Full-aperture backscatter measurements on the National Ignition Facility

D. H. Froula,[a] D. Bower, M. Chrisp, S. Grace, J. H. Kamperschroer, T. M. Kelleher, R. K. Kirkwood, B. MacGowan, T. McCarville, N. Sewall, F. Y. Shimamoto, S. J. Shiromizu, B. Young, and S. H. Glenzer

Lawrence Livermore National Laboratory, University of California, P.O. Box 808, Livermore, California 94551

(Presented on 21 April 2004; published 13 October 2004)

The National Ignition Facility's full-aperture backscatter station (FABS) is described. The FABS uses five independent diagnostics on each of the four laser beams in the initial National Ignition Facility quad to measure the energy, power, spectrum, and near-field amplitude modulations of the stimulated Brillouin and stimulated Raman backscattered light. In initial tests CO_2 and C_5H_{12} gas-filled targets were used to create various laser–plasma interaction conditions which have shown the capability of producing ignition size laser plasmas with reflectivites on the order of 10%. Results are presented for tests in which 16 kJ on target produced between 0.3 and 2.5 kJ of backscattered light. © *2004 American Institute of Physics.* [DOI: 10.1063/1.1789592]

I. INTRODUCTION

The National Ignition Facility (NIF) will employ several high intensity laser beams propagating through large-scale-length plasmas creating high energy density conditions suitable for inertial confinement fusion (ICF) implosions. Ignition designs are sensitive to the strict energy balance between the laser beams and require efficient energy coupling to the target.[1] It is therefore important to temporally diagnose and control the energy backscattered from ignition targets. It is also important to understand backward propagating light in the NIF laser system as a potential source of system damage.[2] The first full-aperture backscatter station (FABS) on NIF uses calorimeters, streaked spectrometers, fast photodiodes, near-field cameras, and time integrated spectrometers to independently measure the characteristics of both the stimulated Brillouin backscattered (SBS) and stimulated Raman backscattered (SRS) light for each of four incident laser beams.

A. General characteristics of NIF backscattered light

The FABS has been designed for a wide parameter space defined by the variety of expected targets and laser conditions that will be employed by the NIF. The laser has been designed to operate at an energy of 1.8 MJ using 192 laser beams. The 192 beams are split into 48 quads (four beams) which can deliver up to 36 kJ of 3ω ($\lambda_0=351$ nm) laser light to the target chamber center. To date, a single quad and one FABS have been activated.

The FABS is designed to measure the light scattered from the target back through the final optics assembly (FOA). The primary mechanism for the backscattered light is stimulated scattering instabilities; a result of the resonant coupling of an intense laser pulse, a scattered light wave, and an ion-acoustic wave (SBS) or an electron plasma wave (SRS).[3] In general, the resulting scattered light wave propagates directly back along the incident laser path. In the case of SBS, the wavelength of the light is primarily a function of the electron temperature and the macroscopic plasma motion and is only slightly redshifted from the lasers fundamental wavelength, $(\lambda_{SBS}-\lambda_0)<4$ nm. On the other hand, the wavelength of the SRS light is dependent on the density at which the scattering process takes place and is typically a broad 60 nm peak centered between $\lambda_{SRS}=450-600$ nm. Typical ICF experiments measure SBS and SRS reflectivities as high as 30% and below 1% depending on the details of the target and the conditions of the laser beams.

B. General FABS system design requirements

The FABS has been designed to measure both SBS and SRS backscattered energies between 5 J and 2 kJ to within an uncertainty of 5%. This requirement has led to the development of a novel calibration and measurement technique that uses time integrated spectrometers. The discussion of this system is presented in detail in Ref. 4. The SBS spectra is to be measured with a resolution of 0.5 nm within a wavelength range of 348–354 nm while the SRS spectra is to have a range of 400–700 nm with a 2.5 nm resolution. Both the spectral measurements are designed to have a temporal resolution of 50 ps over a 10, 30, or 50 ns time window. Spatial amplitude modulations propagating through the FOA are to be resolved to 2 mm.

II. OPTICAL SETUP

The FABS collects light that has been backscattered into the four 40 cm×40 cm square focusing lenses. The backscattered light is collimated by the lenses while passing through the FOA (Fig. 1). Each FOA consists of a debris shield, focusing lens, a doubler crystal, a tripler crystal, and a vacuum window. The FOA transmits about 85% of the backscattered light. About 60% of the backscattered light is then transmitted through the last turning mirror in the NIF

[a]Electronic mail: froula1@llnl.gov

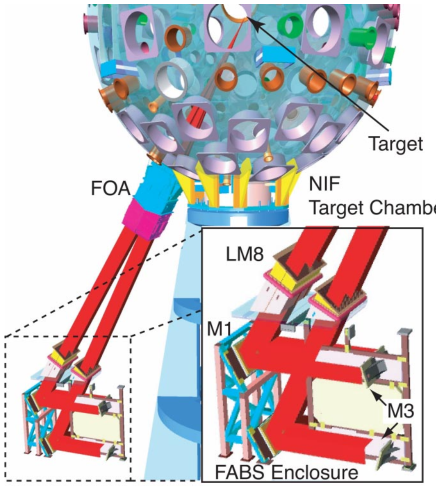

FIG. 1. (Color online) The light backscattered from target chamber center into the FOA is collected and transported through LM8 to the FABS enclosure.

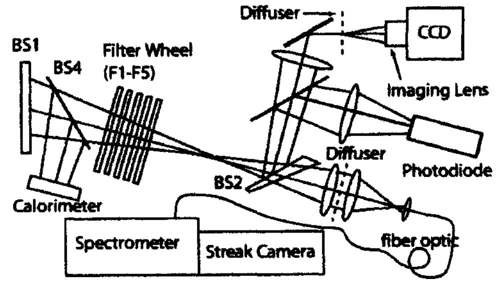

FIG. 2. The optical layout for one side (SBS or SRS) of a single beam is shown.

laser chain (LM8) into the FABS enclosure. The full aperture beams are then reflected off uncoated glass (M1) at an angle of 32° to the normal reducing the backscattered energy to about 2%. The light is focused by a full aperture aluminum coated spherical mirror (M3) through a beam splitter (BS1) that discriminates between SBS and SRS light. BS1 is coated to reflect nearly 100% of the light below 400 nm (SBS) while transmitting light of higher wavelength (SRS). A full-aperture absorbing glass filter can be inserted between M1 and M3 to reduce the fluence on M3 and BS1 during high energy backscatter shots.

Figure 2 shows the optical setup for the SBS light reflected off BS1. The SRS light transmitted through BS1 follows a similar path to the one shown here. Light is imaged onto the SBS calorimeter after reflecting off an uncoated glass beam splitter (BS4). A large area filter wheel selects the down stream energy density using up to five absorbing glass neutral density filters. In theory, the filtering on all individual diagnostics can be set so that each sensitivity is equivalent, therefore, the filter wheel is the only filtering that is changed between shots.

Three reflections from the FOA propagate into the FABS: the back surface of the doubler crystal (2ω light), front surface of the tripler crystal (2ω light), and the back surface of the tripler crystal (3ω light and unconverted 2ω light). The 2ω light reflected off of the doubler crystal counter propagates colinear with the incident laser and is optically filtered out by BS1 in the case of the SBS diagnostics, and temporally gated out in the case of the SRS diagnostics. The reflections from the tripler crystal are spatially filtered at the focus of M3; these reflections propagate slightly off axis due to a slight angle in the tripler crystal.

The SBS near-field light is imaged onto a diffuser using a combination of the focusing mirror (M3) and a plano-cylindrical lens. A standard camera lens images the diffuser onto a 768 pixel$\times$512 pixel charge coupled device camera.

The SBS and SRS spectra are recorded using streak cameras coupled to spectrometers. The light is coupled to the spectrometers using an 8 m 100 μm fiber. A diffuser plate is used to remove spatial intensity modulations allowing reliable coupling into the fiber. A simple optical system relays the light transmitted through the diffuser plate on to the end of the fiber optic.

TABLE I. Details for each diagnostic are given. A summary of the measured system performance is presented: time resolution (Δt), wavelength range (λ), wavelength resolution ($\Delta\lambda$), spatial resolution (Δx). The energy range for each system is determined by the diagnostic, total optical transmission, neutral density filters, and the filter wheel.

Diagnostic details	Manufacturer	Model No.	Energy	Δt	Δx	λ	$\Delta\lambda$
Calorimetry system performance			1 J–2.5 kJ	integrated	integrated	pass<400 nm	
SBS/SRS Cal's	Coherent	J50LP-2A	3 μJ–7 mJ	integrated	integrated		
SBS photodiode system performance			10 mJ–2.5 kJ	200 ps	integrated	pass<400 nm	
SBS diodes	Hamamatsu	R1328U-51	2 nJ–0.1 μJ	60 ps	integrated	300–1100 nm	
Digital oscilliscope	Tektronics	TDS-694		3 GHz			
SBS near-field system performance			1 J–2.5 kJ	integrated	2 mm[b]	pass<400 nm	
SBS CCD	Finger Lakes	KAF-0401E		integrated	9 μm pxls		
SBS streak-spectrometry system performance			10 J–2.5 kJ	100 ps[b]	integrated	6.5 nm	0.13 nm
Streak camera	Hamamatsu	C7700-S20		1%[a]	integrated	300–850 nm	0.0065 nm/pxl
0.5–M spectrometer	Acton	SP-500i		95 ps	integrated	250–500 nm	1.7 nm/mm
SRS streak-spectrometry system performance			10 J–2.5 kJ	50 ps[b]	integrated	375 nm	4.4 nm
Streak camera	Hamamatsu	C7700-S1		1%[a]	integrated	400–1200 nm	0.37
0.15 M spectrometer	Acton	SP-150		10 ps	integrated	400–700 nm	15 nm/mm

[a]The resolution is a multiple of the total time windows: 5, 10, 30, and 50 ns.
[b]Has not been experimentally verified.

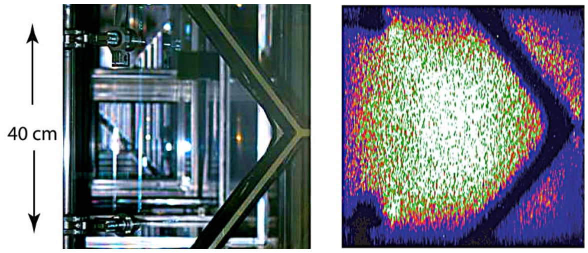

FIG. 3. (Color online) (Left) SBS (10%) and (right) SRS (<1%) spectral results obtained using the streaked diagnostic.

III. DIAGNOSTIC DETAILS

Table I summarizes the details for each diagnostic and the overall systems performance. Each system has been designed to meet the specific design requirements discussed in Sec. I B. The calorimeters are used to measure the total SBS and SRS energy. The calorimeters are prior to the beam blocks and do not discriminate between light backscattered from the target and the ~1% reflections from the FOA. It is therefore necessary to subtract a precharacterized background. The calorimeters measure the backscattered energy to 20%; this uncertainty is a combination of the optical transmission, subtraction of the FOA reflections, and electrical signal noise. Due to the damage threshold of the calorimeters ($250\ \mathrm{mJ/cm^2}$), it is necessary to use neutral density filters for backscattered energies above 30 J. The photodiodes are used to time resolve the backscattered light and confirm that all reflections into the near-field camera are blocked. The streak-spectrometer systems independently measure the SBS and SRS spectral behavior as a function of time.

IV. INITIAL BACKSCATTER RESULTS

The FABS was activated in an incremental process; the laser energy was increased slowly to 3.8 kJ. Low energy shots employed gold foil targets which produced low levels of backscatter and that allowed instruments to be timed and reflections into the FABS enclosure discriminated and properly blocked. CO_2 gas-filled targets that produce high levels of SBS and C_5H_{12} gas-filled targets that produce high levels of SRS were used to activate respective diagnostics. Gas-filled targets between 2 and 7 mm length allowed the backscattered energy to be scaled from 300 J to 2 kJ. The targets were heated on one side by overlapping the 500 μm focal spots of the four beams with a maximum total intensity of $2\times10^{15}\ \mathrm{W\ cm^{-2}}$. The targets were filled with 1 atm of gas producing homogeneously heated plasmas with densities of $n_e=6\times10^{20}\ \mathrm{cm^{-3}}$ and temperatures of $T_e=2$ keV.[5]

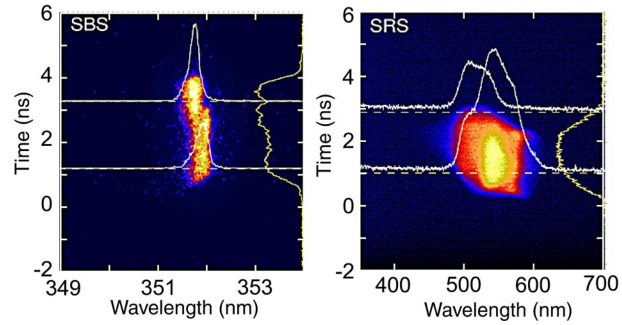

FIG. 4. (Color online) (Left) A picture of the FOA for a single beam (B318) as viewed by the FABS shows the LM8 mirror supports that block about 15% of the backscattered light. (Right) An SBS near-field image of the FOA shows the backscattered light peaked in the center of the lens with a modulation less than 3:1.

Concurrently, the FABS measured the backscatter energy, power, spectrum, and near-field images. The following presents the data for a shot where the laser delivered 3.8 kJ per beam on a 7 mm CO_2 gas-filled target. Figure 3 shows results of the streak camera data for the SBS and SRS systems. The calorimeters measured a total backscatter energy of 1.3 kJ.

Figure 4 shows the SBS near-field image where the mirror structure that holds the last turning mirror (LM8) in the NIF laser chain is clearly evident. During the activation of this diagnostic the SBS amplitude modulations remained less than 3:1. In order to ramp up the backscattered energy, the amplitude modulations in the SBS light were closely monitored to prevent peak fluences above $\sim 2.5\ \mathrm{J\ cm^{-2}}$. During these shots the SBS photodiodes showed no significant light reflected from the crystals indicating that the light measured by the near-field cameras is predominantly from the target chamber center.

ACKNOWLEDGMENT

This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract No. W-7405-ENG-48.

[1] J. D. Lindl, P. A. Amendt, R. L. Berger, S. G. Glendinning, S. H. Glenzer, S. W. Haan, R. L. Kauffman, O. L. Landen, and L. J. Suter, Phys. Plasmas **11**, 339 (2004).
[2] P. E. Young, Phys. Rev. Lett. **73**, 1939 (1994).
[3] W. L. Kruer, *The Physics of Laser Plasma Interactions* (Addison–Wesley, Reading, MA, 1988).
[4] R. K. Kirkwood, T. McCarville, B. Young, M. Schneider, D. H. Froula, D. Bower, F. Holdener, M. Chrisp, B. MacGowan, and S. H. Glenzer, Rev. Sci. Instrum. (Submitted).
[5] S. H. Glenzer *et al.*, *Proceedings of the 3rd International Conference on Inertial Fusion Sciences and Applications*, Monterey, CA, 2004.