The Scattered-Light Time-History Diagnostic Suite at the National Ignition Facility

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Measurements of scattered light are important diagnostics of laser energy coupling and laser–plasma instabilities (LPI's) such as stimulated Brillouin scattering (SBS), stimulated Raman scattering (SRS), or two-plasmon decay (TPD) in inertial confinement fusion (ICF) experiments. At the National Ignition Facility (NIF), scattered-light diagnostics were originally implemented only at limited beam-port (or "quad," collections of four beams) locations, and extrapolation to total scattered light is predicated on assumptions of predominantly backscattered light and symmetry in polar and azimuthal angles, which may not be valid. For polar-direct-drive (PDD) experiments in particular, the existing diagnostics are not adequate to capture the variation in scattered light.

These considerations motivate additional scattered-light measurements between beam ports to infer the total scattered-light distribution. Therefore, the scattered light time-history diagnostic (SLTD) has been developed to measure the time-resolved scattered light in three different wavelength bands—350 to 352 nm (SBS), 430 to 760 nm (SRS), and 695 to 745 nm ($\omega/2$, corresponding to SRS- or TPD-related scattered light at the quarter-critical density)—at 15 locations around the NIF target chamber outside the NIF beam-port envelope.

Figure 1(a) shows the simulated distribution of SBS scattered light in an example PDD implosion, the locations of NIF beam ports, and the locations of the SLTD suite. Figure 1(b) shows a schematic of the instrument. Light enters the SLTD through a set of vacuum and debris windows and is incident on an optical diffuser after being apertured down to a diameter of 5.08 cm. The 250-μm-thick diffuser, which is located around 590 cm from target chamber center, disperses the light forward in a near-Lambertian distribution with a transmission around 0.2. Three optical fibers positioned 20 cm from the diffuser, with a numerical aperture of 0.22 and a 400-μm core diameter, capture the light from the entire surface of the diffuser. The light is contained within a light tube coated black on the interior to minimize multiple reflections.

The light is transported through 2 m of fiber and relayed by a collimator through a set of bandpass filters that differentiate the three channels. The SRS channel is additionally filtered by a flattening filter with a wavelength-dependent transmission (0.1 at 532 nm) that compensates for the wavelength-dependent transmission of the diffuser and sensitivity of the photodiode. Neutral-density (ND) filters are also used to control light fluence on the photodiodes and are individually calibrated. The collimation system was designed so that the projected beam underfills the 10-mm-diam active area of the photodiodes. Filter and collimator transmissions were measured at the appropriate wavelengths and used in the overall photometric calculations.

Hamamatsu R1328U-52 and R1328U-53 fast photodiodes, with 60-ps rise and 90-ps fall times, detect the light over the wavelength bands of interest. Photodiode sensitivity ranges from ~65 mA/W at 351 nm for the SBS channel to ~4 mA/W at 730 nm for the SRS and $\omega/2$ channels and are calibrated individually. Current from the photodiodes is carried by coaxial cables (LMR400 or

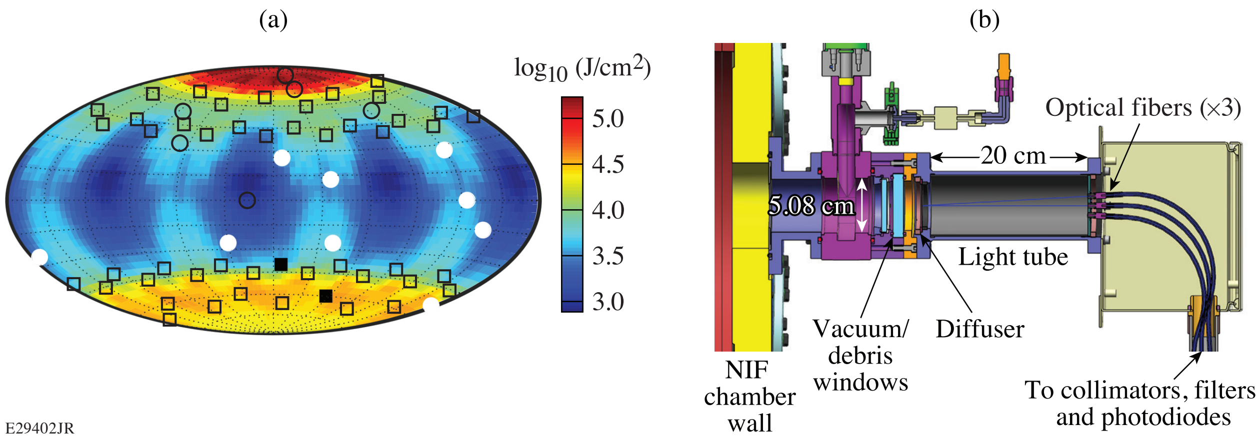

Figure 1
(a) Simulated distribution of SBS scattered light for a PDD experiment overlaid with the NIF laser quad port map (squares). Existing full-aperture backscatter stations are located in two quads (solid black squares), while SLTD's (circles) are being implemented. Out of an eventual 15 SLTD's, a total of six (black circles) have been implemented to date. (b) SLTD optical components include an optical diffuser and optical fibers at the back of a light tube assembly that relay the light to filtered photodiodes.

LMR600) over a distance of 35 to 65 m to a Tektronix MSO58LP 1-GHz digitizer with 12-bit resolution. The digitizer response determines the temporal resolution of the SLTD. The SLTD was designed to achieve measurement accuracy of better than ±15%, temporal resolution of 1.5 ns, and a signal-to-noise ratio >100.

The integrated throughput of the SLTD optical components, including the vacuum and debris windows, diffuser, light tube, and optical fibers, was calibrated at 532 nm using a 200-mJ, 5-ns pulsed source. The throughput was measured to be $5.93 \pm 0.41 \times 10^{-7}$ at 532 nm. Calibration of other SLTD components, including the filters, collimators, and photodiodes, was conducted individually using wavelength-tunable continuous sources between 300 and 800 nm. The total sensitivity of each channel, in terms of volts measured on the oscilloscope per watt incident on SLTD, before accounting for ND filters, is approximately 6.7×10^{-7} V/W (SBS), 6.7×10^{-8} V/W (SRS), and 1.8×10^{-7} V/W ($\omega/2$).

The first six SLTD units, positioned between polar angles of $\theta = 7°$ and 90°, have collected data on a variety of NIF shots. A collection of sample data from the unit at $\theta = 18°$ is shown in Fig. 2, including SBS signal from PDD shot N200715-002, SRS signal from indirect-drive shot N200727-001, and $\omega/2$ signal from x-ray diffraction shot N191016-001. The data demonstrate that requirements on temporal resolution and dynamic range or signal-to-noise ratio are satisfied.

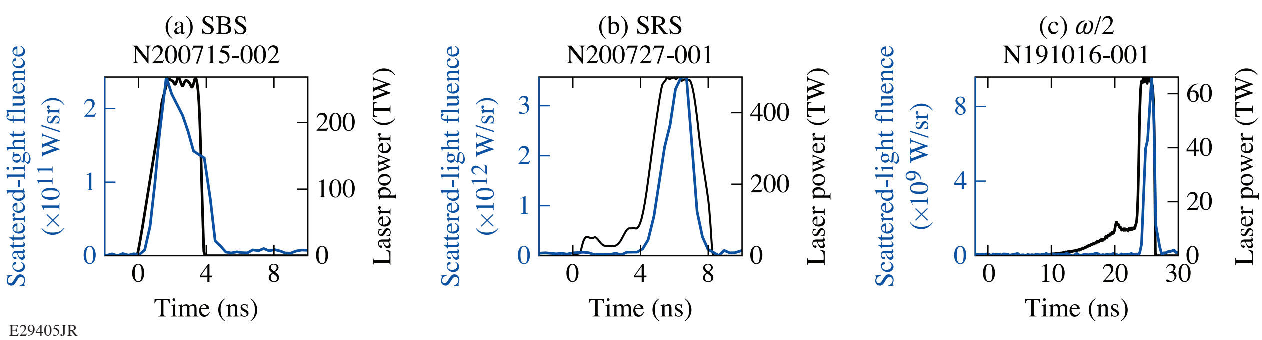

Figure 2
SLTD data obtained at $\theta = 18°$ on different NIF experiments in the (a) SBS, (b) SRS, and (c) $\omega/2$ channels. The SLTD trace (blue curve) is overlaid with the total laser power (black curve).

On a given shot, SLTD data can be used to map out the angular dependence of the scattered-light distribution with an uncertainty in each measurement of ±9%. The measurements can be used to evaluate the relative angular distribution in radiation-hydrodynamic calculations of ICF implosions. A comparison of shot N200715-002 SBS data to *SAGE* calculations of unabsorbed light shows qualitative agreement in the relative angular variation, with a peak near $\theta = 40°$ and less unabsorbed light near the pole and equator, although with some quantitative differences in the trends.

In summary, the NIF SLTD suite is being implemented to diagnose time-resolved scattered light in three wavelength bands—SBS, SRS, and $\omega/2$. Six units have collected data, validating the diagnostic performance. Nine additional units will be installed. The SLTD suite will constrain models of laser energy coupling and LPI in direct-drive and indirect-drive ICF experiments.

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