Multisource Laser Development for Laser-Created Plasmas

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Laser created plasmas are an important source of a wide variety of plasmas affecting many different fields ranging from inertial confinement fusion [1] to fundamental studies in warm dense plasmas. While there has been considerable development in both the understanding of laser-plasma interaction [2] and the development of pulsed laser sources, there has been relatively little research on understanding the effects of laser-plasma interactions subject to multiple beam and/or multiple frequency laser sources. Multiple beam and multiple frequency sources may overcome some of the traditional limitations in laser created plasmas. In particular employing beam combination of many laser sources can provide unique capabilities including improved efficiency, plasma uniformity, decreased laser-plasma instabilities, decreased losses, and tailored plasma profiles that can affect a wide variety of areas.

Most laser-created plasmas are generated from either a single or several coherent laser pulses focused on a given target. This has traditionally offered a number of benefits including simplicity and timing consistency (when dealing with multiple laser pulses). For example, NIF utilizes 192 beam lines that are all driven by a master oscillator at the same optical frequency; most x-ray lasers take place within laser-created plasmas generated by one (or more) laser pulses focused onto a line driven from a single laser oscillator; single pulsed lasers are frequently used for generating warm dense plasmas for basic research, etc. As a result there has been a lot of research into laser-plasma interaction and models developed to simulate laser-created plasmas [2]. This design creates a number of problems however. At high intensities needed to achieve the high energy densities of interest for applications such as fusion, the plasma tends to be dominated by laser-plasma interactions and instabilities such as Stimulated Raman scattering (SRS), stimulated Brillouin scattering (SBS), parametric decay instability, two plasmon decay, Langmuir decay (LDI), electromagnetic decay instability, two ion wave decay, self focusing, and particle trapping. While the details can vary depending on the instability, the instabilities arise from the interaction of the electromagnetic waves of the laser beams and the plasma properties. By utilizing multiple independent laser beams (for example, combining incoherent beams at slightly different frequencies at the same spatial location) many of these instabilities can be reduced [3]. Since the electromagnetic radiation no longer consists of a single wave, the plasma be unable to oscillate with the laser frequency leading to fewer nonlinearities. Additionally, at high densities the laser energy is strongly coupled at the critical density that increases the non-linear effects within this region and (when density gradient closes the critical density) can cause significant temperature gradients. These unwanted effects can be reduced by utilizing multiple beams with different wavelengths, each of which would couple to a different density reducing the temperature gradients. Further research into multi-laser plasma instabilities and laser sources consisting of multiple coherent, partially coherent and incoherent sources and modeling laser-plasma interaction can yield significant improvements in reducing the laser-plasma instabilities.

A second major benefit from employing combined multiple sources is the increased energy efficiency and potential repetition rate allowed by the different sources. For large energy dense plasmas such as NIF, the energy efficiency of the plasma creating is of increasing concern. Most large laser-created plasmas are created by laser systems that are significantly lower efficiency than laser diodes and laser fibers. This is done in large part because these sources are typically not capable of achieving the necessary properties including the energy, beam quality, etc. Research into the development of high intensity laser arrays could provide a useful alternative source that would not only decrease the energy required to create the plasma, but could provide more desirable plasma properties as well. Improving the efficiency saves energy, and is

necessary for applications such as nuclear fusion which requires a larger gain than input energy. The increased efficiency decreases the heat that must be dissipated by the laser source allowing for higher repetition rate as well. Currently NIF is limited to ~ 4 shots/day, which is impractical as an energy source and severely limits the number of experiments that can be conducted based on the available number of shots.

Finally, the flexibility provided by a laser source consisting of multiple sources is of interest for a wide variety of laser-created plasmas. While high energy density laser-created plasmas tend to be dominated by laser-plasma instabilities, for a variety of applications it is often desirable to create plasmas with tailored properties. For example studying warm dense matter requires creating a dense low-temperature plasma for experimental measurements, x-ray lasers can be created by the appropriate temperature and density profiles, x-ray sources require high temperatures with the appropriate ion species for radiation at the wavelengths of interest, etc. Usually these conditions are achieved by adjusting the laser pulse duration, intensity, beam delays (when multiple pulses are used), and the wavelength. While adjusting laser pulse characteristics provides flexibility it is often limited and may require complex pulse combinations to achieve the desired effect [4]. A source consisting of many different lasers/amplifiers allows additional degrees of freedom that could be utilized to enable more control over the laser beam properties. Multiple pulses can mimic arbitrary temporal pulse shapes; different wavelengths can allow pumping different densities simultaneously, or by delaying can heat the same plasma ions while they expand; varying the degree of coherence between the sources can allow for a more direct measurements of laser-plasma interactions through the plasma waves.

Multiple frequency and/or multiple beam laser sources for laser-plasma interactions are not readily available at this time and research is required to identify what kind of beam combination and amount of beams combined will produce certain plasma characteristics. Beam combining of multiple lasers can in principle be grouped into three categories [5]: side-by-side beam combining, coherent beam combining (CBC), and wavelength beam combining (WBC). For side-by-side beam combining laser array elements may operate at different wavelength and no effort has been made to affect or control separate laser parameters. In this case there is no gain in the total intensity (power density) and the total radiance is equal to N (where N is the number of lasers in the array) times the radiance of a single source (provided all the beams are focused on the same area). For coherent beam combining all the elements of the array operate at the same spectrum and the relative phases between the lasers are constant (zero in the ideal case). Such arrays can form constructive interference with the radiance at the central peak proportional to the square of the number of elements in the array (N^2). Partial coherent beam combining is also possible in which case the radiance in the central peak will be proportional to N^{α} with $1<\alpha<2$. For wavelength beam combining all the elements operate at different wavelength and then a dispersive optical optics is used to overlap/combine all the beams in the near and far fields. Wavelength beam combining can provide excellent directionality of the beams however does not change the radiance as phase differences and wavelength are not being controlled. Both CW and pulsed laser arrays have been employed for beam combining designs described above and the feasibility of beam combining for high-power and high-radiance applications had been demonstrated.

References

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