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Tuneable and switchable dual wavelength lasers using optical fibre Bragg grating external cavities

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Two novel external cavity lasers are demonstrated experimentally. The first utilises a Bragg grating fabricated in highly birefringent optical fibre and offers the ability to switch between modes that are separated in polarisation and wavelength. The second utilises two spatially separate Bragg gratings fabricated in mono-mode fibre. Both can be used for tuneable beat frequency generation.

Introduction: Fibre Bragg grating (FBG) external cavity semiconductor lasers have been investigated as stabilised continuous wave and modulated laser sources, and as tuneable sources [1]. These lasers can offer narrow linewidths and a viable cost effective alternative to distributed feedback laser diodes and distributed Bragg reflector laser diodes. Dual wavelength lasers have also been the subject of considerable research interest as sources capable of producing beat signals at microwave frequencies, which is desirable for electronic signal processing systems [2-4]. Beat frequencies have been generated previously using separate laser cavities [3,4]. However, systems employing separate cavities can suffer from phase noise and drift, making a single cavity dual wavelength laser preferable for producing stable beat frequencies. In this paper two novel FBG external cavity lasers are experimentally demonstrated. Both use the light reflected from the FBGs to force the lasers to operate at the Bragg wavelengths.

Hi-Bi laser: The first laser configuration considered is based on High Birefringence (Hi-Bi) fibre and exploits the difference in the wavelength of the Bragg reflection of light populating the orthogonally linearly polarised eigenaxes of Hi-Bi fibre. Feedback from a FBG written in Hi-Bi fibre then results in the laser operating on two linearly polarised longitudinal modes that are separated in both wavelength and polarisation. A Hi-Bi fibre with a beat length of ≈ 1.6mm will produce a corresponding wavelength separation of ≈ 0.3nm between the orthogonally linearly polarised modes of the reflection from the FBG. The fibre used was Fibercore bow-tie, (HB 750) with a numerical aperture of 0.15. The fibre was hydrogen loaded for 7 days in a pressure vessel at 130 bar. The FBG was subsequently fabricated using a wavelength tuneable UV source and phase mask based interferometer [5]. The FBG had a centre wavelength of 810nm, a reflectivity of ≈ 40% and a bandwidth of 0.15nm (FWHM) and was located 250mm from the end of the fibre. The fibre end was angle polished to reduce unwanted reflections into the active laser cavity that could de-stabilise the laser. Light was coupled into the fibre using anti reflection (AR) coated lenses. The output from a 150mW, SDL 5420, non-AR coated 810nm laser diode was coupled into the angle polished end of the fibre. A coupling efficiency of ≈ 40% was achieved. The optical length of the external cavity was ≈ 320mm. A half wave plate was used to adjust the orientation of the polarisation of light with respect to the eigenmodes of the fibre. Tuning of the wavelength separation between the modes was demonstrated by transversely loading the FBG [6]. This altered the birefringence, via the strain-optic effect, of the fibre at the location of the FBG, altering the wavelength separation of the two modes. A series of weights were used to apply a transverse load to the fibre. The weights were placed on a glass slide that was positioned on the FBG parallel to another fibre of the same type that also had its coating removed. Applying the load in line with the slow axis reduced the birefringence of the fibre by decreasing the effective refractive index in the slow axis. The corresponding strain in the fast axis increases its effective refractive index thus lowering the birefringence as in [6], with a concomitant decrease in the wavelength separation of the two modes.

Results: The FBG feedback was observed to reduce the laser threshold to 16mA, a reduction of 46%. The spectrum was observed using an Ando AQ-6310b optical spectrum analyser with a resolution of 0.1nm. Fig. 1 plots the relative intensity of each mode during rotation of the waveplate, where the laser can be seen to switch the wavelength and polarisation of its output. The laser operated in 3 states, in state A and C the laser operated in a single longitudinal mode, orthogonally polarised for each state. In state B both orthogonally linearly polarised modes co-exist, since the eigenaxes of the fibre are equally populated. The laser was seen to be mode hop free in all three states and temperature tuning of the diode could be used to ensure the switchable modes were of equal intensity. No mode or intensity instabilities were seen over a period of several hours. The wavelength separation of the two modes was 0.3nm, which matches the separation expected from a FBG written in Hi-Bi fibre with a beat length of 1.6mm at 810nm. Fig. 2 shows the dependence of the lasing wavelengths upon the transverse load applied to the FBG, with the orientation of the fibre and direction of transverse load also shown. Loads of up to 0.34 N/mm were applied to the fibre, and a linear dependence of the wavelength separation upon the load was observed. These loads can be increased to increase the range over which the wavelength separation can be tuned.

Two FBG laser: The second laser configuration employs two spatially separated FBGs. The FBGs were fabricated in single mode fibre at two different wavelengths, forcing the laser to lase on two longitudinal modes. As the two FBGs were not co-located, strain could be applied independently to each FBG, making both modes independently tuneable. The interference between these two modes can be used to create a beat signal, the frequency of which is a function of the separation in wavelength of the two modes. This results in the beat frequency being tuneable across a wide range. The FBGs were fabricated with a physical separation of approximately 150mm such that each FBG could be individually tuned. The FBGs were fabricated in hydrogen loaded fibre, Spectran (FS-SMC-A0780B), with the same technique as outlined earlier [5]. The Bragg wavelengths were separated by 2nm, the FWHM of each FBG was ≈ 0.2nm and reflectivity was ≈ 25%. The end of the fibre was angle polished to prevent de-stabilising reflections. The coupling efficiency was ≈ 35%. The first FBG, fabricated at 808nm, formed an external cavity approximately 400mm in length, the second FBG at 810nm formed a cavity approximately 650mm long.

Results: As an axial strain was applied to the first FBG the wavelength separation of the two longitudinal modes of the laser decreased. When the two modes are separated by less than ≈ 0.3nm, mode competition effects collapsed both modes into one forming a single longitudinal mode laser, (Fig. 3). The single longitudinal mode continued to dominate the spectrum until the FBGs were tuned to a spectral separation exceeding 0.3nm, when the two tuneable modes reappear. This 0.3nm separation generated the lowest beat frequency achieved of ≈ 130GHz with a corresponding synthetic wavelength of 2.3mm. The maximum beat frequency was >2.28THz, which has a corresponding synthetic wavelength of <0.131mm. Operation was mode hop free over the entire injection current range as demonstrated by Fig. 4 where a dual FBG external cavity laser is compared to the same laser diode under the same conditions but with no optical feedback.

Summary: Two novel external cavity lasers have been demonstrated. Both lasers were shown to be mode hop free and a high degree of stability was observed over several hours. The Hi-Bi fibre based laser demonstrated stable operation on two orthogonally polarised longitudinal modes. The laser could be switched between modes by the rotation of a waveplate, allowing the output of the laser to be switched in both the polarisation and wavelength domains. Alternatively the laser could operate simultaneously on the two modes. Transversely loading the fibre allowed the wavelength separation of the two modes to be controlled. As the wavelength separation between switchable modes of the laser is defined by the fibre birefringence it is readily calibrated, which has applications in multiple wavelength sensing signal processing techniques. Use of a polariser at the output of the laser would allow interference between the modes and thus create a tuneable beat frequency. It also offers a new method for producing a synthetic wavelength for use, for example in the signal processing of sensing systems [2]. Using an electro-optic liquid crystal device to define the polarisation of the light coupled into the fibre would permit the laser to be controlled electronically.

The second system employing spatially and spectrally separated FBGs allowed independent tuning of the two longitudinal modes. The lowest beat frequency achieved was ≈ 130GHz with a corresponding synthetic wavelength of 2.3mm. It is thought that this frequency can be lowered significantly by the use of narrower bandwidth FBGs.

The methods presented here have advantages over alternative techniques such as distributed feedback and distributed Bragg reflector laser diodes as they are spectrally stable and the emission wavelength is stable for the injection current variation. In addition, they are advantageous due to their significantly lower cost, in that the technology can be applied to a low cost non-AR coated laser diode.

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References

[1] TIMOFEEV, F.N., KOSTKO, I.A., BAYVEL, P., BERGER, O., WYATT, R., KASHYAP, R., LEALMAN, I.F., and MAXWELL. G.D.: '10Gbit/s directly modulated, high temperature-stability external fibre grating laser for dense WDM networks', Electron. Lett., 1999, v. 35, pp. 1737-1739.

[2] EZBIRI, A. and TATAM, R.P.: 'Passive signal processing technique for miniature Fabry-Perot interferometric sensor with a multimode laser-diode source', Optics Letters, 1996, 20, pp. 1818-1820.

[3] ONODERA, N.: 'THz optical beat frequency generation by mode locked semiconductor lasers', Electron. Lett. 1996, v. 32, pp. 1013-1015.

[4] TIMOFEEV, F.N., BENETT, S., GRIFFIN, R., BAYVEL, P., SEEDS, A.J., WYATT, R., KASHYAP, R., and ROBERTSON, M.: 'High spectral purity millimetre-wave modulated optical signal generation using fibre grating lasers', Electron. Lett. 1998, v. 34, pp. 668-669

[5] DOCKNEY, M.L., JAMES, S.W. and TATAM, R.P.: 'Fibre Bragg gratings fabricated using a wavelength tuneable laser source and a phase mask based interferometer' Measurement Science and Technology. 1996, v. 7, pp. 445-448.

[6] LAWRENCE, C.M., NELSON, D.V., UDD, E. and BENNET, T.: 'A fiber optic sensor for transverse strain measurement' Experimental Mechanics, 1999, v. 39 (3), pp. 202-209.

Fig. 1 Relative intensity of the orthogonally polarised modes as the polarisation is rotated.

◆ Fast axis mode

△ Slow axis mode

Fig. 2 The dependence of the lasing wavelengths upon the applied transverse load. The direction of transverse load application to the fibre is also indicated.

Fig. 3 The centre wavelengths of the two modes as the first FBG fabricated at 808nm is strained. Region A shows where the laser operates on a single longitudinal mode.

Fig. 4 The spectral stability of the both modes of the dual FBG laser in comparison with the same laser diode stabilised to the same temperature with no optical feedback.

▬▬ Laser diode with no optical feedback

▪ ▪ ▪ Modes of dual FBG external cavity laser

Fig. 1

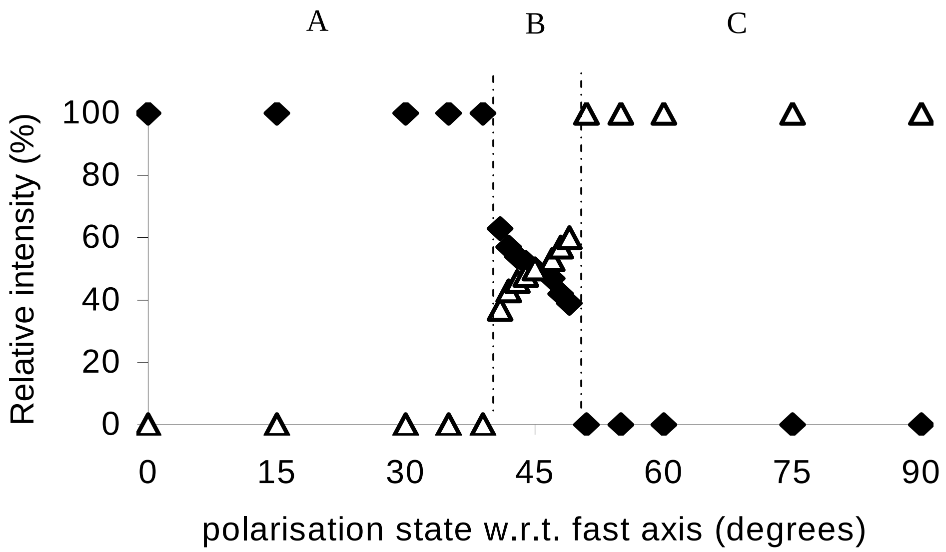
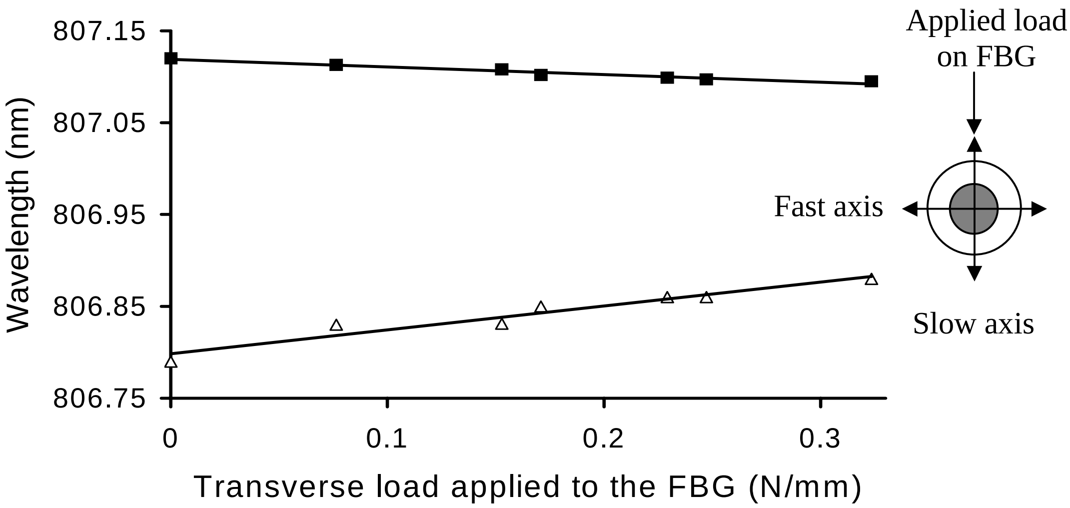
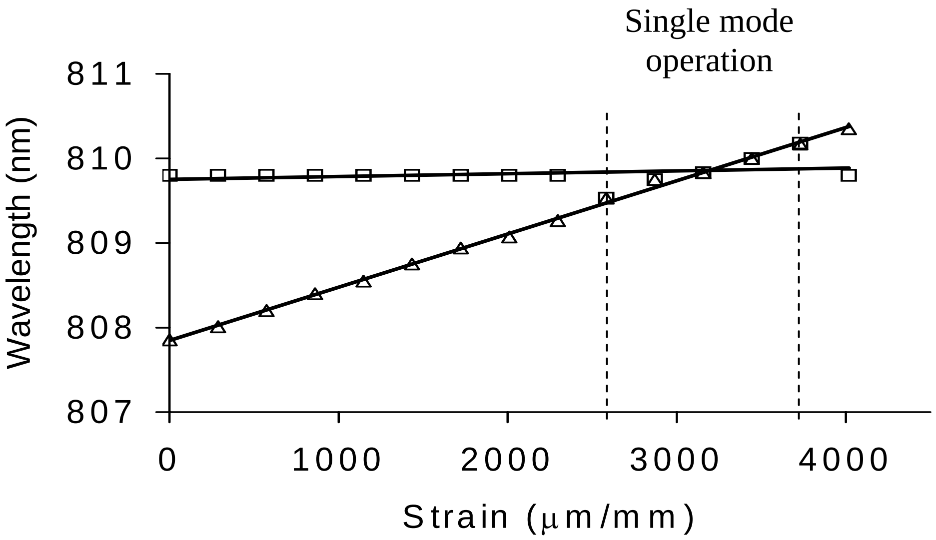

A
B
C
Relative intensity (%)
100
80
60
40
20
0
0
15
30
45
60
75
90
polarisation state w.r.t. fast axis (degrees)

Fig. 2



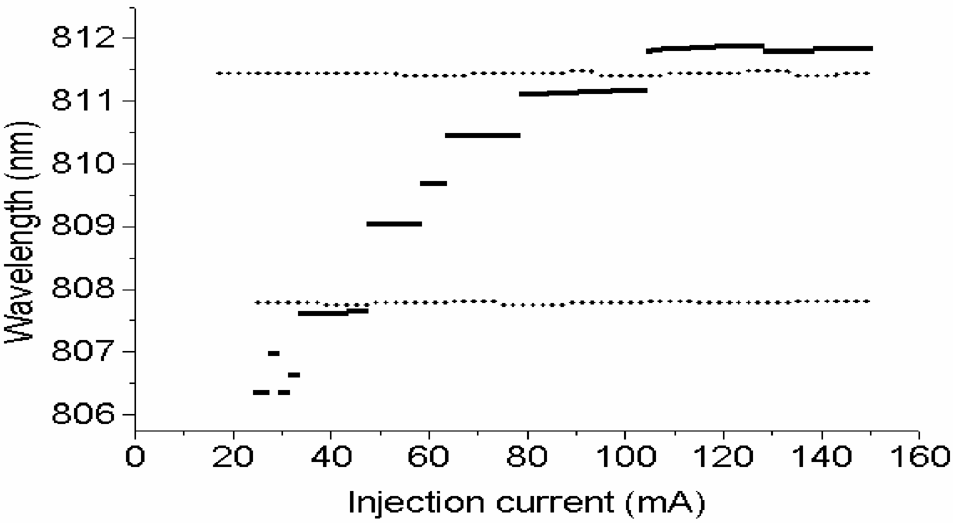
807.15
807.05
806.95
806.85
806.75
Wavelength (nm)
0
0.1
0.2
0.3
Transverse load applied to the FBG (N/mm)
Applied load on FBG
Fast axis
Slow axis

Fig. 3



Single mode operation
811
810
809
808
807
Wavelength (nm)
0
1000
2000
3000
4000
Strain (μm/mm)

Fig. 4



812
811
810
809
808
807
806
Wavelength (nm)
0
20
40
60
80
100
120
140
160
Injection current (mA)

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