CLEO '92 363

SOLITON ENERGY QUANTISATION IN THE OUTPUT POWER OF A PASSIVE FEMTOSECOND SOLITON LASER

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ABSTRACT

The quantised energy of solitons circulating within an all-fibre, passively mode-locked fibre laser causes discontinuities and hysteresis in the output power characteristic.

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The passive generation of femtosecond soliton pulses in erbium-doped fibre lasers has recently caused considerable interest[1,2,3]. The Figure-8 laser configuration [2,3,4] whose operation is based on the soliton-favouring reflection properties of the Nonlinear Amplifying Loop Mirror (NALM)[5] has been the subject of considerable study. Using this scheme, soliton pulses as short as 320 fsec have been obtained. Several distinct regimes of pulse repetition-rate behaviour have been observed[4]. In general, once soliton mode-locked, the pulses are randomly spaced in the time domain and the laser exhibits different operating modes depending upon the input pump power [6]. In this paper we present new experimental results showing the effects of soliton pulse energy-quantisation in the power output from the laser. We also present data showing the spectral changes associated with these effects.

The experimental set-up is shown in Fig 1. The laser was configured to generate transform-limited, 450 fs soliton pulses at 1558 nm. The NALM loop was 35m long (fibre NA=0.15,λ_{co}=960 nm) and the cavity round-trip frequency was 5 MHz. The 980 nm pump power to the erbium-doped fibre amplifier could be controllably and repeatedly varied whilst the average output power, optical spectra and time-domain behaviour were observed at Ports 1 and 2. Since the NALM and isolator act to preferentially transmit the soliton component of the pulses and to reject the remainder. Port 1 gives the soliton component output and Port 2 the residue. The CW laser pump threshold was 10 mW and soliton mode-locking self-started at a "second threshold" power of 45 mW.

Once mode-locked, abrupt, quantised jumps (downwards) in the laser power output at Port 1 were observed as the pump power was reduced. The jumps coincided with the disappearance of individual soliton pulses from the circulating pulse trains and were accompanied by equally abrupt increases in output power at Port 2 (see Fig.2). A simplified explanation of the effect is as follows: solitons in the fibre have a fixed energy (9 pJ in this case) and therefore, if the laser is always to operate in the soliton mode, the output laser power can only change by units of one or more soliton energy quanta. When the pump power is no longer sufficient to sustain the number of circulating solitons, individual pulses must disappear from the cavity. The sudden loss of one or more solitons causes a switch of output power from the soliton port to the residue port as the laser adjusts for any excess circulating power.

Optical spectra measurements at Port 1 before and after a power discontinuity reveal the appearance of additional, low level, symmetric spectral lobes (see Fig.3(a)). The origin of these side lobes is at present not fully understood. This spectral change at port 1 is accompanied by the appearance (enhancement) of a central wavelength component at port 2 (see Fig.3(b)). This component is the excess, soliton residue of the pulses rejected by the NALM, as discussed above.

The results demonstrate the strong preference of the laser to operate in well-defined soliton units and its ability to adapt itself to changes of input pump power, once soliton self-starting has occurred. The ability of the laser to operate with fixed, stable pulse patterns may have applications in word generation and recognition.

References

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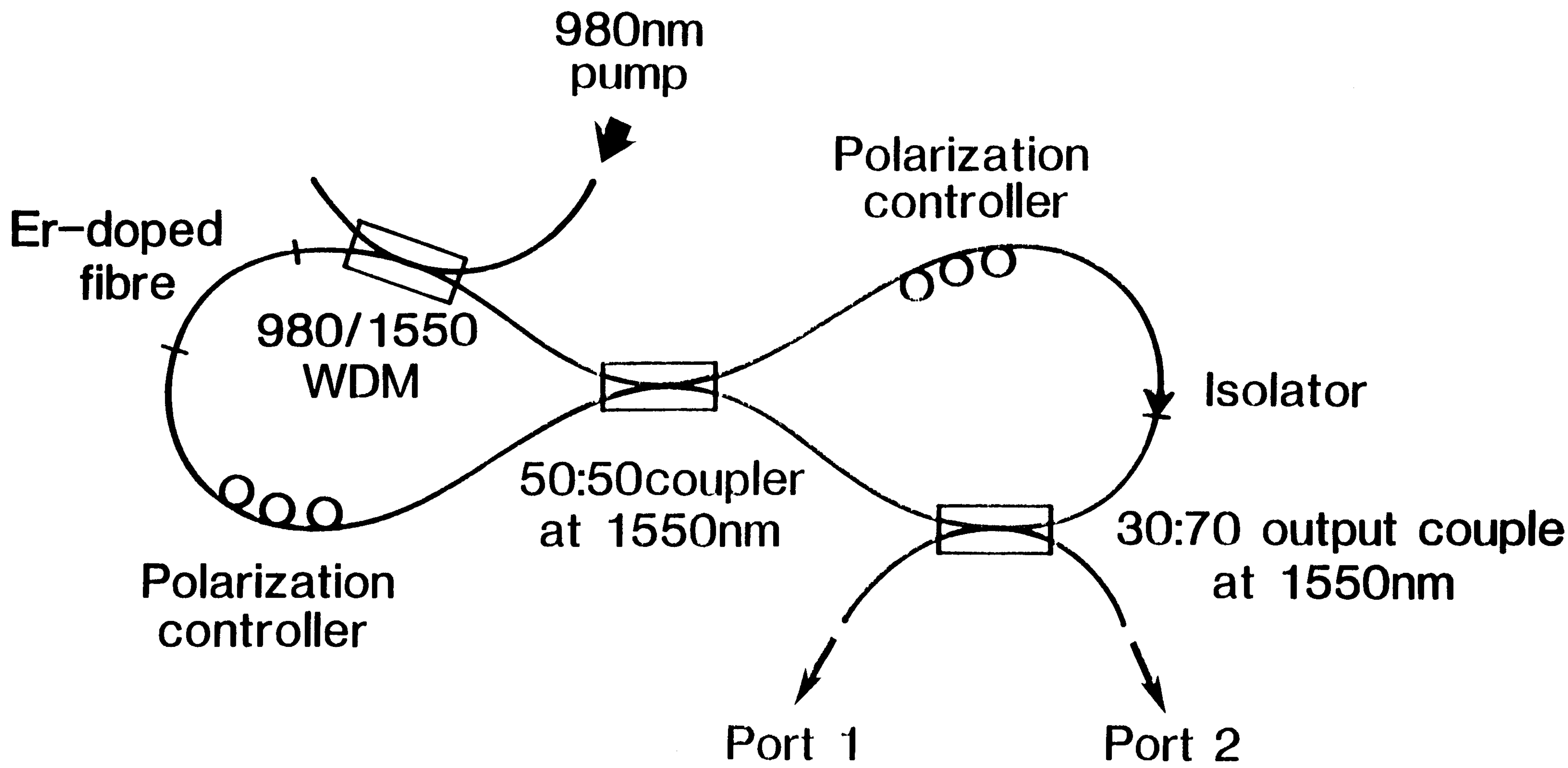
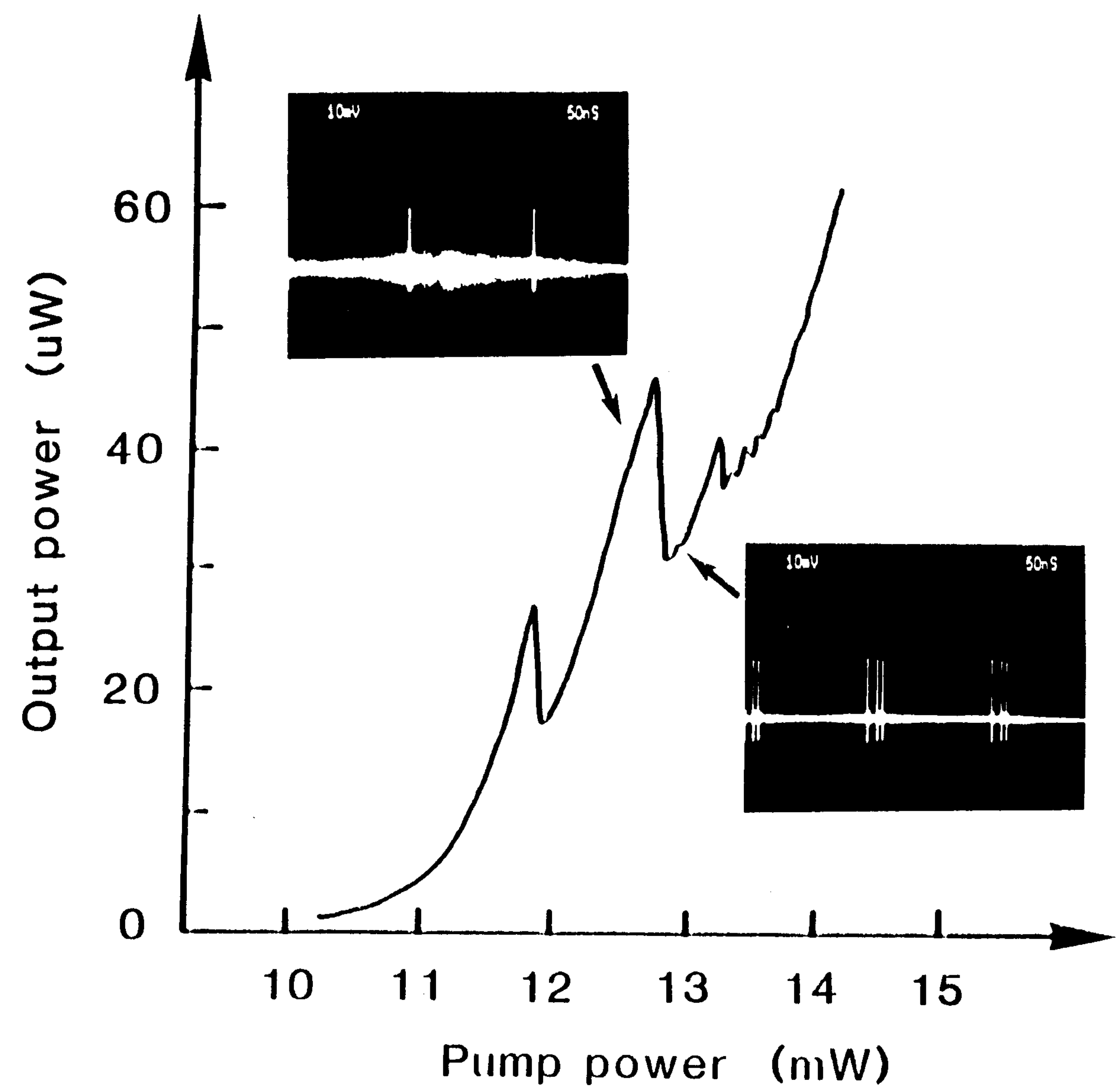
Figure Captions

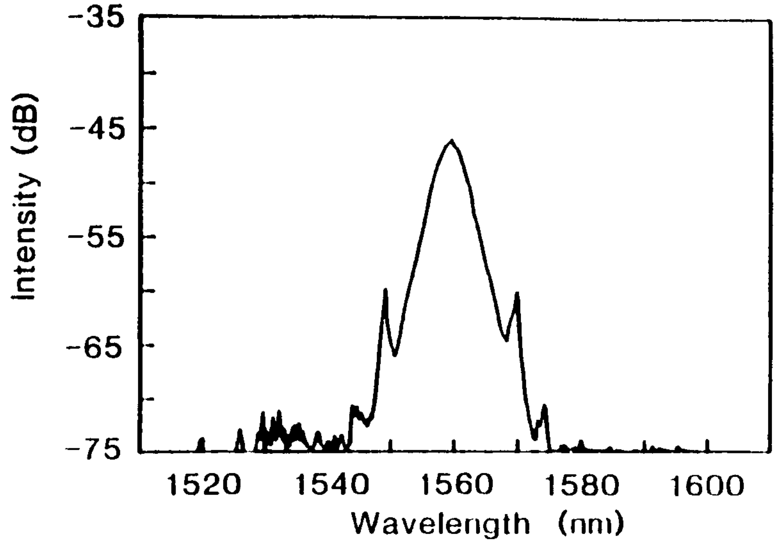
Figure 1 Experimental set-up

Figure 2 Output power characteristic measured at Port 2 (residue port). Inset are photographs of the corresponding time domain behaviour before and after the discontinuity.

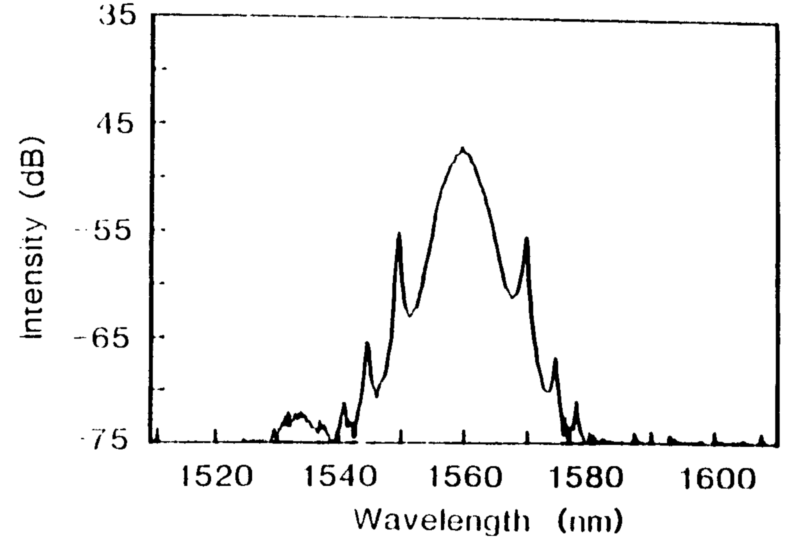
Figure 3 Output spectra at Port 1: (a) before and (b) after a power discontinuity, and at Port 2: (c) before and (d) after a power discontinuity.


980nm
pump
Er–doped
fibre
980/1550
WDM
Polarization
controller
50:50coupler
at 1550nm
Polarization
controller
Isolator
30:70 output couple
at 1550nm
Port 1
Port 2

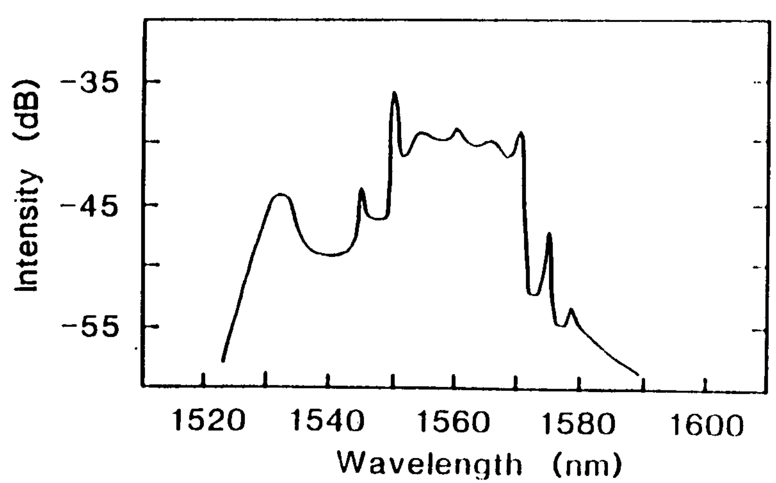

10mV
50nS
60
40
20
0
10mV
50nS
10
11
12
13
14
15
Output power (uW)
Pump power (mW)


-35
-45
-55
-65
-75
Intensity (dB)
1520
1540
1560
1580
1600
Wavelength (nm)

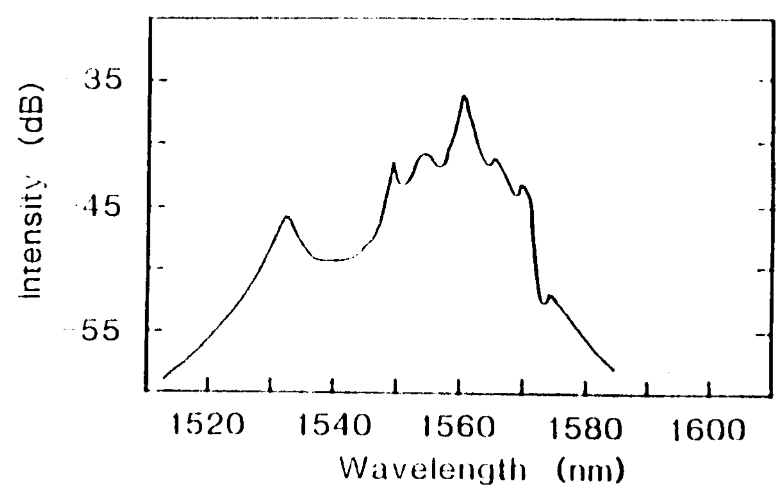
(a)


35
45
55
65
75
Intensity (dB)
1520
1540
1560
1580
1600
Wavelength (nm)

(b)


-35
-45
-55
Intensity (dB)
1520
1540
1560
1580
1600
Wavelength (nm)

(c)


35
45
55
Intensity (dB)
1520
1540
1560
1580
1600
Wavelength (nm)

(d)