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Laser-beam propagation in high temperature hohlraum plasmas

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Abstract. We have developed a new target platform to study propagation and backscatter of a frequency-doubled (2ω) laser beam through large-scale length plasmas at ignition-design densities, intensities and temperatures above 3 keV. The plasma is created by heating a gasfilled hohlraum target with 37 heater beams that deliver a total energy of up to 15 kJ in a 1 ns square pulse. We measure a factor of two higher temperatures than in open geometry gasbag targets investigated earlier. This new temperature regime with a measured beam transmission of up to 80% suggests we can expect good laser coupling into ignition hohlraums at the National Ignition Facility (NIF) using 2ω light.

1. Introduction

Indirect drive inertial confinement fusion (ICF) with frequency doubled light (2ω, 527 nm) is being investigated as a higher gain option for the National Ignition Facility (NIF) because of the possibility of extracting more laser energy [1,2]. Ignition with 2ω light differs from the current design with frequency tripled light (3ω, 351 nm) in that it relies on delivering considerably more energy into larger hohlraums. Larger laser entrance holes would then allow to reduce the peak laser intensity from 10^{15} W/cm^2 with 3ω light to around 3×10^{14} W/cm^2 for 2ω. High plasma temperatures of 3-6 keV are predicted inside a NIF-hohlraum. The stong Landau damping at these temperatures is expected to efficiently reduce stimulated Raman scattering (SRS) and thus hot electron production compared to earlier experiments at lower temperatures. We have developed a new target 'platform' to study laser-plasma interaction in long-scale length plasmas at temperatures above 3 keV at the Omega laser facility. The measurements show that SRS in ignition scale-length plasmas is strongly reduced as the plasma temperature approaches ignition conditions.

2. Creation of long-scale length plasmas at ignition scale temperatures

The plasma is produced by irradiating a cylindrical 2 mm by 1.6 mm diameter gold-hohlraum target with a total energy of up to 15 kJ in a 1 ns square pulse, arranged in 37 heater beams at 3ω. The heater beams are distributed in 3 cones on each side of the target. The hohlraum is filled with a carbohydrate gas at a pressure of 1 atm, resulting in a plasma density of n_e/n_c = 13±0.3 % when fully ionized, consistent with 2ω ignition designs [1] ($n_c=4\times10^{21}$ cm^{-3} is the critial density for 2ω light). The temperature in these targets was directly measured with Thomson scattering (TS) of a 4ω probe beam

(200 J, λ=266 nm) [4]. Light scattered from the hohlraum center through a 0.5x0.5 mm^2 TS-port was collected with an f/10 lens at an angle of 79° and was imaged onto a 1 m spectrometer coupled to a S-20 streak camera. For our plasma conditions the scattering is collective and the plasma temperature can be accurately determined from a multi-ion species fit to ion-acoustic feature. We measure an electron temperature of 3.5 keV in a hohlraum heated with 17.1 kJ. At 8.3 kJ the temperature drops to 2 keV, comparable to earlier gasbag experiments [3].

3. Measurements of beam propagation and backscatter

A dedicated 2ω interaction beam is fired through the preformed plasma along the hohlraum axis to measure propagation and backscatter (Fig. 1). The 1 ns long flat-top interaction beam was delayed by 300 ps relative to the heater beams and had a variable energy of up to 170 J. The beam was spatially smoothed with a distributed phase plate (DPP), producing a vacuum spot diameter of 200 μm, corresponding to an average intensity up to $4.7x10^{14}$ W/cm^2.

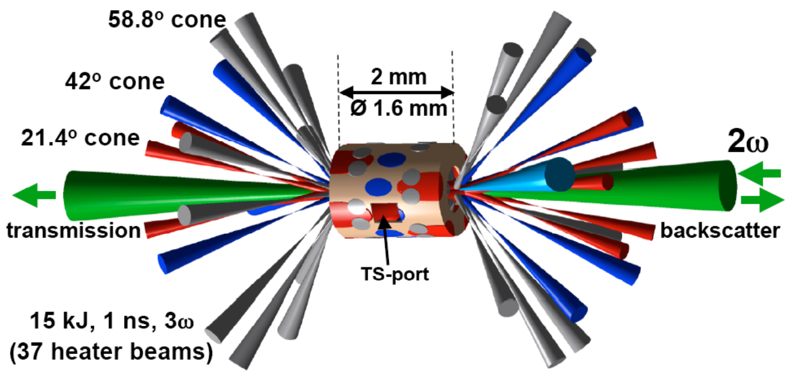

Figure 1. The hohlraum target is heated with 37 laser beams in three cones from each side. A dedicated 2ω interaction beam is fired through the preformed plasma along the hohlraum axis to measure beam propagation and backscatter. The plasma temperature is measured directly with Thomson scattering (TS) though a 0.5x0.5 mm^2 port.

Beam propagation and backscatter within twice the original f/6.7 cone of the 2ω interaction beam was measured with temporal, spectral and angular resolution [5]. We observe a SRS wavelength around 880 nm and a shift of the stimulated Brillouin scattered (SBS) light around 12 Å, consistent with the fill density and high temperatures above 3 keV. This demonstrates that the laser-plasma interaction occurs in the hot plasma inside the hohlraum.

Figure 2 (a) shows the measured integrated beam transmission of the 2ω beam as a function of beam intensity. We observe beam transmissions as high as 80% at ignition design intensities of $3x10^{14}$ W/cm^2. At higher intensities around $5x10^{14}$ W/cm^2 the transmission drops to around 40%. We measure a total SBS reflectivity around 10% at NIF design intensities, and as much as 30% for higher intensities [Fig. 2(b)]. The measured SRS reflectivity from these plasmas is negligible at the 1% level [Fig. 2(c)]. In comparison, earlier gasbag experiments [3] with the same gasfill, density, and scale-length but a peak temperature of only 1.8 keV (open symbols) show a maximum beam transmission of only 40%, large levels of SRS and negligible SBS. When the heater energy is reduced from 15 kJ to 8 kJ, the temperature drops from 3.3 keV to 2 keV and we observe a strong reduction in beam transmission to 25%. Simultaneously the SBS reflectivity drops below 1% while we observe larger

SRS levels around 15%. This demonstrates that SRS is efficiently reduced in these targets as the temperature approaches ignition condition, where Landau damping is strong.

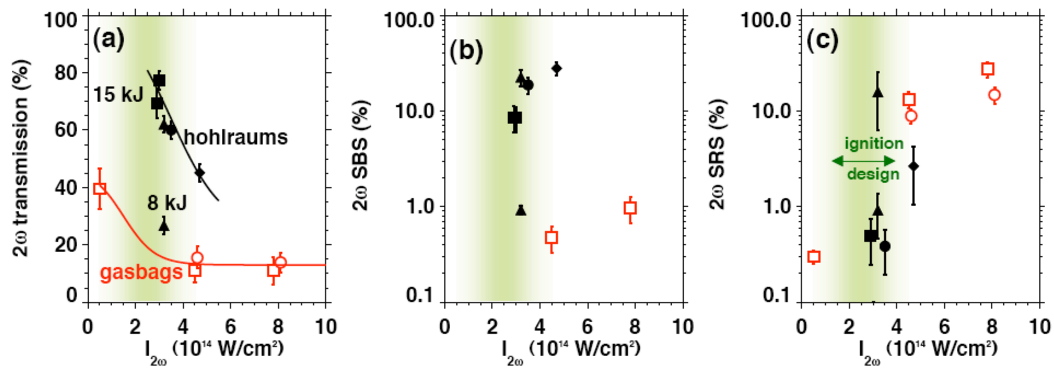

Figure 2. Beam transmission (a), SBS (b) and SRS (c) reflectivity as a function of 2ω beam intensity (filled symbols represent the new hohlraum targets, open symbols earlier gasbag targets). The shaded area around 3×10^{14} W/cm^2 indicates the range of intensities used for current ignition designs.

4. Conclusion

We observe a strong reduction of SRS from hohlraum plasmas when the temperature approaches ignition conditions above 3 keV. A measured beam transmission of up to 80% and only modest levels of SBS in this regime indicate good laser coupling into ignition targets for the National Ignition Facility using 2ω light.

Acknowledgments

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