Effects of Phase and Amplitude Noise on π Phase-shifted DFB Raman fibre lasers

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Abstract: We show that π phase-shifted Distributed Feedback (DFB) Raman fibre lasers of 30cm length are resilient against phase and amplitude errors up to ~5%, with negligible deterioration of the threshold and slope-efficiency of the lasers.

1. Introduction:

The interplay between Stimulated Raman scattering (SRS) and uniform Bragg gratings has been studied extensively by Perlin and Winful through their theoretical work on Raman gap solitons and Raman DFB lasers [1, 2]. In the case of uniform DFB Raman fibre laser structures, their work revealed that very long (~1m) uniform Bragg gratings are required to achieve reasonably low laser thresholds [1]. Hu and Broderick demonstrated theoretically that low threshold high efficiency DFB Raman fibre lasers should be possible to achieve from much shorter lengths by incorporating a centre π phase-shift into the Bragg grating structure [3]. It is worth noting that the above mentioned papers were based on Bragg grating with ideal noiseless coupling coefficient characteristics. In a practical system however, some level of random noise is likely to occur on the grating profile. This includes fibre non-uniformities and fabrication induced imperfections resulting from for example variations in the power level from the UV writing beam and mechanically induced errors. Despite the ability to write long fibre gratings there has not been any experimental demonstration of lasing in a DFB Raman fibre laser structure to date. In this paper we theoretically investigate the effects of phase and amplitude noise on centre π phase-shifted DFB Raman fibre lasers in order to evaluate the impact of grating noise and the feasibility of an experimental demonstrating of the lasers.

2. Model set-up

This analysis is based on solutions generated from solving the standard nonlinear coupled mode equations [1,4].The parameters of the model were based on experimental values of a high NA (NA=0.28) Ge/Si fibre, with an effective mode area of 12 μm^2 and a Raman gain coefficient of $7\cdot 10^{-14}$ m/W. The simulated grating length is 30cm with a π phase-shift in the centre. The propagation losses of the pump wavelength (1540nm) and first order of Stokes wavelength (1652nm) are assumed identical at 0.1dB/m based on expected values from cladding-mode and UV-induced losses respectively. For simplicity we chose a white-noise distribution for both the phase and amplitude of κ. Simulating single-sided CW pumping, the time-dependent behaviour of single-mode lasing output was investigated.

3. Results and discussion:

First we examined the effects of changing κ on the lasing threshold and total output slope-efficiency (vs launching pump) in the noiseless case. We observed that the threshold dropped down from ~40W ($\kappa=20m^{-1}$) to 5.8W ($\kappa=32m^{-1}$) and saturated at ~5.2W for higher grating strengths (Fig.1). We also observed that the slope-efficiency was reduced from ~60% ($\kappa=28m^{-1}$) to ~31% ($\kappa=45m^{-1}$) which is likely due to a reduction of the effective cavity length [5].

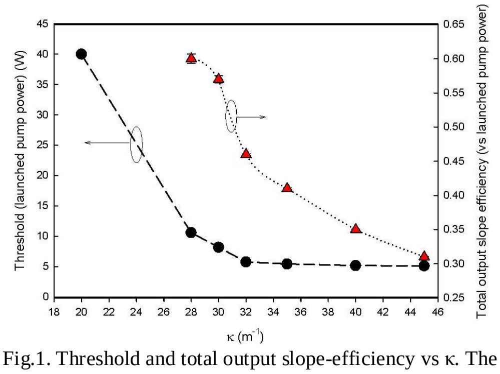

Fig.1. Threshold and total output slope-efficiency vs κ. The uncertainties of the threshold and slope efficiencies were ±0.5W and ±0.03, respectively.

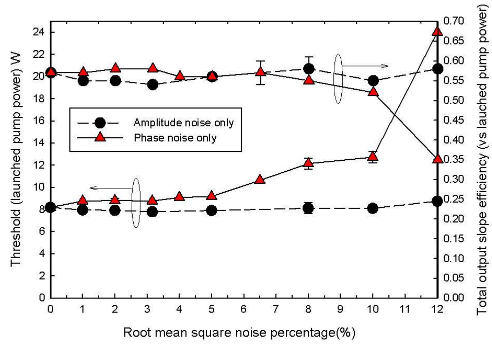

Fig.2. Threshold vs launched pump power and total output slope-efficiency vs individual random phase and amplitude noise.

Following this initial optimisation we separately investigated the effects of phase and amplitude noise on a DFB grating with a mean value of $\kappa = 30m^{-1}$. This value of was chosen due to its relatively low lasing threshold of 8.2W and high slope-efficiency of 57%. Fig.2 shows the threshold and slope-efficiency when increasing the level of rms noise from 0% to 12%. It is evident that the influence of the amplitude noise on the threshold and slope-efficiency of the laser is low up to the maximum rms noise level considered here, since they both remain almost constant within the uncertainties of ±0.5W and ±3% respectively. In contrast, the threshold is seen to rise quickly for rms phase-noise levels above 5%. This could be due to the degradation of wave confinement in the cavity. It is interesting to observe that for rms phase-noise levels up to 5%, the threshold increased only slightly from 8.2 ±0.5 W to 9.2 ±0.5 W. Additionally, the slope-efficiency remains almost constant at ~55% for rms noise levels below ~10%.

Table1: DFB output power for 24W pump power. η_a and η_p are the rms noise coefficients of amplitude and phase, respectively. $\kappa = 30m^{-1}$.

η_a	η_p	Pump (W)	Output (W)
0.00%	0.00%	24	8.9 ± 0.2
0.00%	2.00%	24	8.9 ± 0.2
1.00%	2.00%	24	8.6 ± 0.2
1.00%	5.00%	24	8.3 ± 0.5
2.00%	5.00%	24	8.3 ± 0.5
5.00%	5.00%	24	8.1 ± 0.5
5.00%	10.00%	24	3.1 ± 0.5
10.00%	10.00%	24	2.9 ± 0.5

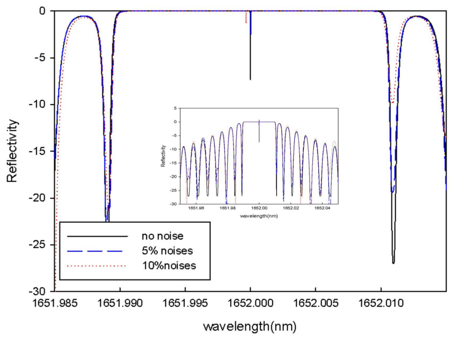

Fig. 3. Reflection spectrum with 0%, 5% and 10% phase and amplitude noise.

To simulate a more realistic grating profile, we next considered the effects of combining both phase and amplitude noise. Table 1 lists the total output power for an incident pump power level of 24W for 7 different combinations and levels of noise. As it can be seen the output powers remain almost identical up a level of ~5% rms noise on both the phase and amplitude. This result is somewhat surprising since a 5% noise level normally is considered fairly substantial on longer gratings. To investigate this point further we analysed the effects of up to 10% rms noise on the reflection characteristics of the gratings. As shown in Fig. 3, there is in fact little change to the stop-band characteristics of the gratings indicating that the feedback characteristics of the structure remain almost unaffected by noise.

4. Conclusion

We studied the effects of the white phase and amplitude noise in a centre π phase-shifted DFB Raman fibre laser for the first time by simulating the nonlinear coupled mode equations with realistic grating parameters. Phase errors degraded the performance of the laser more significant than amplitude errors, but we find that the structure is resilient against the noise and that it remains largely unaffected by phase and amplitude errors up to ~5% rms. We believe that this promises well for a first experimental demonstration of a DFB Raman fibre laser.

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