2051 nm Narrow Linewidth All-Fibre DFB Laser for Holmium-Doped Fibre-Amplifier Applications

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Abstract *We report the design and performance of a single frequency all-fibre 2051 nm distributed feedback (DFB) laser source employing fibre Bragg gratings (FBGs). Output powers up to 36 mW CW and optical signal-to-noise ratios of > 65 dB/0.05 nm are obtained. Heterodyne measurements yield laser linewidths of 130 kHz FWHM. The single frequency source is amplified with a polarization-maintaining Ho-doped fibre amplifier (HDFA) to an output power of 1 W CW.*

Introduction

The development of simple, compact, and robust single frequency laser sources near 2051 nm is important for many emerging applications including LIDAR, spectral sensing, coherent lightwave systems, and WDM transmission[1],[2]. Most previous work on single frequency sources in the 2000 nm band has concentrated on packaged semiconductor lasers[3] and fibre based devices employing distributed Bragg reflector (DBR) technology[4]–[8]. However, semiconductor lasers have output powers of only a few mW, and their linewidths are not suitable for coherent lightwave systems. For DBR lasers, splice losses and temperature induced mode-hops limit stability and prevent them from delivering optimum single-frequency operation. With simple fabrication, low loss, and robust design, DFB FBGs offer good stability and enable single frequency operation without any mode hops, therefore presenting a highly attractive alternative to semiconductor and DBR sources. While some work on 2000 nm band DFB FBG lasers has been previously reported[9],[10], a more comprehensive evaluation of these sources, particularly at 2051 nm, is desirable. In this paper, we describe the design and detailed performance of a compact and stable single frequency DFB FBG laser at 2051 nm with high power, narrow linewidth, and an OSNR> 65 dB/0.05 nm. The laser source is amplified to 1 W output power with an HDFA MOPA configuration.

Experimental setup

Figure 1 shows the experimental setup for the DFB FBG laser. The DFB FBG (iXblue IXC-CLFO-2000) consists of an 80-mm-long active Tm-doped fibre onto which a 60-mm-long DFB FBG grating is written. Apodization techniques for the gratings yield an effective cavity length of 25 mm and a longitudinal mode spacing of 4.0 GHz and reflectivities of the high- and low-reflection sides of $R_{HR} = 99.97\%$, $R_{LR} = 99.0\%$, respectively. Spectral widths of the HR and LR sides are 0.25 nm or 18 GHz and 0.34 nm or 24 GHz, respectively. A $\pi/2$ phase-shift on the index modulation periodicity is written into the cavity, leading to robust single frequency operation of the laser. Passive fibre pigtails (iXblue IXF-PAS-6-130-0.21) couple light into and out of the laser cavity. The DFB FBG is pumped either by a 250-mW semiconductor (SC) laser pump (P1) at $\lambda = 1550$ nm or by a 500-mW fibre laser (FL) at $\lambda = 1567$ nm via a wavelength division multiplexer (WDM) in a counter-pumped configuration. The isolator (ISO) at the output of the laser suppresses unwanted reflections into the laser cavity.

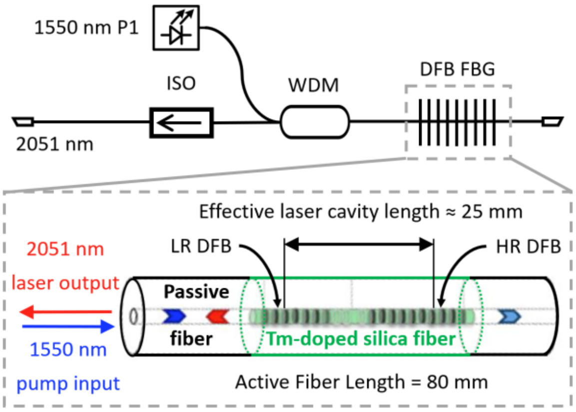

Fig. 1: Topology of the DFB FBG laser

Experimental results

We first investigate the performance of the DFB FBG laser emitting at $\lambda = 2051$ nm and pumped

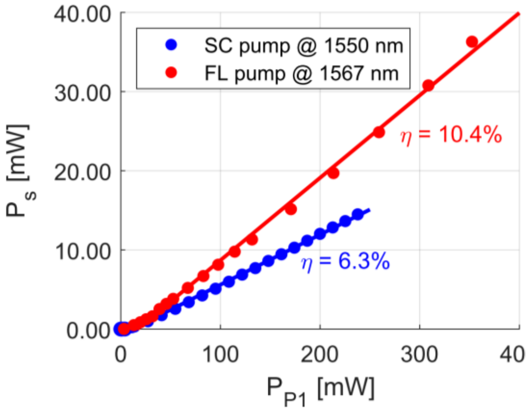

Fig. 2: P_s of a DFB FBG laser as a function of P_{P1} for two different pump lasers

by a single-mode 1550-nm semiconductor (SC) pump diode P1 (Lumentum S34). Figure 2 shows the output power from the DFB FBG laser (P_s) as a function of the pump power (P_{P1}). The laser delivers 14.5 mW of P_s at the maximum P_{P1} of 240 mW, yielding an optical-to-optical efficiency $\eta = \Delta P_s/\Delta P_{P1}$ of 6.3%. The lasing threshold was measured to be P_{P1} = 4 mW. When the same DFB FBG laser is pumped by a FL, P_s = 36 mW at P_{P1} = 350 mW, leading to η = 10.4%.

Figure 3 shows the dependence of the central signal wavelength λ_s on the output signal power. Over the 360 mW range of pump power studied here, the signal wavelength varies by less than 0.2 nm with the very small slopes below 35 MHz/mW. This DFB FBG laser is much more stable with respect to operating parameters than 2000-nm band semiconductor lasers which typically exhibit 0.1 nm/˚C temperature tuning and 0.01 nm/mA current tuning.

Figure 4 shows the spectra of the 2051-nm laser cavity measured for two different types of pump laser P1: the 1550-nm SC Lumentum laser and a 1567-nm FL. For both pumps, the signal is centred at 2051.8 nm and has an optical signal-to-noise ratio (OSNR) larger than 65 dB/0.05 nm. We note that the spectral performance of the DFB FBG laser is found to be quite similar for these two different types of pump sources indicating that fibre-laser pumps can successfully be used to power the single-frequency laser.

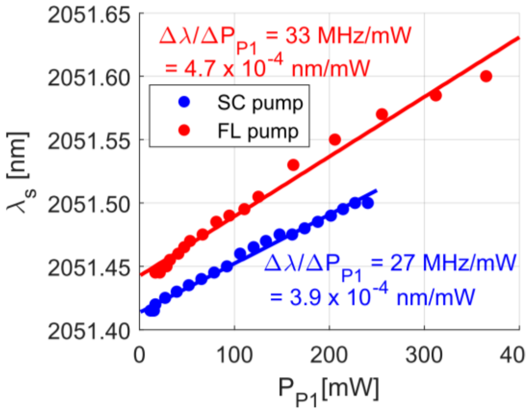

Fig. 3: λ_s for a DFB FBG laser as a function of P_s for two different pump lasers

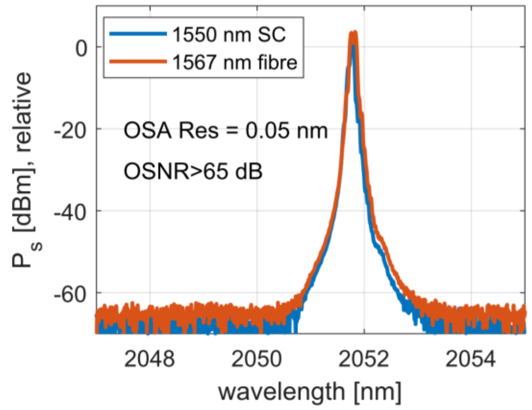

Fig. 4: Output spectrum of the 2051 nm DFB FBG laser for different types of pump

Initial heterodyne measurements of the linewidth of the single frequency lasers yield values of 130 kHz FWHM. This is consistent with previous linewidth measurements of 2000-nm band DFB FBG lasers of ~30 kHz[10]. At the conference, further heterodyne measurements of source linewidth using two independent 2051-nm FBG DFB lasers will be presented, along with linewidth measurements for an amplified source using an HDFA MOPA configuration.

Next, we evaluate the performance of the DFB FBG laser as a seed for the polarization maintaining (PM) two-stage HDFA. The details of the HDFA setup are shown in Figure 5 and described in Ref. [3], where the HDFA was used as a preamplifier stage. As the DFB FBG laser is built using standard (non-PM) fibre, before coupling into a PM HDFA the polarization of the output signal is matched to the slow axis of the

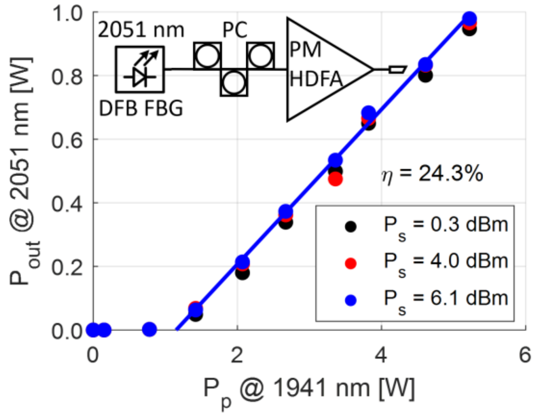

Fig. 5: P_{out} of the HDFA for different P_s levels

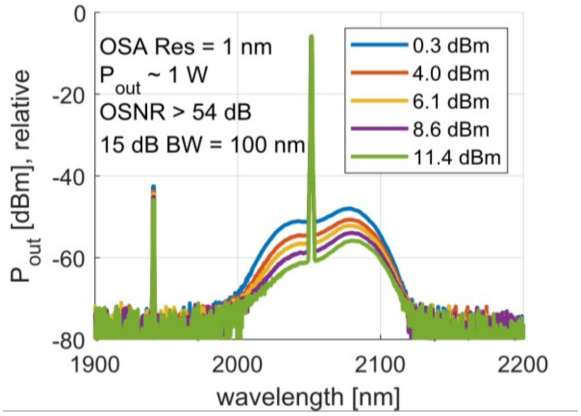

Fig. 6: Spectra of the HDFA output for various input signal levels P_s

PM fibre using a polarization controller (PC). Figure 5 plots the evolution of the HDFA output power (P_{out}) at 2051 nm as a function of the 1941-nm pump power of the HDFA (P_p) for three different levels of P_s. A maximum P_{out} = 1 W is obtained for P_p = 5.2 W. The P_{out} level is insensitive to the P_s levels in the range studied here.

Figure 6 shows the spectra of the amplifier output at P_{out} = 1 W, measured for different levels of P_s. The width of the signal peak is again limited by the resolution of the OSA and no apparent line broadening was observed. We also have not seen any signs of nonlinear processes such as stimulated Brillouin scattering (SBS). The level of the amplified spontaneous emission (ASE) decreases with the increase of P_s leading to enhanced OSNR. The residual 1941 nm pump is visible at the level of –35 dBs with respect to the signal. At low P_s, the 15-dB bandwidth of the amplifier is 100 nm.

Figure 7 shows the OSNR and noise figure (NF) of the amplifier as a function of 1941 nm internal amplifier pump power P_p for two different P_s. An OSNR as high as 58 dB/0.1 nm is reached and NF < 8 dB is achieved.

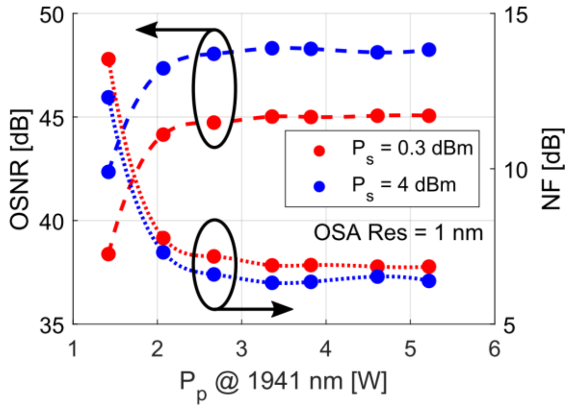

Fig. 7: OSNR and NF of the HDFA as a function of P_p

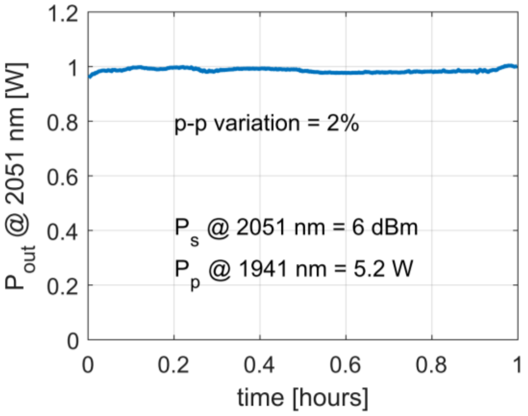

Fig. 8: Long-term stability of HDFA P_{out} at 2051 nm

Figure 8 shows the time evolution of the amplifier P_{out} measured for P_s = 6 dBm (4 mW) and P_p = 5.2 W. The maximum relative peak-to-peak variation of P_{out} is below 2%. Even though the DFB FBG laser is made in a standard fibre, the stable operation of the amplifier suggests that the polarization of the DFB FBG signal is constant in time.

Summary and Conclusions

We have reported the design and evaluation of a single frequency DFB FBG fibre laser using Tm-doped fibres operating at 2051 nm. Output powers up to 36 mW were obtained by pumping the FBG DFB with ≈1550 nm light from either semiconductor or fibre-laser pump sources. Virtually no difference in single-frequency laser performance was observed with the two widely different pump sources, indicating that fibre-laser pumps can successfully be used in this sensitive single-frequency application. OSNR values of >65 dB/0.05 nm and heterodyne linewidths of 130 kHz FWHM were measured for the single-frequency DFB FBG lasers. The variation of output wavelength was measured to be below 35 MHz per mW of pump power. An optically amplified output power of 1 W at 2051 nm was achieved using a PM HDFA to amplify the single frequency DFB FBG. A long-term HDFA MOPA output power stability of 2% over 1 hour was measured for the amplified 2051 nm source, indicating that the power and polarization state of this laser are stable with time. No signs of nonlinear processes such as SBS were observed. Future applications of this highly stable single-frequency laser source include LIDAR, spectral sensing, coherent lightwave systems, and WDM transmission in the 2000-nm band.

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