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Linewidth, RIN, and Low-Frequency Noise Measurements of a 300 mW 2039 nm PM DFB FBG Laser Pumped with a Semiconductor Laser and a Fibre Laser

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Abstract *We demonstrate the performance of a 2039 nm PM DFB FBG laser pumped with two types of 1.5 µm pumps. We obtained output signal powers >330 mW, with slope efficiency >16%, and a single-mode operation with OSNR >65 dB/0.1 nm. Laser linewidth <12 kHz and the RIN<-117 dB/Hz were measured. © 2022 The Authors*

Introduction

Single frequency laser sources in the 2000 nm region are important components for many emerging applications such as LIDAR [1]-[3], spectral sensing [4]-[6], coherent lightwave systems, and WDM transmission [7]. Distributed feedback fibre Bragg grating (DFB FBG) lasers offer reliable single-frequency operation with a narrow linewidth (<10 kHz), therefore presenting an attractive alternative to semiconductor DFB lasers [8]-[11] and fibre DBR lasers [12]-[17]. We have recently reported the use of polarization maintaining (PM) DFB FBG lasers as stable seed sources for both Tm- and Ho-doped fibre amplifiers to generate Watt-level output power [18]. Here, we investigate the performance of PM DFB FBG lasers in terms of linewidth, RIN, and self-oscillation frequency, and contrast the results for the FBG DFB lasers pumped with a semiconductor laser or a fibre laser.

Experimental Setup

We have evaluated a new DFB FBG laser at 2039 nm written in a highly-doped thulium active fibre and therefore optimized for high power efficiency. This fibre laser was counter-pumped using two different types of pump lasers: (i) a semiconductor (SC) pump laser emitting up to 250 mW of power at the wavelength of 1550 nm, and (ii) a fibre laser (FL) pump based on a 940-nm-pumped Er/Yb-doped cavity fibre laser delivering up to 2W of pump power at 1567 nm. The schematic representation of the laser configuration is shown in Fig. 1.

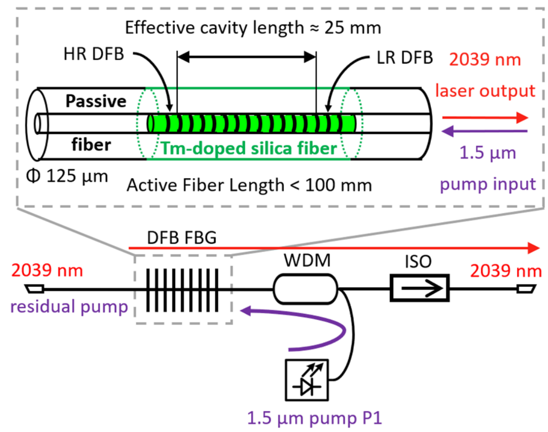

Fig. 1: Schematic of the DFB–FBG laser (top) and the topology of the system used for its characterization (bottom).

For the DFB–FBG under investigation emitting at 2039 nm, a short piece of active fibre (<100 mm) was used and the length of the grating was approximately 50 mm. Apodization techniques for the gratings yield an effective cavity length of approximately 25 mm and a longitudinal mode spacing of ≈ 4 GHz. The reflectivities of the high- and low-reflection sides are R_{HR} > 99%, R_{LR} > 97%, respectively, at the wavelength of 2039 nm. A π phase-shift of the index modulation periodicity is written into the cavity, leading to robust single frequency operation of the laser. Passive fibre pigtails (iXblue IXF-PAS-PM-6-130-0.21) couple light into and out of the laser cavity. The DFB FPG was placed in a thermal package [18] to eliminate mode hopping. PM wavelength division multiplexer WDM1 couples pump and signal light in and out of the fibre laser. The PM optical isolator on the main output side of the DFB FPG suppresses unwanted reflections that could lead to multimode oscillations.

Experimental Results

Figure 2 shows the output power (P_{out}) of the DFB FBG laser and the peak wavelength as a function of the pump power. The inset of the plot shows the zoom on the low power region, where we observe that the slope efficiency obtained with the 1550 nm SC pump (11%) is lower than with the 1567 nm FL (16%), due to the difference in pump absorption at these two wavelengths. Up to 330 mW of output power was obtained using the 2 W FL pump. Thanks to the use of a thermal package [18] the laser did not experience any mode hops and the emission spectrum exhibited a 12 kHz linewidth. The variation of output wavelength was measured to be below 0.17 pm (12 MHz) per mW of pump power and less than 20 pm per ˚C.

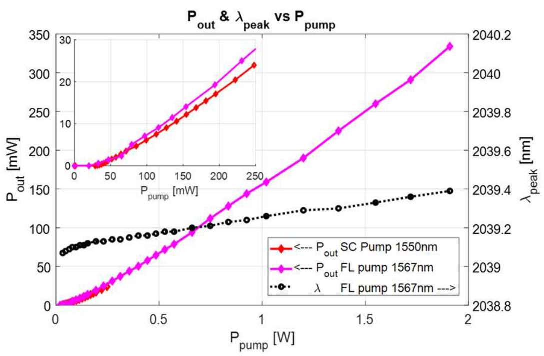

Fig. 2: Output power (diamonds, left axis) and peak wavelength (circles, right axis) of the PM DFB FBG laser vs. pump power. Inset shows the comparison between SC and FL pumps for 250mW of pump power.

Fig. 3 shows the measured state of polarization at P_{out} of 24 mW. The visibility curve (inset), measured by transmitting the output light through a rotating polarizer indicated a polarization extinction ratio (PER) of 27 dB measured after the output isolator. The stability of the polarization (main plot) measured over 100 minutes at minimum transmission shows that the PER remained higher than 25 dB.

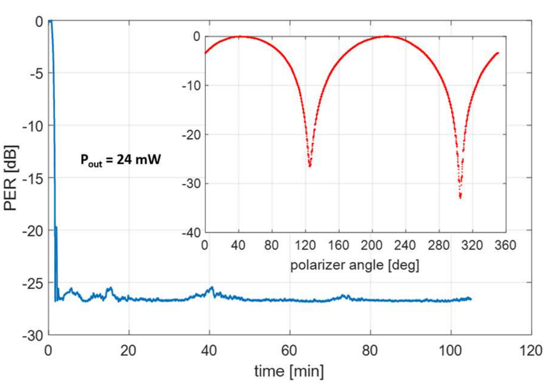

Fig. 3: Polarization characteristics of the DFB FBG laser.

Fig. 4 shows the recorded spectrum of the heterodyne measurement of the DFB FBG laser with an OEwaves reference laser at 2039 nm, which had an ultra-stable narrow-linewidth of 57 Hz. The linewidth of the DFB FBG was estimated to be below 12 kHz using three different fitting functions (i.e., Gaussian, Lorentzian and Voigt). The inset shows the measured and fitted spectra on an expanded frequency scale. Additional measurement of the linewidth of the DFB FBG laser signal amplified to multiwatt-levels by a Tm-doped fibre amplifier will be presented at the time of the conference.

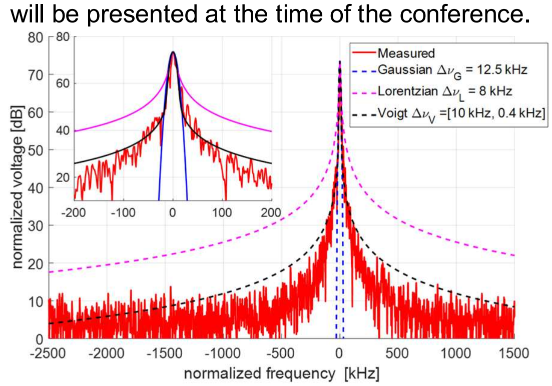

Fig. 4: Measurement of DFB FBG laser linewidth by heterodyning with a narrow-linewidth (57 Hz) 2039 nm laser.

We have also analysed the short-term stability of the DFB FBG laser and have observed low frequency output amplitude self-oscillations in the MHz range occurring above the lasing threshold.

The inset of Fig. 5 illustrates a typical spectrum measured when the DFB FBG laser was pumped with a FL. It features two peaks: the broader peak (coloured in red) corresponds to the relaxation frequency of the thulium ions doping the DFB FBG active fibre, and its central frequency is dependent only on the output power from the DFB FBG laser, as shown by the red curve in the main plot in Fig. 5. This peak is present when the laser is pumped with both SC or fibre laser. We see that the centre of this peak spans from 0.5 MHz at threshold to 3.2 MHz at high output powers.

The narrower peak (coloured in blue) is only present in case of FL pumping and it corresponds to the relaxation frequency of the Er/Yb ions doping the active fibre of the FL pump. The central frequency of this peak only depends on the pump power, and not on the signal output power. It extends from 0.08 MHz at low pump powers to 0.4 MHz at high pump powers.

Both of these output amplitude oscillations must be carefully considered and taken into account when determining the relevant noise spectrum of the FBG DFB laser in device and system applications.

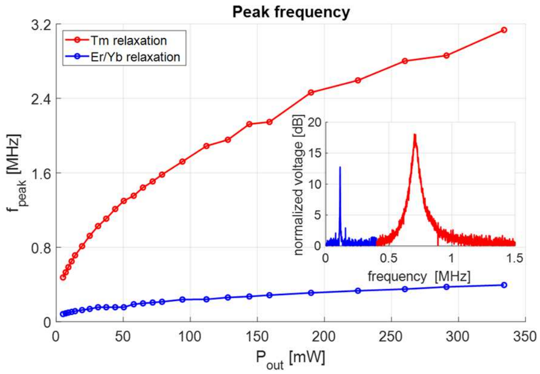

Fig. 5: Central frequencies of the peaks present in the low-frequency noise of the DFB FBG laser pumped with a fibre laser.

Fig. 6 shows the experimentally measured RIN of the 2039 nm DFB FBG laser source using a 1550 nm pump source consisting of a DFB semiconductor laser amplified by an Er-Yb-doped fibre optical amplifier. With this low noise pump source, output powers of up to 26 mW were obtained from the DFB FBG laser. The RIN was computed using the peak of the DFB-FBG output spectrum (analogous to the red peak in Fig. 5). We observe that the RIN decreases with increasing output power and reaches an asymptote of -117 dB/Hz above 19 mW of output power.

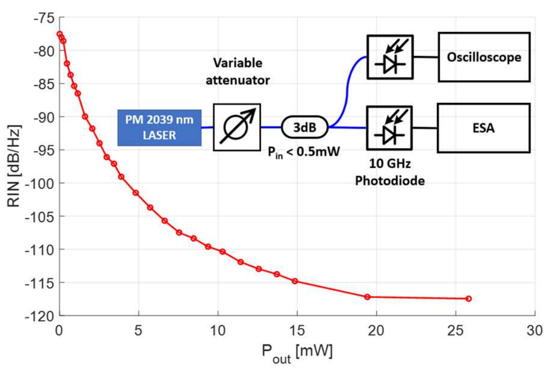

Fig. 6: Measured RIN of the DFB FBG laser pumped with an optically amplifier DFB source at 1550 nm. The inset shows the measurement setup.

Summary and Conclusions

We have reported the design and experimental evaluation of a high-performance polarization maintaining single frequency DFB–FBG fibre laser using Tm-doped fibre and operating at 2039 nm. Output powers up to 320 mW were obtained by pumping the FBG DFB with 1550 nm light from a fibre-laser pump source. Output powers up to 24 mW were achieved when pumping the DFB FBG with a semiconductor pump laser source. By heterodyning the fibre laser with an ultra-stable source exhibiting 57 Hz linewidth, we found that the DFB FBG laser linewidth was < 12 kHz. We have also shown that our laser source offered a PER better than 25 dB with very good polarization time-stability. The experimental RIN of the laser was measured to be -117 dB/Hz at 24 mW output power when pumped with an optically amplified semiconductor laser source.

We observe that our narrow linewidth, high power PM DFB FBG can be used as a highly stable seed laser in fully PM fibre amplifier configurations. This constitutes a critical improvement when compared to the non-PM laser sources used up until now in many optically amplified MOPA configurations.

We show that DFB FBGs pumped with a semiconductor pump laser can deliver low to medium output power but exhibit a cleaner noise spectrum, especially in the low frequency (< 0.5 MHz) range. On the contrary, using a cavity fibre laser pump, offers higher output powers and allows for efficiency optimization by choosing the pump wavelength that maximizes pump absorption. This comes at a cost of more low frequency noise components; however, these can be supressed using special techniques.

We also observe that the DFB FBG lasers presented here can be designed to operate in a broad wavelength range covering the emission band of the Tm-doped or Ho-doped fibre and spanning from 1760 nm to >2100 nm. For example, in other experiments which will be presented at the conference, we have demonstrated the operation of the Tm-based DFB FBGs at the wavelength of 1908 nm. One of the possible applications of the DFB FBG amplified lasers could be as a means of pumping in the 2 µm regime alternative to DBR fibre lasers.

Future applications of this highly stable PM high output power single-frequency fibre laser source include (but are not limited to): LIDAR, spectral sensing, coherent lightwave systems, WDM transmission in the 2 µm band, as highly stable narrow linewidth sources for gravity wave detection experiments, and also as high-power narrow linewidth pumps for parametric amplifiers and for nonlinear frequency generation in the mid-infrared.

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