LLL laser fusion program overview * and future directions in laser fusion systems

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The primary goal of the inertial fusion program at the Lawrence Livermore Laboratory is to demonstrate the scientific feasibility of the inertial fusion concept using high power Nd: glass lasers. We anticipate achieving a most important milestone — ignition — with our full (300 kJ) Nova facility in the mid to late 1980's. Confidence in reaching this goal is based on the significant progress we have made in the state-of-the art high power Nd: glass laser technology, in diagnosing and executing laser fusion and laser plasma interaction experiments, and in theoretical and analytical computer codes which reliably model experimental results. Looking ahead to eventual civilian application, we are also making excellent progress in the areas of commercial reactor design, advanced target design and fabrication, as well as the advanced drivers required.

During the last year and a half, the inertial fusion program at the Lawrence Livermore Laboratory has seen a number of significant accomplishments. The Shiva laser facility, operating at 1.06 μm is capable of delivering up to 30 TW in 100 ps and 15 kJ in 1 ns to laser fusion targets. A large number of diangostics have been developed to study the basic laser plasma interaction phenomenon and to diagnose our implosion experiments. Special care has been taken to develop the capability to cross correlate our density diagnostics throughout the experimental parameter space. Using these diagnostics and the Shiva facility we have progressed from exploding pushers, where up to 3×10^{10} neutrons have been obtained at DT ion temperatures of approximately 5 keV, to ablatively driven implosions, where final fuel densities in excess of 50 times the liquid density of DT have been observed at DT ion temperatures of approximately 0.5 keV.

Using the smaller Argus facility operating at the Nd: glass wavelength of 1.06 μm and its harmonics (0.53 μm and 0.35 μm) we have conducted a series of basic laser plasma interaction experiments. Experiments at the frequency quadrupled wavelength of 0.27 μm are also planned. Results obtained so far are in good agreement with the theoretical predictions which indicate that as the laser wavelength decreases, the absorption increases, while such effects of stimulated Brillouin scattering and hot electron generation decrease. These experiments are designed to answer the important questions of wavelength scaling in laser fusion and will be crucial in determining the optimum wavelength choices for Nova.

Over the last year and a half we have also made significant progress in experiments quantifying such processes as absorption, hot electron generation and stimulated scatter-

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ing at pulse lengths greater than 500 ps. The good agreement between our computer codes and these experimental results show that we have a good understanding of the basic laser plasma interaction phenomena at these conditions, as well as the short pulse length, high intensity regimes that were studied extensively in previous years.

The development of fluorophosphate glasses, high damage level optical coatings, the technology to fabricate high quality optics at apertures exceeding one meter and the routine operation of the 20 chain Shiva laser as a target physics experiments facility guarantees the performance and operation of Nova at the 300 kJ level (1.06 μm). The routine operation of Argus at the frequency doubled wavelength, 0.53 μm, with a 70% conversion efficiency also guarantees that Nova could operate at multiples of the basic frequency at a moderate cost in energy. The actual choice of wavelengths will thus be a trade-off between the cost in energy and target performance. The flexibility of operating Nova at several wavelengths and energies up to 300 kJ is vital to the achievement of the objectives of the U. S. National ICF program.

Looking beyond ignition towards scientific feasibility and eventual commercial application of laser fusion we have designed an upgrade to Nova which would provide 1 — 2 MJ of energy at 0.53 and 1.06 μm, respectively using existing Nova solid state laser technology. This is a particularly attractive option for a facility to bridge the gap between Nova and the construction of a single pulse test facility (SPTF) to demonstrate high gain targets for civilian energy applications.

We have also made significant progress in the area of traget design and traget fabrication techniques required for reactor type pellets. Multi-layered complex targets with surface qualities exceeding reactor design requirements have been produced. Using present day materials and technologies we have developed a reactor design (HYLIFE) which minimizes first wall problems by utilizing a multiple-stream liquid lithium waterfall concept.

Two promising approaces have been identified for advanced drivers: heavy ion accelerators and the krF pulse-compressed (stacker Raman hybrid) laser as a UV laser source with a projected efficiency of up to 5%. This latter concept is actively pursued at LLL and the use of KrF as well as other rare gas halide lasers operation in this mode continues to look very promising. Using our RAPIER KrF laser system we have demonstrated the Raman pulse compression technique obtaining a 75% conversion efficiency with a temporal compression ratio of 5, using pure angle multiplexing we have demonstrated a 3–fold pulse compression from 60 to 20 ns at the 10 J level.

Early investigations and experiments using vanadium doped magnasium fluoride (V: MgF_2) look very encouraging with projected efficiencies of up to 10% and pulsed repetition rates of several Hz. If scalable the combination of V: MgF_2 and the multipass regenerative concept thus offeres the potential of developing a reactor driver using our well developed and well understood large aperture, solid state laser technology.

劳伦斯·利佛莫尔实验室聚变计划概貌及激光聚变系统今后的方向

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利佛莫尔实验室惯性聚变计划的最初目标是用高功率钕玻璃激光来演示惯性聚变概念在科学上的可能性。我们期望用我们总计300千焦耳的Nova装置在80年代中到末期到达一个十分重要的里程碑——点火。确信能达到这一目标，是因为在下列各方面已取得重大进展：高功率钕玻璃激光器的工艺水平，诊断激光聚变实验的实施，激光等离子体相互作用实验，可靠地模拟实验结果的理论和分析计算机编码。展望最后的工程应用，我们在商用反应堆设计，在先进的靶及所需的驱动器的设计和制造方面，也正在取得迅速进展。

在过去的一年半里，劳伦斯·利佛莫尔实验室的惯性聚变计划已经获得若干重大成就。工作于1.06微米的Siva激光装置能在100微微秒时间内将30兆兆瓦激光功率或1毫微秒时间内将15千焦耳能量输出到激光聚变靶上。发展了大量诊断设备，用以研究基本的激光等离子体相互作用现象，诊断我们的聚爆实验。在全部实验参数中，我们特别关注发展若干互相交叉的密度诊断手段。使用这些诊断设备及Siva装置，我们已经从得到了3×10^{10}个中子、5千电子伏离子温度的爆炸推进实验发展到消融驱动内爆实验。在消融实验中，观察到最终燃料密度超过DT液体密度50倍，DT离子温度接近0.5千电子伏。

我们已经使用工作在钕玻璃波长1.06微米及其谐波0.53微米及0.35微米的较小的Argus装置做了一系列基本的激光等离子体相互作用实验。四倍频波长0.27微米的实验也在计划之中。理论预言，随着激光波长的减小，吸收增加，而受激布里渊散射及热电子效应则减弱。到目前为止所得到的结果与理论预计十分符合。

设计这些实验的目的是回答激光聚变中重要的波长定标律问题，这在确定Nova最佳波长选择方面将是至关重要的。

一年半来，我们还在定量研究某些过程（例如吸收过程、热电子产生过程和脉冲长度大于500微微秒的受激散射过程）方面取得了重大的进展。我们的计算机编码与这些实验结果十分符合。表明了我们对于在这些条件下的激光等离子体相互作用基本现象以及对于短脉冲高强激光范畴都有深刻的理解。后者是在前几年广泛研究的课题。

发展氟磷酸盐玻璃、高破坏阈光学涂层、制造口径超过1米的高质量光学器件的技术以及20路Shiva激光器这一靶物理实验装置的常规运转为300千焦耳1.06微米波长的Nova装置的性能和运转提供了可靠保证。转换效率70%、工作在倍频波长0.53微米的Argus的常规运转也保证了Nova能以适中的能量代价在倍频下工作，因此实际上的波长选择将是能量代价与靶性能两者之间的折中。Nova装置可以在若干波长上工作，并达到300千焦耳能量。这两点对于美国国家惯性约束聚变计划课题的成功是至关紧要的。

指望着实现点火，证实科学上的可行性乃至最终完成实用规模的激光聚变，我们利用现有的Nova固体激光技术设计了高级的Nova。它将能在0.55微米和1.06微米提供1～2兆焦

耳激光能量，这个装置很有前途，可望填补为演示实际规模能量应用高增益靶建造的“单脉冲试验装置”与 Nova 装置之间的空隙。

我们在靶设计领域以及反应堆型靶丸所需的制靶技术方面也取得了重大进展。已经生产出表面质量超过反应堆设计要求的多层复合靶。使用现有的材料和技术我们发展了一个反应堆设计（HYLIFE）。这一设计通过利用多重流动液锂瀑布概念使得（反应堆）前壁问题的困难减到最小。

已经确定了两条有希望的途径来发展先进的驱动装备，即重离子加速器及氟化氪脉冲压缩（喇曼混频堆积器）激光器。该激光器是设计效率高达5%的紫外激光源。利佛莫尔实验室正在积极从事后一个途径的研究。KrF的应用以及其它稀有气体卤化物激光以此模式的工作看来仍旧很有前途。使用我们的“RAPIER”氟化氪激光系统，我们已经演示了喇曼脉冲压缩技术，得到了75%的转换效率，其时间压缩比为5。使用纯角度倍加法我们在10焦耳能量水平演示了从60到20毫微秒的3倍脉冲压缩。

早期使用掺矾氟化镁的研究和实验看来是非常鼓舞人心的。这一系统制成的激光器的设计效率可高达10%，脉冲重复率为几赫芝。假如可按比例放大 V: MgF_2 和多通再生概念结合，就会为使用我们已发展成熟和深刻认识的大孔径固体激光技术，研制反应堆驱动装置提供可能。