Performance Characteristics of Single Frequency Er^{3+}:Yb^{3+} Codoped Fiber Lasers

*W.H.Loh, B.N.Samson, L.Dong, G.J.Cowle and K.Hsu**

Optoelectronics Research Centre, University of Southampton, Southampton SO17 1BJ, UK

*Micron Optics Inc. 2801 Buford Hwy, Suite 140 Atlanta, Georgia 30329, USA

Abstract

The performance of Er^{3+}:Yb^{3+} single frequency fiber lasers is reported. With lasing powers up to 60mW, they are shown to have excellent specifications in terms of optical linewidth, signal-to-noise ratio, RIN, SMSR and polarisation purity.

For much of this decade, interest has been sustained in developing high performance single frequency Er^{3+}-fiber lasers [1-3]. For robust single frequency operation, these lasers need to be only centimeters long. Early grating-based fiber lasers relied on Er-germanosilicate fibers, but lasing powers were low - μW typically [1,2], due to low pump absorption in the short cavity. Increasing the Er-concentration to increase absorption is however difficult. Germanosilicate fibers are prone to ion clustering, which degrades the efficiency and destabilises [1,5] the laser. Thus the need to amplify the laser power to useful levels of a mW or more is a drawback where low noise sources are desired.

Considerable effort has been put into investigating solutions for increasing the power from short cavity fiber lasers [3,6]. While the absorption can be increased by changing the pump wavelength [6], this is unlikely to be fully practical till the arrival of green laser diodes. On the other hand, Er^{3+}:Yb^{3+} fibers are mature. With this scheme, the 980 nm absorption can be increased up to 2 orders of magnitude, with corresponding increases in output power.

However, two problems stood in the way. One was the low photosensitivity in these fibers. In addition, the lasers were observed to operate in 2 polarised modes [7], unattractive for many applications. Recently, a Er^{3+}:Yb^{3+} fiber with a photosensitive annular region surrounding the core enabled strong gratings to be written. Also, the resulting lasers were observed to lase in a single polarisation state [8]. We report here on the characteristics of these lasers, and show their potential as high performance low noise narrow linewidth sources.

We first present the performance of a 5 cm distributed feedback (DFB) fiber laser, fabricated by scanning a 100 mW, 244 nm beam across a phase mask. The DFB laser, placed on an aluminium plate without temperature control, is spliced directly to a fiber WDM, which couples the pump from a 40 mW 980 nm laser diode. The 1550 nm arm of the WDM is spliced to a pigtailed isolator. The laser power measured out of the isolator is 4 mW.

At this power, the optical SNR is 65 dB. A scanning F-P interferometer confirmed stable single frequency and single polarisation operation. The optical linewidth, measured with the delayed self-heterodyne technique, is 18 kHz. The RIN is < -153 dB/Hz for frequencies > 10 MHz. The peak RIN of -118 dB/Hz, at the relaxation oscillation frequency of 0.6 MHz, is lower than previous fiber lasers using feedback noise reduction circuits [1]. Estimating the side mode suppression ratio (SMSR) is more involved. The side modes for a 5 cm DFB laser would be GHz away, too close for an optical spectrum analyser with 0.1 nm resolution. We estimate the SMSR from the rf frequency spectrum during the self-heterodyne measurement, in the 1-7 GHz frequency range. Any side modes should show up as a beat signal (with the main mode) in that range. No such beat signals were observed. From the main mode beat signal level, we conclude that neighbouring side modes are < 50 dB below the main mode, resolution limited by the noise floor.

To determine the single polarisation state purity, the laser output was connected to a polarisation controller and a polariser. By adjusting the polarisation controller, the output from the polariser was reduced by 50 dB. The 2nd polarisation mode is thus effectively nonexistent. Table 1 summarises the device characteristics of the Er^{3+}:Yb^{3+} DFB fiber laser.

Output Power	4 mW
Optical Linewidth	18 kHz
Optical Signal-to-Noise Ratio	65 dB
Relative Intensity Noise, RIN (> 10 MHz)	< -153 dB/Hz
Peak RIN (at 0.6 MHz)	-118 dB/Hz
Side Mode Suppression Ratio (SMSR)	< -50 dB
Single Polarisation State Purity	50 dB
Wavelength Stability	0.01 nm/°C

Table 1. DFB fiber laser device characteristics

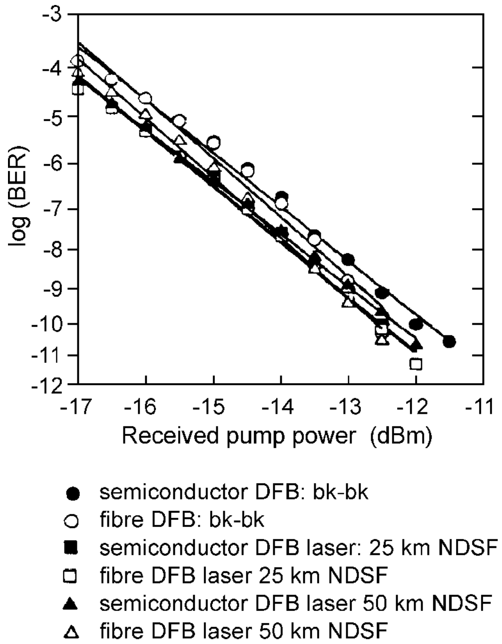

Fig. 1. (Top right) Comparison of BER performance of DFB fiber and semiconductor lasers

Finally, transmission tests were performed in a 10 Gb/s NRZ system over 50 km of standard fiber. A diode DFB laser (with 8 MHz optical linewidth) was also similarly tested for comparison. Fig. 1 shows the plots of the Bit Error Rate (BER) performances, establishing that no problems or penalties are incurred in using the fiber laser.

These findings show that Er^{3+}:Yb^{3+} DFB fiber lasers are excellent for applications requiring single frequency low noise sources. However, some applications, e.g. CATV, require more power. Unfortunately, at high pump powers, these lasers invariably fall off in power [8]. These behaviours, repeatable and occurring over time scales of many seconds, are attributed to thermal effects, changing the refractive index and dephasing the grating. However, high power single frequency operation can be achieved, as described below.

Fig. 2(a) shows the configuration of a Er^{3+}:Yb^{3+} fiber Bragg grating laser (FBGL). One end consists of a dielectric mirror (R=99.86% at 1.55 µm), while the other end is a centimeter long Bragg grating (R=98% at 1536 nm) written directly in the doped fiber, and situated a few mm away from the dielectric mirror. The entire laser is < 1.5 cm in length.

Fig. 2(b) shows the lasing characteristic of the FBGL. A maximum power of 58 mW (at the output of the isolator) is obtained for 500 mW pump power. A scanning F-P interferometer confirmed single frequency operation. The RIN is < -168 dB/Hz for frequencies > 10 MHz, with a peak RIN value of just -133 dB/Hz at the relaxation oscillation frequency of 2.8 MHz. The optical linewidth was measured to be 500 kHz. Single polarisation state purity was confirmed to be better than 50 dB.

The 60 mW FBGL has a reasonable net efficiency of 12% with respect to pump power, but it is clear that the efficiency is much better at lower pump powers. This is due to the 'bottleneck' effect, arising from the finite energy transfer rate from excited Yb^{3+} to Er^{3+} ions. As the transfer rate is a strong function of the ion separation, optimising the Yb^{3+} and Er^{3+} concentrations and their ratio may enable output powers exceeding 100 mW. It was recently argued that the Yb^{3+}-Er^{3+} energy transfer can usefully act as a low-frequency filter, buffering Er^{3+}:Yb^{3+} lasers against pump noise [9].

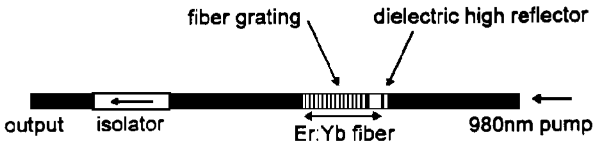

Fig. 2 (a) Configuration of FBGL.

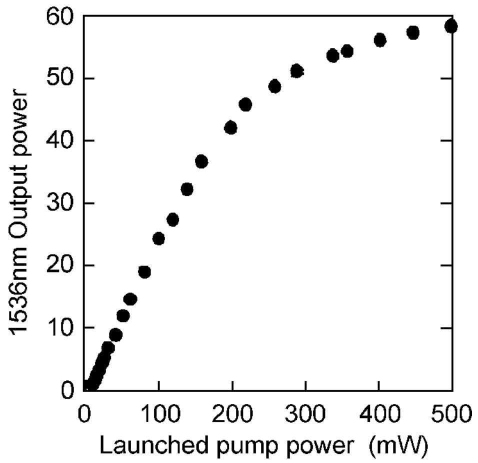

Fig. 2(b) Lasing characteristic of FBGL

However, as this also leads to the 'bottleneck' problem, the degradation in laser efficiency at high pump powers would appear to outweigh the advantage of any limited immunity against pump fluctuations.

The results clearly show that high performance single frequency short cavity fiber lasers are finally a realistic option. They are now capable of producing reasonable output powers, and possess excellent low noise characteristics under free-running conditions. Only centimeters long, they are compact, easy to fabricate and package. In 10 Gb/s NRZ transmission tests over standard fiber, they perform equally well compared to a diode DFB laser. Although the fiber lasers are not necessarily superior in digital transmission tests, they may hold advantages over DFB diodes. Apart from ease of fabrication, fiber lasers have a wavelength insensitivity to temperature at least an order of magnitude better, which could be attractive in dense WDM systems requiring tight wavelength tolerances. Also, as WDM transmitters, fiber lasers may afford better reliability, e.g. for a 16-channel WDM transmitter, by first combining the pump powers from all the pump diodes before redistributing them to each of the fiber lasers, a failure in any one laser (pump) diode will simply result in only a small reduction in the transmitter power of each channel.

References

1. G.A.Ball, C.E.Holton, G.Hull-Allen and W.W.Morey, IEEE Photon. Technol. Lett., 17, 420- 422 (1992).

2. J.L.Zyskind, V.Mizrahi, D.J.DiGiovanni and J.W.Sulhoff, Electron. Lett. 28, 1385-1387 (1992).

3. J.T.Kringlebotn, J.-L.Archambault, L.Reekie, J.E.Townsend, G.G.Vienne and D.N.Payne, Electron. Lett., 30, 972-973 (1994).

4. F.Sanchez, P.Le Boudec, P.-L.Francois and G.Stephan, Phys. Rev. A., 48, 2220-2229 (1993).

5. W.H.Loh and J.P.de Sandro, Opt. Lett., 21, 1475-1477 (1996).

6. W.H.Loh, S.D.Butterworth and W.A.Clarkson, Electron. Lett., 32, 2088-2089 (1996).

7. W.H.Loh, L.Dong and J.E.Caplen, Appl. Phys. Lett., 69, 2151-2153 (1996).

8. L.Dong, W.H.Loh, J.E.Caplen, J.D.Minelly, K.Hsu and L.Reekie, Opt. Lett. 22, 694-696 (1997).

9. S.Taccheo, P.Laporta, O.Svelto and G.DeGeronimo, Opt. Lett., 21, 1747-1749 (1996).