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Using the SBS phase conjugation and pulse compression technique, a conventional long pulse ruby laser was successfully converted to give 300 ps pulses at 1 Joule energy level. The technique allows the use of smaller amplifiers than required in a conventional short pulse laser which in turn leads to operation at increased repetition rate. The completed laser when operated at 1.5 Hz produces stable output parameters. Each laser pulse is characterised by a sharp rise and a measured pre-pulse level of less than 10^{-6} *of the main pulse, making it suitable for LIDAR Thomson scattering measurements.*

INTRODUCTION

LIDAR (light detection and ranging) Thomson scattering as applied at JET[1] requires the use of a short pulse (300 ps) ruby laser. The laser has to operate at or near the ruby wavelength in order for the scattered spectrum to fall in the wavelength region of fast high gain detectors, either a streak camera or MCP photomultipliers. The minimum energy required per pulse in this application is about 1 Joule. In the existing LIDAR Thomson scattering diagnostic a 4 Hz modelocked laser is used. For the new divertor diagnostic we found it useful to investigate the possibility of using Stimulated Brillouin Scattering (SBS) pulse compression[2,3] to achieve the desired laser parameters. Previous work with Nd-lasers using this technique both for the fundamental wavelength and at the frequency doubled wavelength suggested that this should be possible.[4,5,6] A further driving motive for this work was the availability of an existing long pulse ruby laser that could potentially be converted at a relatively low cost.

Thermal distortions normally found when operating at higher repetition rates are compensated, if the SBS compression is made to work with phase conjugation. Like any other compression technique, SBS used in post-compression offers the possibility of reducing the power level at the amplifiers thus allowing smaller aperture amplifiers. For these reasons we expect more readily to be able to operate at higher repetition rates.

I. GENERAL DESCRIPTION

A. Description of Laser

The laser consists of an oscillator, a telescope with 7 times magnification, a spatial filter, two double pass amplifiers, two compression cells, three Faraday isolators and one quarter wave isolator. The oscillator consist of a 6 mm diameter x 100 mm flashlamp pumped ruby rod inside an optical cavity. The cavity consists of a plane mirror at one end and a multiplet etalon output coupler, a saturable absorber glass for passive q-switching and a 1.4 mm aperture for transverse mode selection. The cavity is a three-rod Invar structure of 715 mm length.

The spatial filter inside the telescope generates a gaussian intensity distribution of the beam. Each of the Faraday isolators consists of a Faraday rotator, a 45^{o} quartz rotator and a dielectric polarizer. The Faraday rotators use permanent magnets and either Tb-glass or a TGG crystal for the final isolator operating at high power. The compression cells are 4 m stainless steel tubes filled with mixtures of Argon and SF_6 at approximately 20 atm. pressure (Fig. 1).

The oscillator generates a single transverse, single longitudinal mode 20 ns pulse of 7-8 mJ energy. This pulse is expanded by the telescope to overfill the amplifier aperture. The pinhole inside the telescope generates a proper gaussian intensity distribution. Two identical amplifiers (12.5 mm diameter x200 mm) amplify the input beam with a combined single pass amplification of ~ 50 . The focusing of this pulse into the compression cell is achieved entirely by the thermal focusing of the two amplifiers operated at ~ 1.5 Hz. The effective focal length is of order 2.5 m. The 1.2 ns compressed pulse from the first compression cell is reflected with better than 50% efficiency. After the second amplification this pulse reaches an energy of ~ 3 J.

The second stage of compression is completely passive. The pulse after first compression goes through a quarter wave isolator and is focused by a 1.3 m focal length lens into a gas mixture to give a 300 ps reflected pulse. The energy of this pulse is ≥ 1 J.

B. Oscillator

It is imperative for SBS pulse compression that the laser pulse is a single longitudinal mode and has uniform spatial distribution. The cavity is a plane-plane cavity with a multiplet etalon as the output coupler. The surfaces of the multiplet etalon are formed by two uncoated quartz etalons, 20 mm and 2.5 mm thick respectively and a 120 mm long quartz tube. The oscillator operates as a passively q-switched oscillator by using a saturable absorber glass. Single mode operation is realised when pumping the rod slightly above threshold. Single transverse mode is selected by an appropriate size aperture in the cavity.

With the chosen etalon and cavity length we find that single mode operation is always observed. Amplitude stability should be better than ± 10% to guarantee stable operation of the complete laser. Fig. 2 shows the amplitude stability of a series of 20 laser pulses in one pulse train. The FWHM pulse duration is 20 ns. The oscillator can be operated with shorter pulse duration by increasing the thickness of the saturable absorber. In some experiments we used 14 ns oscillator pulses. When operating too close to threshold the amplitude remains constant but the lasing time jitters by more than 100 μs. Large jitter means that the pulse does not occur at the time of maximum amplification of the amplifiers and consequently leads to variations of the final output amplitude. Increasing the oscillator capacitor bank energy by 3-6% results in stable operation with jitter less than 50 μs.

C. Amplifiers

The absorption of the pumping radiation is highly dependant on the c-axis of the ruby material. The orientation of the c-axis in rods used for ruby lasers is not collinear with the geometric axis of the rod to get maximum amplification. This non symmetry causes cylindrical distortion of the amplified beam. The degree of distortion becomes worse as we increase the repetition rate. To overcome this problem we have used two identical amplifiers with the planes containing the c-axes of the two crystals oriented orthogonally. Between the two amplifiers we use a 90 degree quartz rotator to match the polarization of the laser beam to the c-axes. The compensation of the thermal cylindrical distortion is verified by the observation of the far field distribution. We find the distribution after a single pass to be better than two diffraction limits when operating at the maximum repetition rate given by our power supplies, 1.5 Hz.

D. Compression Cells.

The compression cells are 4 m long stainless steel thick wall pipes with windows at both ends. The first cell is filled with compressed gas, typically 3 atm. of SF_6 and 20 atm. of argon. The SBS mirror is achieved by focusing the laser beam into this cell. The focal length required for compression depends primarily on the length of the pumping laser pulse. In our investigations we found that the thermal lensing of the two amplifiers was close to the optimum focusing required for the proper compression regime.[4] The thermal focal length was 2.5 m and we used this lensing only.

The pulse length resulting from the first compression is 1.2 ns (Fig. 3a). Our investigations showed that lower compression ratios can be achieved by choosing a longer focal length. By introducing a -4 m focal length lens before both amplifiers, a pulse length of 2 ns is observed (Fig. 3b). The optimum pulse duration for maximum efficiency of the second compression cell is about 2 ns. Pulse durations of less than 1 ns leads to poor efficiency of the second compression. Additionally this produces power loading close to the damage threshold of the optical elements near the end of the amplifiers, in particular the TGG crystal.

The second cell is filled with .3 atm. of SF_6 and 20 atm. of argon. The focal length of the second focusing lens was varied between 1 m and 1.6 m. For better interaction in the second compression cell, the cell is positioned at a distance of 8 m from the final aperture on the laser bench. At this distance the image of the last aperture is small and closely behind the focal point. No telescope is used between the two compression stages. Instead we chose to weakly focus the beam entering the amplifiers (~ 7 m focal length) which in turn leads to a divergent beam reflected from the first compression cell. This makes the beam size sufficiently large to avoid damage of optical components after the second compression and moves the focal point nearer to the image point of the output diaphragm. The dependence on the incident beam duration is illustrated in Fig. 4. Fig. 4a corresponds to a .6 ns pumping pulse, Fig. 4b is for a 1.2 ns pulse and Fig. 4c is for a 2 ns pulse. The energy of the pumping beam in all three cases is about 3 J and the energy of the compressed beam of order 1 J. In all three cases we get pulse durations of ~ 300 ps. The .6 ns pump beam was created with a shorter oscillator pulse (14 ns). Operation in this mode caused damage of the TGG crystal. The 1.2 ns beam was chosen for convenience of operation with focusing by ruby rod thermal focusing only. The far field intensity distribution of this second compressed beam was about twice the diffraction limit and the size of the output beam at the image plane was equal to the size of the pump beam at the same location.

E. Isolators

For lasers with SBS phase conjugation mirrors, polarization dependant isolators are required because all parameters of the incident and the reflected beams are equal. In our laser we use two types of isolators, Faraday isolators and quarter wave plate isolators. Faraday isolators are used when circular polarization can not be tolerated which is the case for ruby rod amplifiers. The contrast of each isolator is ~ 100. To guarantee that the reflected beam from the first compression does not reach the oscillator with sufficient energy to cause a second oscillator pulse we need three isolators.

II. RESULTS

An important parameter of the laser pulse used for LIDAR Thomson scattering measurements is the pre-pulse and post-pulse level of lasing. A typical specification is a pre-pulse level of 10^{-8} of the main pulse and a post-level of 10^{-6}. This specification is mainly aimed at a mode-locked laser with low energy pulses at 10 ns intervals which can take a shortcut in the optical path and arrive at the detectors simultaneously with the scattered signal. Such pre- and post pulses do not exist in this scheme. Measurements using a streak camera at high gain show a pre-lasing level of less than 10^{-6} to within 300 ps of the peak of the main pulse. The absence of pre-pulses is a natural consequence of working above the threshold for Stimulated Brillouin Scattering and the large difference in cross section relative to spontaneous Brillouin scattering.

During these investigations the laser was mostly operated at 1.33 Hz. The limit for the given power supplies was 1.5 Hz. At these repetition rate we find that we have nearly reached thermal equilibrium of the amplifiers after six pulses. A mechanical shutter stops the first six oscillator pulses from going to the amplifiers. The stability of both the oscillator and of the final output pulse is illustrated in Fig. 5 which shows the energy of the oscillator and the energy of the final output pulse in a burst of 30 pulses. The figure shows the six pre-pulses in the oscillator train. The stability of the oscillator energy is better than ± 10 % and the stability of the output pulse is ± 15 %. There is no apparent correlation between the variation of the oscillator and the output energy. Note that the final output energy shows no sign of degradation during the period of the pulse train

The stability of the pulse shape was monitored by recording approximately every third pulse on a streak camera. Fig. 6 shows an overlay of 8 pulses. The pulse shape shows only minor changes and the duration of each pulse is constant. When changing repetition rate the thermal lensing of the amplifiers changes. To maintain proper conditions for compression the addition of a single lens is required. This lens should be introduced before the amplifiers and the focal length should be adjusted to maintain the position of the effective focal point in the compression cell.

III. CONCLUSIONS

An existing long pulse ruby laser was successfully converted to a useful laser for LIDAR Thomson scattering measurements, with 300 ps laser pulses of 1 Joule output energy. One of our objectives was to make the laser operate at the highest possible repetition rate. With the existing power supplies the laser operates at 1.5 Hz in 20 second bursts. We see no degradation in the performance in going from single pulse operation to this repetition rate. We feel that the limit to operation at higher repetition rates is given by the temperature rise that can be tolerated in the amplifier rods. We expect this limit to be in the range of 5 to 10 Hz.

During our investigations we also demonstrated operation at low repetition rate with a simple amplifier. Even in this case some compensation of cylindrical distortion is compensated by phase conjugation. Use of two crossed amplifiers is only required at higher repetition rates.

The characteristics of the laser with SBS pulse compression is in some ways better than a conventional mode-locked laser. Due to the non-linear process, the rise of the laser pulse is very steep which should in principle allow better time resolution of steep gradients in the plasma. The divergence of the output beam is less than twice the diffraction limit.

It should be pointed out that this technique not only applies to a ruby laser but could equally well be applied to other lasers, e.g. alexandrite or Nd-lasers at both fundamental and doubled frequencies.

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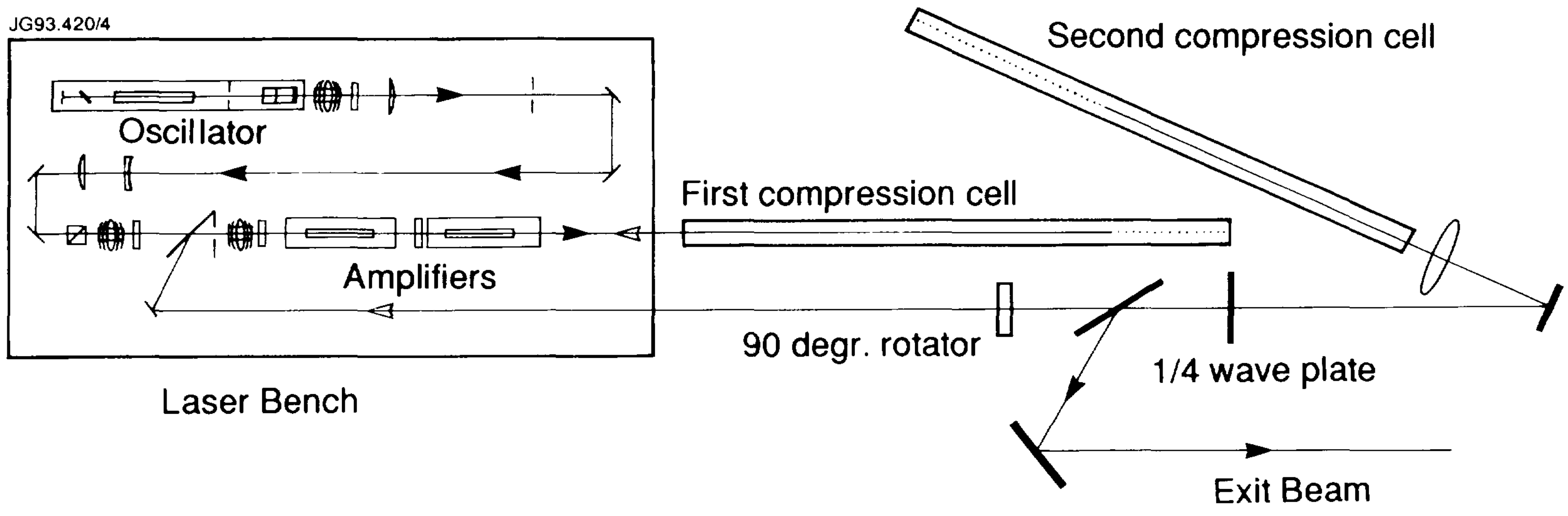

Figure 1 Layout of laser with compression tubes

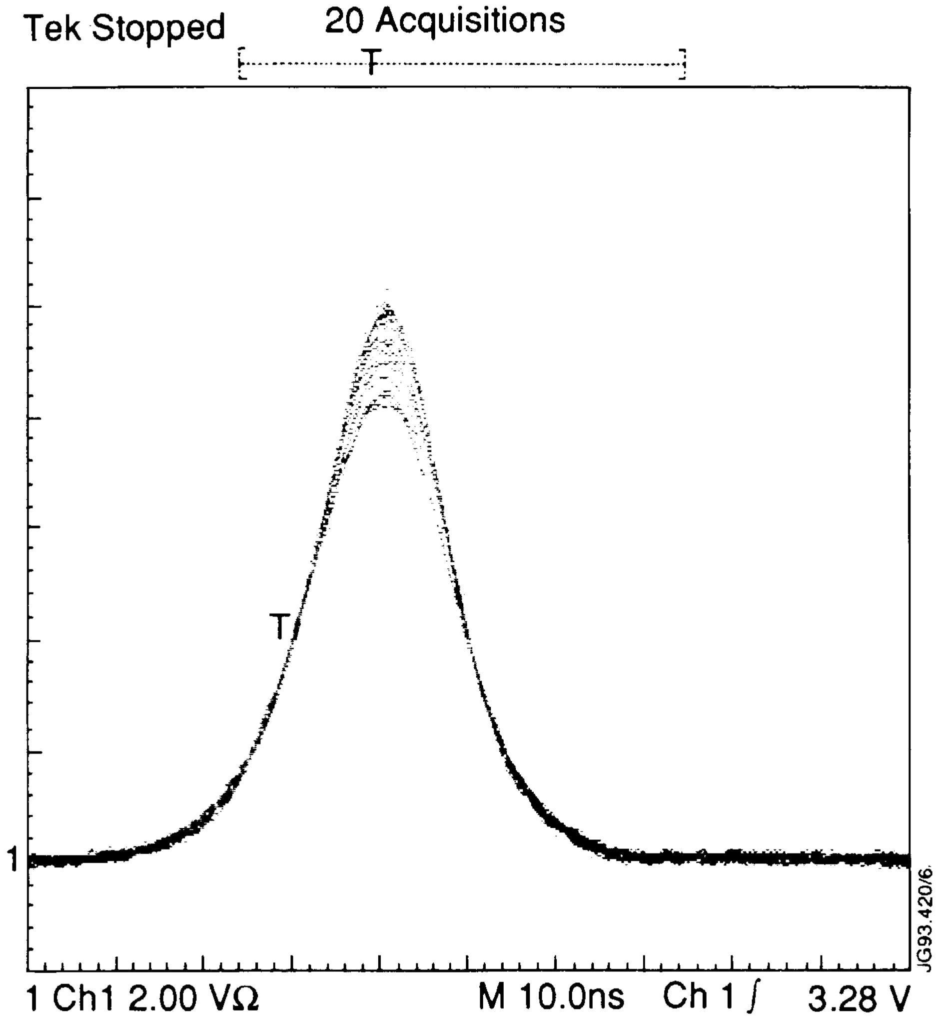

Figure 2 Oscillator pulse train (20 pulses).

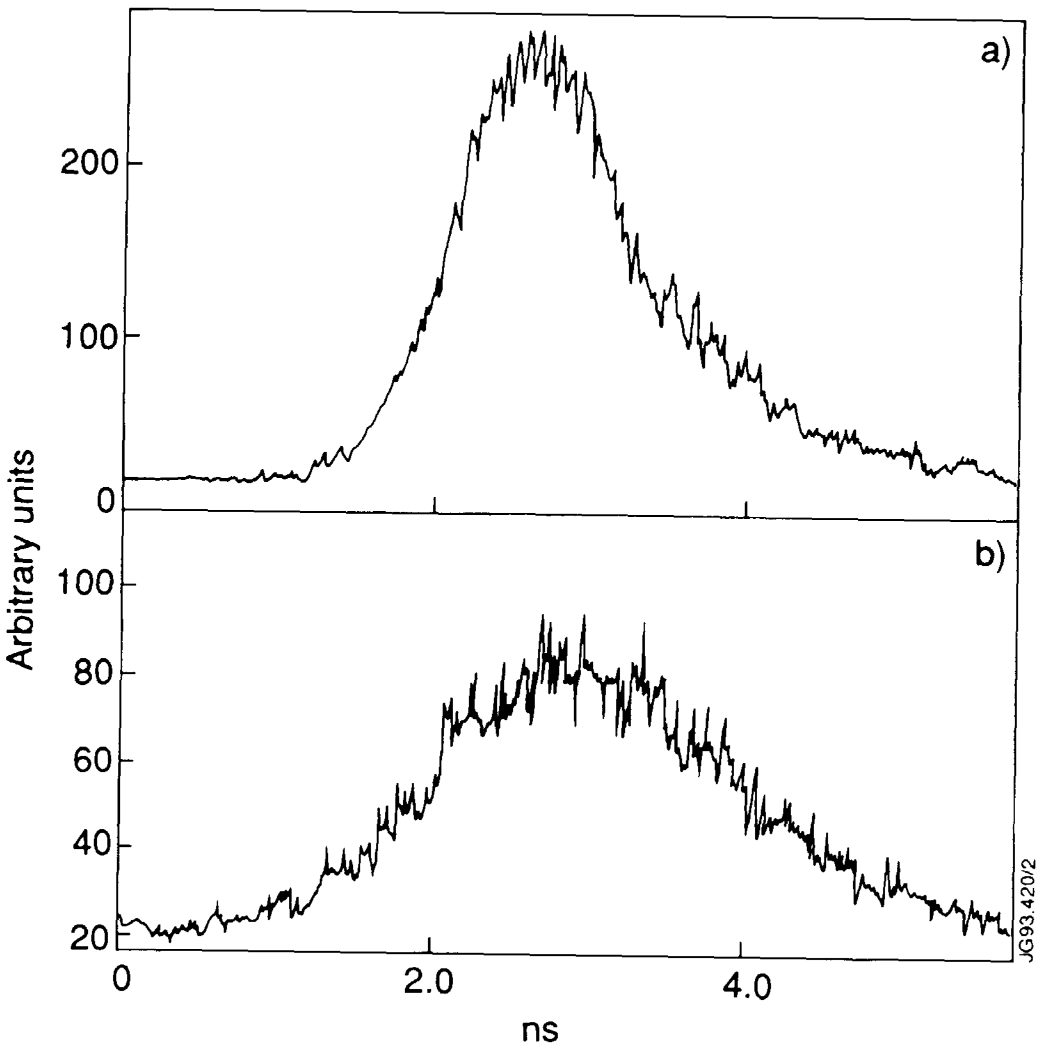

Figure 3 Pulse shape after first compression using 20 ns oscillator pulse. 3a) 2.5 m effective focusing lens. 3b) 4 m effective focusing lens.Horizontal scale: 10 ps/pixel

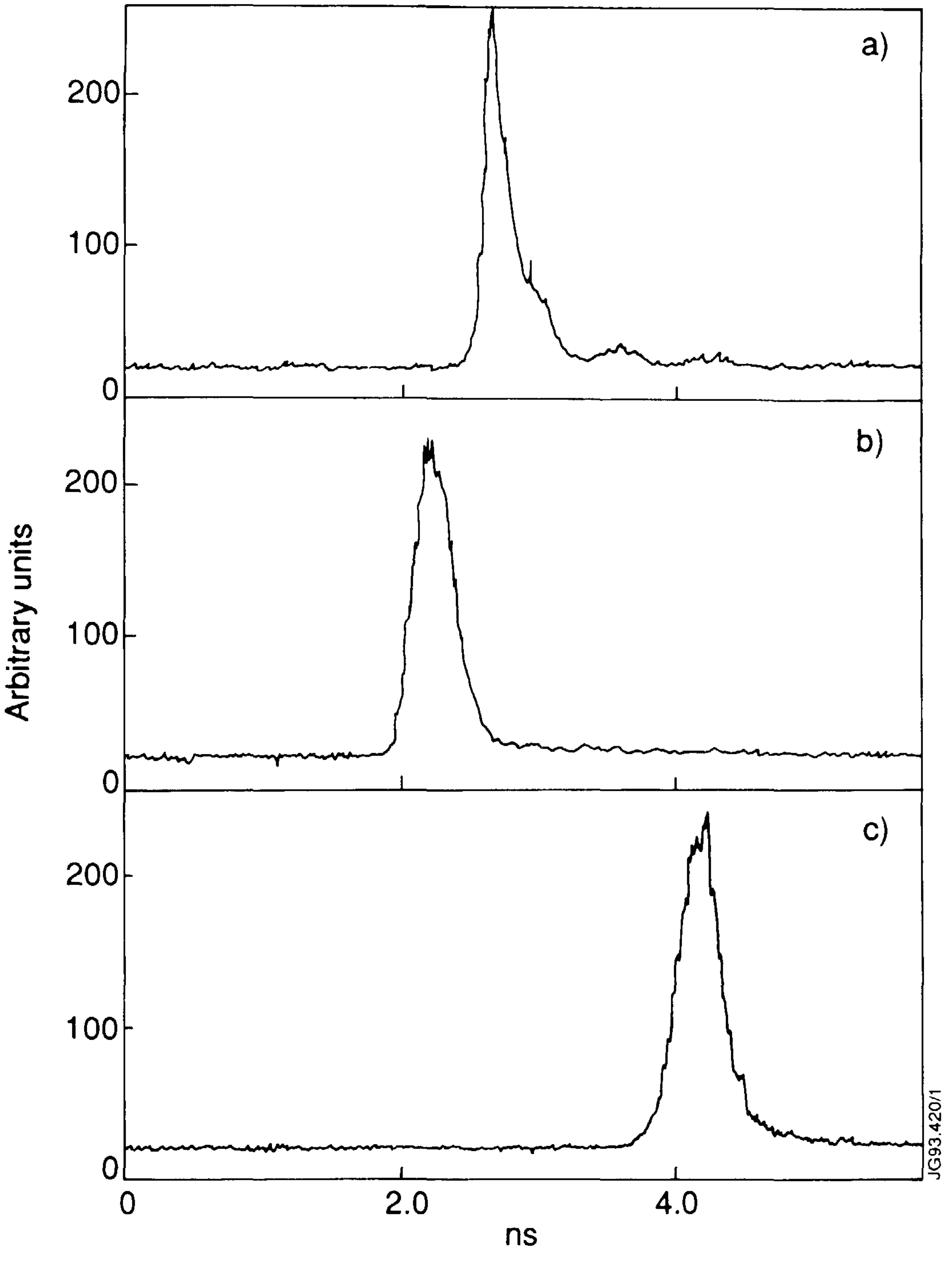

Figure 4 Pulse shape after second compression stage at near 1 Joule energy. Pulse duration of pumping pulse 4a) 0.6 ns., 4b) 1.2 ns and 4c) 2 ns.

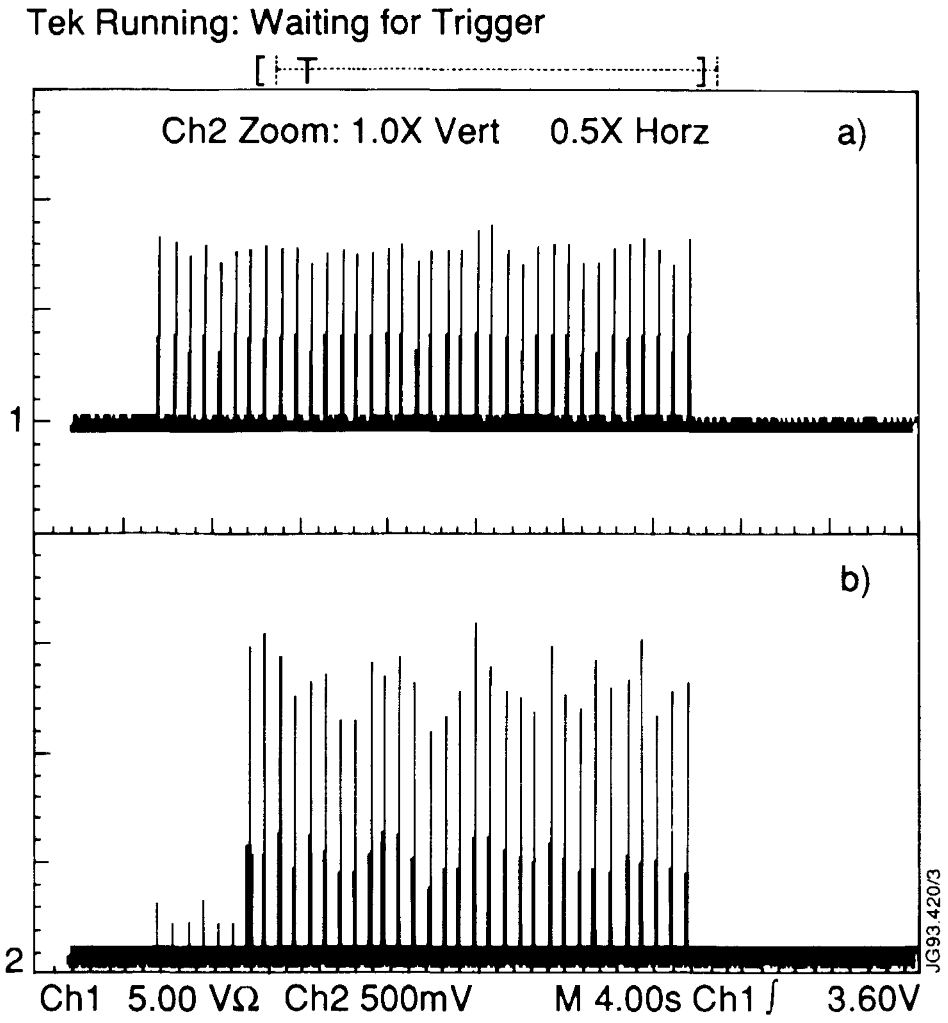

Figure 5 Stability of oscillator energy and final output energy in pulse train of 30 pulses. Top trace shows the oscillator energy monitor, bottom trace is the final output energy monitor.

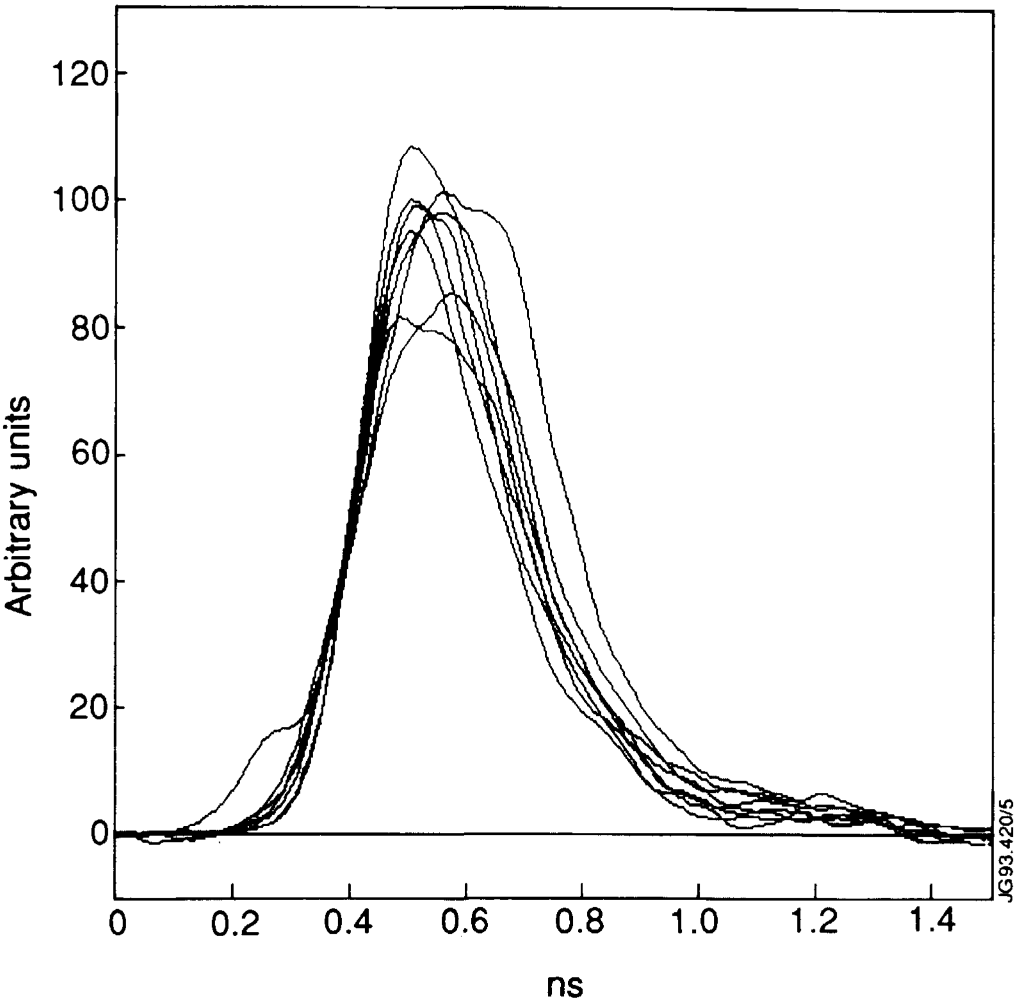

Figure 6 Stability of final output pulse shape in the same pulse train. 8 pulses are shown. Horizontal scale 1.5 ns.