CLM - P 232

CLM - P 232

United Kingdom Atomic Energy Authority

RESEARCH GROUP

Preprint

A TWO PULSE Q-SWITCHED HIGH POWER RUBY LASER

D. E. EVANS
M. J. FORREST

Culham Laboratory
Abingdon Berkshire

1970

CLM - P 232

A TWO PULSE Q-SWITCHED HIGH POWER RUBY LASER

by

D.E. EVANS
M.J. FORREST

(To be submitted to Journal of Physics E: Sci. Inst.)

A B S T R A C T

The optical cavity of the oscillator section of a giant pulse ruby laser has been split, by means of a pair of prisms, into two parts which can be Q-switched independently. The laser generates two equal multi-megawatt giant pulses during a single operating cycle, and the relative delay between the two is continuously variable over several hundred microseconds.

U.K.A.E.A. Research Group,
Culham Laboratory,
Abingdon
Berks.

February, 1970

CONTENTS

Introduction

Measurement of the electron temperature and density of laboratory plasmas by Thomson scattering of Q-switched ruby laser light has become a standard diagnostic technique. In the early work, the spectral distribution of the scattered light was constructed from the results of many plasma machine and laser discharges (DeSilva, Evans and Forrest 1964); subsequently multichannel spectrometers were developed (Watson and Beach 1969) and these permitted the acquisition of an entire spectrum from a single laser pulse. Improved methods of data-handling afforded by on-line computing facilities make it possible to contemplate measuring several scattered light spectra at different times during one plasma machine discharge, and this entails the use of a multi-pulsed Q-switched laser system. Such a laser should generate at least two multi-megawatt giant pulses during a single operating cycle, and the relative delay between the two should be within the operator's control and continuously variable over several hundreds of microseconds.

Existing Multiple Pulse Lasers

Sequences of pulses have been generated by repetitively Q-switching continuously pumped YAG:Nd (Geusic, Hensel and Smith 1965, Smith and Galvin 1967) and ruby (Evtuhov and Neeland 1969) using rotating high reflectivity mirrors. These systems are characterized by low pulse power (~ 30 kW) and long delay between pulses (> 5 msec) and are consequently unsuitable for use in plasma scattering experiments.

A double giant pulse ruby laser employing a conventional electro-optically shuttered resonant cavity has been built (Wetzels and Alfs 1969) in which the optical shutter, a Pockels' cell, is opened and closed twice during a single laser discharge. On the first occasion, the shutter is only partially opened so that the resulting pulse is inhibited from removing the entire inverted population, and the time for recovery of the inversion is correspondingly reduced. Two pulses of equal power, spaced in time between 100 nanoseconds and 400 microseconds are obtained.

A technique for forcing the rapid restoration of the population inversion in an otherwise conventional laser has been exploited by Fourney, Matkin and Waggoner (1969). By discharging a secondary condenser into the pumping lamp shortly before the second pulse is required, pairs of equal power pulses separated by 10 to 20 microseconds have been produced.

A random multiple giant pulse output can be generated by Q-switching a laser cavity with an optical shutter having a switching time long compared with the pulse build-up time (Midwinter 1965, Newbery 1968) and this observation has led to a method for producing controllable double-pulsing. The Q-switch is rapidly opened part way, whereupon one giant pulse emerges, partially depleting the population inversion. After an interval, the Q-switch is opened fully, and a second pulse is emitted. Two equal pulses, the sum of whose energies was 70% of that obtained when the cavity was conventionally Q-switched, having a relative time delay capable of being varied between 30 nanoseconds and 6 microseconds, have been obtained in this way (Newbery, 1969).

Split Cavity Double Pulse Laser

The principle adopted in the prototype double pulse laser system which forms the subject of the present paper was earlier exploited by Kruzhilin (1966), though in an inflexible fashion. It depends upon treating the laser ruby as though it were composed of a bundle of separate long narrow rubies. The population inversion in each is assumed to be uninfluenced by that in its neighbours. Scattering or diffraction of radiant energy from a light field growing in one member of the bundle into those adjacent, is assumed to exert negligible influence on their inversion. If this assumption is correct then each part can be Q-switched independently. In our prototype, the laser optical cavity was split into two parts by a pair of TIR 90° reflecting prisms, which were placed immediately following the ruby in the optical cavity as shown in Figure 1. Each section contained an ADP Pockels' cell Q-switch (Electro-optic Developments PC 12), a polarising beam splitter (Photocolor Corporation cellophane pellicle quint stack), and a hard-coated, multi-layer dielectric mirror of near 100% reflectivity. The Pockels' cells were independently switched in the half-wave mode and the time delay between their two trigger pulses was governed by a standard electronic delay unit. The ruby was a 4" x 9/16" Linde SIQ 60°-cut rod with plane parallel ends perpendicular to the cylinder axis. It was pumped by a close-wound helical Xe flashtube operated at an energy of 5.25 kJoules. The output reflector was a sapphire flat having 26% resonant reflectivity. The optical path length in each cavity was 60 cm. The pulses produced in this oscillator assembly passed through a telescopic lens system, magnification 1.6, into a laser amplifier consisting of a 9" x $\frac{3}{4}$" ruby rod with Brewster angle output face, pumped by a helical Xe flashtube operated at 18.5 kJoules. The pair of right angle prisms which split the optical cavity were mounted on a slide which could be traversed across the diameter of the ruby, and this enabled us to select the fraction of ruby volume which would contribute to each pulse. In this way, we were able to compensate for inequalities in the two halves of the ruby and so equalise the two pulses. It also permitted us to operate the laser with the ruby entirely within one or other cavity, and this was helpful both during the alignment and in assessing the performance of the split cavity system by comparing it with the conventional arrangement.

Performance of the Double Pulse Laser

Initially the oscillator was operated in the free-running mode that is, with polarizer removed and Pockels' cell unstressed. This allowed us to determine the length of time during which an inverted population was maintained in the ruby. It also served to measure the time between firing the pump lamp and the onset of free lasing, which indicates the earliest moment that the first giant pulse can be generated. An oscillogram showing the output of an RCA 7265 (S20) photomultiplier which viewed the laser oscillations through a Number 70 Wratten filter is presented in Figure 2. This shows the onset of oscillations 200 microseconds after the ignition of the flashtube. These oscillations persist for approximately 1 millisecond.

Giant pulses were detected by a vacuum photodiode (Instrument Technology Ltd. Type HCB 1) matched into a Tektronix 519 oscilloscope, and a TRG calibrated cone calorimeter measured the total energy emitted. Figure 3(a) shows the pair of giant pulses which were obtained from the oscillator when the two halves of the optical cavity were separately switched with a time delay of 10 microseconds between them. The two pulses appear simultaneous in the oscillogram, whose time scale is 20 nanoseconds per cm, because two separate beam sweeps have occurred. The total energy in the two pulses in this case was 2.85 joules, and since they appear to be closely similar it may be assumed that this energy was divided about equally between them, giving powers of approximately 70 MW each. Figure 3(b) shows a pair of similar pulses, again separated by 10 microseconds, which have been passed through the amplifying stage. The two pulses continue to be equivalent and the total energy shared between them is now 33 joules; the power of each is approximately 800 MW.

The foregoing observations were repeated for a variety of separation times between the pulses. No degradation in performance was discernible until either the first pulse was triggered earlier than 200 microseconds or the second pulse later than 850 microseconds after ignition of the flashlamp. So pulse separation is continuously variable within the range 0 to 650 microseconds. Figure 4 shows a typical pair of pulses spaced 120 microseconds apart, and it will be noted that the pulse heights are equal.

The slide carrying the TIR prisms was traversed so that the ruby operated wholly within one cavity and a giant pulse was produced whose energy was rather more than 2.85 joules. This showed that the sum of the energies in the pulses emerging from the two halves of the laser was approximately equal to the energy obtained when the laser operated within a single conventional cavity.

The angular divergence of each of the two pulses was measured by screening off one or other half of the output and observing the far-field pattern due to the unscreened half. In this way, the light emerging from the oscillator was found to have an angular divergence of 5 milliradians, while that from the amplifier had an angular divergence of 3 milliradians.

Conclusions

It has been shown that a ruby placed in an optical cavity divided axially into halves can be regarded as two independent lasers in the sense that the population inversion in one half is uninfluenced by that in the other. Our result suggests that it is likely that this will remain true even when the optical cavity is divided into more than two parts. Pairs of equal giant pulses, whose separation in time can be varied in a controlled way between 0 and 650 microseconds, with no significant alteration in their characteristics, have been obtained. After amplification, their individual powers were 800 MW. The sum of the energy in the two pulses equalled the energy of a single giant pulse generated when the oscillator ruby was wholly contained in a single optical cavity.

Acknowledgements

We are indebted to Mr E.P. Butt whose requirement for a multi-pulse laser stimulated this work. The experiment benefited from the technical advice of Mr. P.D. Wilcock.

References

DeSilva, A.W., Evans, D.E., and Forrest, M.J., Nature 203 1321 (1964).

Evtuhov, V. and Neeland, J.K. IEEE J. of Quantum Elect. QE-5 207 (1969).

Fourney, M.E., Matkin, J.H. and Waggoner, A.P. Rev. Sci. Inst. 40 205 (1969).

Geusic, J.E., Hensel, M.L. and Smith, R.G. Appl. Phys. Letts. 6 175 (1965).

Kruzhilin, Yu.I. Instrum. Exper. Tech. (U.S.A.) No.1 160-1 Jan-Feb 1966. Translated from Pribory i Tekhnika Eksperimenta, No.1 154 Jan:Feb (1966).

Midwinter, J.E. Brit. J. Appl. Phys. 16 1125 (1965).

Newbery, A.R. Brit. J. Appl. Phys. Ser. 2 1 1849 (1968).

Newbery, A.R. Opto-Electronics 1 134 (1969).

Smith, R.G. and Galvin, M.F. IEEE J. of Quantum Elect. QE-3 406 (1967).

Watson, J.L. and Beach, A.D., Brit. J. of Appl. Phys. (J. Phys. D) 2 129 (1969).

Wetzels, W. and Alfs, A., Rev. Sci. Inst. 40 1642 (1969).

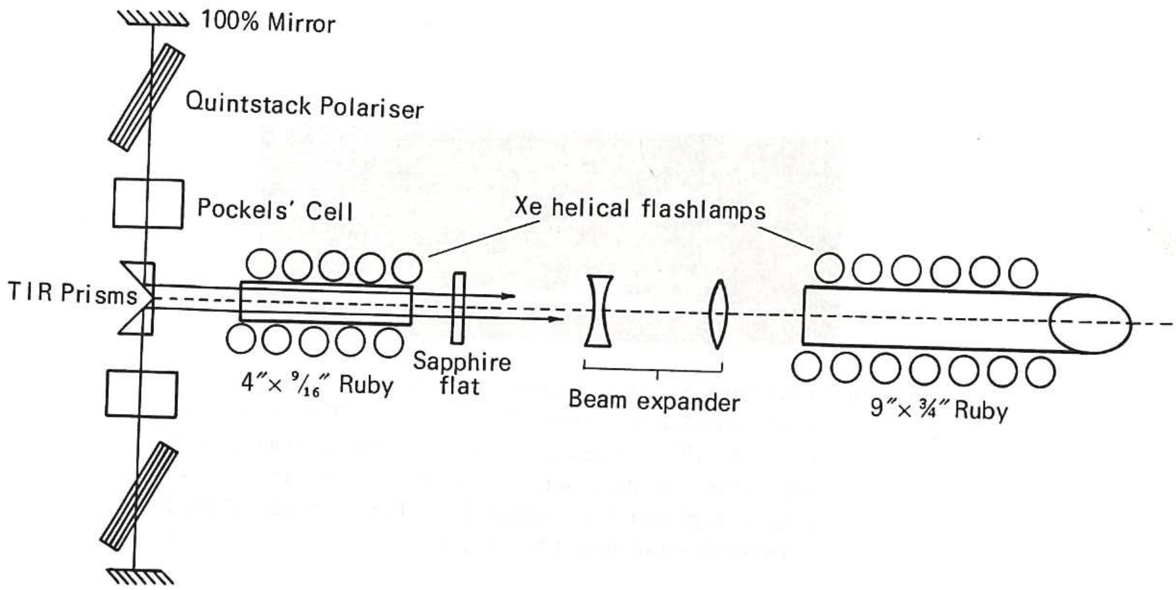

Fig.1 Diagram of the Double Pulse Laser System

CLM-P232

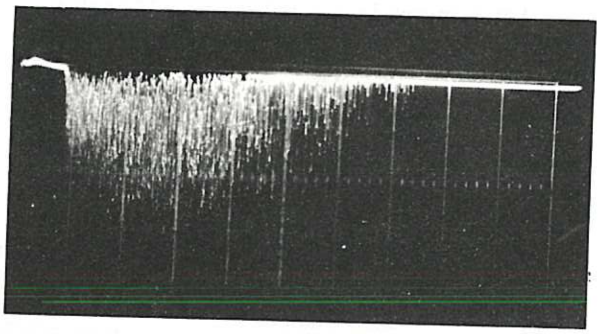

Fig.2 Oscillogram of photomultiplier signal showing laser output in the free-running mode of operation. Time scale is 200 microseconds cm^{-1}.

CLM-P232

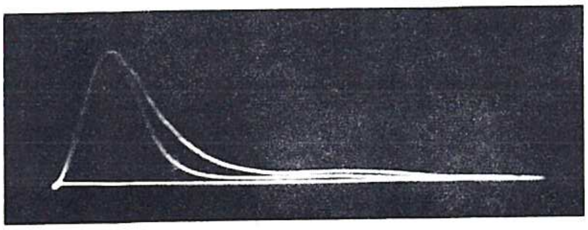

Fig.3(a) Tektronix 519 oscillogram of double pulse output from laser oscillator section. Time scale is 20 nanoseconds cm^{-1}. Double sweep pemits two pulses, whose real separation in time was 10 microseconds, to be displayed together for comparison. Total energy shared between the two was 2.85 joules. CLM-P232

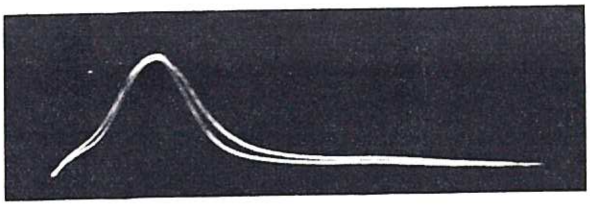

Fig.3(b) Tektronix 519 oscillogram of double pulse laser output from laser amplifier. Time scale 20 nanoseconds cm^{-1}. Total energy in two pulses was 33 joules. CLM-P232

1cm

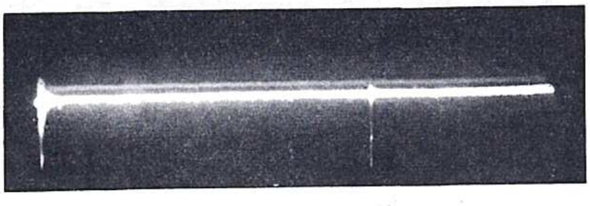

Fig.4 Photomultiplier signal showing two pulses separated in time by 110 microseconds. CLM-P232

1cm