400mW, 1060nm ytterbium doped fiber DFB laser

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ABSTRACT

We report for the first time, more than 400 mW of output power at 1056.1nm from a distributed feedback (DFB) fiber laser. The DFB fiber laser comprises a simple π-phase-shifted Bragg grating written into a photosensitive ytterbium-doped fiber. The laser operates with a single longitudinal mode at a wavelength defined by the phase shift and the grating period. Without any internal polarisation selection mechanism, the cavity supports orthogonal polarisation modes, which operate simultaneously. The DFB fiber laser was pumped by a 976nm amplified spontaneous emission (ASE) source based on a ytterbium doped jacketed air clad (JAC) fiber pumped by a 915nm multimode laser diode source. An output of 400mW at 1056.1nm was obtained from the output port while 70mW was obtained from the other port, when pumped with 1.5W of 976nm radiation. The total output from the DFB fiber laser was approximately linear with increasing pump power and the overall performance was limited by the available pump power. The spectral characteristics and signal to noise ratio remained similar over the pump power range. The output of the DFB was in single-mode fiber (ie. M^2~1).

Keywords: Fiber laser, DFB laser, ytterbium laser

INTRODUCTION

All-fiber distributed feedback (DFB) lasers have inherent fiber compatibility, ultra-low relative intensity noise, very narrow linewidth, high side-mode extinction ratio and very high signal to noise ratio, making them a very useful source for a number of applications from telecoms to sensing [1-6]. Up to now, fiber DFB laser output power has been typically in the range 1 to 20 mW, limited by the pump absorption, heat dissipation, or saturation of the gain medium by the high intracavity powers concentrated around the phase shift region. Where higher powers are required, success has been achieved by amplification of the DFB fiber laser signal in a MOPA configuration, to powers of several Watts, without degradation of RIN or linewidth characteristics[7]. With the pursuit of high power narrow linewidth MOPA devices, a 10-fold increase in the power of the seed laser will reduce the amplification required and produce a high power precision source in its own right.

In this paper, we report the use of a double-clad fiber pump source which can deliver high output power in a standard single-mode fiber in order to pump an ytterbium-doped DFB fiber laser. We obtained the highest ever reported output power from an all-fiber DFB laser with more than 400mW. Power levels that were previously only attainable with much larger "bulk" systems can now be obtained with compact and efficient all in-fiber sources.

EXPERIMENTAL SETUP

The experimental set-up is shown in Figure1. It comprises mainly of an ytterbium doped fiber ASE source and an ytterbium doped DFB fiber laser.

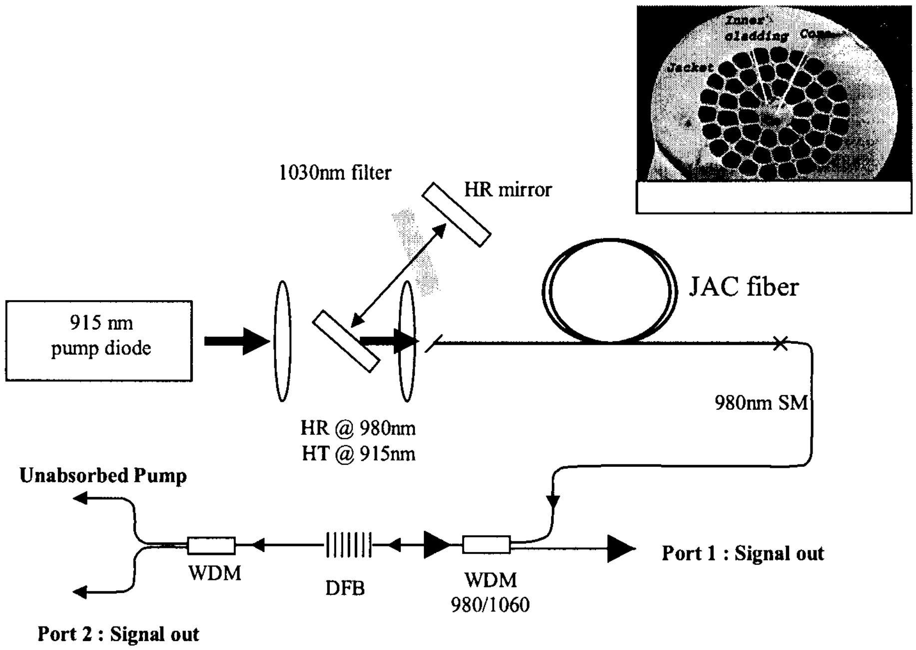


Figure 1 : Experimental set-up showing the JAC ASE source and DFB fiber laser configuration

Pump Source

The pump laser consisted of an ytterbium doped jacketed-air clad (JAC) fiber [8] (Figure 1 inset) pumped by a broadband multimode laser diode at 915nm. The JAC ytterbium doped fiber has a 10 µm diameter, 0.1 NA core at the centre of a 28µm diameter inner cladding (NA ~0.5). The inner cladding is surrounded by an air-hole structure, raising the NA and therefore allowing a tighter pump confinement. The end of the JAC fibre facing the pump diode was angle-cleaved in order to avoid any feedback which would have created instability in the JAC fiber source. An additional 1030nm filter was used to suppress unwanted 1030-1060nm emission. The output end of the JAC fiber is spliced to a standard 980nm single mode fiber. The absence of feedback insures that the JAC fiber operates in ASE mode. The characteristics of the 976nm source are shown in Figure 2. The ASE power is then launched through a 980 / 1060 nm coupler into the DFB fiber laser

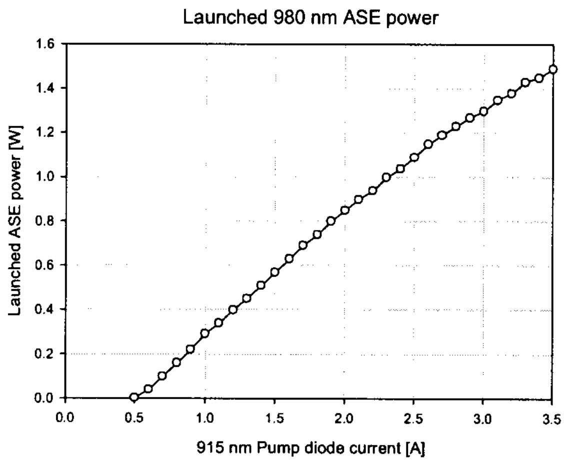


Figure 2(a) : Launched 980nm ASE power vs. 915nm diode drive current

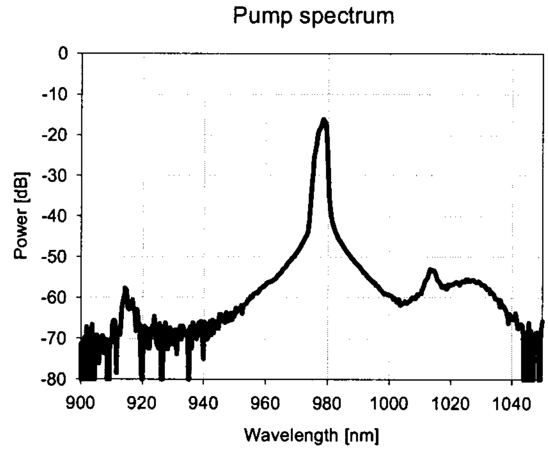


Figure 2(b) : Output spectrum of ASE source

DFB Laser

The DFB fiber comprises a π-phase-shifted Bragg grating written into a photosensitive ytterbium doped fiber using a continuous grating writing technique with a continuous wave UV laser source at a wavelength of 244nm. The phase-shift is offset from the centre position to get uni-directional operation [9][10]. The grating is lightly apodised to suppress grating side lobes and increase the suppression of higher order longitudinal modes. The reflection spectrum measured for the grating is shown in Figure 3, limited by the approximate 20pm resolution of the optical spectrum analyser. The effective refractive index contrast of the grating is estimated to be 1.5×10^{-4}, by comparison with a model. The fibre comprises a germanium, boron, ytterbium doped aluminosilicate core. The relative concentration of boron and germanium provide control over the photosensitivity and the core refractive index. The ytterbium concentration is around 6×10^{25} ions/m^3 and the core diameter and NA are 5.6μm and 0.14 respectively. The laser operates with a single longitudinal mode at a wavelength defined by the phase shift and grating period. Without any internal polarisation selection mechanism, the cavity supports two orthogonal polarisation modes, which operate simultaneously. The dual polarisation operation is characterised separately on a polarisation analyser, with a standard single mode semiconductor diode as a pump source. The wavelength separation of the two polarisation modes, defined by the combined birefringence of the grating and fiber, is expected to be <20pm as the individual polarisation modes cannot be distinguished on an optical spectrum analyser, with a limiting resolution of 20pm. The DFB fiber laser is operated in counter-pumped configuration with respect to the output end, through a 980/1060 nm WDM coupler spliced to the 976nm high power amplified spontaneous emission (ASE) source, as shown in Figure 1.

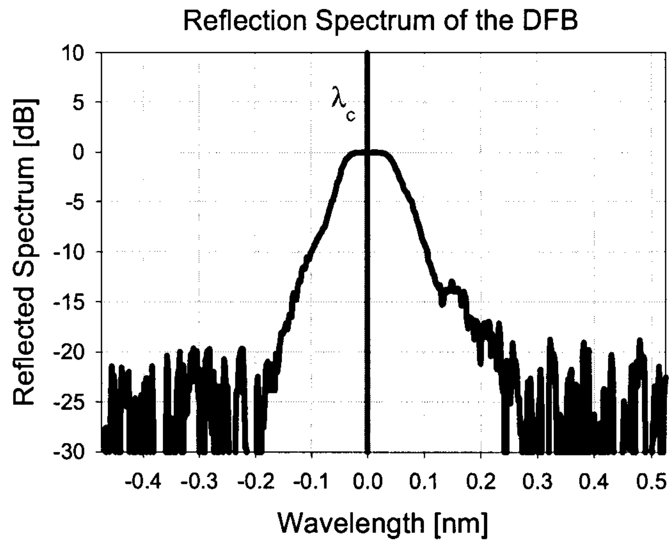
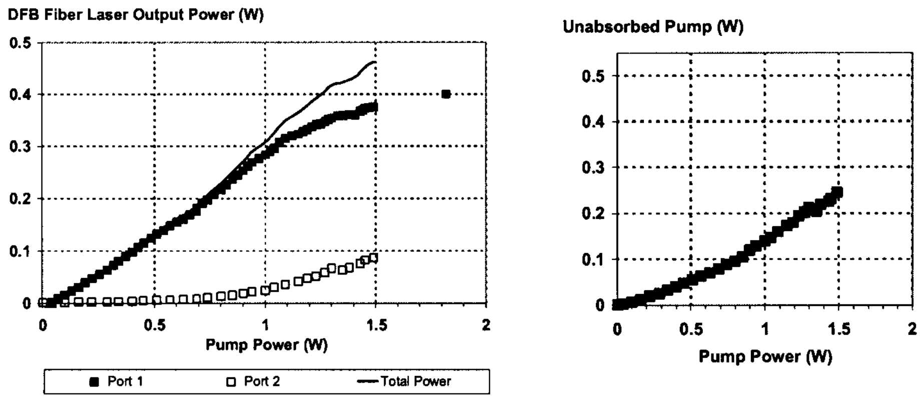


Figure 3: Grating reflection spectrum

The power emerging from Ports 1 and 2 of the DFB fiber laser and the unabsorbed pump power are separated using 980/1060nm WDM couplers and measured using calibrated power meters. In the analysis of results, no adjustment is made for the transmission loss through splices or WDM components. Following the power measurement, the output spectrum from Port 2 of the DFB fiber laser was monitored as a function of pump power using an Advantest QC8347 optical spectrum analyser with a resolution of 0.02 nm, although recorded data was unable to be extracted from the equipment.

RESULTS - DISCUSSION

The output power from Ports 1 and 2 as well as the unabsorbed pump power are shown in Figure 4 as a function of launched pump power. The slope efficiency is measured as 35% and 38% with respect to launched and absorbed pump respectively. Figure 4(a) shows the total output power is linear with respect to launched power, but that the directionality of the laser decreases with higher pump powers. This relation is shown in Figure 5.



(a) (b)

Figure 4 : Power performance of the DFB Fiber Laser (a) Output power from Port 1, Port 2 and the total power, (b) unabsorbed pump power.

Low power DFB fiber lasers have a typical uni-directionality figure around 20 dB [8], however in this particular laser we observed a roll-off in the uni-directionality for pump powers larger then 450mW. We believe this deviation in the uni-directionality is due to heating of the grating, especially near the pump launched end, by conversion of absorbed pump power to heat through the quantum defect and background losses. The non-uniform temperature distribution leads to the expansion of the fiber, causing chirping in the grating period, which in turn results in the variation of the reflectivity and laser cavity configuration. This problem can be avoided simply by more efficient heat removal schemes, or by continued development of the grating refractive index profile and fibre composition.

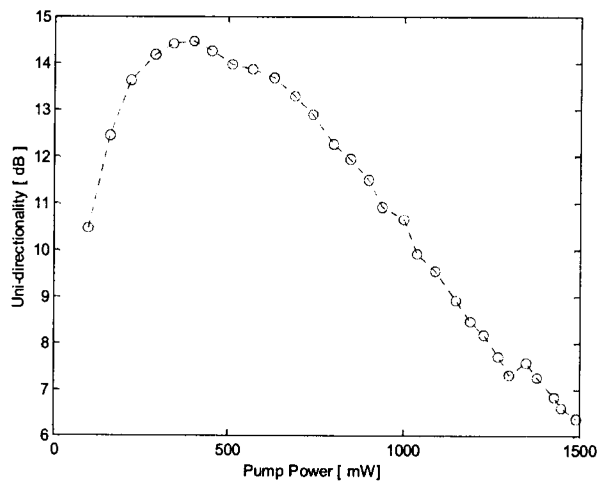


Figure 5 : Uni-directionality of the DFB laser w.r.t. launched power

The output spectrum (from Port 1) was qualitatively monitored throughout the experiment, showing a spectrum similar to that in Figure 6 at all pump powers. The data in Figure 6 was obtained separately, using a high power single mode 976nm semiconductor diode (Bookham) as a pump source. Figure 6 was recorded for the DFB fiber laser operating with a pump power of 570mW.

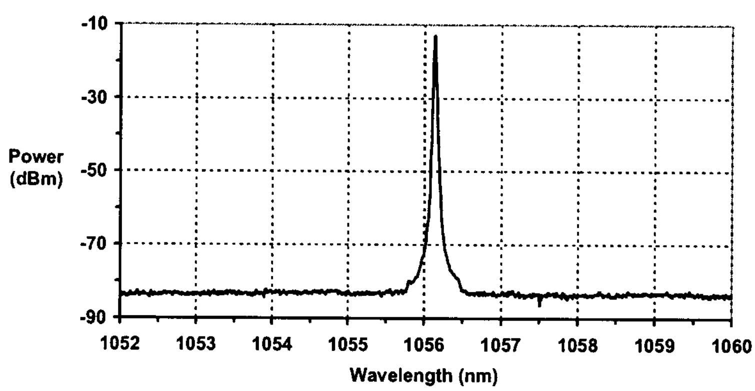


Figure 6 :Output spectrum of DFB fiber laser operating with a pump power of 570mW

CONCLUSION

We have demonstrated for the first time, more than 400mW of output power at 1056.1nm from a distributed feedback (DFB) fiber laser. Using a simple high-power continous wave ytterbium doped fiber ASE pump source, high output power can be attained while maintaining the DFB fiber performance (i.e. spectral purity and signal to noise ratio). The output of the DFB was in single-mode fiber (i.e., $M^2 \sim 1$).

With development of the grating refractive index profile and fibre composition, higher efficiencies and stronger uni-directionality may be attained. Such developments, coupled with increased pump power availability should enable output powers from DFB fiber lasers to continue on upwards.

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