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A Self-Starting, Passively Mode-Locked Erbium Fibre Laser

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We report a novel self-starting, passively mode-locked erbium fibre laser. The scheme is based on the reflection properties of a nonlinear amplifying loop mirror and provides a stable source of picosecond pulses.

Nonlinear optical loop mirrors (NOLMS) [1] are of considerable interest for optical switching and mode-locking of fibre lasers. Reverse biased NOLMS [2] have already been incorporated in conventional active mode-locking systems to act as intra-cavity pulse compressors[3] and also as all-fibre passive mode-lockers [4]. However, in such systems the requirement for loop biasing by means of induced fibre birefringence leads to polarisation control problems and hence to environmental instability. Recently, Nonlinear Amplifying Loop Mirrors (NALMS) [5,6] have been shown to offer improved pulse switching properties both in terms of input switching power (full amplitude switching powers as low as 200 μW have been reported[5]) and on/off contrast. In this paper we report for the first time the use of a unbiased NALM in a novel, all-fibre, self-starting, passive mode-locking configuration. We believe this development will lead to remarkably simple, stable and practical sources of picosecond pulses at 1.55 μm for soliton communication systems.

The laser configuration is shown in fig.1. At low input powers the NALM acts as a conventional loop-mirror reflecting light back to the port from which it came. Thus low intensity light circulating anti-clockwise in the isolator loop enters the NALM at port A and is reflected back to the same port, i.e. towards the isolator, where it is lost. As the intensity of light incident at port A is increased, the loop becomes nonlinear and light is switched to port B, whereupon it circulates counter-clockwise in the isolator loop. In this instance the light passes through the isolator and provides feedback to the gain medium. The system thus experiences lowest loss for high light intensities and is therefore biased to operate in a pulsed mode. Furthermore, the low input power required to switch a NALM operating at high gain means that pulsed operation is able to build up from noise at the NALM input.

The experimental configuration employed a loop coupler arranged to give

50:50 coupling at 1550 nm. The unidirectional isolator loop had a total length of 2m. The isolator was polarisation insensitive, with an insertion loss of 0.4 dB and an isolation of 40 dB. The doped fibre was 2m long and contained 800 ppm Er^{3+} (λ_c =1230 nm, NA=0.14). A 980/1550 WDM coupler was inserted into the NALM to permit pumping of the amplifier and to provide output coupling (0.5 %). The remainder of the NALM loop was constructed from single-mode fibre having λ_c=960 nm, NA=0.15 and D=-5 ps/nm/km. Using a Ti:Sapphire pump laser at 980 nm, the system properties were investigated for total NALM loop lengths of 12m and 102m. The total round trip loss of the system was $\approx$4 dB in both cases. Since the laser's operation is based on an unbiased NALM, the system could in principle be constructed from all polarisation-maintaining fibres, resulting in complete environmental stability. However, as a first demonstration we have used conventional fibres and therefore polarisation controllers were required in both the unidirectional and NALM loops.

In operation it was found that the laser passively mode-locked at the cavity round trip frequency once a certain input pump power level was reached ($\approx$ 100 mW for 104 m, $\approx$ 200 mW for 14 m), although when mode-locked, the input pump power to the system could be reduced well below the power required for self starting. The pulses were in general square, as expected from the S-shape of the NALM reflectivity curve. This switching characteristic means that the laser cavity loss decreases progressively with pulse amplitude until a certain point is reached, when it starts to increase again. Thus the power of the internal circulating pulse is clamped to this peak value and it's width must increase to accommodate a higher average circulating power. The effect is shown in fig.2, where for increasing pump power the output pulse amplitude is constant whereas the width increases proportionally. The shortest pulses so far obtained were 150 ps FWHM (see fig(3)) at a repetition rate of 16 MHz using the 14m system. In this case the internal circulating peak power in the isolator loop was estimated at 100 W, which is close to the calculated nonlinear switching power of the loop. The shortest pulses generated with the 104 m system were 500 ps with a circulating peak power of 10 W.

These experiments clearly demonstrate the potential of the new figure-eight self-starting, mode-locked fibre laser configuration. Further improvements are expected with the use of polarisation-maintaining components to eliminate the fibre birefringence effects which are currently limiting the pulse width. In this case the laser is expected to generate solitons with widths of a few picoseconds or less.

References

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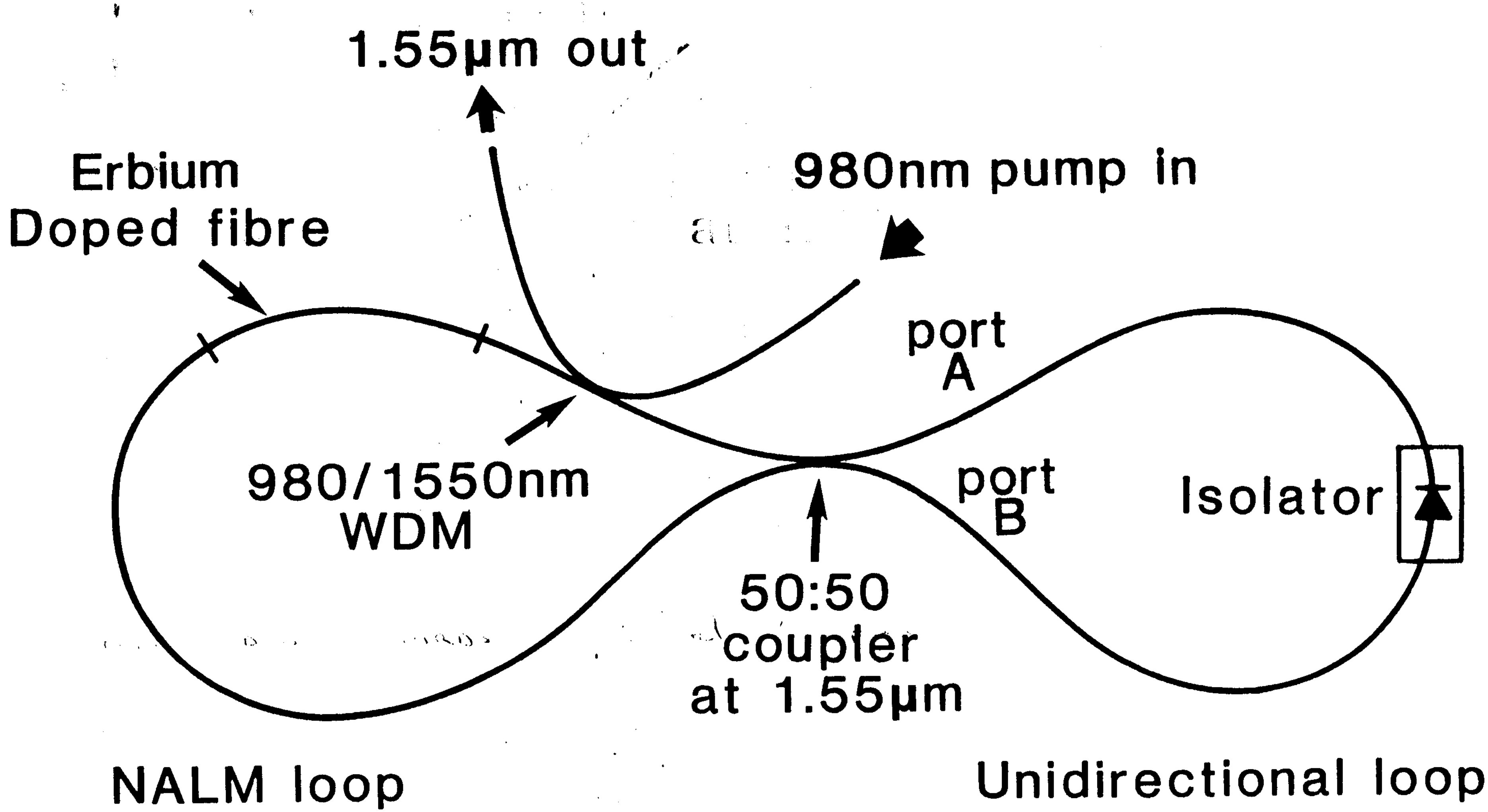
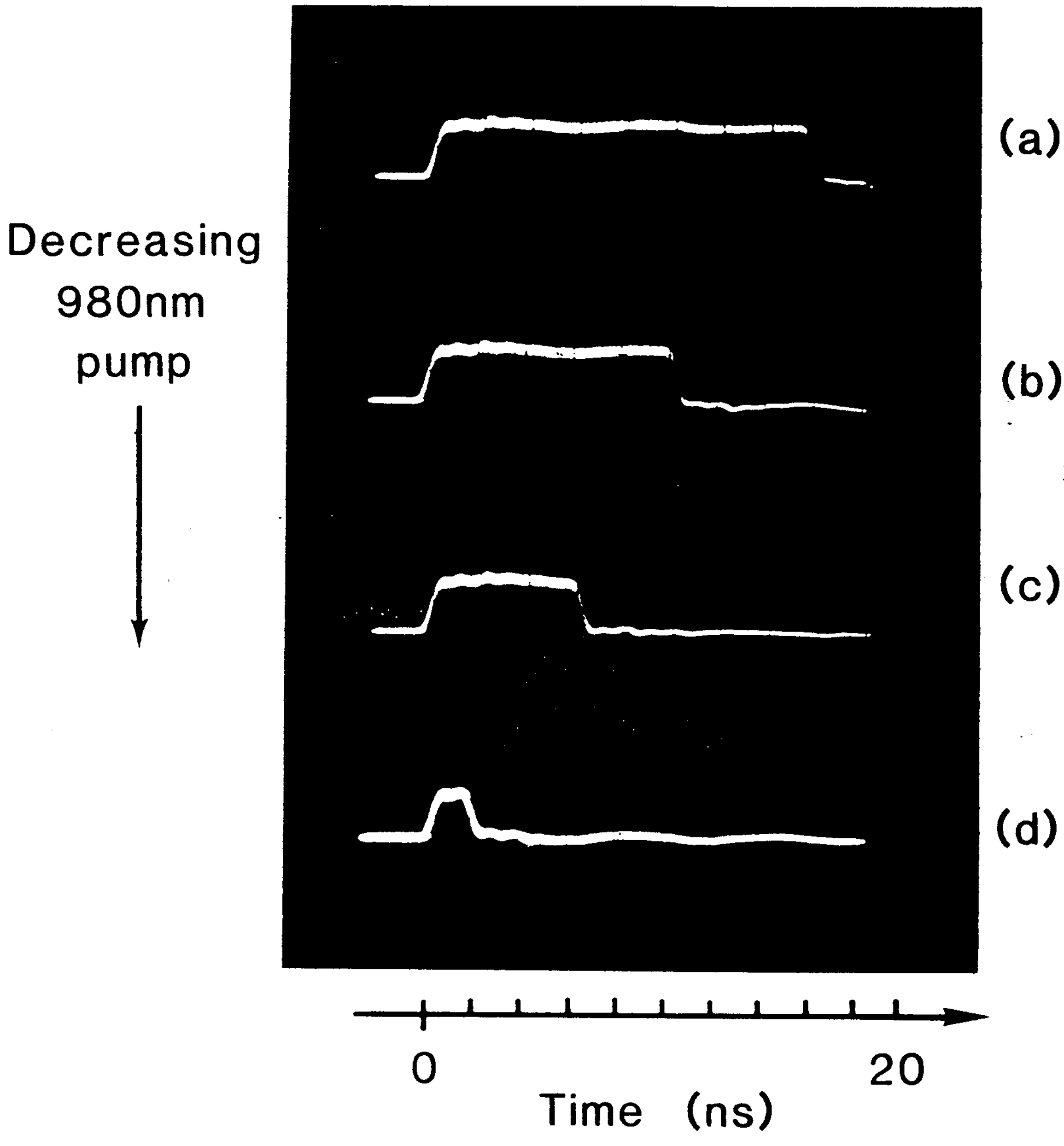
Figure captions

Figure 1) Experimental configuration of the self-starting, passively mode-locked fibre laser.

Figure 2) Output pulse shape for 104 m mode-locked fibre laser as a function of pump power. Input 980 nm pump powers were (a)155 mW, (b)115 mW, (c)75 mW and (d)40 mW. The system self started at an input pump power of 80 mW.

Figure 3) Pulse output from the 14 m mode-locked fibre laser.


1.55μm out
Erbium
Doped fibre
980nm pump in
port
A
980/1550nm
WDM
port
B
Isolator
50:50
coupler
at 1.55μm
NALM loop
Unidirectional loop


Decreasing
980nm
pump
(a)
(b)
(c)
(d)
0
20
Time (ns)

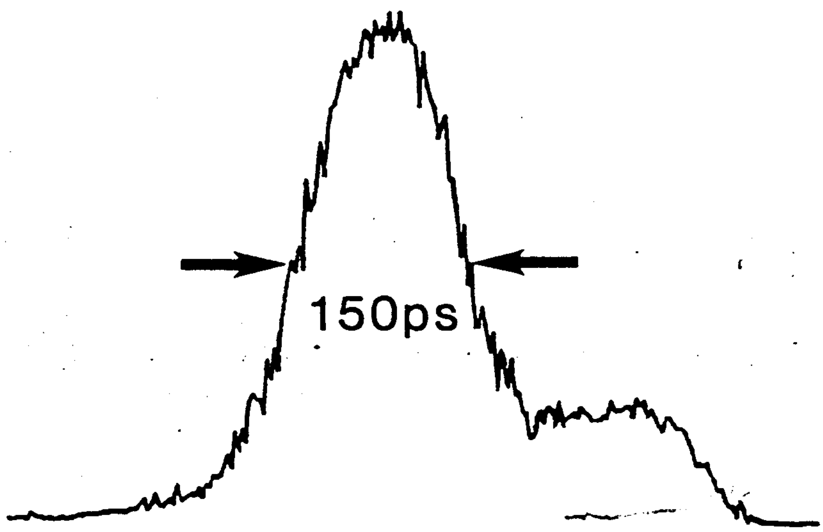


fig 3. D. J. Richardson et al. 'SELF STARTING