LASER BEAM SMOOTHING AND BACKSCATTER SATURATION PROCESSES IN PLASMAS RELEVANT TO NATIONAL IGNITION FACILITY HOHLRAUMS*

B.J. MacGOWAN, R.L. BERGER, B.I. COHEN, C.D. DECKER, S. DIXIT, S.H. GLENZER, D.E. HINKEL, R.K. KIRKWOOD, A.B. LANGDON, E. LEFEBVRE†, J.D. MOODY, J.E. ROTHENBERG, C. ROUSSEAUX†, L.J. SUTER, C.H. STILL, E.A. WILLIAMS
Lawrence Livermore National Laboratory, University of California, L-473 P.O. Box 808, Livermore, California 94550, U.S.A., †Centre D'Etudes de Bruyeres le Chatel, France

Abstract

We have used gas-filled targets irradiated by the Nova laser to simulate National Ignition Facility (NIF) hohlraum plasmas and to study the dependence of Stimulated Raman (SRS) and Brillouin (SBS) Scattering on beam smoothing at a range of laser intensities (3ω, 2 - 4 10^{15}Wcm^{-2}) and plasma conditions. We have demonstrated the effectiveness of polarization smoothing as a potential upgrade to the NIF. Experiments with higher intensities and higher densities characteristic of 350eV hohlraum designs indicate that with appropriate beam smoothing the backscatter from such hohlraums may be tolerable.

As part of an integrated plan for attainment of ignition on NIF we are now carrying out studies to evaluate the effectiveness of beam smoothing at reducing backscattered light (SRS and SBS) as we depart from the point design hohlraum conditions. These studies are intended to allow us more latitude in choosing the eventual ignition design. We are also exploring new implementations of laser beam smoothing more representative of what will be possible on baseline NIF and potential modifications. This work extends previous studies [1,2] that validated the baseline NIF beam smoothing design through interaction experiments on Nova. The previous work concluded that backscatter from the NIF (300eV) hohlraum would be at tolerable levels and could be further reduced by the addition of Smoothing by Spectral Dispersion (SSD)[3].

We have performed experiments with Kinoform Phase Plates (KPPs)[4] and SSD using a high frequency modulator (17 GHz) capable of generating bandwidths up to 1.6Å at 3ω. NIF will use such a high frequency modulator, rather than the 3GHz modulators used for previous Nova experiments, in order to reduce the beam dispersion required for SSD. Lower dispersion will improve laser propagation through spatial filter pinholes and the hohlraum laser entrance hole (LEH), but has the potential drawback that smoothing at large spatial scales does not occur. KPPs will be used in place of Random Phase Plates (RPP)[5] used in previous Nova experiments. RPPs produce an intensity distribution in the target plane that is an Airy function with as much as 16% of the light missing the LEH. KPPs can be designed so that the intensity distribution is essentially flat topped with up to 95% of the light entering the LEH[4]. A potential problem with KPPs is that the focal spot can have more long-scalelength intensity inhomogeneities. One goal of these experiments was to verify that the combination of a high frequency modulator and low dispersion SSD with a KPP focal spot gives results consistent with our previous experiments[1,2]. The new experiments also tested Polarization Smoothing[6] by incorporating wedged KDP crystal plates in the final optics. The wedges separate the incident light into two orthogonal polarization components slightly displaced in the focal plane, leading to the averaging of intensity variations as the two speckle patterns are added incoherently. These techniques reduce filamentation of hotspots in the focus and, in the case of polarization smoothing, reduce the intensity in hot spots.

Current target designs for the NIF consist of gas-filled, gold hohlraums, 9 mm in length, heated with a 1.3 MJ laser (430 TW peak power) at 3ω ($\lambda_0 = 0.351$ µm wavelength)[7]. The laser energy is delivered to the hohlraum by 192 beams in shaped pulses about 20 ns long, producing a peak radiation temperature of 300eV. The beams are focused with f/20 lenses arranged in groups ("quads") of 4 to produce effectively f/8 beams. Symmetric capsule implosions are accomplished by using two rings of beams, inner and outer, that reach the hohlraum wall at different distances from the LEH and have different path lengths within the hohlraum plasma. At the time of maximum power the laser intensity peaks at 2 10^{15}Wcm^{-2} at the best focus of the f/8 quad, with other regions, along the 3 to 5 mm beam path, at intensities between 10^{15} and 2 10^{15}Wcm^{-2}. Over most of their path length, the laser beams interact with a low-Z, fully-ionized, gas (a mix of He and H_2), but for the last 400 µm, with high-Z, high T_e gold plasma blown off from the hohlraum wall. The low-Z plasma between the hohlraum wall and the LEH has electron temperature (T_e) from 3 to 6 keV and electron density (n_e) from 7%n_{crit} to 12%n_{crit} ($n_{crit} = 9\ 10^{21}$ cm^{-3} for 3ω).

To assess the usefulness of different smoothing schemes we used the laser plasma interactions code F3D[8] to calculate the plasma response to the laser intensity near focus within the NIF plasma. In the past we used the calculated increase in the fraction of laser light in high intensity speckles caused by plasma self focusing (filamentation) as a measure of the effectiveness of the smoothing technique. In our calculations we find that 0.6 – 1.6 Å of SSD bandwidth at 3ω, or application of polarization smoothing, reduces filamentation. If both smoothing schemes are used, the distribution of intensities can be held to the KPP vacuum value (i.e. filamentation is suppressed)[6]. Although such comparisons are useful the observable in any smoothing experiment is often the amount of back scattered laser light rather than the amount of filamentation that occurs. Hence the calculation has been modified to predict the amount of SBS and SRS backscatter[8]. In F3D, the incident and reflected light make use of the paraxial approximation because the light is primarily amplified within the incident light cone. The short wavelength acoustic waves and Langmuir waves that respectively Brillouin scatter and Raman scatter the light are spatially enveloped. Anomalous damping is applied to the Langmuir and acoustic waves to account for secondary decay processes. The 3D fully nonlinear hydrodynamic response includes the quasi-linear effects of heating, induced flows, and density modification. Fig. 1 shows the results of such calculations for plasma conditions typical of the NIF inner beams. The calculations show that SSD has its biggest effect on SBS with a more subtle reduction in SRS expected. The calculations show a clear benefit to polarization smoothing either alone or in combination with SSD. Future calculations will study the effectiveness of these smoothing techniques for other laser and plasma conditions.

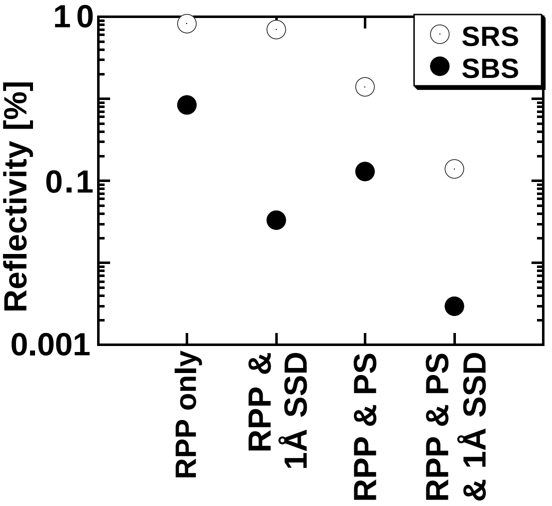

FIG. 1. Calculation (F3D) of the SBS and SRS expected from a 10% n_{crit} *low-Z (CH) plasma at 3keV when irradiated with a beam of intensity 2* 10^{15}*Wcm*$^{-2}$*. With a range of smoothing options. The calculations model a RPP, alone, or in combination with SSD with 1Å of bandwidth at 3ω, or polarization smoothing or both. These plasma and laser conditions correspond to the NIF inner beam and the 300eV NIF point design hohlraum.*

Experiments were performed using the Nova laser with targets developed to reproduce the plasma conditions and length scales of the NIF. The two plasma conditions that are important for the NIF are the inner beam plasma, which is a large scale length low-Z plasma with a high gain exponent for SRS and SBS, and the outer beam plasma which has shorter scale lengths and a higher gain exponent for SBS in the plasma near the gold wall[2]. The low-Z plasma encountered by the inner beam was modeled with gasbag targets, which are nearly spherical volumes of a high molecular weight gas (C_5H_{12}) retained by two thin membranes. Symmetric irradiation by nine "heater beams" leads to the production of 6 -15%n_{crit} plasmas with 1 - 2 mm scale lengths and T_e of 3 keV. The high-Z plasma with which the NIF outer beams interact was modeled with cylindrical, "Scale-1" hohlraums, 1.6mm diameter by 2.7mm long, filled with methane gas. The gas retards the expansion of the gold wall irradiated by the Nova beams and forms a shelf of gold similar in density and temperature to that seen by the NIF outer beam[2].

Both experiments used the tenth Nova beam as an interaction beam configured at f/8 and with the capability of SSD and polarization smoothing. SSD used a 17GHz phase modulator to produce bandwidths of up to 5Å at 1ω (1.6Å at 3ω). A 1200 mm^{-1} grating was used to skew the pulse front by 150 ps, corresponding to 2 color-cycles of SSD[3]. (Each f/20 NIF beamlet will have one full color cycle of SSD so NIF f/8 "quads" will have two color cycles of SSD across their width). Polarization smoothing(PS)[6] was effected using an array of Type I KDP doubler crystals cut at a wedge angle of 270 µrad. The crystal wedges were inserted in the beam after the 3ω conversion crystals and were oriented such that the 3ω polarization vector was at 45° to the e and o axes of the crystals. The wedges deflected the beam 0.8 mm in the target plane with the speckle patterns due to the two polarization components displaced 30μm relative to each other. The one-dimensional SSD displaced the laser speckle patterns in the target plane in a direction orthogonal to the direction of displacement due to the polarization smoothing wedges.

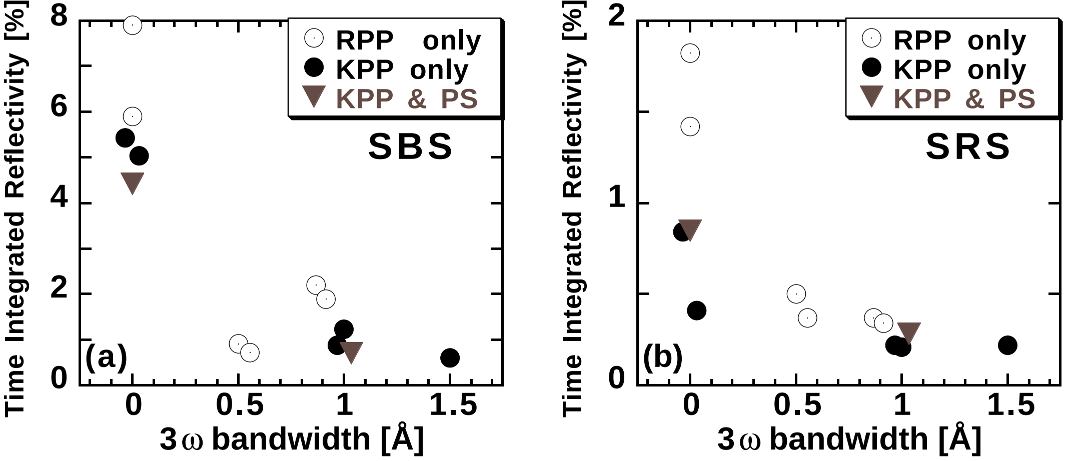

FIG 2. (a) SBS and (b) SRS backscatter measurements from Scale-1 methane-filled hohlraums modeling the gold plasmas encountered by the NIF outer beams.

Fig. 2 shows measured SBS and SRS reflectivity as a function of SSD bandwidth for the scale-1 methane filled hohlraums. Both SBS and SRS are time integrated during the shaped pulse experiment, with the interaction beam intensity peaking at 2 10^{15}Wcm^{-2}. The experimental uncertainty is ±25%. in the reflectivity. Data taken with the old RPP/SSD combination are shown for comparison[1] as open circles. The newer data with the KPP and the 17GHz modulator (solid circles) are consistent. Data taken with gasbag plasmas also showed results that were consistent with the older data taken with RPPs and low frequency SSD. Hence this preliminary assessment of the data indicates no significant difference between the NIF implementation of beam smoothing (KPP and 17GHz SSD) and that of our older experiments (RPP and 3GHz SSD). Fig 2 also shows two data points taken with the addition of polarization smoothing (triangles) that lie among the other data, implying that, at least in this experiment, there was little benefit to polarization smoothing for the laser and plasma conditions relevant to the NIF outer beams.

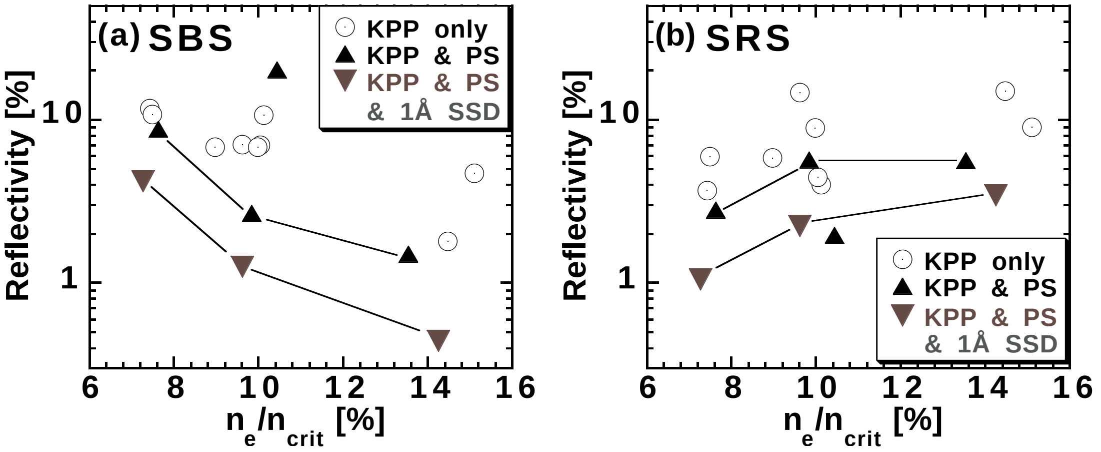

FIG. 3. (a) Peak SBS reflectivity and (b) SRS reflectivity at peak T_e (t = 1 nsec), for gasbag plasmas. (Experiments above 13%n_{crit} used a RPP in place of the KPP)

Fig. 3 shows tests of polarization smoothing performed in gasbag plasmas, representing the low-Z plasmas through which the inner NIF beams propagate. Most of the data in Fig. 3 had a probe beam irradiance of 2 10^{15}Wcm^{-2} corresponding to the NIF 300eV point design. The data in the range 13% - 15% n_{crit} had an interaction beam irradiance of 4 10^{15}Wcm^{-2}, consistent with that in higher temperature (350eV) NIF hohlraum designs. The bulk of the data with PS lie below the unsmoothed data (open circles), while the experiments with PS and 1Å SSD have the lowest backscatter levels (total scatter is less than 6%), especially for the case of SBS indicating that there is some benefit to polarization smoothing for this inner beam case. Fig 3 shows data from one shot that lies off the curves joining the rest of the data sets. Some similar data points were recorded in gasbag plasmas in experiments that increased the SSD bandwidth in order to examine the effect of SSD alone (data are not shown here). These "anomalous" data points showed an increase in one scattered signal (SRS or SBS) and a significant reduction in the other scattered signal, possibly indicating that the smoothing affects one scattering process which then allows the other to grow. The phenomenon was not restricted to experiments with polarization smoothing but seemed to occur when we were making a change to improve smoothing by either method (i.e. increasing bandwidth or adding PS). These kind of "anomalous" results were obtained on less than 10% of the experiments and had not been seen in previous smoothing experiments on Nova. We are continuing to examine the data from these experiments in detail in order to understand the mechanisms by which SRS and SBS are affected by the smoothing and by each other. A more complete discussion of these results will appear in a longer paper.

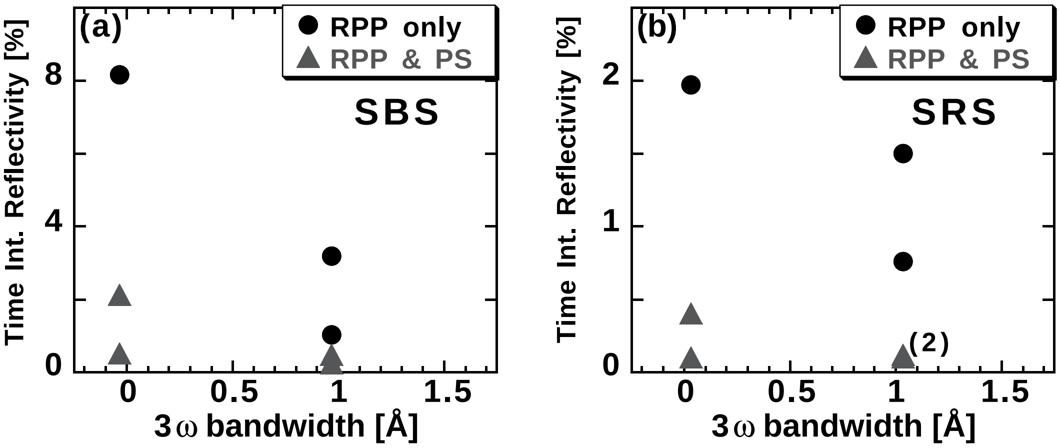

FIG. 4. (a) SBS and (b) SRS time integrated reflectivity for scale-1 gas filled hohlraums irradiated at 4 10^{15}Wcm^{-2} to simulate NIF outer beams in higher temperature (T_{rad} ~ 350eV) hohlraums. "2" indicates two overlapping data points.

Fig. 4 shows the results of tests of beam smoothing of the NIF outer beams at the higher irradiances expected in 350eV hohlraums. The targets were scale-1 gas-filled hohlraums and the interaction beam was smoothed with a RPP and SSD, with and without PS. The results show a significant benefit to using PS in higher intensity applications. Coupled with the small amount of data taken with the higher density gasbag plasmas (Fig. 3) we may conclude that the plasma and laser conditions expected in 350eV ignition-scale hohlraums are not necessarily going to produce large amounts of backscatter. Furthermore, the indications that higher intensity interaction beams (up to 4 10^{15}Wcm^{-2}) do not produce dramatically worse backscatter problems may allow more latitude in designing the KPPs that shape the NIF focal spots. Instead of designing for a flat intensity profile with the lowest possible peak intensity, we may allow the peak intensity to increase in order to better shape the sides of the focal spot. The polarization smoothing results motivate re-examination of schemes to incorporate such smoothing on NIF as a retrofit and plans for tests with a small number of beams on NIF itself. A fuller discussion of this data and modeling will be published in a longer paper. However, the results of the studies shown here are that SBS and SRS in NIF-scale hohlraums should be at tolerable levels with moderate amounts of beam smoothing, even at the higher intensities and densities expected in 350eV ignition hohlraums.

*This work was performed under the auspices of the US. Department of Energy by the Lawrence Livermore National Laboratory under contract No. W-7405-ENG-48.

REFERENCES

[1] B.J. MacGowan, *et. al.*, Proceedings of the IAEA, 16th International Conference on Plasma Physics and Controlled Nuclear Fusion, Montreal, Quebec, Canada, Oct. 1996, Fusion Energy 1996 Vol 3, 181 (1997).
[2] B.J. MacGowan, *et al.*, Phys. Plasmas **3**, 2029 (1996).
[3] S. Skupsky, *et. al.*, J. Appl. Phys. **66**, 3456 (1989).
[4] S.N. Dixit, *et. al.*, Opt. Lett. **19**, 417 (1994).
[5] Y. Kato, *et. al.*, Phys. Rev. Lett. **53** 1057 (1984).
[6] E. Lefebvre, *et. al.*, Physics of Plasmas, **5**, 2701 (1998).
[7] S.W. Haan, *et. al.*, Phys Plasmas **2**, 2480 (1995).
[8] R.L. Berger, *et. al.*, Physics of Plasmas, in press (Dec 1998).