QUANTUM WELL MODULATORS FOR THULIUM DOPED FIBRE LASERS

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Introduction

Rare-earth doped single-mode optical fibres are ideal sources for producing mode locked pulses of very short duration since they have large flourescence linewidths. To make full use of the linewidth very fast modulators or saturable absorbers are necessary.

This work investigates the use of Multiple Quantum Well (MQW) modulators for modelocking and Q-switching fibre lasers. The particular attraction of this approach is that MQW modulators offer good on/off ratios for low voltage drive and are compact in size. Work carried out by Whitehead et al [1] led to the development of the Asymmetric Fabry Perot modulator (AFPM) structure which can achieve very high contrast by using MQW electro-absorption to obtain complete destructive interference of light reflected from the device.

Model

We have used a relatively simple, but realistic, model for field dependent absorption in MQW diodes. The zero field solution is fairly simple and described for a single well using the one dimension quantum mechanical continuity equations. With constant field applied, the extra field causes a potential gradient across the quantum wells. By transforming variables, Schrodinger's equation can be expressed as a differential equation with Airy function solutions [2, 3]. Two methods were used to find the energy levels. At moderate and high electric fields, the energy levels were found by locating the peaks in the density of states and determining their widths using the Full Width at Half Maximum (FWHM). At low electric fields the Breit-Wigner parameterisation was applied by measuring the phase shift of the Airy function.

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In calculating the absorption spectrum, all the broadening was qualified by the FWHM of the Lorentzian and was taken to be constant with the applied field. The calculated absorption spectrum was then compared with the experimental absorption spectrum in the continuum, and the relative strength of the excitons were obtained by fitting to and then averaging over a number of published experimental results, for the well widths used in our calculation [4].

AFPM Fabrication and Assessment

The above approach was used to design a GaAs/AlGaAs AFPM for use with a Thulium doped fibre laser system, operating at 810 nm wavelength. 42Å GaAs wells with Al(44%)GaAs barriers were chosen for this wavelength. Greatest modulation is achieved at the exciton peaks where the largest changes in absorption occur [5]. We selected a barrier width of 110Å which gave negligible interwell coupling and for a 54 period structure offered an intrinsic region thickness of 1μm thus reducing the device capacitance. The structure of the 810nm AFPM is shown in Figure 1. Bragg, Multi-Layer Stacks (MLS) were used as back reflectors. To obtain the widest high reflection band and the highest reflectivity with fewest periods a large index difference between the MLS components is required. The limit on this is the wavelength at which the higher index semiconductor begins to absorb significantly. Thus GaAs is ruled out because it absorbs strongly at wavelengths close to the required MLS centre wavelength (~ 810nm). A ternary alloy with 0.15 Al mole fraction was therefore chosen as the high index layer, with AlAs as the low index layer. The requirement for the AFPM is a minimum back reflectivity of ~95%, which was achieved with 14 periods for the MLS.

The samples were processed such that the optical window was approximately 250μm x 250μm after depositing gold contact pads on the top P^+ layer. The completed modulators were mounted on T05 headers. Figure 2 shows the measured reflectivity change for a typical device as a function of wavelength for different bias voltages. The absorption coefficient is mainly dependent on the background doping, well width fluctuation and compositional broadening. Reasonable agreement with the predicted reflectivity, Figure 2 insert, is obtained.

Absorption Saturation Measurements

The absorption saturation measurements were made using a Ti-sapphire laser. An electric chopper was used to produce a train of square pulses of 0.2ms duration at a repetition rate of 200Hz. This low 15:1 duty cycle was necessary to reduce thermal effects in the sample. The laser spot was Gaussian with a measured e^{-2} radius of 6μm. The zero field saturation power of the e1-hh1 exciton is measured to be at ~1mW which is low due to the reduction in carrier sweep out rate caused by the large barrier height of 44% Al concentration with 110Å thickness. However, in the presence of electric field, due to increase in sweep out rate, the saturation intensity increases with applied voltage [6, 7]. Figure 3 shows the change in peak e1-hh1 exciton absorption with power. For the AFPM devices operated at low power, a contrast ratio of 7:1 with an insertion loss of 40% was achieved. Increasing the incident power on the device increases the insertion loss to 48% and increases the on-resonance reflectivity (at reverse bias 30V) from the low power value of 10% to a value of 36% at 27mW input power giving a reduced contrast ratio of 1.4. At high power, the optically generated carriers gives rise to many-body effects, dominated in quantum wells by phase space filling and fermion exchange. This many-body interaction causes the band edge to shift to longer wavelength leading to a drop in off-state resonance reflectivity. The increase in on-state reflectivity at higher powers is believed to be caused by further absorption changes combined with a change in refractive index. This dispersive change reduces the optical path length in the cavity and changes the operating condition from the on-resonance state to off-resonance state. Such saturation behaviour can reduce the modulation depth considerably in the fibre laser application.

Q-switching and Mode-locking Experiment

Figure 4 shows the experimental setup [8]. Optical gain is provided by a 188.5cm length Thulium-doped fluorozirconate. Optical pumping was provided by an Ar laser pumped Ti-sapphire laser operating at 785nm via an input coupler butted against the fibre end. The input coupler has high transmission (75%) at the pump wavelength but high reflection (99%) at the lasing wavelength (810-815nm). At the other end of the fibre the optical beam is collimated and focused onto the AFPM using x40 and x10 lenses, respectively. A band pass filter was used to prevent residual pump energy from saturating the AFPM. The AFPM was driven by a DC voltage source and RF signal generator connected via a Bias-Tee. The output beam was detected by a high speed InGaAs detector whose responsivity was 0.11 at the lasing wavelength.

Continuous spiking and Q-switching was obtained using the nonlinear properties of the MQW structure, without applied RF drive. Continuous spiking changed to Q-switching as the focusing point on the modulator was changed. Figure 4 shows a typical Q-switched result. A pulsewidth of 200ns with a peak output power of 0.43W has been achieved when the pump power incident was 167mW. Mode-locked operation was obtained when a 48.36MHz sinusoidal wave was applied to the AFPM together with suitable DC bias. Figure 5 shows the mode-locked pulse trains obtained within a 400ns Q-switch envelope, indicating 6ns pulse duration and a maximum power of 0.5W, for 10V peak sinusoidal modulation.

Conclusion

We have demonstrated for the first time switching and active mode-locking of a Thulium doped fibre laser using a MQW AFPM. Additional studies have shown that exciton saturation at high intensities reduces the modulation depth obtainable from such devices significantly.

We are currently studying a number of strategies to increase the power handling of MQW modulators in order to obtain continuous mode-locking of fibre lasers.

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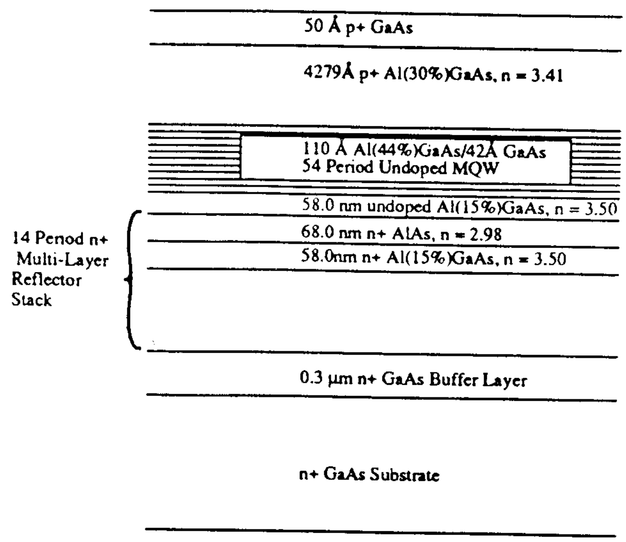

Figure1: Device structure for Asymmetric Fabry Perot Modulator (AFPM) designed for use with Thulium doped fibre laser.

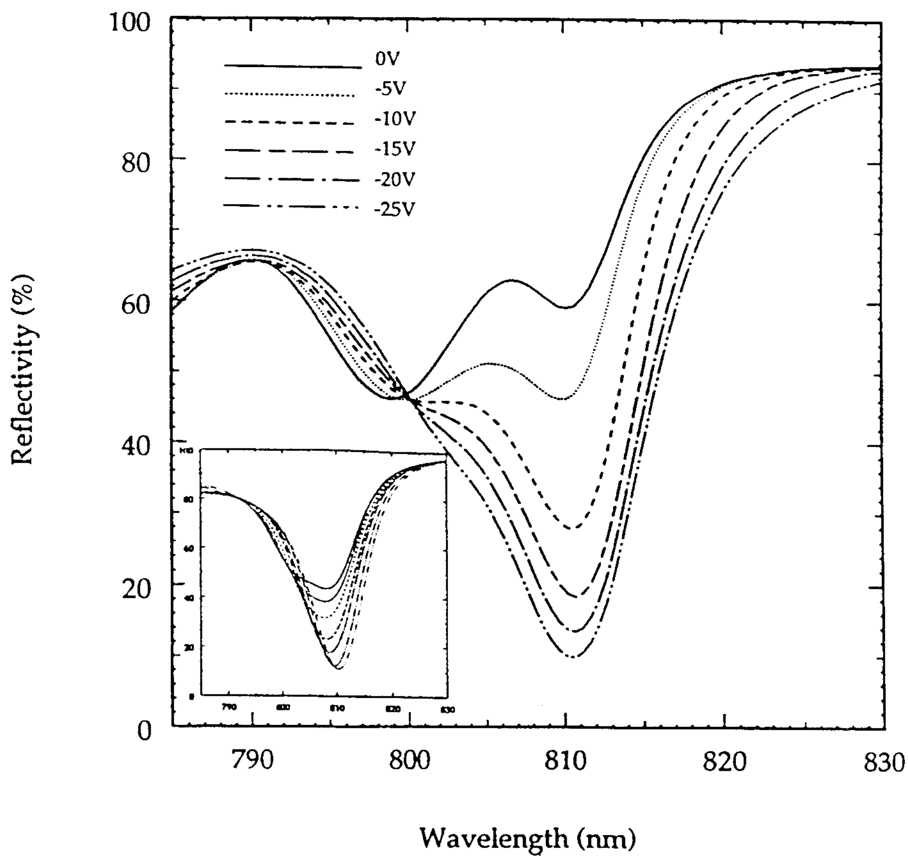

Figure2: Measured reflectivity spectra for 810nm AFPM. The insert shows the modelled reflectivity spectra with E=0 kV/cm (————), E=100 kV/cm (..........), E=150kV/cm (- - - - -), E=200 kV/cm (— — — —), E=230 kV/cm(—·—·—), E=270 kV/cm (—··—··), E=300 kV/cm(—···—···) using the 21meV Lorentzian broadening for 810nm AFPM.

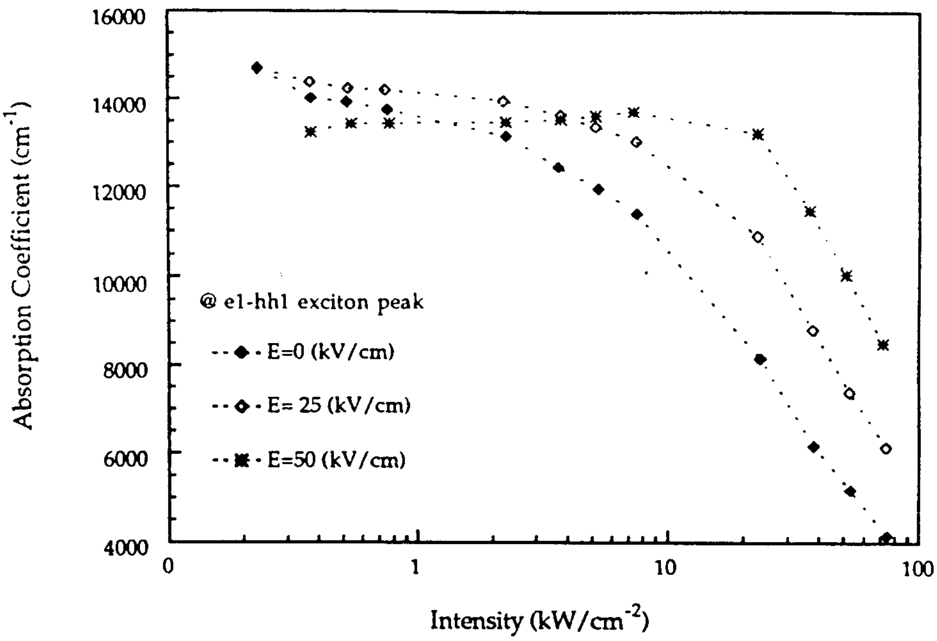

Figure3: Measured saturation characteristics of GaAs/AlGaAs MQW modulator.

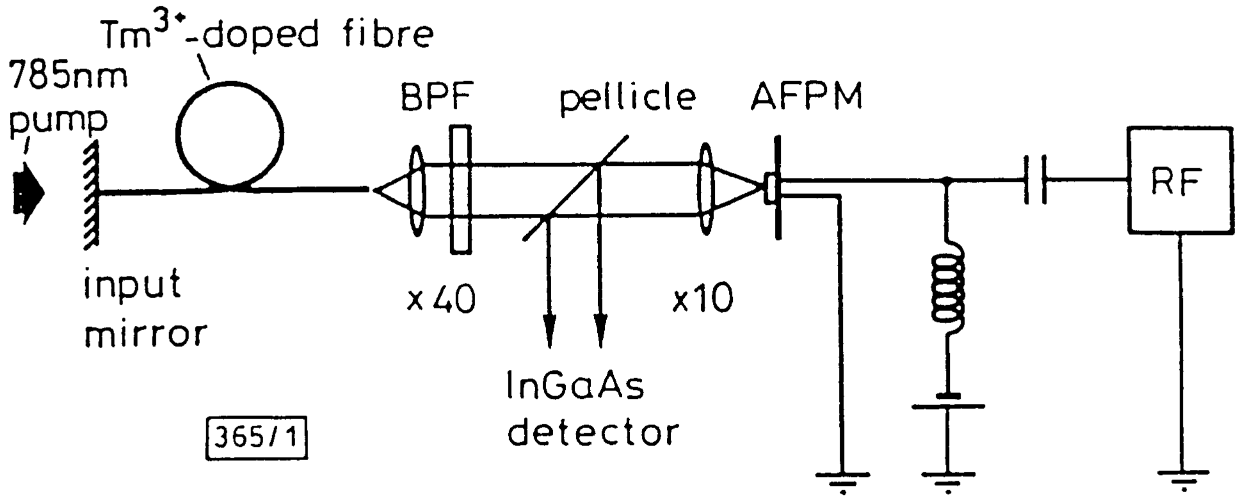

Figure4: Experimental setup of mode-locked Q-switched Thulium doped fibre laser.

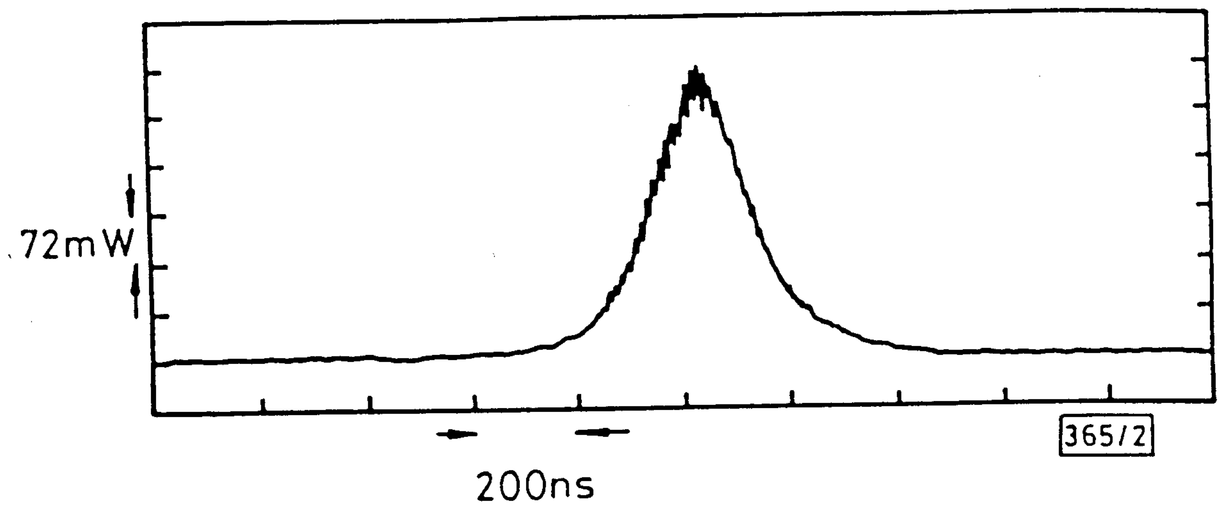

Figure5: Passive Q-switched pulse from Thulium doped fibre laser with AFPM reflector.

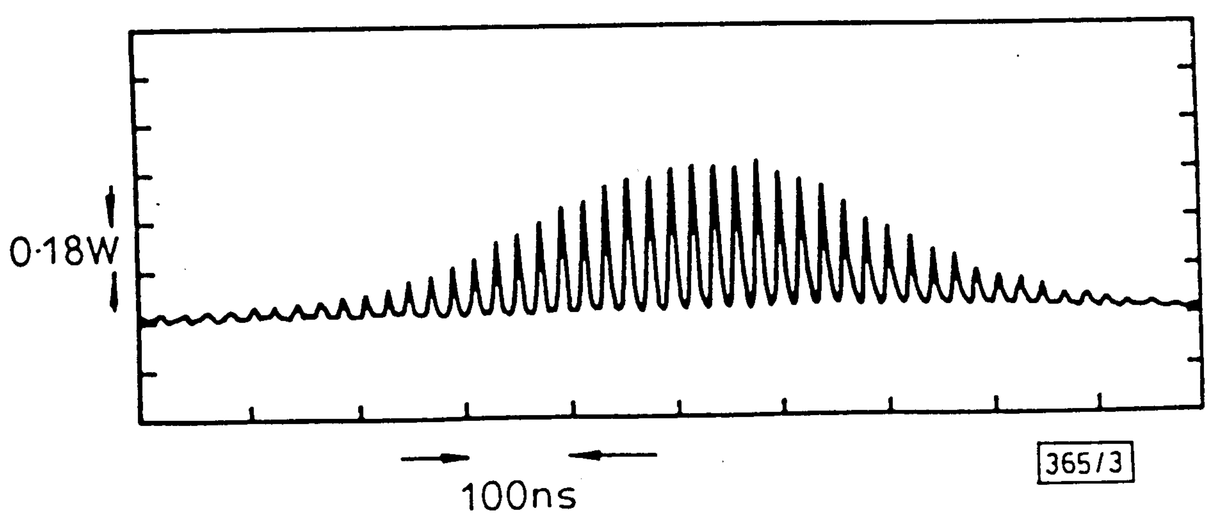

Figure6: Mode-locked pulses within a Q-switched envelope for Thulium doped fibre laser with sinusoidally driven AFPM reflector.