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Overview of Laser Technology at Los Alamos National Laboratory

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Los Alamos National Laboratory has had a long history of involvement in the laser sciences and has been recognized both for its large laser programs and smaller scale developments in laser technology and applications.

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Los Alamos National Laboratory has had a long history of involvement in the laser sciences and has been recognized both for its large laser programs and smaller scale developments in laser technology and applications. The first significant program was with the Rover nuclear-based rocket propulsion system in 1968 to study laser initiated fusion. From here applications spread to programs in laser isotope separation and development of large lasers for fusion. These programs established the technological human resource base of highly trained laser physicists, engineers, and chemists that remain at the Laboratory today.

Almost every technical division at Los Alamos now has some laser capability ranging from laser development, applications, studies on nonlinear processes, modeling and materials processing. During the past six years over eight R&D-100 Awards have been received by Los Alamos for development of laser-based techniques and instrumentation. Outstanding examples of technology developed include LIDAR applications to environmental monitoring, single molecule detection using fluorescence spectroscopy, a laser-based high kinetic energy source of oxygen atoms produced by a laser-sustained plasma, laser-induced breakdown spectroscopy (LIBS) for compositional analysis, thin film high temperature superconductor deposition, multi-station laser welding, and direct metal deposition and build-up of components by fusing powder particles with a laser beam.

OVERVIEW OF LASER TECHNOLOGY AT LOS ALAMOS NATIONAL LABORATORY

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INTRODUCTION

In 1943, in the midst of World War II, Los Alamos National Laboratory was established to develop the world's first atomic weapon. By 1945 with this goal successfully achieved, there was talk of disbanding the group of highly trained men and women that been assembled for so short a period to do what had never in history been accomplished. Through the action of several far-sighted government officials including General Groves, the Army head of the atom bomb project, the Los Alamos National Laboratory was established as a national resource which continues to this day to serve the National Defense. Increasingly, however, due to the end of the cold war and a shift in national priorities, Los Alamos and other National Laboratories are being looked to as a resource for new ideas and new technologies that can increase the national competitiveness in light of foreign competition. Laser technology and applications is an important part of this competitive base.

Los Alamos National Laboratory is located in the Jemez mountains about 35 miles northwest of Santa Fe and ninety miles northwest of Albuquerque. The Laboratory employs about 8,000 technical and administrative staff in addition to about 6,000 support personnel. The annual budget is close to 1 billion dollars. Funding comes from a variety of sources including the Department of Energy, Department of Defense, other government agencies, and the private sector. Funding from the private sector has increased substantially during the last four years as the mission of the Laboratory changes from weapons to other national needs. The Laboratory is operated by the University of California for the Department of Energy.

The Laboratory has had a long history of involvement in the laser sciences and has been recognized both for its large laser programs and smaller scale developments in laser technology and applications. Certainly, not all laser programs can be described in the limited space allotted here. The purpose, therefore, of this discussion is to present an overview of laser technology at Los Alamos and to outline the wide range of laser capabilities within the Laboratory.

HISTORICAL BACKGROUND OF LASERS AT LOS ALAMOS

The start of significant laser technology at Los Alamos can be traced back to 1968 and the Rover project the goal of which was to develop a nuclear-based rocket propulsion system. In principle, such a system could produce high thrust but the question remained as to the ignition system for the small thermonuclear "charges" that would propel the rocket. The suggestion was that high-energy CO₂ laser pulses if properly focused on a small pellet of thermonuclear fuel could produce an implosion resulting in the fusion. In 1969, the Weapons Testing Division at Los Alamos authorized a small scale effort to study this possibilities. Three scenarios were envisioned: development of a one-joule picosecond glass laser, study of CO₂ lasers that could be scaled to high energy, and development of chemical lasers. At about the same time, programs to study laser-initiated fusion were started at other laboratories in the US and abroad. The Los Alamos system was unique in stressing the development of large CO₂ lasers. In 1972, the Director of Los Alamos, realizing the importance of pushing the Laboratory's development activities into new areas, authorized an expanded laser program. As a result, a new Laser Division was established which was chartered to continue investigations into the possibilities of laser fusion as well as investigate new uses of lasers.

One promising "spin-off" application was laser isotope separation, especially for uranium although many other applications of laser isotope separation were under study, such as the purification of silane needed for semiconductor manufacture. The uranium separation technique was based on the photolytic dissociation of uranium hexafluoride vapor cooled by a supersonic expansion. Cooling was required to achieved the desired isotopic selectivity upon irradiation by a combination of infrared and ultraviolet lasers. This method seemed promising and as a result, the program expanded at such a rate that a separate Applied Photochemistry Division was split off from the original Laser Division. Both programs continued but by 1983, funding levels had stabilized and even decreased for some programs. It was eventually decided by Washington to select the atomic vapor process, under development at Livermore, over the Los Alamos molecular-based process and work on uranium ceased at Los Alamos.

Following the demise of the uranium project, work began on applying the same separation process to plutonium, another strategic material. In many ways, plutonium was a more efficient system for the molecular isotope separation process and should result in more efficient and cost effective operation. By the late 1980's, however, with the need for plutonium and uranium decreasing (there was actually an abundance of reactor grade uranium on the world market), the plutonium project was halted.

Throughout this time, work continued on development of large lasers for fusion. The Los Alamos system evolved into the Antares project. Originally specified at 100 kilojoules/pulse, budget cuts and other constraints resulted in a scaled back system producing 40 kilojoules. During this development phase, with much additional research being carried out at Los Alamos and across the world on the physics of laser fusion, it was discovered that megajoules, not kilojoules, of laser energy would be required to produce a thermonuclear reaction. The long wavelength of the CO₂ laser and even glass lasers (being developed at Livermore) produced undesirably hot electrons inhibiting attainment of the fusion process. Shorter wavelengths seemed more promising. Unfortunately, unlike the glass laser, the CO₂ laser does not easily lend

itself to the production of shorter wavelengths via frequency conversion processes. As a result the Antares project was halted following the checkout phase and work was diverted to development of large krypton-fluoride excimer lasers.

As result of these programs a highly trained group of laser physicists, engineers, and chemists was assembled many of which remain at the Laboratory today. Although the large laser programs are gone, in its place are a large number of smaller programs which are applying this expertise to a wide range of problems never imagined back in 1969 at the inception of the first large laser program at Los Alamos.

LASERS AT LOS ALAMOS TODAY

Although two divisions were originally chartered at Los Alamos to develop laser technology, today laser research and applications are spread throughout the Laboratory. Almost every technical Division has some laser capabilities. These capabilities range from laser development, applications, studies on nonlinear processes, and modeling. Some of the larger projects will be described here.

Optical Diagnostics and Sensors

Development of laser-based optical diagnostics can be traced back to the late 1970's with application of established techniques to a variety of problems. During the past six years over eight R&D-100 Awards have been received by Los Alamos for development of laser-based techniques and instrumentation.

Raman spectroscopies:

- combustion diagnostics (monitoring the effluent of coal gasification systems at Morgentown, WV)
- explosives research (monitoring vibrational liquids subjected to high pressures)
- detection of hydrogen isotopes in fusion reactor mixes

Fluorescence spectroscopy:

- chemical agent detection on the battlefield
- combustion diagnostics
- H-atom florescence as an aiming aid in neutral particle beam applications
- LIDAR for remote sensing of the atmosphere
- single molecule detection

Laser-induced breakdown spectroscopy:

- development of real-time monitors for toxic airborne particles
- lead in paint detectors
- detectors for metal contaminants in soils
- scrap metal sorting

Absorption spectroscopy:

- long pathlength white cells to measure weak absorptions in gases
- development of sensitive interferometer-based detection schemes

- development of thermo-optic-based, field-deployable methods for chemical agent detection

Unique laser sources --- Over the years the Laboratory has established some unique laser capabilities. These include:

- three femtosecond laser spectroscopy laboratories
- Los Alamos Bright Source-II which uses amplified pulses from a XeCl excimer laser to generate 250 femtosecond pulses of 250 mJ having focused power densities of 10^{20} W/cm² on target
- state of the art industrial-type lasers including pulsed and cw 1.2 and 2 kilowatt fiber optic delivered Nd:YAG wavelengths for welding and cutting
- a unique, short pulse, tunable infrared laser system developed specifically to study fast events in biological systems

Some outstanding examples of particular laser-based programs are listed below.

LIDAR Applications to Environmental Monitoring --- Los Alamos has been involved in applications of LIDAR since the 1970s. The LIDAR Team, composed of at least 20 personnel, currently has several systems at its disposal for environmental studies. These include: a Nd:YAG laser-based airborne elastic scattering system operating at 1064 nm which is mounted on a standard aircraft pallet; a Nd:YAG laser-based elastic scattering system mounted in a truck for measuring atmospheric aerosols; an excimer-based Raman and fluorescence-scattering system mounted in a truck to measure absolute water-vapor concentrations, biologic and organic materials; and a miniaturized elastic scattering LIDAR system that fits in a large suitcase. These systems have and are being applied to a wide range of monitoring problems including the Department of Energy sponsored Mexico City Air Quality Initiative and the Water Evapotranspiration Over Complex Terrain and Canopies study. Work is also continuing to adapt the LIDAR systems to unique platforms such as satellites and helicopters.

Single Molecule Detection --- Using techniques of fluorescence spectroscopy, it is possible to detect single molecules in solution. The method is applicable to fluorescent molecules or any molecule that can be tagged with a fluorescent dye. Because fluorescing molecules, for the most part, emit photons at wavelengths red-shifted from the exciting laser wavelength, fluorescence measurements can generally be done background free, achieving single molecule detection. The solution containing the molecule of interest at low concentration is flowed through a small volume using a flow cytometer. Because of the picoliter volume of the region probed by the laser beam and the low concentration of molecules, statistically, only a single molecule will be in the probe volume at one time. Irradiation of the probe volume by an intense laser beam induces fluorescence in the molecule resulting in a photon burst as the molecule traverses the laser beam. Typically 10-20 photons are emitted by the molecule due to cycling of the molecule between the ground and excited states. Many applications of the technique are being pursued at Los Alamos including its use for sequencing DNA in the National Human Genome Project. The method is diagrammed in Fig. 1. In this technique, a single strand of DNA is supported by a bead and each base is labelled

with a unique fluorescent dye molecule. Then an enzyme cleaves one nucleotide at a time from the DNA strand. The cleaved nucleotide is then carried in flowing water to the flow cytometer where the color of the fluorescent dye is detected. The color indicates the base type.

High-kinetic energy oxygen atom source --- A laser-based high kinetic energy source of oxygen atoms has been developed at Los Alamos. The source is based on a continuous laser-sustained plasma formed at atmospheric pressures or above in the throat of a nozzle (Fig. 2). The plasma is sustained by a continuous CO₂ laser beam of up to 1.5 kilowatts energy. Gases passing through the nozzle enter a region of low pressure to form an atomic beam of highly energetic atoms (5 eV or higher). The technique was originally developed to study the etching of spacecraft surfaces in low earth orbit due to free oxygen atoms. Recently it has also been used to beneficially oxidize high temperature superconductors and conventional electronic materials. Of particular interest is the processing of GaAs with fast atomic oxygen to form chemically stable GaAsO₄.

Laser-induced breakdown spectroscopy --- For the past 15 years, Los Alamos has been involved in developing laser spark spectroscopy for application to real-world problems. This method, termed laser-induced breakdown spectroscopy (LIBS) uses a powerful focused laser pulse to generate a hot microplasma in gases, liquids, and on solid surfaces. The technique has several advantages over conventional analytical techniques including minimal sample preparation, remote analysis capabilities, compact instrumentation, and simplicity. Several instruments have been developed based on LIBS. These include a mobile real-time toxic airborne particle detector, a scrap metal sorter, a lead in paint monitor, and an analyzer for metal contaminants in soils. Work is continuing in several areas.

Materials Processing

Superconductor fabrication --- One area of intense research world-wide over the past eight years has been the development of high temperature superconductors. The ability to make reliable superconductors that can carry high currents at liquid nitrogen temperatures or above will have dramatic economic impact. At Los Alamos a number of superconductor fabrication techniques are being pursued. One successful technology is laser ablation of bulk superconducting material to produce a thin film superconductor. A diagram of the method is shown in Fig. 3. Excimer laser pulses are focused on the bulk material located in an atmosphere at reduced pressure. The ablated material is ejected from the surface and impacts an adjacent substrate. Upon repeated ablation, a relatively thick layer can be built up. Los Alamos has been a leader in development of this technique and to date has achieved the thickest films with excellent current carrying capacities.

Laser welding --- Nd-YAG laser welding has been developed and used extensively at Los Alamos to weld precision assemblies and components. Laser welding, as is electron beam welding, is a high energy density process used to make narrow joints

with minimized heat input compared to other welding processes such as gas-tungsten arc welding. Nd-YAG laser beams (commercially available up to 2.8kw) delivered through fiber optics provide a flexible welding source that are easily switched to several work stations. At these stations the part and laser beam relative motion are controlled by 3 to 5 axis systems that operate in air or inert gas to control oxygen pick-up in the weld fusion zone. Passage of the beam into environmental containment chambers through a quartz or glass window eliminates the need to place any part of the laser in the chamber. Toxic or radioactive materials can be processed in these controlled environments without worker exposure or contamination hazards. Figure 4 shows a typical system that uses a 1kw Nd-YAG laser switched to 3 different glove boxes. Inside is a precision weld fixture and weld chucks that hold a part to be joined. The laser head is attached to a vertical motion axis, the weld fixture rotates the part and can be moved in the "XY" horizontal plane directions. The welding process can be videotaped with annotated angular position recorded with time. Other welding diagnostics such as plume intensity, plume spectroscopy or laser parameters are also recorded into a computer database.

Direct metal deposition---Los Alamos is in the process of developing a rapid prototyping process called Directed Light Fabrication (DLF) to build up metal parts by fusing metal powder particles in the focal zone of a laser. Motion and process commands are generated that control the laser and motion system to deposit a planar layer at a time of the desired part from a solid three dimensional computer model. Multiple layers build-up and result in a near-net shape, fully dense metal part that can be used in structural applications. This processing by-passes traditional thermomechanical processing involving multiple steps and expensive capital equipment used to make metal parts. Figure 5 shows the laser head above a hollow I-beam part that has been built of 316 stainless steel. Loose powders at the base can be reused or recycled to the powder hopper.

References:

Much of the information for this paper has comes through direct discussions with personnel involved in the areas described. While it is not possible to acknowledge them all here, we wish to thank them for their assistance. Some references specifically cited in this paper are listed below.

- "Chemical and Laser Sciences Division Annual Report 1991" compiled by the communications group of CLS-Division. Los Alamos Unclassified Report Number LA-12331-PR.
- "Los Alamos Science", Number 20, 1992. Published by Los Alamos National Laboratory, Los Alamos, NM.
- "Los Alamos Science", Number 7, 1983. Published by Los Alamos National Laboratory, Los Alamos, NM.

Fig. 1. Method of sequencing DNA using methods of single molecule detection.

Fig. 2. Schematic diagram of high kinetic energy oxygen atom source.

Fig. 3. Bulk superconducting material is laser-ablated onto a substrate to fabricate superconducting thin films.

Figure 4: (Left) Nd-YAG laser welding work station. (Right) The laser beam passes through a window inside the flexible seal permitting fiber optic and laser equipment to remain outside the glove box. The beam is switched to two other similar stations. A precision weld is made on a ring component.

Figure 5: A hollow I-Beam is made by fusing 316ss powder a layer at a time in the focal zone of the laser beam. The beam and powder are delivered through the nozzle shown at the top. The part is fully dense and near net shape.

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