and has been compressed in its time domain. It has reached CW power levels of nearly a million watts in a short burst and a wavelength near the X-ray region. Most patents granted are related to the technology of lasers with power above 1000W. The emphasis is on higher and higher power, longer life in the case of well-tried lasers, compactness and ruggedness for field use and the invention of better and newer lasers. The sole function of these lasers is: processing materials, generating plasmas, separating isotopes, etc. The workhorse of industry remains the CO_2 laser, that for general use the HeNe, and that of surgery the Ar+ and YAG lasers. The use of excimer and metal vapor lasers in medicine are common. In the case of CO_2, the emphasis is on high frequency devices to improve welding performance. The interest in waveguide CO_2 is due to its compactness and small power which makes it ideal for medical use.

A high power laser alone does not draw attention of manufacturer/designers. The metal vapor laser (e.g. Copper vapor laser, gold vapor lasers, Manganese vapor laser, etc.),

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semiconductor lasers (e.g. GaN, InGaN, AlGaInP, AlGaAs etc.), Nuclear pumped laser, N_2-pumped dye laser, Nd: YAG-pumped dye laser etc. are also receiving special attention. Control and delivery systems play an important role in high-power laser design. Several automatically operating controls have been designed for CO_2 lasers. When laser beams are applied to the human body the control of power and of the focal spot location become important.

III. LASER RELATED MATERIALS AND COMPONENTS

Laser materials and components could be categorized as (i) those required for the generation of laser radiation (ii) those required for the detection of laser radiation (iii) those required for the modification of laser radiation. The focus at present is on the material detection and modification. New materials being developed are alexandrite for solid state lasers. The electro optic materials are $LiNbO_3$, MgO:$LiNbO_3$, Fe:$LiNbO_3KNbO_3$, $AgGaS_2$, $AgGeSe_2$. Among tunable laser most materials being developed are Cr:GSGG, Cr:GGG, Cr:$BeAl_2O_4$, Ti:Al_2O_4. Relatively new materials for single frequency lasers are Er: YAG, Yb:YAG, Nd:YVO_4, Tb:YAG, Nd:$GdVO_4$, Nd:Cr:GSGG and variant of yttrium aluminium garnet(YAG) and gadolinium scandium gallium garnet (GSGG) doped with Er,Tb, Nd. These are used in slab as well as rod geometry. Material for components such as hard coatings, high strength dielectrics, semiconductors, ceramics, better active media continue to be developed. The crystal/ materials Nd:YAG, Nd:KGW, Nd:YAP, Nd:Cr:GSGG, $LiNbO_3$, Fe:$LiNbO_3$,Gadolinium gallium garnet(GGG), Potassium dihydrogen phosphate(KDP), ADP, $Bi_4Si_3O_{12}$(BSO), HgCdTe are developed at SSPL, BARC, IISc, DSC, and IITK. Flash lamps for pumping ruby, Nd: YAG, Nd: glass lasers have been developed by BARC. Paper capacitors have been developed by BARC, and by private manufacturers. Ceramic capacitors are manufactured routinely by BEL. Thyratrons are essential for operating many pulsed lasers (such as N_2, CVL, and excimer). Krytrons, which are cold-cathode thyratrons and are used for Q-switching, solid state lasers, need to be developed. The optical components like, prisms, lenses, laser mirrors, windows, and special gratings etc., are available in the country through commercial and institutional channels. The dielectric mirrors have been made in BARC, CSIO, DSC, IISc, and NPL. Generally, all laboratories acquire dielectric mirrors from source abroad. The work for developing ZnSe/Ge or coated mirrors for CO_2 has been undertaken in India. Holographic gratings for laser work (i.e. for tuning) are systematically carried out at IITM, CSIO, IISc, IITD, IITK, IRDE etc. The latest kind of mirrors viz, phase-conjugate mirrors need to be developed. For a variety of lasers-in particular, Ar+, Kr+ and CVL lasers-critical components required are beryllia and almina tubes.

IV. STATUS OF LASER FACILITY

Indian Institute of Technology, Delhi (IITD) have optical fiber splicing and characterization set-up, high power lasers, optical fiber fusion facility, diode pumped Nd: YAG laser, facility for optical phase conjugation with photorefractive, OTF bench, dynamic holographic recording set-up, thermoplastic photoconductor holocamera, image processing system with CCD camera, photon-correlator, laser ablation system, real-time spectroscopy system, excimer lasers, liquid helium closed cycle cryogenic systems, vibration-free platforms and argon laser for holographic work, spatial light modulators, polarizing microscope, optical multichannel analyzer, titanium sapphire laser etc. Indian Institute of Technology, Kharagpur (IITKGP) has fiber optics lab, high power semiconductor lasers, integrated optics lab, etc. Instruments Research & Development Establishment (IRDE), Dehradun, is a pioneering institution in the fields of laser range finders, laser range sensors, laser warning systems, photonics and holographic products, and fiber optics systems, software for optics design, single point diamond turning facility for micro-machining, laser interferometer, etc. International School of Photonics (ISP), Cochin have facility like ultra-fast Ti-sapphire laser, ultra-fast T-sapphire amplifier, 5 watt CW DPSS laser, Q-switched Nd: YLF green laser, optical parametric oscillator, Nd: YAG lasers, high power argon ion laser, diode pumped Nd:YVO_4 laser, ring-dye laser, pulsed dye laser, helium-cadmium laser, Nd: glass laser, carbon dioxide laser, nitrogen laser, semiconductor diode lasers, He-Ne lasers etc. Indian Institute of Technology, Guwahati (IITG) has Q switched high power Nd:YAG laser, laser ablation set-up, multiple beam interferometry set-ups, fiber optics communication set-up etc. Raman Research Institute, Bangalore provide femtosecond laser system with amplifier, generating 100fs laser pulses, frequency doubler and tripler, and single shot autocorrelator, nanosecond Nd: YAG laser with second harmonic output, UV-VIS spectrophotometer, monochromator, fiber optic spectrometer, laser beam profiler, ultra high vacuum chamber (300 lts volume), 10W NdVO_4 pump laser, pulsed Nd: YAG laser capable of giving out 10ns pulses at a rate of 10 pulses per second. The fundamental IR radiation has energy of 850mJ per pulse, frequency doubled green 450mJ and the frequency tripled UV 200mJ. University of Pune, Pune provides Zeiss Axiovert microscope (Inverted) with laser interface + CCD + monitor, excimer lasers, Nd: YAG (oscillator + amplifier), ruby laser (oscillator + amplifier), CO_2 laser (CW), optical multichannel analyzer, He-Ne lasers etc. University of Kerala, Thiruvananthapuram provides He-Ne and diode lasers, optical fibers, and optical fiber kits. In Laser Science & Technology Centre, Delhi (LASTEC) the facilities include high power lasers viz., combustion driven high power gas dynamic laser, chemical oxy-Iodine laser, low energy solid state lasers, Nd-YAG laser designator cum range finder, beam control technologies, electro-optic countermeasures, laser materials, laser-related optics, thin film coatings, laser crystal / glass materials.

V. LASER IN SCIENTIFIC RESEARCH

Optic research using lasers comprises of holography, optical data storage, processing, communication and computing, integrated optics and speckle phenomena, metrology, etc. There has been tremendous activity in the area of non-classical states of light using nonlinear optical phenomena. The major theoretical groups in the field at BARC,IITD and University of Hyderabad have been variously active in the esoteric subjects of nonclassical light , quantum fluctuations, six-wave mixing, non-equilibrium phase transitions in the presence of non-classical light, phase conjugation, squeezed states etc. Less esoteric and somewhat laboratory oriented research in non–linear optics is pursued at BARC,CAT,IACS,IITK, TIFR and the universities of Burdwan, Cochin, etc. Laser and photonics related activities, opto-electronics and optical-communication is a research programme being conducted by IIT Delhi. The research areas include fiber-optics, laser electron acceleration in dense plasmas, real-time optical processing, laser Raman and photoluminescence, spectroscopy, non-linear integrated optical devices, millimeter wave free electron laser, photon induced interface modifications. Shri G.S. Institute of Technology & Science, Indore (SGSITS) run programme in optoelectronics with specialization in optical communication. At present, the department has mobilized its maximum research activities in the areas of laser physics, optical electronics, fiber optics and nonlinear optics. The research activities at Devi Ahilya Vishwavidyalaya, Indore include free electron lasers and quantum well lasers. Institute of Plasma Research, GandhiNagar, Gujarat involved in research in various aspects of plasma science including free electron laser, dusty plasmas and other nonlinear phenomena. Work is going on in the area atomic spectroscopy (like interaction of intense laser fields with atomic systems, wave mixing, spectroscopy of ions and short lived isotopes.), molecular spectroscopy (resonance and time resolved Raman spectroscopy, dynamic of excited states, laser photoelectron spectroscopy), laser analytical spectroscopy (detection trace & ultra-trace quantities of elements, applications to cosmology, nuclear physics, hydrology, biomedical sciences, oceanology, geoscience etc. studies of photo ionization in the atmosphere by high power lasers and syncyclotron radiation sources. The laser spectroscopic activities in Bhabha Atomic Research Centre (BARC) involve programmes like high-resolution atomic spectroscopy, laser optogalvanic spectroscopy , multiphoton ionization spectroscopy, high resolution infrared diode laser spectroscopy of polyatomic molecules, laser Raman spectroscopic studies on biological molecules, semiconductors, phase transitions, laser optoaccoustic and laser-induced fluorescent spectroscopy, laser spectroscopy techniques for trace analysis, spectroscopic studies on supersonic nozzle beams , theoretical studies on interaction of laser radiation with atomic systems, spectroscopy and chemistry of laser photo dissociation products, laser –produced plasmas etc. The work at IITK is in multiphoton processes, Doppler free broadening, optogalvanic spectroscopy, photochemical reactions, laser Raman spectroscopy, solid state spectroscopy, laser-induced fluorescence, spectroscopy of high temperature superconductors etc. In IRDE, laser and photonics related activities are being pursued in Departments. The areas of research include optical networks, fiber optics, fiber-optic communication, image processing, integrated optics, optical communication, photonics, laser physics, non-linear optics etc. In IITG, the major focus of research in the department is in the following areas lasers and photonics, laser matter interaction, plasma diagnostics, optical interferometry, optoelectronics, integrated optics, etc. In Raman Research institute, Bangalore the interests have widened to include laser cooling and trapping of atoms, study of ultrafast processes and intense laser-matter interactions. The areas currently under study include random lasers, non-linear optics, laser cooling and trapping of atoms, intense laser matter interactions. In Physical Research Laboratory (PRL), the research activities include quantum computation & quantum information, quantum optics, optical resonators and optical fibers. In International School of Photonics (ISP) the research areas include laser induced plasma spectroscopy, fiber optic sensors, photo-acoustic studies, non-linear optics etc. In university of Kerala, the research activity is on topics like non-linear optics materials, holography, fiber optic sensors, laser applications etc. Raja Ramanna Centre for Advanced Technology, Indore (RRCAT) engaged in R & D in non-nuclear front line research areas including various types of lasers, laser related components and laser-based instruments. Commercial ruby lasers were being used for the study of stimulated Raman scattering at IIT Kanpur. Laboratory models of He-Ne, Ar-ion, carbon dioxide, nitrogen, nitrogen laser pumped dye, Cu-Vapor, Ar-ion pumped dye and Cd-plasma recombination lasers are some of the lasers developed at IIT Kanpur. The major research activities include high resolution laser spectroscopy, non-linear optics, laser plasma studies, laser Raman studies, medical applications of lasers, photonic devices, electro-optic materials and devices. The laser spectroscopic work at BHU includes novel laser based techniques of photoaccoustic, optogalvanic, thermal lensing and photoionization spectroscopy etc. At IITM work has been done in laser Raman spectroscopy, stimulated Raman scattering, photoaccoustic spectroscopy, gain spectroscopy, photo isomerism studies etc. Pico second and femto second spectroscopy has essentially been possible due to short pulsed lasers and dramatic development in detection electronics and sensors. The Physics Department at IIT, Bombay has a vibrant research program with work going on in frontier areas of optics and laser spectroscopy. The areas under laser and optics being pursued include non-linear optical processes and ultrafast optical switching, holographic interferometry and laser spectroscopy. The activity at Tata Institute of Fundamental Research (TIFR) laboratory includes time-resolved chemical and spectroscopic studies using nanosecond and picoseconds laser sources. Lasers and heavy ion beams from an accelerator are being increasingly used to understand the processes which occur in astrophysical and plasma environments. Ultra short (femtosecond) lasers producing very high peak powers are being used to explosively ionize matter and study its behavior at these extreme, "implosive" excitation conditions. Nonlinear optical properties of emerging and novel materials are being studied to understand how material structure influences its optical response. The research areas at Department of Nuclear and Atomic Physics include Interaction of electrons, ions and neutrals with laser excited molecules, Interaction of matter in intense laser fields, Non-linear optics, quantum computing and optical communications. The main objective of Centre of Excellence in Lasers & Optoelectronic Sciences (CELOS) is to strengthen research activities in the field of lasers & optoelectronic sciences and to build them to a level of competence comparable with international standards. The thrust areas of research at this centre include laser technology, non-linear optics, laser-matter Interaction, fiber optics, optical fiber sensors, optical neural network, photonic materials development, and optoelectronic devices. The department of Physics at IIT, Madras carries out research in many frontier areas, optical and laser physics, ultrafast lasers and optical amplifiers. The first semiconductor laser in India was developed at BARC in 1965. Centre for Advanced Technology (CAT) built first copper vapor laser. It is the most powerful laser emitting visible light. Copper vapor lasers capable of giving up to 40 Watt average power had been developed at CAT. These lasers are also used to pump tunable dye lasers whose wavelengths can be changed. Another important laser developed by CAT is the carbon dioxide (CO_2) laser. CAT has developed technologies of several types of CO_2 lasers namely, low power slow flow CO_2 laser, high power fast flow CO_2 laser, tunable CO_2 laser and high pressure pulsed CO_2 laser and is also pursuing applications of these CO_2 lasers in medicine and industry.

VI. BIOMEDICAL APPLICATION OF LASERS

The most revolutionary applications of lasers in medical science are in dermatologic surgery, neuro surgery, oncological surgery, ophthalmologic surgery, oral surgery and so on.

Laser surgery removes excess prostrate tissue by ablation and enucleation. For smooth hair free skin, laser treatment works on hair root without harming surrounding skin. CAT has been developing CO_2 lasers for surgery and nitrogen laser for treatment of tuberculosis. The treatment consists of inserting a needle from the back of the patient into the cavity and then irradiating the cavity with the nitrogen laser beam which is transmitted through an optical fibre inserted through the needle into the cavity. Exposure of the burn wounds to nitrogen laser results in complete healing of the wounds. CAT has taken up development of analytical instruments laser fluorimeter for detection of low concentration of uranium in water samples. This instrument uses a nitrogen laser to excite fluorescence in uranium source. The intensity of this fluorescence is a direct indication of the concentration of uranium in water. In IITD, the quasi elastic laser light scattering and laser Doppler velocimetry are used to get information about the size and movement of the microorganisms, cells, organelles, and molecules. These studies are related to the diffusive motion, self-propelled motion (e.g. of sperms) and motion in electric fields. The effect of time, dilution and certain cations (e.g. K^+, Ca^{2+}) on the velocity distribution of human sperms has also been investigated. Electrophoretic light scattering technique is being used to differentiate electro kinetically diseased blood cells. In IITM work has been initiated on monitoring chest movements by holographic and speckle interferometry with a view to get diagnostic information and cardiac displacements or mal functions. Reluctance of tissues and blood samples for HeNe light is also being studied. In IITK work on the differential fluorescence spectra of diseased samples of tissues and body fluids has been initiated. Laser as well as conventional spectroscopic studies of the lens and gall bladder stones has been done in BHU. Lasers are finding wide ranging applications in medicine and have already revolutionized the treatment of various disorders, ranging from retina to angioplasty. Newer areas should be taken up are investigations of interaction of laser beams of different wavelengths with different tissues of the human body and laser based techniques for diagnosis. Laser surgery has many advantages over conventional surgery. In laser surgery there is virtually no bleeding, far less trauma to the patients and healing is faster. CAT therefore decided to develop a surgical laser based on a 60W CO_2. This surgical laser has an articulated arm with seven elbows to allow the surgeon to guide the laser beam.

VII. LASERS IN MATERIAL PROCESSING

The main application of sufficiently high powered lasers (CO_2, Nd:YAG/Glass) in industry is in material processing. Several manufacturers in our country have installed high power lasers (CO_2, CW, 2kW) for laser drilling, profile cutting, welding and surface treatment of metals.CAT has also developed a fast glow high power CO_2 laser capable of giving up to 5 KW power continuously. This laser can easily cut steel sheets more than one cm thick.

Laser welding is suitable for welding dissimilar metals. Using the 4 KW high power CO_2 laser, CAT scientists have successfully cladded an even harder material on the blades. Similarly, a technique was developed to improve ceramic coating to turbine blades by laser glazing. In the area of surface modification of materials by high power laser, research and development work is being carried out at Defence Metallurgical Research Laboratory (DMRL). Using a 5kW CO_2 laser, a variety of processes such as hardening, alloying and melting of steels, Ti alloys, Al alloys and ceramics are being developed to prevent from erosion and corrosion. In IITM grinding wheels of SiC/Al_2O_3 have been dressed using Nd:YAG laser radiation. In BARC a variety of special problems of nuclear reactor technology are being handled by laser materials processing. Work on surface hardness enhancement of aluminum alloys and on erosion of polymers has been initiated in IITK.

VIII. RECOMMENDATIONS

The work on laser metrological instruments, laser spectroscopy instruments for trace analysis, mineral exploration, forensic science, pollution monitoring, medical diagnosis etc. should be given priority. The development of micro channel plate, diamond turning lethe for optical components, production technology of holographic gratings should be encouraged. The technology of holographic element including gratings, computer-generated holograms and optical information processing should be made available to institutions. Laboratory and institution should organize workshop and research training program every year on laser technology, holography & coherent optics, laser material processing, laser in industry, laser crystals, engineering optics, fibre optics communication, laser spectroscopy etc. to encourage interaction among working scientists. Regular programmes to train technicians should be taken up. Future requirement of laser specialist in R&D institutions, industries and hospitals need special attention. Laser physics and technology is already being taught in several academic institutions. This should be augmented by providing more laboratory facilities to institutions. The establishment of national facility for growing laser, nonlinear optical and optical crystals/ materials is recommended. Encouragement to multi institutional, multidisciplinary programmes with time bound target for biomedicine, laser materials processing and optical computing are required.

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