Status of fusion implosion experiment at LLL *

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One of the near term goals of the inertial confinement fusion program at the Lawrence Livermore Laboratory, is to demonstrate ignition of thermonuclear burn. The fusion conditions required for this goal are DT fuel ρR and ion temperature valuse exceeding 0.3 g/cm^2 and 5 keV respectively. Extrapolations of present experiments using the Shiva laser gives us confidence that we can achieve these fusion ignition conditions with our 300 kJ Nova laser facility presently under construction.

The Shiva laser system, capable of focusing up to 15 kJ at 1 nsec and 30 TW at 100 ps, was developed to study the physics of laser driven inertial confinement fusion (ICF) and attain intermediate milestones on the path to demonstration of fusion ignition. In experiments perforemed over the past year and a half, we have achieved compressed DT fuel densities of up to 20 g/cm^3, or 100 times the liquid density of DT. Although the DT burn temperatures obtained were rather low, ~ 0.5 keV, neutron yields of 10^7 imply that inertial confinement-time product values ($n\tau$) in excess of 3×10^{14} cm^{-3} sec were achieved.

Extensive target diagnostics have been developed for Shiva. These diagnostics are routinely used to measure neutron yield and spectrum, energy balance, alpha, beta, X-ray, optical, ion and proton spectra and temporally, spatially and spectrally resolved X-ray and alpha particle emissions of the imploding traget. Four instruments have been developed to investigate implosion dynamics and to determine the fuel density of the imploded fusion pellet. The first neutron interval timing, is used to measure the time interval between the peak of the laser pulse and the later neutron emission from the imploded fuel. Comparing results with code calculations gives indirect indications of target performance. The second and more direct technique utilizes an imaging X-ray spectrometer to measure the spatial extent, at the time of peak neutron production, of Argon tracer seed gas introduced into the DT fuel. Comparing results with those obtained from our α zone plate coded imaging technique for exploding pusher experiments, indicates good agreement between the two methods. The Argon imaging spectrograph will be used in the intermediate density regime when the α-particle range prohibits the use of the zone plate coded imaging technique. The third utilizes radiochemistry, or neutron activation techniques to obtain a direct measurement of the average density-radius product ($\rho \Delta r$) of the various target elements at peak neutron production. From measurements such as these, the final DT fuel density can be inferred. The fourth technique involves X-ray backlighting. By creating an intense X-ray source and spatially and temporally

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resolving the transmission of these X-rays through the target, detailed information about the target dynamics can be obtained. We have recently carried out preliminary experiments demonstrating various aspects of this technique.

During the past year we have irradiated both exploding pusher and ablatively driven targets with simple pulse shapes, producing higher neutron yields than previously attained from both types of targets. A series of terget irradiations with exploding pusher designs at 15 to 20 TW in a 90 ps pulse resulted in a maximum neutron yield of 3×10^{10} and DT ion temperatures of approximately 5 kV. In addition the experiments further extended our confidence in our simple exploding pusher model. The exploding pusher targets were also used to correlate fuel densities as inferred from radiochemistry neutron activation techniques, and argon and a zone plate imaging. The exploding pusher high neutron yields produced easily detectable quantities of Al^{28} by neutron activation of silicon in the target shell, and made possible the determination of the $\rho\Delta r$ of the imploded shell. The inferred fuel density from this experiment, was then compared with data from the α zone plate camera and argon imaging spectrometer on the same shot. A simple isobaric-isothermal model has been developed which relates pusher $\rho\Delta r$ values to final fuel densities. Irradiation of ablatively driven targets designed for high compression at 7 to 10 kJ with pulses from 0.7 to 1 ns duration have produced a maximum neutron yield of 1×10^8. Average DT fuel density of 10 g/cm^3 with individual experiments indicating densities of up to of 20 g/cm^3 have been observed. Results of these, and other experiments, will be reviewed.

利佛莫尔实验室聚变聚爆实验情况

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劳伦斯·利佛莫尔实验室惯性约束聚变计划近期目标之一是演示热核点火。为此目的所需要的聚变条件是氘氚燃料的 ρR 值大于0.3克/厘米^2，离子温度大于 5 千电子伏。由 Shiva激光器目前实验结果的外推使我们确信，我们可以用目前正在建造中的300千焦耳 Nova 激光装置达到这些聚变点火条件。

能使15千焦耳能量 1 毫微秒脉宽或使30兆兆瓦功率100微微秒脉宽的激光会聚的Shiva激光系统，经发展后已用以研究激光驱动的惯性约束聚变的物理过程，并向聚变点火道路当中的阶段里程碑推进。在过去一年半所进行的实验中，压缩 DT 所获得的密度已达20 克/厘米^3，或DT 液体密度的100倍。虽然所获得的 DT 燃烧温度相当低（～0.5千电子伏），但是 10^7 的中子产额意味着我们所获得的惯性约束同时间的乘积($n\tau$)已大于 3×10^{14} 厘米$^{-3}$。

为 Shiva 装置发展了广泛的靶诊断装置。这些诊断装置常规地用于测量内爆靶的中子产额及谱分布、能量平衡、α 粒子、β 粒子、X射线、光学、离子和质子谱以及时间、空间和光谱分辨的X射线、α 粒子辐射。发展了四种手段，用以研究聚爆动力学和确定聚爆靶丸的燃料密度。第一种是中子时间间隔定位。它用于测量激光脉冲峰值和其后聚爆燃料所发射的中子辐射之间的时间间隔。将这些结果与计算机编码相比较，可间接推知靶的性能。第二种，也是较直接的技术，是利用X光谱仪成象技术来测量在中子峰值产额时间基点处引入 DT 燃料的氩示踪气体的空间伸展。将这些结果与爆炸推进实验所使用的 α 粒子编码板成象技术所得到的结果相比较，发现两种方法的结果相当符合。氩成象的摄谱技术将用于中等等离子体密度范畴的测量，这时由于 α 粒子的射程，无法使用编码板成象技术。第三种使用放射化学技术，或中子活化技术，以便直接测量各种靶在峰值中子产额处平均密度与半径的乘积（$\rho\Delta r$）。由这些测量可以推断最终的 DT 燃料密度。第四种技术是X射线背景光照明法。产生一强X射线源并对这些X射线穿透靶的透过率做空间和时间分辨，就可以获得靶动力学的细节。最近我们在进行预备实验，演示这一技术的各个方面。

去年，我们用简单的整形脉冲辐射爆炸推进靶和消融驱动靶，中子产额比以前从这两种靶获得的都高。一系列脉宽90微微秒、功率15～20兆兆瓦的爆炸推进靶辐射实验，得到了3×10^{10}的最高中子产额，相应的 DT 离子温度约为 5 千电子伏。这些实验进一步加强了我们对于简单爆炸推进模型的信心。正如放化中子活化技术和氩谱、α 编码成象技术所推断的那样，爆炸推进靶还用来推算燃料密度，爆炸推进产生的高中子产额很容易生成靶壁激活硅，所产生的Al^{28} 的量足以探测出来，这使得有可能测定聚爆靶的 $\rho\Delta r$。然后将此实验所推断出的燃料密度与同次打靶获得的 α 粒子编码相机及氩成象谱仪的结果相比较。已经发展了一个简单的、把推进层 $\rho\Delta r$ 值与最后燃料密度关联起来的等压一等温模型。以0.1～1毫微秒、7～10千焦耳激光辐照为高压缩设计的消融驱动靶所产生的最高中子产额为 1×10^8。据观察，单次实验的DT燃料密度可达 20 克/厘米^3，平均值为 10 克/厘米^3。本文将评论这些实验和另外一些实验的结果。