MASTER

METAL VAPOR RAMAN COMPRESSOR

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I. INTRODUCTION

The high efficiency and short wavelength of the rare gas halide lasers make them potentially attractive drivers for inertial confinement fusion. However, the lack of energy storage capability constrains their operation to pulse durations which are more than an order of magnitude too long for the ICF application. Therefore, efficient means for the time compression of rare gas halide laser pulses must be found if they are to play any role in ICF in the future. A conceptually simple method for accomplishing this is pulse compression in a backward Raman amplifier. The feasibility of this idea has recently been demonstrated with the KrF laser as pump and CH_4 as the Raman medium.¹ At NRL, an alternate system based on the XeCl laser as pump and Pb vapor as the Raman medium has been proposed.² The NRL scheme has the advantage that a near resonance with an intermediate state for the first Stokes and the lack thereof for the second Stokes permit the attainment of larger compression ratios without incurring second Stokes parasitics in the backward direction. The relevant waves and energy levels for this scheme are shown in Fig. 1. The objectives of the present work were to demonstrate the feasibility of a long Pb vapor cell and to assess the potential of the XeCl-Pb system as a Raman pulse compressor.

For this work, a narrow bandwidth XeCl laser was developed and an 8 m Pb vapor cell was constructed. Details on the laser device and the results of the experiment are given in the following sections.

Fig. 1

II. INJECTION LOCKED XeCl LASER

The laser source used for these experiments was an x-ray preionized, XeCl discharge laser, based on a device described by Lin and Levatter,³ and designed and built at NRL. A sketch of the device is shown in Fig. 2. The laser head is machined from a solid aluminum block, and has interior dimensions 15 x 15 x 105 cm, with walls 2.5 cm thick. The electrodes, separated by 3.5 cm, have a modified Rogowski profile, and the discharge region is approximately 80 cm long. The interior walls are lined with Kynar plastic to prevent arcing, and the top electrode is supported by a block of the same material, which serves as the insulation for the high voltage feedthrough. The laser windows are tilted at $1\frac{1}{2}^\circ$ to the optical axis, and have a clear aperture of 3.8 cm. The x-rays for preionization are provided by a small electron-beam gun below the laser chamber. The cathode of the e-gun is a single $\frac{1}{2}$ -mil tantalum foil edge, and the anode is a similar foil, 2.7 cm away. Electrons striking the high-z anode are stopped, producing x-rays which travel upwards, through a 1/16th aluminum plate which separates the e-gun chamber from the laser, and then through the 1/16-inch aluminum cathode of the laser to ionize the gas mixture. The e-gun is driven by a compact, low-inductance, two-stage Marx bank with .04 μ f/stage. The Marx bank is capable of 200 keV operation, although in practice it has been operated at the lowest voltage at which the switches fire reliably, approximately 100 keV. At this setting the total current from the e-gun is about 2400 A and the preionization density in a typical laser mix has been measured to be 10^9 cm^{-3} .

The energy for the laser discharge originates in the high voltage storage capacitor which pulse charges a 3-plate water transmission line, 183 cm long by 80 cm wide, with plate spacing of 1.9 cm. The water line

Fig. 2

is connected by a polyethylene insulated strip line to a pressurized rail gap, which in turn is connected by a similar strip line to the feedthrough of the laser head. The water line and strip lines are calculated to have an impedance of $\frac{1}{2}$ ohm, and the capacitance of the water line is .11 μ f. In operation, the Marx bank switches and the storage capacitor switch are fired simultaneously by a low jitter commercial trigger generator. The electron beam current rises in 50 ns, while the preionization density rises more slowly, reaching its peak in a few hundred nanoseconds and then slowly decaying. Simultaneously, the voltage on the self-triggered rail gap rises as the water line is charged until the switch fires at a voltage determined by the pressure in the rail gap. The voltage on the laser head then rises very rapidly until the gas breaks down. The discharge voltage is measured by a commercial high voltage probe at the top of the anode feedthrough and the discharge current is measured by a Rogowski belt around the feedthrough. Because of the requirement that the laser be injection-locked, efforts were made in the design to minimize jitter in the laser circuitry. The crucial components are the trigger generator and storage capacitor switch, both from a commercial supplier, and the rail gap. The specification on the jitter for the commercial components was 1 nsec. The jitter of the rail gap is dependent on the rise time to the self-triggered switch. Accepted practice assumes a jitter of 1% of the rise time, and for this reason the inductance of the pulse charging circuit was minimized, resulting in a rise time of the voltage at the rail gap of about 250 ns. When operated for injection-locking, the jitter of the laser has been observed to be less than 5 ns.

The laser is injection-locked using two small uv-preionized lasers of standard laboratory design, one operated as an oscillator and the other as an amplifier. The oscillator is a short discharge device, 40 cm long.

It has a stable resonator consisting of a grating and curved output mirror, with two intra-cavity etalons and an aperture to achieve narrow band operation. The gas mixture is relatively rich in HCl and Xe to maximize the gain. The amplifier is 70 cm long and is operated with a relatively lean mixture to avoid super-radiant emission. The output from this combination is a $\frac{1}{2}$ millijoule pulse, with FWHM of ~ 10 nsec. This pulse is injected through the 80% reflective back mirror into the unstable resonator cavity of the x-ray preionized laser. The positive branch unstable resonator cavity has $M=10$, using a scraper mirror with a 3 mm hole as the output coupler. Because of the spacing of the convex mirror from the scraper, the output beam is severely apertured, with a "good" beam 2 cm in diameter. A sketch of the optical layout of the injection-locked system is given in Fig. 3. Successful injection-locking was monitored by observing the laser spectrum with an Optical Multichannel Analyzer, and the bandwidth of the laser was observed to be $< 0.05 \text{ cm}^{-1}$, using a Fabry-Periot interferometer.

The x-ray preionized laser was operated with both He/Ar/Xe/HCl and Ne/Xe/HCl mixtures. The latter was found to yield longer pulses of higher energy, although the laser power was approximately the same. The neon buffer also apparently broadened the discharge, so that the output beam was more homogeneous. While the laser output has been as high as 2.5 J, with 30 MW of power using a stable resonator, the smaller area of the unstable resonator mode, together with some additional losses (probably due to deterioration of the optics), resulted in much smaller energies and powers during these experiments. The output energy in the "good" beam was typically .5 J with the He buffer, and 0.8 J with the Ne buffer. In both cases, the typical output power in the established beam was about 8 MW.

XeCl INJECTION-LOCKING ARRANGEMENT

SYSTEM JITTER $\leq 2 \text{ ns}$

LINEWIDTH $< 0.1 \text{ cm}^{-1}$

INJECTED PULSE. 1 mJ, 12 ns FWHM

OUTPUT PULSE $> 1.0 \text{ JOULE}$, 70 ns FWHM

Fig. 3

III. BACKWARD RAMAN AMPLIFICATION IN Pb VAPOR

A schematic for the pulse compression experiment is shown in Fig. 4. For this work, the unstable resonator on the XeCl regenerative amplifier was arranged to give a slightly converging beam which focused at a distance of approximately 25 m from the output mirror. The nearly circular output contained, in addition to the central dark spot, corresponding to the hole in the scraper, a set of closely spaced rings where the intensity is appreciably higher than in the space in between. A circular aperture was used to pass a portion of the beam between the outer edge and the central hole. This beam was split into two beams by a partial reflector. The stronger one containing 150 mJ was used to pump the backward amplifier, and the weaker one containing 30 mJ was focused into a 1 m Pb vapor cell with a 2 m focal length lens. The pump beam had a diameter of 1 cm as it entered the amplifier and a diameter of 5 mm upon exit. It was then passed through an aperture of the same diameter and stopped by a lucite plate to avoid damage to the turning mirrors for the input Raman beam. It was verified that the simultaneous irradiation of the lucite plate by the intense pump beam did not affect the transmission of the input Raman signal, although noticeable damage on the surface of the plate did develop after a large number ($\sim 10^2$) of shots.

Approximately 20% of the 30 mJ pump into the 1 m Pb vapor cell was converted to Raman output. The temporal behavior of the Raman output was quite erratic. Two examples of the Raman output from the oscillator are shown in Fig. 5. The uy component of the emerging beam was removed by a filter, while the Raman component was recollimated by a 1 cm focal length lens so that it approximately matched the pump beam in the amplifier. The Raman beam was delayed with respect to the pump beam by about 30 nsec (i.e.,

Fig. 4

Fig. 5

the leading edge of the input entered the vapor zone 30 nsec after the leading edge of the pump beam has left it) so it would interact with the mid 50 nsec portion of the pump where the intensity is the highest. The Raman pulse just before entering the amplifier had a typical energy of 3 mJ.

To provide for the backward interaction with a 50 nsec pump pulse, a 10 m cell with an 8 m heated zone was constructed. A piece of 304 high temperature, low carbon stainless steel pipe with 2" O.D. and 1.5" I.D. was used for that purpose. Slightly oversized ceramic tubes were slid over the stainless steel over the entire heated zone before it was placed inside semi-cylindrical heaters. The purpose of the ceramic tubes was to prevent the heaters from "seeing" the stainless steel which tends to have a reducing effect on the heaters and would otherwise cause rapid erosion of the heaters at the operating temperatures. Five pairs of semi-cylindrical heaters nominally rated for a maximum temperature of 1200°C served as the heat source. The entire assembly was then surrounded by firebricks. Due to the length of the cell, stainless steel wicks were used only near the ends of the heated regions. This appeared to be a totally satisfactory means of filling the entire hot zone with the metal vapor even at the high diluent gas pressures used. A major drawback of this Pb vapor cell was that in spite of the proximity of the adjacent heater pairs, substantially colder regions still resulted where the heater pairs met. While these colder regions (of several cm in extent) did not appear to affect the overall metal vapor pressure, they probably contained substantially larger fractions of dimers and higher n-mers, which can absorb both the pump and Raman radiation, than the uniformly heated regions.

Some examples of the backward amplified Raman pulses are shown in Fig. 6. The vertical scale here is the same as for the input Raman pulses shown in

Fig. 5. These data were obtained at a temperature of 1080°C, corresponding to a Pb vapor pressure of 4 torr, and a He pressure of 300 torr. Under these circumstances, the integrated backward Raman gain was in the range of 5-10. This is in reasonable agreement with an earlier measurement of the gain coefficient for stimulated forward Raman scattering in which Ar was used as the diluent gas.⁴

Spontaneously generated Raman emission in the forward direction was also observed from the amplifier. The substantially higher Raman gain in the forward direction is believed to have resulted from a combination of temporal spikes (see Fig. 4), spatial hot spots, and the forward-backward gain asymmetry, with the last estimated to contribute no more than a factor of two towards the difference for the pump bandwidth used. At temperatures exceeding 1100°C absorption of the pump radiation became evident. The absorbing species appeared to be saturable, since the absorption was most pronounced near the leading edge of the pump pulse. The absorption is most likely due to the dimers and higher n-mers of Pb. If it were due to the dimer alone, the estimated saturation fluence would indicate that the hot-to-cold transition regions (both near the ends and at the heater discontinuities) contained nearly an order of magnitude more dimers than the uniformly heated regions (calculated on the basis of equilibrium data).

IV. DISCUSSION

At the outset of this work it was felt that the construction of the 8 m Pb vapor cell would probably pose the gravest problem in the experiment. While some initial difficulties were in fact experienced, the oven worked with great reliability in its final configuration. The most severe drawback of the current design is the presence of colder sections at the heater discontinuities. These cold regions are believed to have been responsible for producing the dimers and larger clusters of Pb which in turn led to pronounced absorption of the pump beam at temperatures in excess of 1100°C. On the positive side, no distortion of either the pump beam or the Raman beam was evident even at the highest temperature (~ 1200°C) to which the oven was taken.

The experiment suffered from the lack of a spatially and temporally uniform pump beam. The attainment of a pump beam which is clean both in space and time should clearly be a prerequisite in any backward Raman pulse compression scheme. While pulse compression was not achieved in the present experiment, a backward Raman gain coefficient was deduced from the experimental data. It is approximately $7 \times 10^{-10} \text{ cm W}^{-1}$ at 1080°C (corresponding to 4 torr Pb vapor) and for 300 torr of He buffer gas.

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