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LOSSES IN FIBER LASER CAVITIES

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ABSTRACT

A passive cavity ring-down technique has been used to measure the intrinsic losses of a fiber laser cavity. The results show that very low cavity losses can be obtained using conventional mirrors butted to the fiber.

Losses in fiber laser cavities. Morkel, Farries & Payne.

Summary.

Fiber lasers have been fabricated in a number of cavity configurations including the direct butting of cleaved fiber ends against bulk mirrors to form a Fabry-Perot resonator[1]. Although this technique is versatile, the optical loss incurred at the butted fibre ends has in the past been uncertain. For example, it is unclear whether the alternative technique of applying reflective coatings directly to the fiber ends gives lower losses [2]. An indication of the excess loss of a laser cavity (ie excluding output coupling) is also desirable in order to predict the optimum value of the output coupling. The optimum output coupling is that which gives the maximum amount of laser output power for a given degree of pump power.

We present in this paper results which give a direct indication of the excess loss in a butted fiber laser cavity, from which it is possible using well known expressions[3] to deduce optimum values of the output coupling.

The experimental configuration is shown in Fig.1. A Q-switched Nd:YAG laser operating at 1.064 μm was used to inject pulses of 150 μs into the passive fiber laser resonator which contained Nd-doped fiber. The fiber had an NA of 0.24, core diameter 2.7 μm, loss 4 dB/km and 500 ppm Nd dopant concentration. The cavity path length was chosen to be long

(190m) compared to the Q-switched pulse length in order to prevent any overlap effects within the fiber resonator. Each pulse from the Nd:YAG laser injected into the cavity shuttles back and forth giving rise to an exponentially decaying train of pulses from the output mirror, as shown in Fig.2. The spacing of the pulses gives the cavity round trip delay time and the decay of the pulse envelope gives the round trip feedback. In order to emphasise the effect of intrinsic losses, the two mirrors were chosen to have maximum reflectivity (>99.5%) at 1.064 μm. This necesitated the use of digital signal averaging of the Si:APD detector output to recover the small signal.

After an integer number N of cavity round trips the intensity feedback can be written as

$$\mathrm{Log}_{10}(\mathrm{feedback}) = N.(\,-2\alpha L/10^4 + \log_{10}(R_1 R_2 (1-k))\,)$$

Where:

α = Fiber loss in dB/km.

N = Number of cavity round trips.

L = Fiber length.

R_1, R_2 = Mirror reflectivities.

k = Loss incurred at mirror butts.

From the data in Fig.2., Log_{10}(feedback) can be plotted as a function of round trip number and the result is shown in Fig.3. The slope of the line gives the round trip loss, from which, knowing the fiber loss to be (4 ± 0.5) dB/km, we can deduce that k<4%. Thus each individual butt loss represents a loss of less than 0.1 dB.

The butt loss was found to be highly dependent on fiber cleave quality, as expected. However, the measurement was repeated a number of times, using a York FK11 fiber cleaver to prepare fresh fiber ends each time. A standard deviation of less than 3% in the cavity feedback was found showing excellent repeatability. The sensitivity of the measurement to fiber end preparation suggests that cavity ring down may find application in checking cleave quality.

Using the well-known expression for optimum output coupling in low loss laser cavities $T_{opt}=(g_o.L_i)^{½}-L_i$ [3], we can derive an upper limit on the optimum output coupling as a function of unsaturated gain per pass in Nepers (g_o, typically 0-3 for Nd fiber under laser-diode pumping). We see that for an unsaturated gain of 3 and cavity excess loss (L_i) <4%, the maximum value for the optimum output coupling is ~30%. This figure is in agreement with previous empirical determinations using a range of mirror reflectivities.

In conclusion, using a simple technique we have determined the butt loss in fiber laser cavities to be very small and consequently the application of coatings directly to the endfaces is unnecessary. The optimum output coupling for a typical Nd-doped fiber laser will be (20-30)% for maximum efficiency.

[1] R.J. Mears, L. Reekie, S.B. Poole & D.N. Payne.

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[2] M. Shimizu, H. Suda & M. Horiguchi.

High-efficiency Nd-doped fibre lasers using direct-coated dielectric mirrors.
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Losses in fiber laser cavities. Morkel, Farries & Payne.

Fig.1. Experimental passive-cavity configuration.

Fig.2. Detector output showing pulse decay within fiber cavity. First peak due to stray light pickup from Nd:YAG laser.

Fig.3. Plot of $\log_{10}$(feedback) vs. number of round trips. Data taken from fig.2.

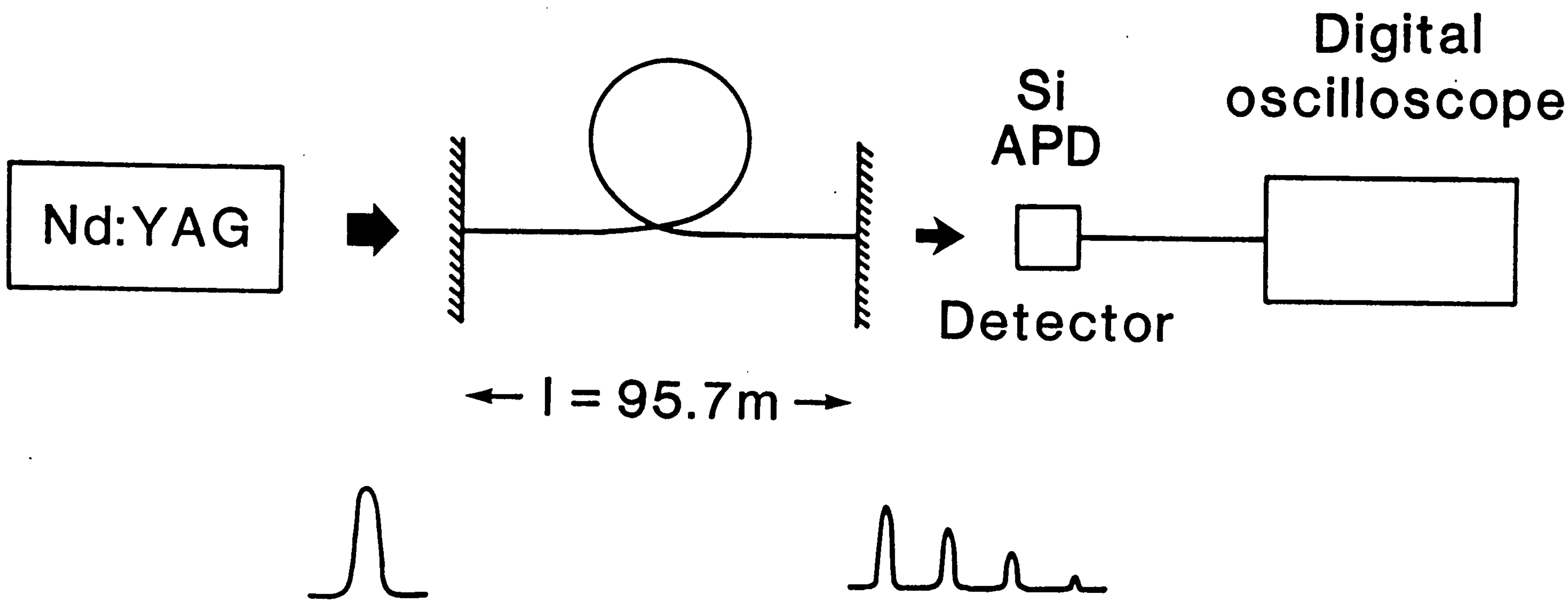

FIG 1

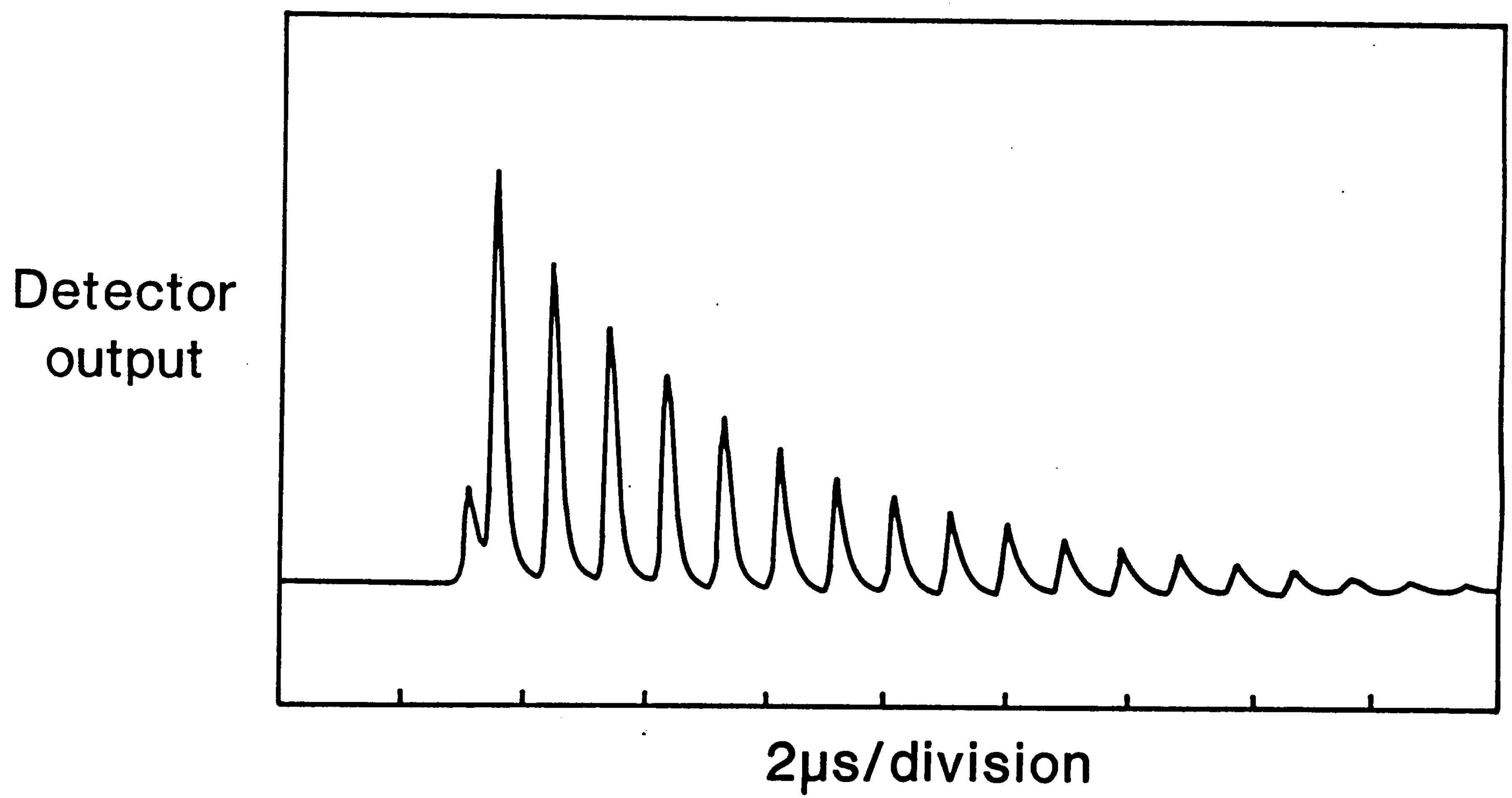

FIG 2

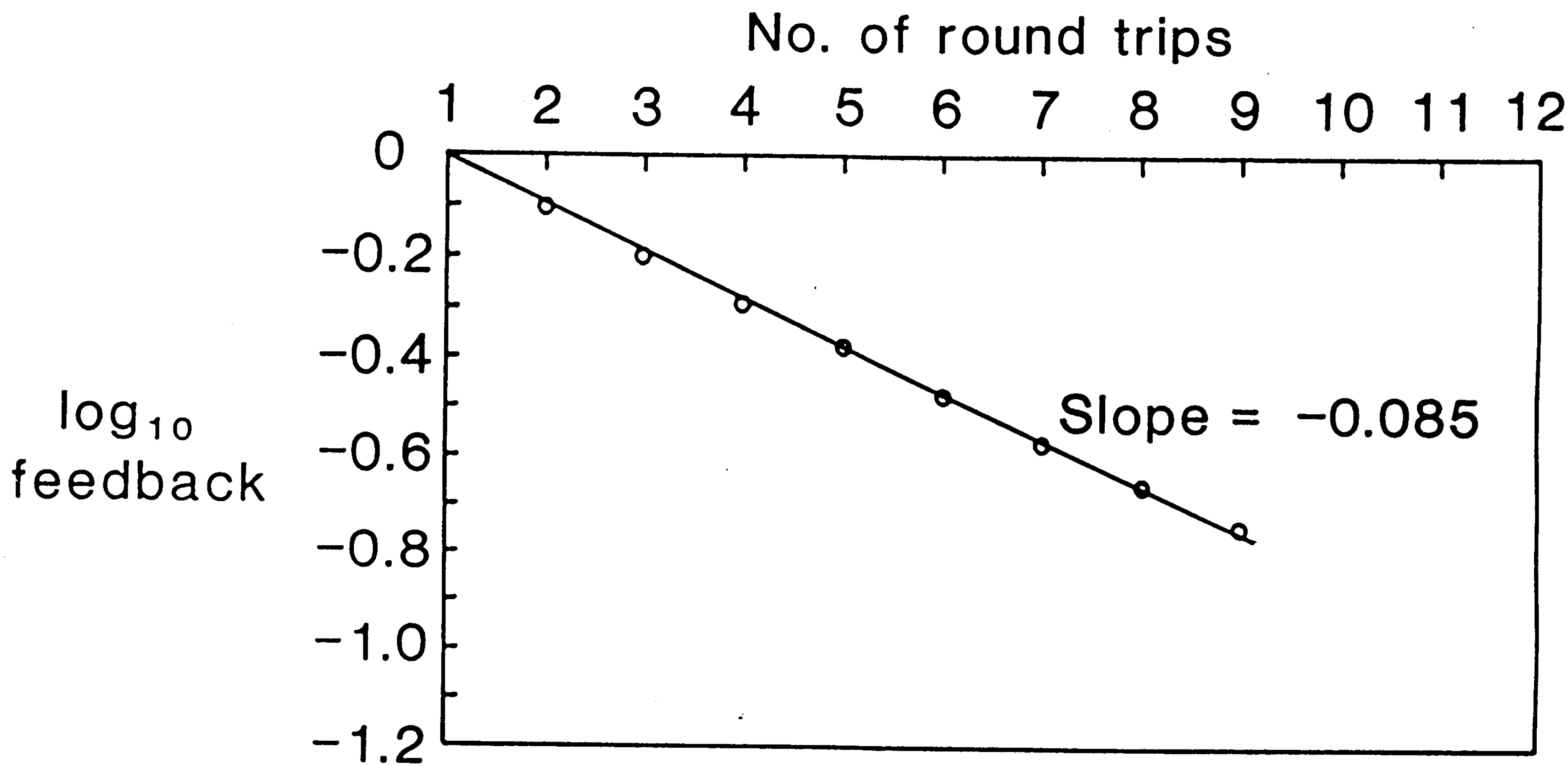
No. of round trips
1 2 3 4 5 6 7 8 9 10 11 12
0
−0.2
−0.4
−0.6
−0.8
−1.0
−1.2
log10 feedback
Slope = −0.085

FIG 3