ACTIVE MODE-LOCKING OF LASERS USING GaAs AND GaP PICOSECOND SWITCHES

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Received 10 July 1980

Active mode-locking of coumarin dye lasers has been achieved using either a GaAs or GaP picosecond high voltage switch to drive an intra cavity Pockels cell in a Q modulation technique. Pulses of 30–50 ps were generated with a peak power of ~500 kW, while pulses as short as 20 ps were observed. The method can be generally applied to various laser systems over wide spectral ranges.

Passively mode-locked flashlamp pumped lasers provide convenient and relatively low cost sources of picosecond pulses [1,2]. The tunability of the passively mode-locked dye laser [3,4] is somewhat overshadowed by the difficulty in obtaining suitable saturable absorbers which can be used over the complete spectral range of lasing dyes [5]. To overcome this, active mode-locking techniques such as acousto-optic modulation have been applied to mode-lock a flashlamp pumped dye laser in the blue spectral region [6]. In addition, several other novel methods of passive or active modulation of pulsed lasers have been reported. These include direct pumping of the laser medium itself using the fundamental or harmonic output of a mode-locked laser [7,8], the use of optical Kerr effect modulators [9,10], active modulation of saturable absorbing dyes [11], direct modification of the physical parameters of the saturable absorber [12], the use of a rotating interferometer [13], pulsed Q modulation [14] and many others. Although picosecond pulses are generated with most of these techniques, they either cannot be used over a broad spectral extent or they involve extreme care in matching cavity lengths or the use of expensive ancillary equipment.

In this paper we report on the generation of mode-locked trains of pulses of ~30 ps duration using a simple picosecond switching technique which can be generally applied over a wide spectral range and laser type.

A basic schematic of the experimental arrangement is shown in fig. 1. Two identical dye laser systems were used where the passively mode-locked arrangement was employed to synchronously derive the driving voltages for the active modulation of the second system. This type of laser which has been described previously [4] consisted of a 18 mm od, 10.5 mm id ablative flashlamp and a 13 mm od, 6 mm id dye cell placed along the focal lines of a 180 mm long reflecting elliptical cavity head. Brewster angled windows on the dye cell were set for preferential transmission of horizontally polarized light. Typically electrical energies of ~1000 J were deposited into the flashlamps. The rhodamine 6G laser (1.5 X 10^-4 M in ethanol) was passively mode-locked and operated with a 75 cm cavity length formed by a 50% reflective output mirror and a 199% total reflector at 600 nm on to which a 2 mm thick contacted dye cell was
placed containing a $5 \times 10^{-5}$ M ethanolic solution of 
DODCI. Without tuning elements in the cavity output 
energies of $\sim 100$ mJ in a mode-locked train with a 
baseline duration of $\sim 3$ ps were obtained at $\sim 610$ nm. 
A typical output of this mode-locked laser is shown 
in fig. 2(a). The pulsewidths were measured to be $\sim 5$ 
ps using a Photochron streak camera.

The actively modulated laser cavity is shown in 
fig. 1. It contained a $1.5 \times 10^{-4}$ M ethanolic solution 
of coumarin 6 as the active medium, in an identical 
cavity head to that described above. Mirror $M_1$ was a 
$\sim 100\%$ reflector over the range 500–600 nm. The 
other remaining elements in the cavity were a 25 mm 
long KDP Pockels Cell (P.C.) and a 10 mm long Glan 
Thompson polarizer $P$, set to transmit vertical polar­
ization only. Both these elements were placed in close 
contact with each other and such that the polarizer 
was $< 1$ mm from the output mirror $M_2$, giving a 
round trip time of the Pockels cell-polarizer arrange­
ment of $\sim 350$ ps. A 90% reflector was originally used 
as the output coupler but successful operation has al­
so been demonstrated with a 40% output coupler.

The operation of the modulation technique is as 
follows. Initially the flux generated with a preferen­
tial horizontal polarization would be rejected from 
the cavity by the polarizer $P$ and thus prevents the 
build up of laser action. If however the half wave volt­
age $\lambda/2$ is rapidly switched to the Pockels cell to ro­
tate the polarization for the short “on” period, the 
flux will be transmitted by the polarizer and returned 
through the arrangement during this switching time 
such that a short pulse can be generated in the cavity. 
If the synchronism is arranged such that further 
switching can be made to coincide with the return of 
this amplified burst of light at the Pockels cell then 
further amplification of this pulse together with gain 
saturation in subsequent round trips should lead to 
the generation of a train of short pulses.

The introduction of ultrafast high voltage switch­
ing techniques using semi conductor materials [15] 
enables the switching of pulses of several kilovolts in 
tens of picoseconds [17]. GaAs is especially suitable 
because in addition to its ultrafast turn on time it 
switches off in $\sim 100$ ps due to rapid recombination 
of the photo induced charge carriers [16]. Previous 
reports have indicated that Pockels cells could be 
switched on using these devices [15] in $\sim 40$ ps [17, 
18]. In our case added inductance and capacitance as-

Fig. 2. Storage oscilloscope traces of (a) Passively mode- 
locked rhodamine 6G dye laser 500 ns/div. (b) Corresponding 
output from GaAs switch 500 ns/div and 1.5 kV peak ampi­
tude. (c) Actively mode-locked coumarin 6 dye laser 500 ns/ 
div. (d) As in (c) on expanded time scale of 10 ns/div.
associated with the unoptimised Pockels cell design increased the open time of the unit such that round trip passage (~350 ps) through the Pockels cell and polarizer was possible.

Both semi insulating Cr doped GaAs and GaP [19] switches were successfully used for the generation of high repetition rate ultra short high voltage pulses in this experiment. The irradiated gap between the conducting electrodes to the switches was 4 mm so that d.c. voltages of ~3 kV could be held off without breakdown. The 0.25 mm thick GaAs or alternatively 0.5 mm GaP crystals were placed on a piece of printed circuit board and impedance matched to a 50 Ω line, with the switched voltage terminated into 50 Ω at the Pockels cell. Trains of kilovolt pulses were obtained by directing ~50% of the passively mode-locked laser output onto the device, which typically gave an 80% switching efficiency. Fig. 2(b) shows such an output from a GaAs switch with a peak amplitude of ~1.5 kV and lasting for the duration of the input mode-locked train.

Two schemes of operation of the switches were utilized. In the first, the voltage necessary to derive the $\pi/2$ polarization rotation was applied across the switch. Integration of the ~100 ps generated voltage pulses by the Pockels cell required that voltages greater than the static $\lambda/2$ voltage had to be switched for maximum transmission. Alternatively the scheme as indicated in fig. 1 was used where a d.c. bias was directly applied to the Pockels cell, although low enough such that it did not permit the laser gain to exceed the applied loss. The remainder of the voltage necessary for 90° rotation of the polarization and consequent laser action was then applied and switched across the GaAs. Typically a half wave voltage of 4 kV was needed for 100% modulation of the coumarin 6 dye laser output.

The cavities of the passively mode-locked and actively mode-locked lasers were approximately adjusted to be the same optical length. Initially optimization of the cavity lengths was carried out by observing the mode-locked output of the coumarin 6 laser using a fast photodiode—oscilloscope combination. A cavity length difference of ±0.5 cm was tolerable to give a modulated output, but the pulse quality was poor even when observed on the oscilloscope, and modulation was not 100%. Typical mode-locked pulse trains of the actively modulated coumarin 6 dye laser are shown in fig. 2(c) on a time scale of 500 ns/div and in 2(d) on an expanded time scale of 10 ns/div. These show complete modulation of the output and scope-diode limited pulse durations. The trains lasted ~3 μs and the envelope had a similar profile to that of the unmodulated output. No intra cavity tuning element was included and laser action occurred over a bandwidth of 2.3 nm centered at 533 nm. Inclusion of a Fabry-Perot should give tunability over the coumarin 6 gain bandwidth without effecting the modulation technique. The output energy in a mode-locked train was ~5 mJ.

Fine adjustment of the cavity length and its effect on the output pulses was observed using a picosecond electron optical streak camera [20], operated with a 15 ps time resolution. The laser output was directed into an optical delay arrangement in the usual manner [20] to give sub pulses separated by 150 ps. Fig. 3(a)
shows a microdensitometer trace of a 38 ps pulse recorded ~400 ns from the beginning of the actively mode-locked output train. Pulselengths in the range 30–50 ps were usually generated with some as short as 20 ps being observed. The temporal characteristics of the pulse depend on the part of the mode-locked train from which it is selected as a finite time is necessary for pulse build up, on the matching of the cavity lengths to less than 0.5 mm, and to the gain and gain saturation of the amplifying medium. In addition, pulses similar to the 95 ps duration pulses of fig. 3(b) were also recorded even as late as 500 ns into the mode-locked train. Apart from being broad and structured (perhaps due to slight cavity mismatching) some inter pulse noise is also apparent. Part of this signal is due to noise generated in the streak camera image tube due to scatter since the total mode-locked train was incident on the photocathode [21]. However, it is more likely that the major contribution to background noise arises from leakage of flux through the Pockels cell due to its finite turn off time, which has been shown to be longer than the turn on time [17, 19]. It can be seen in fig. 3(b) that a slow decay to the baseline does in fact follow the main pulse.

It has been shown however, that using this technique 100% modulated trains of pulses ~40 ps can be readily produced. By placing a low concentration solution of a saturable absorber either extra cavity or preferentially intra cavity (such that it would be incapable of mode-locking the laser alone) in a hybrid arrangement, it should be possible to remove inter pulse noise and to further reduce the pulse durations.

This method of mode-locking is not restricted to a narrow wavelength band. By slightly changing the voltage on the Pockels cell, mode-locked outputs of coumarins 120, 2, 47, 102 and 30 were also demonstrated, with result similar to those reported above, giving tunability over the range 430 nm to 535 nm.

Although other methods may be able to produce shorter pulses in dye lasers, this simple technique also lends itself to modulation of laser systems which would be difficult to mode-lock by an alternative scheme. Results using this method applied to the modulation of a rare gas halide laser system will be submitted at a later date.

Financial support from the S.R.C. is gratefully acknowledged. One of us (W.M.) is supported by a studentship from C.N. Pq of Brazil.

References