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Nuclear Instruments and Methods in Physics Research A 544 (2005) 48–54
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

Models of gain curves for fast ignition ☆

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Available online 13 March 2005

Abstract

We consider gain curves for Fast Ignition that have the following ingredients: hydrodynamic efficiency of the implosion for a range of drive intensities, density of the assembled fuel resulting from the reflected shock produced at the culmination of the implosion, effective particle range produced in the laser–plasma interaction as well as the heat capacity of the ignition region as determined by Atzeni. The dependence of the gain curves on the coupling efficiency from ignition laser to fuel, allowed in-flight-aspect-ratio, compressed fuel density profile and fraction of implosion energy in the compressed fuel is shown. In addition the fraction of the total driver energy devoted to the ignition driver that maximizes the gain is shown. These estimates will be made for systems where the implosion is directly driven with a laser of various colors or indirectly with a heavy ion beam.

PACS: 52.57.Bc; 52.57.Fg; 52.57.Kk; 52.58.Hm

Keywords: Fast ignition; Heavy ion fusion; Laser; Direct drive; Optimization; Gain curve

1. Introduction

Fast Ignition [1] is an inertial fusion scheme in which fuel ignition is obtained by directly heating pre-compressed fuel using an external heating source, such as energetic electrons or protons produced by high-intensity laser irradiation. This scheme is thus distinct from conventional inertial fusion schemes where the ignition region is heated with PdV work produced during the implosion.

In this note we apply a simple gain model for Fast Ignition that because of length limitations will be described elsewhere [2]. The model includes a treatment of the hydrodynamic efficiency of the implosion directly driven by lasers including laser–plasma coupling efficiency [3] and total (hohlraum and hydrodynamic) coupling efficiency for capsules imploded in distributed radiator targets by heavy ion beams [4], a treatment of details of the implosion [5], a representation of the

☆This work was performed under the auspices of the US Department of Energy by the University of California, Lawrence Livermore National Laboratory, under Contract no. W-7405-Eng-48.
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0168-9002/$ - see front matter
doi:10.1016/j.nima.2005.01.279

effects of stagnation at the culmination of the implosion [6], a fit to an ignition model [7], and a relation between the required short-pulse (ignition) laser intensity and particle range [8]. This crude model must ultimately be checked with detailed hydrodynamic and particle transport calculations. However, the simplicity of this model allows us to investigate millions of realizations of possible fuel assemblies. We can use this model to find where the optimal configurations lie in implosion velocity-drive intensity space and what the associated gains are. More importantly we can understand how gain varies with various assumptions employed in the model and can direct our efforts to understand the most important. In addition, this model is employed to understand some engineering tradeoffs.

The plan of the paper is as follows: Section 2 shows how gain and details of the implosion depend on the in-flight-aspect-ratio (IFAR) or drive intensity and the total system energy. Section 3 shows how the gain curves depend on various system and physics parameters. Section 4 applies this methodology to distributed radiator targets driven by heavy ion beams. Section 5 summarizes the work.

2. System dependences for nominal model

The nominal model utilizes an implosion driven by $\frac{1}{3}$ micron light and a coupling efficiency between short-pulse laser and ignition region of 25%. Fig. 1 shows the gain contours for 3 MJ total laser energy (implosion and ignition laser). Note that the maximum gain occurs at moderate IFAR and low laser intensity. This corresponds to rather low fuel density, approximately 100 gm/cm^3. Fig. 2 shows the maximum gain as a function of compression laser intensity and total laser energy, while Fig. 3 shows the maxima in total energy-IFAR space. The maxima between IFAR 50 and 100 have convergence ratios of 10–20. These implosions can tolerate 2–4 times the asymmetry in low order modes. Fig. 4 shows the ignition laser energy corresponding to the gain maxima as a function of IFAR and total laser energy. Because high fuel densities are required for small ignition energies, small ignition energies correspond to high implosion velocities and large IFARs. Obtaining high gain will require large (hundreds of

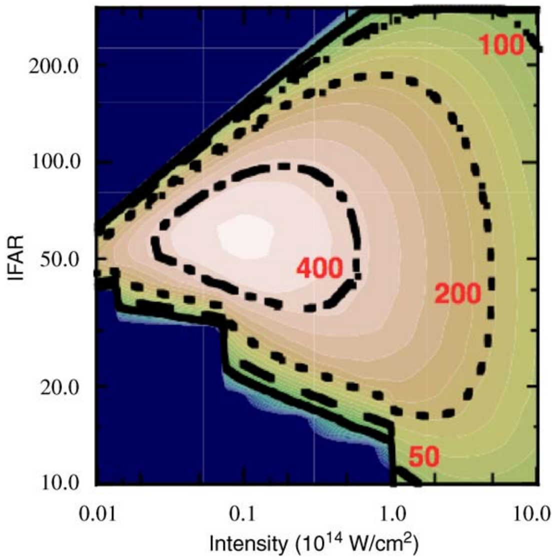

Fig. 1. Gain contours as a function of implosion laser intensity and in-flight-aspect-ratio (IFAR) for total energy 3 MJ for the nominal model.

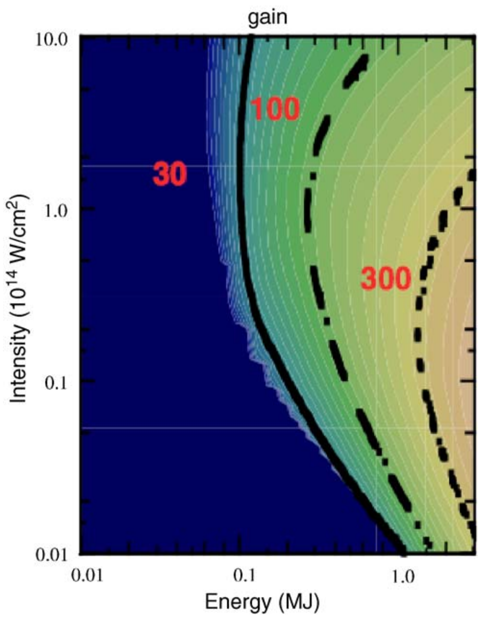

Fig. 2. Gain contours as a function of drive laser intensity and total laser energy (E). The gain is first maximized over IFAR.