Simultaneous dual polarisation operation of a diode pumped femtosecond fibre laser

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The behaviour of a diode pumped figure-of-eight ytterbium/erbium-doped fibre laser which generates subpicosecond pulses is described. This laser is observed to mode-lock simultaneously in two orthogonal polarisation states with distinct temporal and spectral characteristics.

The figure-of-eight erbium-doped fibre laser [1] has been proposed and demonstrated as a source of ultrashort duration solitons [2-4] at around 1.5 μm, the low loss window of silica. Fibre doped with both erbium and ytterbium has the advantage over solely erbium-doped fibre that it has a wide absorption spectrum and may be efficiently pumped by inexpensive, high power AlGaAs laser diodes at around 980 nm with wide flexibility in the pump wavelength. In this Letter we report a figure-of-eight fibre laser incorporating a diode-pumped erbium/ytterbium-doped fibre as the gain medium and describe its dual polarisation behaviour.

Fig 1. Schematic diagram of Yb/Er figure-of-eight laser cavity

The layout of the laser cavity is shown in Fig. 1. The active loop (NALM) consisted of a 3 dB fibre coupler, 10 m of diode-pumped Yb:Er-doped fibre supplied by IRE-Polus and 50 m of dispersion shifted fibre. The passive loop contained a 10% fibre output coupler, and a Faraday isolator (FI). Two fibre strainers were used to control the polarisation within the cavity (PCs). The total cavity length was 74 m with an average dispersion of −0.6 ps/μm/km.

The modelocked operation of the laser was characterised both temporally and spectrally. When the output was examined using a slow photodiode the oscilloscope trace revealed the pseudorandom train of pulses periodic at the cavity round trip time that is characteristic of this type of laser without repetition rate control [2-4]. Fig. 2 shows a typical autocorrelation with the corresponding spectrum inset. The autocorrelation had pronounced wings and was used to control the polarisation within the cavity (PCs).

The figure was broad (1.7 times the pulse transform) and had an unusual flat topped envelope. It was observed that if the polarisation of the input light to the autocorrelator was rotated then different pulse durations were observed. To investigate this further a half-wave plate at 1.55 μm and a linear polariser were placed after the laser output to allow a polarisation-resolved study of its

\[ T = G \left[ 1 - \frac{1}{2} (1 + \cos \Delta \phi) \right] \]  

where \( G \) is the gain of the amplifier and \( \Delta \phi \) is the total phase shift between the two counterpropagating pulses in the loop and is given by

\[ \Delta \phi = \frac{\pi}{2} \left( G - 1 \right) L \frac{2\pi}{\lambda} n_2 L \]  

in which \( l \) is the intensity of the input pulse, \( \lambda \) is the wavelength, \( n_2 \) is the nonlinear refractive index of silica and \( L \) is the loop optical path length. The transmission will reach its maximum value of 1 and so allow pulses to propagate around the cavity when the switching criterion \( \Delta \phi = \pi \left( G - 1 \right) L \frac{2\pi}{\lambda} n_2 L \) can be satisfied for two different optical path lengths as they propagate around the loop and the birefringence of the fibre provides such a differential path length.

It can be seen that the flat topped spectrum initially observed is simply the sum of the two component spectra and the apparently

Fig. 2. 1-Polarisation unresolved autocorrelation trace (with spectrum inset) of typical pulses produced by the modelocked fibre laser
variable pulse durations were caused by the changing contributions from the two components as the input polarisation to the autocorrelator was rotated. The sidebands that formed antisymmetrically on the two orthogonally polarised spectra are typical of the effect of the cross-phase modulation between the two components. This asymmetry simply reflects the walk-off of the two pulses, one forward and the other relatively backwards. Cross-phase modulation may also be responsible for modifying the pulse shape, leading to the pronounced wings on the autocorrelation, although a contribution to this may be due to incomplete separation of the two components caused by the waveplates that were used not having a relative phase delay of exactly \( \pi/2 \). No other pedestal was observed and when the output was examined using a slow photodiode the oscilloscope showed no CW component.

The dual wavelength/polarisation switching of the NALM and the cross-phase modulation effect is very similar to that of soliton trapping [6] and observed by Islam et al. [7]. In this case, however, it is not possible to state categorically that the pulses polarised along the two axes are bound together, as the same results could be obtained from two independent orthogonally polarised trains of pulses at different wavelengths that both satisfy the NALM switching criterion and experience cross-phase modulation when walking through each other over several cavity round trips.

In conclusion, we have demonstrated simultaneous subpicosecond and micrometre-cavity modulated operation in two orthogonal linearly polarised states of a figure-of-eight fibre laser. The pulses generated in the two states were of different durations and power levels and had different central wavelengths. A possible mechanism for this behaviour has been proposed.

Acknowledgments: The authors gratefully acknowledge the SERC for the overall financial support of this research programme. M. J. Guy is supported by a studentship from the SERC.

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Electronics Letters Online No: 19931340

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References


Fig. 3 Autocorrelation traces with inset spectra for pulses polarised along one linear polarisation axis, and pulses polarised along the orthogonal polarisation axis.

a. Polarised along one linear axis
b. Polarised along orthogonal axis

time, ps

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References


Temperature measurements of telecommunication lasers on a micrometre scale

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Indexing terms: Semiconductor lasers, Temperature measurement

Temperature maps of laser diode facets obtained by photothermal reflectance microscopy are presented. Biased double heterojunction InGaAsP lasers were investigated. The temperature images reveal the influence of laser mode on the spatial distribution of the heat dissipated in the device. Moreover, a study of the modulated reflectance as a function of the injection current is achieved.

Introduction: We have used photothermal reflectance (PTR) on a micrometre scale in order to measure the alternative operating temperature of laser diode facets. This technique enables us to determine the local temperature field of the device in operation (below and above threshold), and is particularly suitable for detecting local defects that could induce catastrophic optical mirror damage, as well as helping in the investigation of the resulting degradation which occurred at the facet of the laser. We present for the first time the laser mode influence on the spatial distribution of the heat source in laser diodes. We show that the temperature distribution below laser threshold is spread when compared with that observed when lasing is established. In the first case the form of the temperature image is mainly related to the laser's bandgap distribution, whereas in the second case a sharper form has been found. To better understand the modulated reflectance signal on the facets of these lasers, we have measured it at the centre of the active zone, as a function of injection current. Our results display the laser threshold by an increase of the signal amplitude, related to the growth of the heat power density in the centre of the active zone. Moreover, we see that temperature modulation dominates for all the current range, except at very low injection where carrier density modulation is the main cause of the AC reflectance signal [3].

Experimental setup: A probe beam (670nm) is focused (\( \approx 1.0 \mu m \)) on the sample surface by means of a microscope. The beam is reflected back by the surface of the sample and deviated in the direction of an Si photodiode. The device is mounted on an x-y translation stage of step size 0.1 \( \mu m \), and is operated with a current of the form: \( R(t) = R_0 + A(t) \cos(2\pi f t) \). High modulation frequencies \( f \) (20kHz to 20MHz) were employed to confine heat near the source zone, improving the spatial contrast. The reflected probe beam intensity carries a small modulation at frequency \( f \), because the sample reflectance \( R \) is modulated by the periodic temperature rise \( \Delta T \) and carrier density modulation \( \Delta n \) (\( \Delta R = (1/R) \Delta R + (R/\Delta R) \Delta n \)). The output AC signal from the Si detector is lock-in analysed (reference in phase with the AC driving current) and its DC component is used to normalise the lock-in signal, giving the experimental values of \( \Delta R/R \). We have studied cleaved, uncoated, InGaAsP/InP distributed feedback (DFB) buried heterostructure (BH) lasers. The lasers are 215\( \mu m \) long and operate at 1.55\( \mu m \); the active layer is 100–200 nm thick and 2(\( \approx 0.5 \mu m \)) wide.

Results and discussion:

(c) Photothermal reflectance images of laser facets: Fig 1 represents the amplitude of \( \Delta R/R \) on the facet of the laser for \( f = 20 \text{MHz} \).