Accelerating the quest for inertial fusion energy using ultra-high peak power X-rays

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Abstract:

The demonstration of energy gain by nuclear fusion in the laboratory and its industrial utilization as an unlimited energy source has been a grand challenge for physicists and engineers for 70 years. This vision has shifted closer to reality after the successful demonstration of multi-megajoule energy yield from deuterium-tritium plasmas in indirectly driven inertial confinement fusion implosions on the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory. These experiments exceed fusion powers of 100 PW in a single event, vastly exceeding human's total annual power capability by a factor of 5,000. This achievement came after increasing the fusion energy yield by a factor of 3,000 since the first experiments on the NIF about a decade ago. Currently, several avenues towards power generation by fusion ignition and high fusion yield are beginning to emerge where efforts towards laser and target technology developments have been launched recently through the U.S. DOE's IFE-STAR and FIRE programs.

A leading target design for delivering high fusion yield at repetition rates of seconds uses laser-driven polymer foam capsules wetted with liquid nuclear fuels. Current target and fusion power plant design studies urgently need data on the Equation of State (EoS) and validation of simulations of the adiabat and hydrodynamic stability at megabar to gigabar pressures. For this purpose, we have launched a new program at SLAC to provide these data by performing high precision experiments with powerful X-ray sources. Precision data are required because the fusion capsule design must be robust to the presence of radiation cooling from polymer ions. Further, plastic capsules were abandoned earlier on the NIF and replaced by diamond ablators due to stability issues that will need to be overcome in future fusion power applications.

Our program uses three hard X-ray laser sources, i.e., LCLS at SLAC, EuXFEL, and SACLA, and three energetic lasers, i.e., NIF, Omega, and Titan. While the former facilities are used to resolve the transition of the wetted foam target to the plasma state at megabar pressure the latter facilities are poised to explore target performance towards gigabar pressure states. Recent studies have developed new X-ray imaging techniques with sub-micron spatial resolution and measured shock propagation, instability growth, and heating of foam targets. In addition, X-ray Thomson scattering with spectral resolution of $\Delta E/E = 10^{-6}$ have resolved the ion feature and plasmons in laser-driven plasmas and are continuously developed to measure the physical properties of fusion plasmas. I will show examples that use self-seeded X-rays, stochastic correlation of SASE spikes, and Quantum-entangled X-ray photons to accomplish these goals.