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Abstract

The Nova laser facility at Lawrence Livermore National Laboratory performs experiments in pursuit of laser fusion and explores the physics of high-energy-density plasmas. When the laser light is focused onto a target, a number of mechanisms can reflect or scatter the light back through the focus lens. The Backscatter Spectroscopy System (BSS) is a diagnostic that measures the properties of this reflected or scattered light. Just before the main focus lens on each of the ten Nova arms is a KDP crystal array for converting the 1 μm laser light to shorter harmonic wavelengths. This array rotates ~10° about the beam axis to select the 351 nm wavelength where most of the experiments are run. The BSS consists of a fused silica plate inserted into one of the beam lines before the KDP array. The reflector plate is shaped like one of the array elements and is aligned with it to minimize the effects of diffraction. The plate is mounted in a mechanism to allow alignment as well as rotation with the KDP array when the converted wavelength is changed. The plate is mounted 10° off normal so that light can be reflected out of the beam tube. Roughly 4 percent of target-reflected light reflects off this plate and is transported to an optics table where it is analyzed. To transport the light to the optics table, an alignment insensitive relay lens system is used with a vacuum cell and turning mirrors. The instrumentation on the table includes a 0.5 meter spectrometer with an optical streak camera for time-resolved spectral information, a small photodiode array for intensity data, and a film pack for beam structure and system alignment information.

Introduction

The Nova Laser Facility [1] is used for laser fusion research and for related experiments with high-energy-density matter. The laser includes 10 arms and can now irradiate targets with up to 20 kJ of 0.35 μm (3ω) light in 1 ns pulses. When the laser finally operates at full energy, it will produce 40 to 70 kJ of 3ω light in 1 to 2.5 ns pulses. This energy can be focused to a spot diameter that is a small fraction of a millimeter, producing laser intensities well in excess of 10^{15} W/cm^2. Furthermore, Nova can irradiate targets with 0.53 μm (2ω) light, if desired, and is capable of irradiating targets with 1.05 μm (1ω) or 0.26 μm (4ω) light as well. In addition, the laser can produce a wide variety of pulse shapes, which allows it to undertake sophisticated and difficult target experiments.

For target experiments, the light from each arm is focused onto the target by an f/4, 80 cm diameter fused silica lens. Various instruments measure the visible (and UV) light, x-rays, and neutrons emitted from the target. Although the emission of neutrons or x-rays from a target surface is generally isotropic or lambertian, the emission of scattered light is very directional. In many cases, the largest scattered light intensity is directed back through the lens that focuses light onto the target. Thus, to understand the properties of the light scattered by the target and to infer the mechanisms that are responsible, measurements of the light scattered back through the lens are important. This paper describes the design of the Backscatter Spectroscopy System (BSS), which allows us to measure the properties of the light reflected back through one of the lenses.

System Design Requirements

The BSS was designed to reflect target light out of one of the main beam tubes and onto an optics table for analysis. To achieve this goal, there were a number of design criteria that we considered during project development.

The system was to be easily aligned to the center of the 10 Beam chamber and have long-term stability. That is, we did not want to have a system that required realignment on a regular basis. The optics for relaying the reflected light had to operate between 230 nm and 702 nm. The system could not be sensitive to any particular plane of polarization and had to transmit both s and p planes equally.

The light piping as well as the optics table had to be light tight since the expected signal level was very low. Otherwise, room light leaking into our system could affect the data. The instrumentation on the optics table was to consist of a 0.5 meter spectrometer, a photodiode array, a 4 x 5 inch film pack, and an optical streak camera.

The system was also to be capable of ±20 percent accuracy in determining amount of target reflected light.

Light Sampling Methods

One way to sample light reflected from the target down a beam tube is to make the last turning mirror before the chamber partially transmitting. The entire beam can be sampled this way, giving the most representative data on reflected light. The Nova diagnostics system was not designed to include this type of sampling, and to retrofit one of the 74 cm diameter laser beam lines would be an expensive option. To use the full beam method, the last turning mirror would have to transmit light from roughly 200 nm to 1000 nm, without distorting the wavefront. In addition, the 110 cm diameter mirrors would still have to handle up to 6 J/cm^2 at 1 micron, which would further complicate the situation.

To make this diagnostic less expensive while still giving representative data, we opted to sample a portion of one of the beams using a beamsplitter technique. The method entails inserting a partially reflecting optic into the main laser beam after the last turning mirror, and reflecting the light from the target out of the beam tube (see Fig. 1). Out of the 10 beams entering the Nova target chamber, we chose one of the two horizontal beam tubes for ease of sampling and installation.

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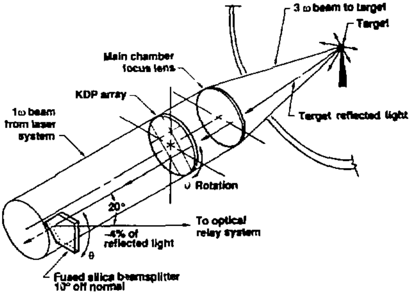

Figure 1. BSS light sampling method.

Beamsplitter Considerations

There are a number of problems that must be addressed to use the beamsplitter method of beam sampling. Before the laser beam enters the target chamber, it passes through a KDP crystal array for wavelength conversion and then through the main focus lens. This means that light reflected from a target is recollimated by the focus lens if it is at the incoming converted wavelength. Other wavelengths will be slightly converging or diverging when they reflect off the BSS beamsplitter. To address this problem, we designed an image relay system to transmit the light to the optics table. This system will be discussed in more detail in a subsequent section.

Sticking an off-axis beamsplitter into the beam tube will reflect target light out of the main beam. The laser beam on the way to the chamber will therefore be reduced in intensity in the area of the beamsplitter due to reflective losses. Ideally, the amount of reflected light should be as high as possible to aid signal resolution of the BSS instrumentation, but transmitted light should also be as high as possible to reduce laser beam fluence variation. These requirements are unfortunately mutually exclusive.

As a compromise, the beamsplitter was made out of AR coated, high grade fused silica. This has a higher fluence threshold than borosilicate glass and also yields more similar amounts of Fresnel reflectance over the range of design wavelengths. The beamsplitter was coated on one surface with a sol-gel AR coating that maximizes transmittance at 2 to 3ω. At 1ω, the beamsplitter reflects about 4 percent from the uncoated surface and slightly less from the coated surface. This method of coating reduces the laser beam fluence variation while giving sufficient reflection for the optics table instrumentation. It also reduces the second surface reflection from the beamsplitter which improves time resolution on the streak camera data.

Unfortunately, when the laser beam encounters the sharp edge of the beamsplitter, edge diffraction can cause hot spots and self-focusing in the KDP array and main focus lens. To reduce these problems, the beamsplitter was shaped like one of the triangular elements at the edge of the array. When aligned with the array element, the diffracted light falls in the area of the array frame instead of in the middle of one of the elements. The problems are not eliminated by this method but are located where they can do the least harm.

One other problem caused by the beamsplitter is error in beam focus position due to nonparallel surfaces. If the beamsplitter has some wedge in it, the portion of the main laser beam that passes through it will not focus at the same spatial position as the rest of the beam. Therefore, the beamsplitter was specified to have no more than 1 arc second angular difference between the two surfaces. This translates to a maximum focusing error of 7 microns at the center of the target chamber.

Beamsplitter Holder

To change from 2ω to 3ω light conversion, the KDP array rotates about the beam axis approximately 10°. The BSS beamsplitter was designed to rotate about the center of the beam as well, to reduce the diffraction problems at both rotational positions of the array. This required the development of a large radius, goniometric-type holder for the beamsplitter. The holder was designed to grip the beamsplitter securely and allow a number of motions needed for alignment with the array and with the instrumentation.

A sketch of the holder is seen in Fig. 2. The holder has X, Y, and θ motion capability for aligning the beamsplitter with the appropriate array element. It has α and β tilting capability for final alignment of the system to the target. It also has end of travel Φ adjustment for locating the beamsplitter at the correct rotational positions with the KDP array. The Φ rotation will ultimately be done via an electric motor-driven actuator, although presently the mechanism is held in place at the 3ω position.

The β rotation is also used for setting the angle of incidence of 10°. This angle was chosen to reduce the reflectance difference between the s and p polarization planes and still allow room for reflecting the light out of the beam tube. At this angle, s and p reflections are within 8 percent of each other.

The entire beamsplitter mechanism is surrounded by a telephone booth type of enclosure, which allows a person to enter for ease in adjusting the holder. The booth was built light tight to contain the main laser beam and to improve BSS data.

Image Relay System

Because of space limitations, the optics table had to be located about 8 m from the beamsplitter on a higher elevation platform. Due to the angular difference of light reflecting off the beamsplitter with wavelength, this location required the use of a lens relay system. A 63.5 mm aperture is located as close as possible to the beamsplitter but outside of the main laser beam. A dual lens system relays a 1:1 image of the aperture to the optics table where the light is then analyzed. See Fig. 3 for an illustration. The plano-convex relay lenses are made of uncoated fused silica, with 2175 mm focal length at 632.8 nm.

We considered a number of criteria before designing the lens relay system. The point at which the laser beams focus on the target can vary by a few

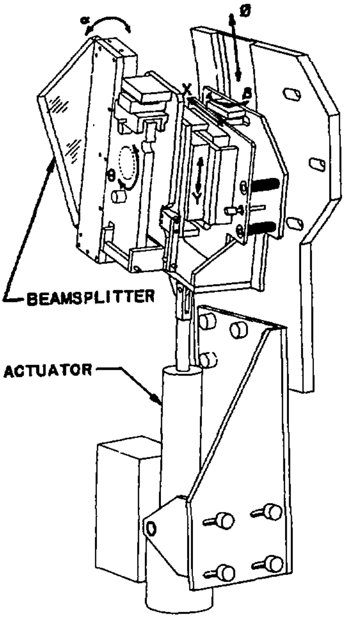

Figure 2. Beamsplitter holder.

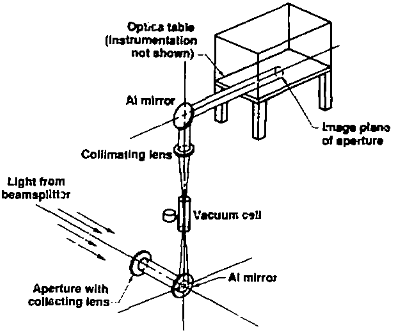

Figure 3. Optical relay system.

millimeters. This means that light reflecting off a target can emanate from a different point in space, depending on the type of shot. Because of this and other expected systematic errors, the relay system was designed to accept reflected light from a 5 mm radius off the target. The larger field of view also aids in system alignment stability.

With the 5 mm possible offset and the angular difference with wavelength at the aperture, the image size on the optics table will vary in size. This is due to the fact that the relay lenses are not achromatic and the possibility that clipping could occur at the second lens. However, the aperture image on the table is 52 mm diameter or larger for all design wavelengths. Therefore, all instrumentation uses 50 mm diameter as the maximum useful light size for data analysis. Although the lenses were designed for 230 nm wavelength and there is a sizable change in index of refraction in fused silica to 702 nm, the 2 m focal length lenses provide reasonably good imaging at any wavelength.

Midway between the lenses, the relayed light passes through a focal point on its way to the image plane. Because of the high power of the Nova laser and amount of target reflection, it is possible to have air breakdown at the focal point. If this were to happen, the fluence data measured on the optics table would not be accurate. For this reason, we designed a vacuum cell with fused silica windows that is positioned at the focal point. The cell is sufficiently long to accommodate focusing from any of the expected wavelengths.

To transport the reflected light to the optics table, two mirrors are used. The mirrors are aluminum with a thin magnesium fluoride overcoat to inhibit oxidation. With this type of mirror, there is a preferential reflection of the s plane of polarization which is undesirable in this diagnostic. To overcome this problem, the mirrors are mounted with the planes of reflection 90° to each other. This way, both s and p polarization planes are reduced proportionally at the optics table.

The mirrors are mounted in off-the-shelf, gimbal-type holders and enclosed in light tight boxes. The lenses are also held in stock adjustable lens holders. All relay paths from the aperture to the optics table are enclosed in light piping. The resulting system is well contained, as desired.

Optics Table Instrumentation

The instrumentation used to analyze the target-reflected light is mounted on an optics table that is fully covered with a blackout enclosure. See Fig. 4 for a detailed layout. The 0.5 m spectrometer with an optical streak camera is used for time-resolved spectral information. A small photodiode array provides information on intensity data about the reflected target light. The optional film pack is intended to give information on beam structure and system alignment.

The light entering the optics table is divided into the various paths by uncoated fused silica beamsplitters. The beamsplitter for the streak camera instruments is a 12° wedge, which separates the two reflections for timing reasons. The image plane of the aperture is approximately at the same location for all instruments.

A 2 mW HeNe laser with beam expander is used to align the instruments to the target. A removable pellicle is installed on a kinematic mount whenever

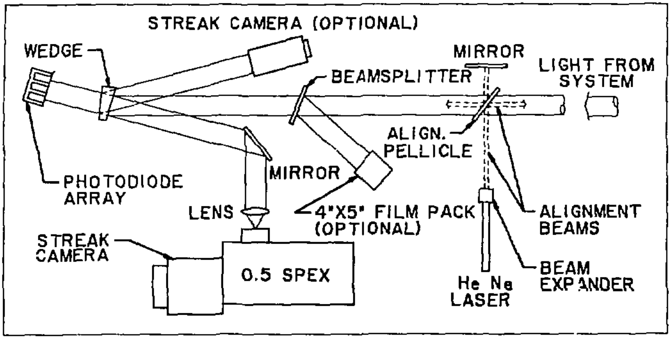

Figure 4. Optics table layout.

alignment is done. More details of this will be given in the next section. The beam expander is included to reduce the laser spot size at the target.

Diagnostic Alignment

The beamsplitter holder, mirrors, light piping, and optics table were installed in their predetermined locations. Then a plexiglass model of the beamsplitter was mounted in its holder, approximately 10° off normal. Using a long range television system that looks down a beam tube to the KDP array, the beamsplitter model was aligned with the appropriate array element. The alignment laser beam was centered in the light piping using cross hairs at the optics, and then directed onto an "X" inscribed on the plastic model.

For final alignment, the plastic model was removed and the actual beamsplitter was installed in its place. The holder was adjusted to reflect the laser beam onto a reticle placed at the target position. With the pellicle installed on the optics table, the instruments were then aligned to the laser beam as well. After we were sure the system was working as expected, the access booth around the beamsplitter holder was installed.

Data and Operation

With the BSS system in operation, we have conducted numerous experiments with 0.35 μm light onto plasma targets of various materials. Calorimeters which measure the total light backscattered into the lens have shown that at the highest intensities (1×10^{15} W/cm^2), approximately 1 percent of the total incident energy is backscattered. This was independently measured by the photodiodes on the BSS table which have the advantage of being separately calibrated and of having a well characterized spectral response.

A large amount of data was obtained using the 0.5 m spectrometer in conjunction with an optical streak camera. The spectrometer provides a wavelength resolution of ∿ 0.1 Å over a 200 Å range, while the streak camera has a time resolution of ∿ 50 ps. Since small wavelength shifts (< 10 Å) were expected and laser pulses as short as 1 ns were used, the temporal and spectral resolution was necessary to observe the desired features.

The targets generally used were thin enough to burn through during the laser pulse and were either plastic or gold. The target material determines the properties (size and electron temperature) of the plasma which is formed by the laser. The plastic targets were interesting because they continued to show a significant amount of backscattered light after the target burned through. Typical streaked spectrometer data from a plastic target is shown in Fig. 5.

Figure 5. Typical streaked spectrometer data.

Long-term stability of the BSS alignment has been excellent. After the initial setup, alignment was monitored periodically with little adjustment required. Despite construction work around the beam tube, including the enclosure around the beam splitter holder, system alignment did not change. In over a year of operation, the BSS system has proven it meets its design criteria amazingly well.

References

[1] E. M. Campbell, J. T. Hunt, E. S. Bliss, D. R. Speck, R. P. Drake, Rev. Sci. Instr. 57, 2101 (1986).

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