THE PASSIVE MODELOCKING OF THE CONTINUOUS WAVE RHODAMINE B DYE LASER

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The recent development of techniques for femtosecond pulse generation has realised the possibility of measurements and investigations with femtosecond resolution. For many applications, the high amplitude stability and low interpulse jitter make the purely passively modelocked dye laser the most attractive source of hypershort pulses. Passive modelocking has also produced the shortest 'directly generated' pulses. However, since its realisation in 1972 [1] nearly all passively mode-locked systems have operated in the spectral region around 615 nm using the active/passive dye combination of Rhodamine 6G and DODCI [1–6], and culminating the generation of 27 fs pulses from an optimised and dispersion compensated cavity [6]. Consequently, the majority of subpicosecond spectroscopy has been limited to this excitation region except in the cases where expensive systems have been developed employing amplification and continuum generation [7] or external pulse compression [8].

We have recently reported femtosecond pulse generation in the yellow [9,10] and the near infra red [11] using Rhodamine 110, Rhodamine 6G and Rhodamine 700 in passively modelocked lasers. Here we report a further extension of purely passive mode-locking to Rhodamine B, achieving subpicosecond pulse generation from 616 nm to 658 nm, with pulses as short as 220 fs being obtained from simple linear cavities with no dispersion compensation.

The experimental configuration is shown in fig. 1. A basic five mirror cavity arrangement was used, whose parameters were easily adjustable to meet the criteria proposed by New [12] for complete mode locking. The dye laser was pumped by the "all lines" output of a Spectra Physics 2020 argon ion laser which was coupled into the gain medium (1.5 X 10^{-3} M Rhodamine B in ethylene glycol) by a focussing mirror M1 of 50 mm radius of curvature. This active dye was circulated through a vertical 100 μm thick, jet stream between two mirrors (M2, M3) of 100 mm radius of curvature which comprised the active medium folded section. A retroreflector arrangement was employed in the passive folded section which consisted of a focussing mirror (M4), and a retroreflecting mirror (M5) of 25 mm radius of curvature. Mirrors of both 50 mm and 100 mm radius of curvature were used in the position of M4. For this uncom-
pensated cavity, all the mirrors used had broadband dielectric coatings of 100% reflectivity and a dielectric coated tuning wedge was used to achieve wavelength selection and to provide two outputs from the dye laser. A fast photodiode (BPW28) was used to monitor one of these outputs while the other permitted pulse-width measurements, where a standard collinear second harmonic generation autocorrelation technique employing LiT03 was used to determine the duration of the dye laser pulses. The “real time” facility of our autocorrelator enabled routine optimisation of the dye laser performance.

The saturable absorber used was the dye 1,3'-diethyl-4,2'-quinolythiacyanic acid dye (DQTCI) whose absorption for a 3:1 ethylene glycol:ethanol solution is shown in fig. 2. A peak extinction coefficient of $11 \times 10^4$ €mol$^{-1}$ cm$^{-1}$ at 628 nm was measured for DQTCI.

Using passive dye concentrations of the order of $4 \times 10^{-5}$ M, subpicosecond pulses were obtained over the range 616–658 nm, with $M_4$ of 100 mm radius of curvature. Figs. 3(a) and (b) show autocorrelation traces taken at 625 nm and 655 nm, near the extremes of the tuning range of this active/passive combination, recording pulsewidths of 340 fs and 430 fs respectively (assuming sech$^2$ pulse profiles). The shortest pulse duration of 220 fs obtained at 635 nm is shown in fig. 3(c). With this particular $M_4$, the cavity round...
Fig. 4. Auto-correlation trace of shortest pulse duration recorded at 637 nm from the 10 ns cavity.

trip time was optimised at 14 ns and the laser supported two equally spaced pulses in the cavity resulting in an output train of pulses separated in time by 7 ns. This regime was found to give the best stability and tuning range. Typical thresholds for femtosecond modelocked laser action were around 6.0 W, depending on the wavelength and the concentration of the saturable absorber. The laser was generally pumped 2.0 W above threshold to give output powers ranging from 3 mW to 20 mW.

Other laser cavities with different round trip times (7 ns, 10 ns) and a different radius of curvature for M4 (50 mm) were also investigated. With shorter cavities the laser was less stable and tended to operate on a multi-pulse mode with groups of two or three pulses separated by the cavity round trip time. This regime tended to result in rather high average output powers — as high as 100 mW. However, it was possible to operate the laser in a single pulse mode when pumping just above threshold (4.0 W for a $2 \times 10^{-5}$ M concentration of DQTCI). Fig. 4 shows the auto-correlation trace of a pulse of 230 fs duration obtained at 637 nm from a cavity of 10 ns round trip time with M4 of 50 mm radius of curvature with one pulse per round trip. Hysteresis and bistability between single, double and triple pulse modes were observed in all of these cavities. They were minimised in the first cavity described here.

A spectral investigation revealed that the pulses were not bandwidth limited (the 3.3 nm measured bandwidth should be able to support a 130 fs pulse.) The observed chirp is probably due to the broadband “double stack” dielectric mirror coatings used [13,14].

In conclusion we have demonstrated the passive modelocking of the CW Rhodamine B dye laser with the saturable absorber DQTCI, tunable from 616–658 nm. With appropriate dispersion compensation in the cavity and with no bandwidth restriction, a highly stable source of sub-100 fs pulses of minimal temporal jitter and significant average power should be readily available over the tuning range presented here. This is currently under investigation as is the extension of purely passive modelocking to further regions of the spectrum.

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References