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Long Cavity Length and Single Longitudinal Mode Composite Cavity Fibre Laser with Active Feedback Cavity

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ABSTRACT

In the following paper is presented an investigation of a composite cavity fibre laser with active feedback cavity. By employing strong-reflection and active feedback cavity, an in-house fabricated 12cm long composite cavity fibre laser was able to sustain single longitudinal mode operation at 60μW without mode hopping

Keywords: *Fibre Laser, Composite Cavity*

1. INTRODUCTION

In this paper is presented a design of a fully integrated composite cavity fibre laser by writing three strong FBGs within one continuous section of EDF, as shown in figure 1. Although the modeling is comparable to that of the traditional semiconductor external cavity laser [1-2], the analysis shows that this design gives rise to new results which are previously not pertinent to passive external feedback lasers.

Conventional erbium doped fibre lasers usually have short cavity lengths, in the order of a few centimeters, to attain single longitudinal mode operation. An alternate means is the use of optical feedback. A totally integrated coupled-cavity fibre laser was demonstrated by Chernikov et al., which consisted of a passive feedback cavity, and 1cm section of heavily doped EDF spliced into the main cavity [3]. It demonstrated robust single-frequency operation with reduced linewidth [3].

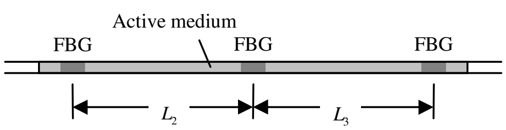

Figure 1. Composite cavity fibre laser design.

It is well-known that, to a conventional Fabry-Perot cavity laser, any external optical feedback can strongly influence its lasing threshold, output power, emission spectrum, noise characteristics [4]. Some research work reported that self injection fibre lasers (external feedback via FBG) were capable of achieving highly stable single mode and single polarization operation [5-7]. Recent reports have demonstrated a continuously tunable lasers based on external cavity constructed by the micro-electro-mechanical (MEMS) technology [8], the use of fibre grating external cavity designs for direct modulation at 2.5Gbit/s [9], and also the use of fibre grating external cavity to facilitate beat-frequency tunable dual-mode lasers [10].

The active feedback cavity CCFL design is applied and shown in the following to be able to realize a longer and yet single mode fibre laser. Increased presence of active medium as a result of longer cavity length should also improve the laser's pump conversion efficiency as the residual pump power are utilized by the feedback cavity. By using large reflections, it is thought that the effects of small feedback from unintentional sources would be minimisd. A fibre laser sensor head design based on a long cavity CCFL could possibly be more sensitive than a DBRFL or DFBFL sensor head, due to the increased gauge length whilst maintaining single mode.

2. THEORY

A model of the CCFL is shown in figure 2. The device is divided into four regions by the positions of the three reflection points. E^+ and E^- are the transverse electric waves in the forward and backward directions respectively. r and r' are the amplitude reflection coefficients for the forward and backward directions. To solve the boundary value problem for the fields inside the CCFL, the forward and backward components of the fields are related through the three reflection coefficients, so that the multiple reflections are accounted for [1,2].

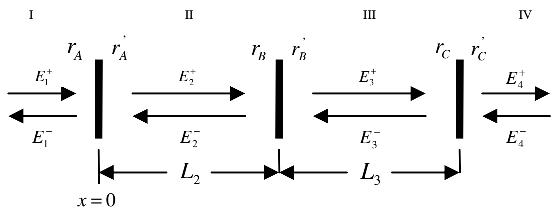

Figure 2. Composite cavity fibre laser model

Assuming that all emission in the wavelength range of interest is generated from within the device, such that $E_1^+\big|_{x=0} = E_4^-\big|_{x=L_2+L_3} = 0$, the following expression for the general condition can be obtained.

$$1 = r_A^{'} r_B e^{i\phi_2} g_2 + r_B^{'} r_C e^{i\phi_3} g_3 + r_A^{'} r_C e^{i(\phi_2+\phi_3)} g_2 g_3 \qquad (1)$$

$\phi = 2kL$ and $g = e^{2(\gamma-\alpha)L}$ are defined (for regions II and III only) as the round trip phase and round trip gain respectively, k is the propagation constant, γ and α are the linear gain and absorption coefficients per unit length. The threshold condition for g_2 is obtained by rearranging (1).

$$g_2 = \frac{1 + r_B r_C e^{i\phi_3} g_3}{-r_A r_B e^{i\phi_2}\left(1 + \frac{r_C}{r_B} e^{i\phi_3} g_3\right)} \qquad (2)$$

Since $g_3 \le 1$ for a conventional semiconductor extended cavity laser, analysis for cases where $r_C g_3 > 1$ and its implications had been left out.

Feedback Parameter

A complex feedback parameter z_C can be defined to describes the change in phase and threshold gain to the primary cavity L_2 due to feedback.

$$z_C = \frac{1 + r_B r_C e^{i\phi_3} g_3}{1 + \frac{r_C}{r_B} e^{i\phi_3} g_3} = e^{G_C + i\phi_C} \qquad (3)$$

So that (2) can be simplified to be

$$g_2 = \frac{e^{-i\phi_2}}{-r_A r_B} z_C = \frac{e^{-i\phi_2} e^{i\pi}}{r_A r_B} e^{G_C + i\phi_C} \qquad (4)$$

From (4), the phase and threshold gain conditions of a composite cavity laser can be obtained.

$$p2\pi = -\phi_2 + \pi + \phi_C \qquad (5a)$$

$$2\gamma_{2th} L_2 = 2\alpha_2 L_2 + \ln\left(\frac{1}{r_A r_B}\right) + G_C \qquad (5b)$$

Comparing with the standard laser expressions, ϕ_C in (5a) accounts for the optical feedback, and G_C in (5b) represents an additive adjustment to the required threshold gain. According to (3), z_C is a periodic function of ϕ_3, whose locus follows a circular path in the complex plane. Figure 3 shows the loci of z_C for various values of $r_C g_3$, which appear as non-concentric circles with centers along the real axis. The locus of z_C for $r_C g_3 = 0$ is $(1 + 0i)$, which is consistent with no feedback. In figure 3 r_B is fixed at 0.8 for ease of comparison. By examining (3) for $\phi_3 = \pi$, two special conditions can be identified by setting the denominator or numerator to zero.

$$r_C g_3 = r_B \qquad (6a)$$

$$r_C g_3 = {r_B}^{-1} \qquad (6b)$$

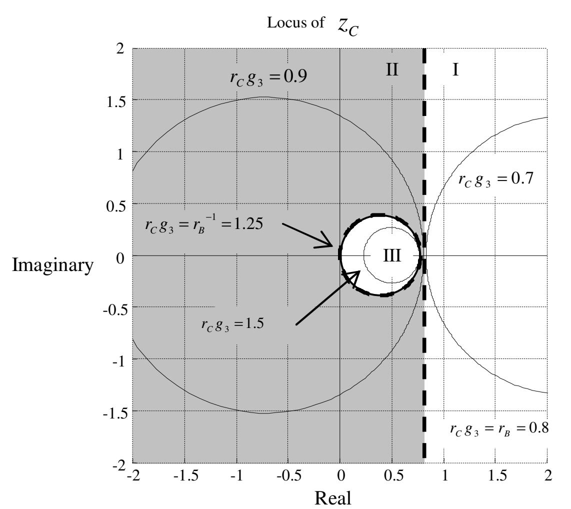

Figure 3. The loci of z_C when $r_C g_3 = 0.7$, 0.9 and 1.5 are shown as solid lines. (6a) and (6b) are shown as dot-dashed lines. $r_B = 0.8$.

The locus of z_C becomes a vertical line (infinitely large circle) going through $\left(\frac{1 + r_B^{\ 2}}{2}, 0i\right)$ in the case of (6a), and a circle passing through the origin for (6b). These two conditions divide the range of $r_C g_3$ into three qualitatively different groups: $0 \le r_C g_3 < r_B$, $r_b < r_C g_3 < r_B^{-1}$ and $r_C g_3 > r_B^{-1}$. In figure 3, the three groups are distinguished by roman numerals I, II and III respectively.

Threshold Gain Adjustment Parameter

G_C is limited between $\ln|z_C|$ at $\phi_3 = 0$ and at $\phi_3 = \pi$. It can be seen that G_C for $\phi_3 = 0$ decreases monotonically as $r_C g_3$, but approaches $\pm\infty$ at the boundary values of (7a) and (7b) for $\phi_3 = \pi$. It can also be seen that significant reduction in G_C is possible about $r_C g_3 = r_B^{-1}$. According to (5b), a lower value of G_C will result in a lower threshold, which in turn suggests relaxed pump power requirements, or better pump conversion efficiency, or that medium with lower gain can be used to fabricate the laser.

Distinct Cases of Operation

By manipulating (5a), the lasing modes can be identified by solving

$$\phi_C = \angle z_C(\phi_3) = (2p-1)\pi + \frac{L_2}{L_3}\phi_3 \qquad (7)$$

The corresponding G_C that is required can be identified by substituting ϕ_3 into (3). Mode wavelengths can also be identified according to $\lambda = \dfrac{4\pi L_3}{n_3 \phi_3}$. Thus the relative threshold and spectral characteristics can be determined.

By using small reflections, most conventional coupled-cavity or external feedback lasers operate in the first case, where $0 \le r_C g_3 < r_B$. However, the other case $r_B^{-1} < r_C g_3$ is not available to traditional coupled-cavity or external feedback lasers due to the lack of active medium in the extended cavity. However, a significant difference is the profile of G_C.

3. EXPERIMENT AND RESULTS

A 12cm long CCFL designed as figure 1 is fabricated in our own lab using the scanning UV side exposure technique. All three FBGs are 5mm in length with about 80% power reflection (i.e. $r_C \approx 0.9$). Given the presence of the active medium, such a strong reflectivity should place the operation of the CCFL in the case of $r_B^{-1} < r_C g_3$. The EDF used is specified to have 33.4 dB/m peak absorption near 1530, and 13.2 dB/km background loss near 1200nm.

Figure 4 shows the profile of the reflecting spectrum when the CCFL was scanned with a tunable laser. As expected, strong resemblance with a typical FBG profile can be observed. The fuzziness on either side of the profile is attributed to the cases where resonance can be achieved. The 8dB insertion loss between the peak of the profile to the reference (obtained by replacing the CCFL with a 100% broadband reflector) is attributed to the splices and absorption of the EDF.

Figure 5 shows the returning lasing characteristics of the CCFL obtained using an optical spectrum analyzer. It can be observed that approximately 85% of the total measured power can be credited to the lasing wavelength. Also shown is the lasing characteristics of a 5cm long DFBFL which was fabricated using similar EDF as a comparison. It can be clearly seen that the output power of the CCFL is at least double to that of the DFBFL. This is most likely due to the more efficient use of the pump power as a result of having a longer length of active medium.

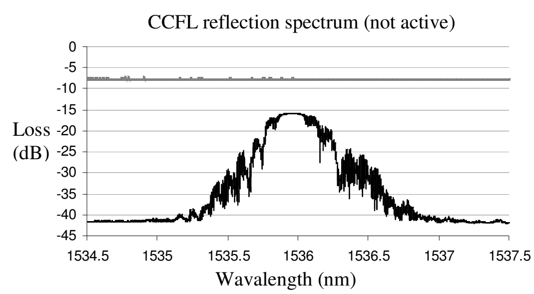

Figure 4 Reflection spectrum of the CCFL. Reference at -8dBm obtained using a 100% broadband reflector.

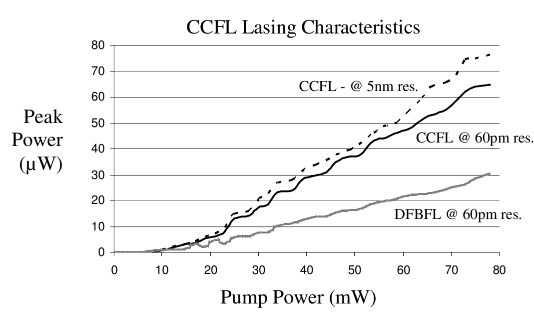

Figure 5 Threshold characteristics of the CCFL and DFBFL, recorded using an optical spectrum analyzer set to 60pm or 5nm resolution bandwidth as indicated.

Figure 6 shows the emission spectra of the CCFL (and DFBFL for comparison) when pumped at 37mW. It can be seen that the 3dB linewidth is approx 0.1nm. Further investigation using a Fabry Perot scanning filter also indicated single mode output. Despite the calculated mode spacing is approximately 60pm, no mode hopping or multimode behaviors were observable for pump power up to 80mW (CCFL output at 65µW). It this thought that during the fabrication process, by manually moving the fibre to write the third FBG, the cavity is not exactly 9cm, thus the modes that fall within the FBG profile would not share the same threshold gain. Further mode competition mechanisms possibly caused the CCFL to be single mode.

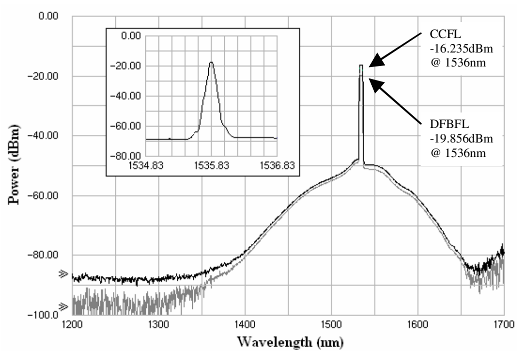

Figure 6 Emission spectra of the CCFL and DFBFL recorded at 5nm resolution bandwidth are plotted in black and grey respectively. Insert shows the CCFL spectrum observed with 60pm resolution. All three spectra are recorded at 37mW pump power.

5. CONCLUSION

The general behavior of a CCFL with active external feedback was investigated taking into account multiple reflections. It was shown theoretically that mode-limiting performance attained by the traditional small-reflection approach can be achieved also by having large-reflection with gain medium in the external cavity. It was also shown that such a design can offer reduced lasing threshold. An in-house fabricated 12cm long CCFL with high reflectivity Bragg gratings exhibited single longitudinal mode operation that is free of mode jumping, for up to at least 65µW output power.

6. REFERENCES

[1]. A. Olsson and C. L. Tang, *"Coherent Optical Interference Effects in External-Cavity Semiconductor Lasers"*, IEEE J. Quantum Electronics, Vol. QE-17, No. 8, pp. 1320-1323, Aug. 1981

[2]. J. H. Osmundsen and N. Gade, *'Influence of Optical Feedback on Laser Frequency Spectrum and Treshold Conditions'*, IEEE J. Quantum Electronics, Vol. QE-19, No. 3, pp. 465-469, Mar. 1983

[3]. S.V. Chernikov, J.R. Taylor and R. Kashyap, '*Coupled-cavity erbium fiber lasers incorporating fiber grating reflectors'*, Optics Lett., Vol. 18, No. 23, pp. 2023-2025, Dec. 1993

[4]. M.Premaratne, A.J. Lowery, Z.Ahmed and D. Novak, '*Modeling Noise and Modulation Performance of Fiber Grating External Cavity Lasers'*, IEEE J. Selected Topics in Quantum Electronics, Vol. 3, No. 2, pp. 290-303, Apr. 1997

[5]. Y.Zhao and C. Shu, *'Single-Mode Operation Characteristics of a Self-Injected Seeded Fabry-Perot Diode with Distributed Feedback from a Fibre Grating'*, IEEE Photonics Tech. Letters, Vol. 9, No. 11, pp. 1436-1438, Nov. 1997

[6]. K. Hsu and S. Yamashita, *'Single-Polarization Generation in Fiber Fabry-Perot Laser by Self-Injection Locking in Short Feedback Cavity'*, IEEE Journal of Lightwave Tech., Vol. 19, No. 4, pp. 520-526, Apr. 2001

[7]. S. Yamashita and G.J. Cowle, *'Single-Polarization Operation of Fiber Distributed Feedback (DFB) Lasers by Injection Locking'*, IEEE Journal of Lightwave Tech., Vol. 17, No. 3, pp. 509-513, Mar. 1999

[8]. X. M. Zhang, A. Q. Liu, C. Lu and D. Y. Tang, "Continuous wavelength tuning in micromachined littrow external-cavity lasers", IEEE J of Quantum Electron., vol. 41, no.2, 187-197, 2005

[9]. M. Becker, M. Rothhardt and H.L. Althaus, *'Wavelength-switchable fiber grating laser with wavelength stabilization'*, SPIE Optical Eng., Vol. 45(3), pp. 034202-1 to 034202-4, Mar. 2006

[10]. W. Wang, M. Cada, J. seregelyi, S. Paquet, S.J. Mihailov and P. Lu, *'A Beat-Frequency Tunable Dual-Mode Fiber-Bragg-Grating External-Cavity Laser'*, IEEE Photonics Tech. Letters, Vol. 17, No. 11, pp. 2436-2438, Nov. 2005