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Summary

A new class of high-gain hybrid fusion concepts, combining magnetic and inertial confinement in a cylindrically symmetric configuration, is being proposed and investigated [1]. A large current is discharged through a cryogenic fiber forming a confined Z-pinch [2]. Surrounding the fiber pinch is a thin cylindrical shell of solid DT fuel which is imploded onto the pinch by a uniform distribution of x-rays emitted by a "dynamic" gold holhraum." The holhraum is being irradiated from the outside by x-rays from an outer array of tungsten wires carrying high currents, ~10 MA, as in the new PBFA-Z configuration. The physics of the concept is well matched to the engineering strides made in pulsed power capability, such as higher currents delivered to the load, and more uniform plasma hohlraum sources [3]. Experiments on PBFA-Z could inexpensively explore the ignition regime, and find optimal parameters. The paper accents preliminary theoretical calculations [1] and predicts nominal fiber-shell target designs in preparation for potential experiments on PBFA-Z.

Concept Description

Experiments [4] and 2-D simulations [4,5] of annular liners driven by magnetic compression are accompanied by the magnetic Rayleigh-Taylor instability and destruction of shell by nonlinear bubble-spike structures, as described by Hussey *et al*. [6] using an elegant heuristic model. The concept proposed here completely avoids magnetic compression. A magnetic central "hot spot" is formed by discharging a ~ 1 MA current through a ~ 50 μm radius, cryogenic fiber Z-pinch. Surrounding the fiber pinch is a thin ~ 600 μm shell of solid DT fuel which is imploded by x–rays emitted by a dynamic gold hohlraum irradiated by x–rays from the tungsten wire array load. Note that the return current path of the central fiber pinch is provided by a large radius outer wall which is remote from the pinch-shell-hohlraum-wire array system. Ordinary nonmagnetic Rayleigh-Taylor instabilities could be greatly minimized by using such a dynamic gold holhraum as an x–ray driver for imploding the shell. The shell then collapses on the pinch, and by adiabatic compression the pinch is strongly heated from a few keV to fusion temperatures, > 60 keV, becoming the *primary* hot spot. During the compression, a portion of the energy stored in the surrounding magnetic field is converted to pinch energy which helps to alleviate the driver energy ($1/2\ I^2\ \Delta L \rightarrow p\ \Delta V$).

The alpha particles emitted from the primary hot spot are trapped and localized by the B_θ field and deposit their energy on the inner, one gyroradius thick, surface layer of the collapsed shell. This forms the *secondary* hot spot which triggers a thermonuclear burn wave throughout the outer layers of the imploded fuel shell. Preliminary modeling [1] indicates that ignition can occur for shell velocities ~ 10^5 cm/s, which is much lower than the 3 to 5×10^5 cm/s velocities needed in ICF. In the proposed MIC scheme, hot spot heating is "ohmically assisted," thereby reducing the driver requirements to only 1 TW/cm^2, compared to the > 100 TW/cm^2 believed necessary for conventional ICF. We note that the central ignitor density at peak compression is only ~ 1g/cc, and is thus quite low by ICF standards, while fusion energy gains per pulse exceed 500. Hence, the main advantage of this hybrid concept is the achievement of high fusion gain with much lower implosion velocities and driver power fluxes, ~0.1 TW per square centimeter, compared with what is believed necessary for conventional ICF.

MIC is similar to "Magnetic Target Fusion" (MTF) [7–9] in the sense that the target plasma is magnetized and preheated. The essential difference is that in MTF the target plasma is *wall-confined* by an imploding metal liner. The imbedded magnetic field in MTF merely serves to thermally insulate the target plasma from the wall during the implosion. In MIC, the target plasma is *magnetically confined,* and well separated from the imploding DT fuel shell during the implosion up until the moment of contact. The fuel formation (densification) process needed to get a high fuel burn-up fraction is they *decoupled* from the hot spot formation process. This means that a high-R fuel shell can be formed on a longer implosion time scale compared with ICF, reducing driver powers to the ~ 5 TW level easily achieved by PBFA-Z [3]. This feature is quite unlike MTF, where the fuel and hot spot are contained in the same plasma, and ICF where the dense fuel shell and the central hot spot are formed on the same (implosion) time scale. Pulsed power > 45 TW is available in the existing facilities, like PBFA-Z, to do fusion-relevant experiments near break-even conditions [3].

Fiber pinches with currents approaching the Pease-Braginskii current have remained stable over 100 Alfvén transit times if the current ramp is sufficiently rapid [2]. Fiber pinches do suffer unlimited expansion due to the m = 0 instability which reduces their density and precludes any possibility of achieving fusion ignition for a bare pinch. We use a phenomenological turbulent heating model of Rosenbluth [10] and Loverberg *et al*. [11] and predict that, irrespective of radiation cooling and ohmic heating, the fiber radius evolves according to

$$r(t) = \frac{C}{N^{1/2} I^{3/2}} \int_0^t I^{5/2} dt$$

where I(t) is the current, N is the line density (nuclei/cm), and C is a numerical constant. Through this result, the pinch plasma density and temperature are linked, if the current waveform is specified, and thus the initial target plasma conditions at the instant of contact with the imploding DT shell can be identified. The critical shell/pinch compression phase is studied using a three-region slug model: the hot, low density adiabatic pinch region, the shocked inner shell region and the unshocked outer shell region. The shell is sufficiently cold, ~ 1 eV, and resistive, and thus moves through the magnetic field unimpeded. Assuming that the cryogenic pinch radius is initially 50 μm, and taking the pinch parameters at moment of contact (r_p = 400 μm, T_p = 3 keV), the nominal shell parameters needed for ignition are as follows: Initial shell radius, R_0 = 2.5 cm; initial shell thickness, Δ_0 = 600 μm; (aspect ratio R_0/Δ_0 = 40), initial velocity 1000 m/s, imploded shell radius (thickness) at moment of pinch contact, R_f = 875 μm (Δ_f = 950 μm). At peak compression the pinch temperature rises to nearly 70 keV which provides a sufficiently high alpha particle production rate to ignite the inner layer of the shell during the 3 ns dwell period.

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