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A Nd:YAG LASER WHOSE ACTIVE MEDIUM EXPERIENCES NO HOLE BURNING EFFECTS

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ABSTRACT

An arrangement is described in which the effect of the standing waves on the active medium is eliminated by placing it between $\frac{1}{4}$-wave retardation elements. As a result the active medium experiences no hole burning or mode competition effects. The emission characteristics of this laser were found to be different from those of a standard laser system. The laser could be operated at repetition rates of up to 40 pps and its output consisted of completely regular pulses whose period and amplitude could be controlled by the pumping process.

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INTRODUCTION

In a standard laser system with the active medium placed between two resonant reflectors, hole burning effects occur which result in mode competition and mode pulling effects. These effects have a profound influence on the emission characteristics of a laser. In solid state lasers operating in the TEM_{00} mode, hole burning plays a significant part in the time development of the relaxation oscillations since the growth or decay of one longitudinal mode leads to considerable disturbance of all other modes. These interdependent transient effects result in irregular spiking or damped relaxation oscillations.

Nd:YAG lasers operating in the TEM_{00} mode emit strongly damped irregular pulses. These are generally attributed to hole burning and multimode oscillation, as well as to thermal effects, such as pump-induced birefringence of the rod. The latter can be minimised by appropriate choice of pump geometry [1]. The former are an intrinsic property of the cavity characteristics and the active medium [2].

We have investigated the emission characteristics of a laser in which the active medium experiences no hole burning effects. Stimulated emission is caused by the action of circularly polarized light in the laser rod, and thus at the onset of a laser mode a constant intensity electric field is experienced simultaneously at all positions of the active medium. We have found that the output characteristics of a Nd:YAG laser operating in this way greatly differ from those of a standard laser cavity under identical conditions. Output energies of 17 mJ were obtained in the form of long pulse trains from a Nd:YAG system operating in the TEM_{00} mode. The separation of the pulses could be readily controlled by adjusting the pumping energy. This system may find useful applications in micromachining, such as drilling small holes [3], in high speed photography and in multiframe interferometry [4].

THE LASER ARRANGEMENT

For the present experiments we have used a commercially available Nd:YAG laser which could be fired at repetition rates of up to 40 pps. The laser rod was 75 mm long and 6.3 mm in diameter and it was pumped by a linear xenon flashlamp in a cavity with a diffused reflector. The laser rod and the flashlamp were cooled by circulating a cooling liquid through the cavity.

The experimental set up is shown in fig. 1a where the arrangement of the standing waves within the resonant reflectors is also drawn. The back mirror of the laser cavity had a reflectivity of 100% and a curvature of 5 m. The output mirror was plane with a reflectivity of 44%. Two Glan-Thomson polarizers were placed next to the two mirrors so that the light in those sections of the cavity was horizontally polarized. The active medium, a Nd:YAG rod, was placed in between a $\frac{1}{4}$-wave retardation plate and a Pockels cell with a $\frac{1}{4}$-wave voltage on it (the same effect could be produced by another $\frac{1}{4}$-wave plate in place of the Pockels cell). The $\frac{1}{4}$ wave plate could be rotated about the laser axis and oriented so that the retardation caused to one of the two analysed waves was in line with the acceleration caused to the same wave by the Pockels cell. In this way two perpendicularly polarized standing waves could be set at the position of the laser rod, but differing by $\lambda/4$ in the positions of the maxima. The resultant is a uniform electric field along the whole of the laser rod in the form of two circularly polarized waves travelling in opposite directions. The two polarizers ensured that the only way in which standing waves could be established within the cavity is the arrangement shown in fig. 1a. Fig. 1b shows the maxima of the two standing waves and their relation to the two birefringent elements and the mirrors.

RESULTS

Figure 2a shows the shape of the pumping light pulse and the oscillogram contains ten superimposed pulses at a repetition rate of 20 pps.

Figures 2b and 2c show typical oscillograms of the output of the Nd:YAG laser operating in the arrangement of figure 1. Lasing starts at 80 μs from the beginning of the trace shown in figure 2a. It can be seen from the oscillograms that after the first three or four pulses the period of oscillation is completely regular. The threshold of the laser was 6 J. The oscillograms of figure 2b and 2c were taken at a pumping level of 3 times above threshold with an output energy of 15 mJ. Figure 2d shows the output of the laser with the $\frac{1}{4}$-wave retardation elements removed from the cavity. Irregular damped oscillations were then obtained under identical conditions of operation. Figure 2c shows the output of the laser at a pumping level of 1.5 times the threshold energy. At these low pumping levels completely regular pulse trains were obtained as indicated by the oscillogram. Figure 2f shows ten superimposed pulse trains when the laser was operated at a repetition rate of 20 pps. The oscillogram indicates the reliability of the pulse trains in time, but the pulse height could vary by as much as 25% from shot to shot. The pulse duration was in the range of 200-300 ns. Figure 2g shows typical heavy burn patterns of the TEM_{oo} mode as obtained on developed unexposed polaroid film.

The separation of the pulses could be changed by changing the pumping rate. The duration of the pulses was of the order of 200-300 ns but, these could also be varied according to the pumping energy. We have experienced difficulty however in controlling the TEM_{oo} mode which depended strongly on the pump repetition rate and the orientation of the $\frac{1}{4}$-wave plate. For a particular repetition rate the $\frac{1}{4}$-wave plate had to be slightly readjusted to control the TEM_{oo} mode. We also found that in order to obtain the best results the $\frac{1}{4}$-wave plate had to be slightly rotated. These effects were attributed partly to the compensation of the pump-induced birefringence in the laser rod. The TEM_{oo} mode was also strongly dependent on the mode selecting aperture. For a cavity length of 80 cm an aperture of 1.6 mm was used. Bigger apertures resulted in difficult mode control or in interrupting of the pulse trains. One of the interesting features of the laser was that when the Pockels cell was switched off the laser did not work. It is obvious from fig. 1 that in this case there is no way in which standing waves can be established in the cavity.

Figure 3a shows the input-output energy curve of the laser whilst fig 3b shows the input-output energy curve when the $\frac{1}{4}$-wave retardation elements are removed from the cavity. It can be seen that there is no more than 10% decrease in the energy of the system as compared with that of a standard laser with polarized light. The threshold energy of the two systems is also the same.

The pulse interval of the relaxation oscillations of a four level laser is related to the pumping energy by [2,5].

$$\frac{1}{T^2} = \frac{1}{4\pi^2 \tau t_c} \left(\frac{W}{W_T} - 1\right) \qquad \ldots(1)$$

where

T	=	pulse interval
W	=	pumping energy
W_T	=	threshold energy
t_c	=	the cavity decay time
τ	=	the lifetime of the upper laser level under laser operation conditions i.e. $1/\tau$ is the rate at which atoms leave the upper laser level.

Figure 3c shows a plot of $\frac{1}{T^2}$ against $\frac{W}{W_T}$ (the number of times above threshold that the system is pumped). It can be seen that the interception on the $\frac{W}{W_T}$ axis is very near the theoretical limit of 1.

From eg. (1) and the gradient of the graph in fig. 3c we obtain:

$$\frac{1}{4\pi^2 \tau t_c} \simeq 14 \times 10^{10}\ S^{-2}$$

for the cavity used $t_c \simeq 5 \times 10^{-9}$ S which gives an effective lifetime for the upper laser level of ∿ 50 μs under laser operation conditions. The measured fluorescence lifetime of Nd:YAG is 220 μs [6]. The effective lifetime of the upper level of Neodymium lasers under laser operation conditions is well known to be much smaller than their fluorescence lifetime [7,8].

DISCUSSION AND CONCLUSIONS

We have shown that a Nd:YAG laser can be operated in such a way that the active medium does not experience the effects of standing waves in the cavity. The output of the laser consists of regular undamped relaxation oscillations which are reproducible to a very high degree of accuracy in the time domain (fig.2). The laser operates very near its theoretical expectations for the period and time development of the pulses, which could be controlled by the pumping pulse only. Output energies of 17 mJ were obtained in a TEM_{00} mode, comparable with those of a standard laser operating under identical conditions.

Regular pulse trains with individual pulse widths in the region of 200-300 ns find application in micromachining. Laser drilling of small holes, for example, requires pulses whose time separation allows the evaporated material to escape from the hole [9]. An intensity modulator after the laser could ensure the correct intensity of the pulses needed for drilling a particular meterial. The main difficulty lies in the control of the TEM_{00} mode and the reproducibility of the height of the pulses, but these could be improved by better pumping and reflecting cavity arrangement [1].

Note that because the first mode to oscillate experiences no hole burning effects, the growth of the neighbouring modes will not depend on the decay of the first. Hence, the latter will continue to oscillate at threshold, drawing its energy from neighbouring frequencies within the fluorescence spectrum which corresponds to its adjacent modes. In this way line narrowing of the emission of the laser could take place, although this has not been checked in the present work. Regular pulse trains with narrow spectrum are very useful for applications in high speed photography and multiframe interferometry [4].

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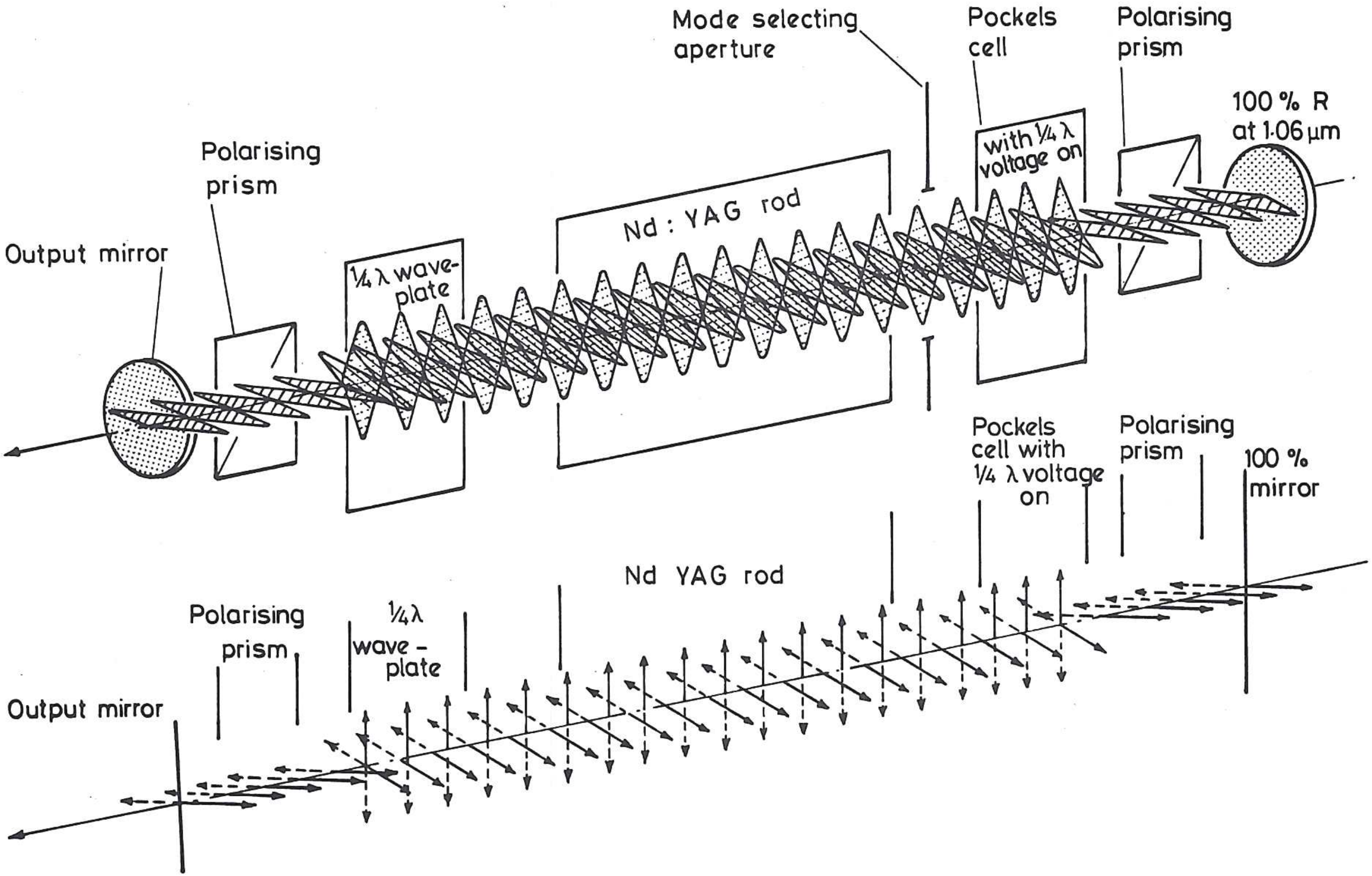


Fig.1 (a) The experimental arrangement. The standing waves are drawn schematically to illustrate the effect of the two birefringent elements.
(b) The maxima of the two standing waves corresponding to (a) are drawn and their position relative to the two birefringent elements is indicated.

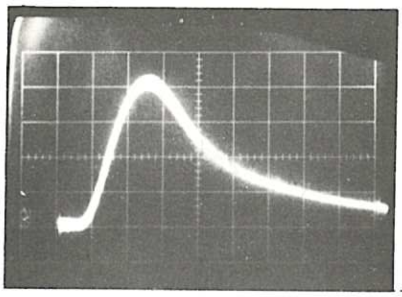
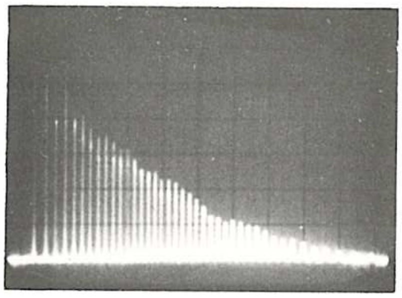
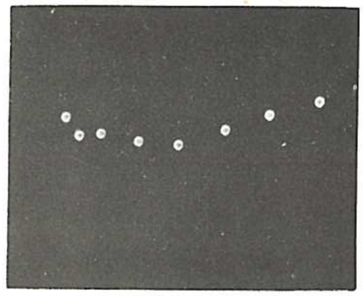
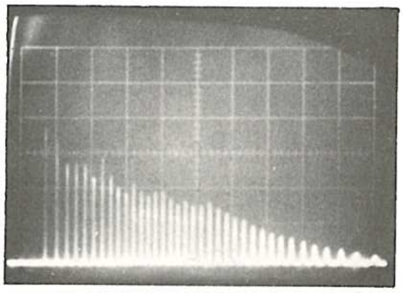


Fig.2 (a) Ten superimposed oscillograms of the light pumping pulse; Time scale 50 μs/div.; Pumping energy 16 J; Pump repetition rate 20 pps.

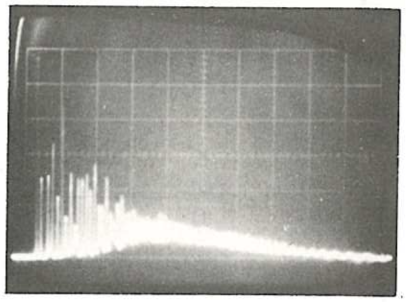




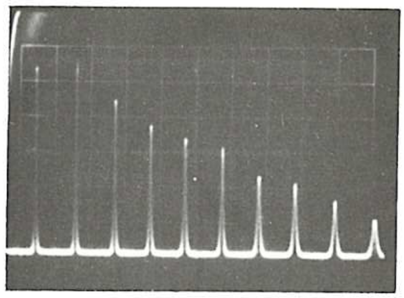
(b), (c) Typical oscillograms of the output of the laser drawn in Fig.1. Time scale 10 μs/div; Pumping energy 16 J; Output energy 15 mJ; Pump repetition rate 20 pps. Lasing starts 80 μs after the beginning of the trace in oscillogram (a).



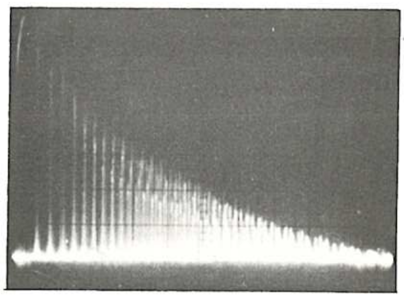
(d) Typical oscillograms of the output of the laser with the birefringent elements removed from the cavity. Pumping energy 16 J. Output energy 17 mJ; Pump repetition rate 20 pps; Time scale 10 μs/div.



(e) Typical oscillogram at a pumping level of 1.5 times the threshold energies. Output energy 4 mJ.

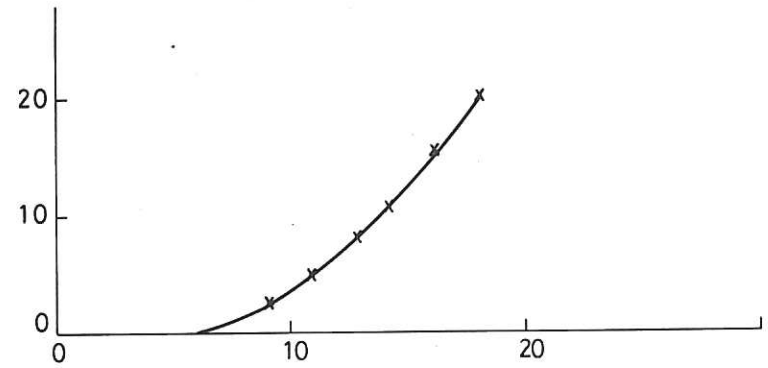


(f) Ten superimposed pulse trains at a pump level of 3 times above threshold energy indicate the reliability of the output. Output energy per pulse trains 15 mJ; Repetition rate 20 pps; Time scale 10 μs/div.

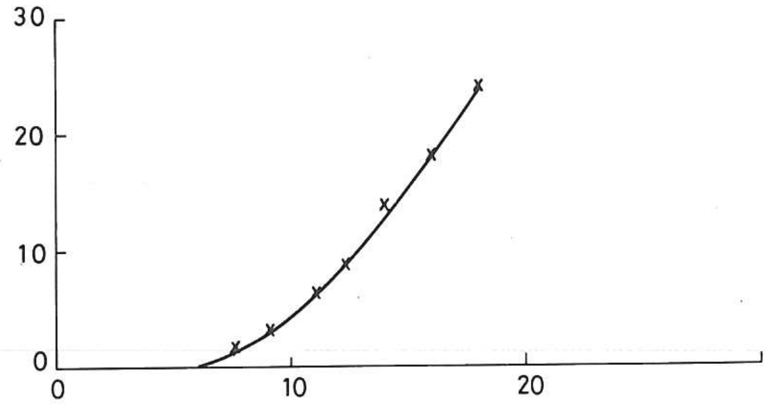


(g) The output of the TEM_{00} mode as obtained or developed unexposed polaroid film placed in front of the laser.

Fig.3 (a) Input-output energy curve of the arrangement shown in Fig.1. Threshold energy 6 J.



(b) Input-output energy curve with birefringent elements being removed from the cavity. Threshold energy 6 J.



(c) A plot of $(\frac{1}{T})^2$ against $(\frac{W}{W_T})$. Gradient $= 14 \times 10^{10}\ s^{-2}$.