accepted for publication.

Stable multiple wavelength generation in all-fibre DFB lasers

Morten Ibsen, Erlend Rønnekleiv, Oliver Hadeler, Gregory J. Cowle, Michalis N. Zervas and Richard I. Laming

Optoelectronics Research Centre, University of Southampton
SO17 1BJ Southampton, United Kingdom.
Tel: +44 1703 593138, Fax: +44 1703 593142, Email: mi@orc.soton.ac.uk

1. Introduction

Fibre DFB lasers [1] exhibit many attractive features and being based on and around a fibre Bragg grating they exhibit the robustness in performance offered by these, together with inherent fibre compatibility. They can readily be manufactured to operate in both a single longitudinal and single polarisation mode and strong preferential output has also been demonstrated by offsetting the phase-shift from the centre position [2]. As the technology of fibre Bragg grating fabrication and manipulation have reached a level where the formation of complex refractive index profiles are possible [4,5], the step towards all-fibre systems is approaching at rapid pace. Multiple wavelength laser configurations have been demonstrated [3] and applications of these to, for example accurate frequency referencing in wavelength division multiplexed (WDM) systems has been proposed. Some of the previous demonstrations have suffered from the necessity to reduce the homogeneous linewidth to allow stable, multiple wavelength operation.

In this paper we demonstrate multiple wavelength Moiré DFB fibre lasers operating CW at room temperature on two wavelength channels separated by 25, 50 and 100 GHz respectively. The output power from each wavelength channel is ~0 dBm for ~60 mW pump power @ 980 nm.

2. Laser design and experiment

The DFB gratings are written using a multiple exposure technique based on a grating plane by plane basis illumination with interferometric control that allows for very complex structures to be formed [4,5]. The Moiré structure is generated using apodisation, achieved by dephasing subsequent exposures with respect to each other on the fly, and hence is formed in just one writing procedure. The alternating regions of positive and "negative" refractive index change are obtained by inserting a discrete π-phaseshift after each half period of the sinusoid (Fig. 1). In order to obtain the preferential output from the lasers, the phase-shift

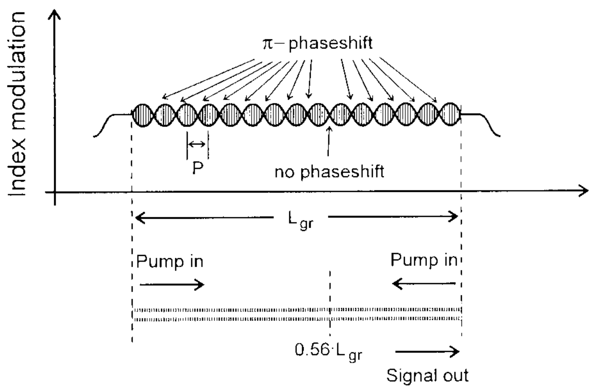

Fig. 1 *Refractive index profile and phase-shift position in the multiple wavelength DFB fibre laser.*

is offset by 6% from the centre position [2]. At this phase-shift position no π-phase-shift is inserted (Fig. 1) thereby effectively shifting the two halves of the laser by π. The wavelength separation between the channels is determined by the period P of the modulation and is given by

$$\Delta\lambda_{sep} = \frac{\lambda_B^{\,2}}{2 \cdot n_{ave} \cdot P} \quad (1)$$

where λ_B is the average Bragg wavelength in the structure and n_{ave} is the average refractive index. The DFB fibre lasers are written using ~100 mW of CW UV-light at 244 nm from a frequency doubled Ar-ion laser, and the total coupling coefficient, κ, in the gratings is estimated to be 350 m^{-1}, yielding an effective coupling coefficient in either channel of ~175 m^{-1}. The lasers are written using UV-light polarised orthogonal (s-pol.) to the axis of the fibre. This has been demonstrated as a technique to generate a differential grating strength [6] and subsequent single polarisation mode operation of the lasers [2]. The fibre used in the experiment is a fibre configuration providing a photosensitive boron/germanium ring around a phosphorus Er/Yb-doped core [7]. To enhance the photosensitivity even further the fibre is deuterium loaded at 70°C and 60 atm. for 7 days. The fibre has strong pump absorption of ~250 dB/m at 980 nm, and an absorption of ~35 dB/m at 1535 nm, up to ~60 mW at 980 nm is used to pump the lasers.The lasers are all 5 cm long and the total writing time for each of the devices is just 20 min.

3. Results and discussion

Fig. 2 shows the lasing characteristics of the two wavelength channels in each of the 3 lasers. The wavelength channels are separated by 100 GHz, 50 GHz and 25 GHz. The output power vs. pump power shows slope efficiencies of ~ 10 % for the two wavelength channels in each of the 3 configurations.

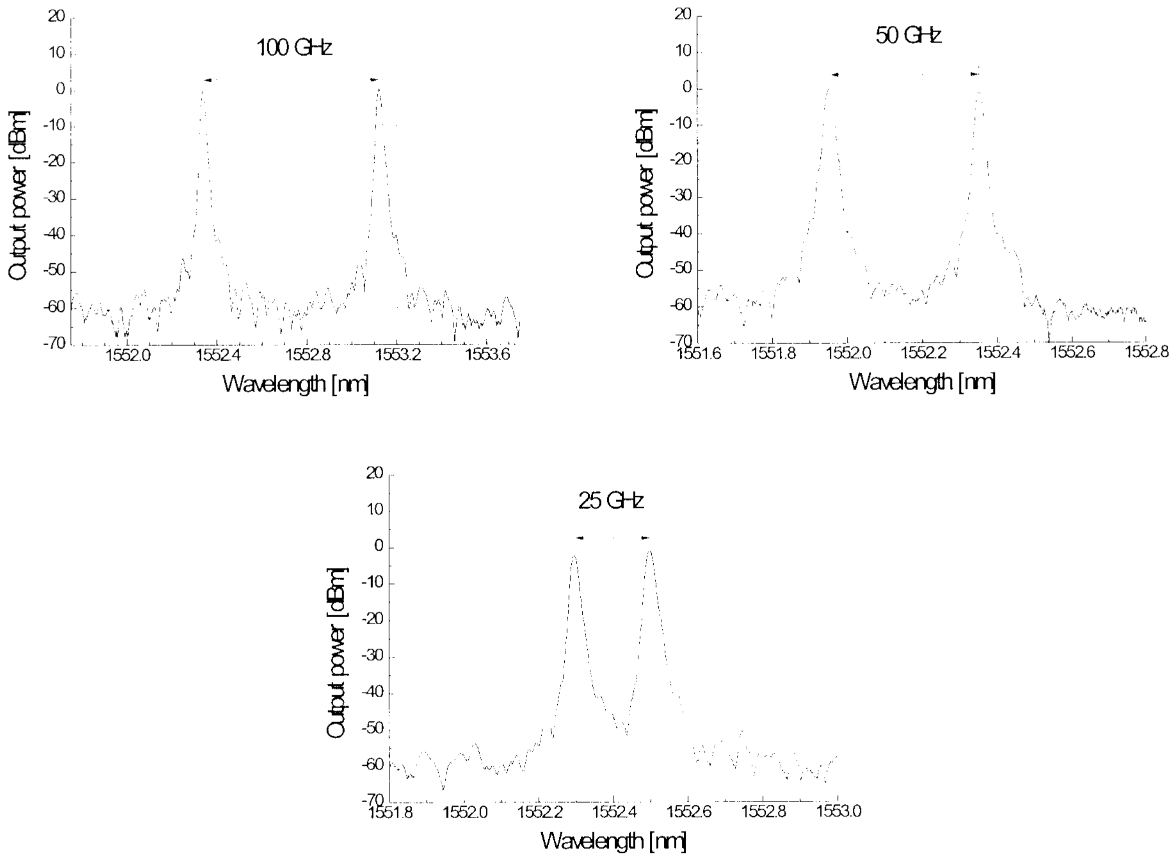

Fig. 2. *Lasing spectra for the 100 GHz, 50 GHz and 25 GHz channel separation multiple wavelength DFB fibre lasers.*

Furthermore it shows that near identical channel output powers of ~0 dBm are obtained for the maximum pump power of ~60 mW @ 980 nm for each of the wavelength channels in the lasers. The power in each of the channels is stable to within 0.1 dBm and the wavelengths to ~0.1 pm (12.5 MHz) measured with a wavemeter (0.1 pm res.). Results of measurements on the noise performance and linewidth of the lasers will be presented at the conference.

Due to the homogeneous broadening mechanisms and the related homogeneous linewidth of the erbium in the silica-phosphoros glass host, one would expect that the laser would only lase in the mode that reaches threshold first, because this mode then would clamp the gain for all other modes within the homogeneous linewidth. However we believe this is avoided in this multichannel fibre DFB structure because of the strong hole burning provided by each of the wavelength channels. The maximum number of wavelengths that can be made to lase using this technique is obviously determined by the maximum gain available in the length of the fibre used for the DFB structure.

One advantage of these structures is that the wavelength/frequency matching of several channels are simplified as they effectively are dictated and locked together via the superstructure. Such effective frequency locking is a parameter that is of great importance in sensor systems where for example beat frequencies are measured. In WDM systems precise channel allocation is desirable to minimise the potential crosstalk that can occur between adjacent channels. Furthermore temperature stabilisation and packaging are simplified because the wavelength channels are effectively contained within the same length of fibre.

4. Conclusion

We have successfully demonstrated an all-fibre DFB laser configuration allowing stable CW operation on two closely spaced wavelength channels at room temperature. The channel separations demonstrated are 25 GHz, 50 GHz and 100 GHz making the lasers attractive for WDM systems and well-suited for sensor purposes.

Acknowledgments

The authors wish to acknowledge Martin J. Cole and Michael K. Durkin for their help in establishing the grating writing facility and Liang Dong for providing the fibre used for the lasers. This work was in part funded by Pirelli Cavi, Italy, and the ORC is an EPSRC (UK) funded interdisciplinary research centre.

References

[1] LOH, W. H. and LAMING, R. I.: '1.55 μm phase-shifted distributed feedback fibre laser', *IEE Electron. Lett.*, **31**, (17), pp. 1440-1442, 1995.

[2] IBSEN, M., RØNNEKLEIV, E., COWLE, G.J., BERENDT, M.O., HADELER, O., ZERVAS, M.N. and LAMING, R.I.: 'Robust high power (>20 mW) all-fibre DFB lasers with unidirectional and truly single polarisation outputs', in proceedings to *CLEO '99*, paper CWE4, Baltimore, USA, 1999.

[3] CHOW, J., TOWN, G., EGGLETON, B. J., IBSEN, M., SUDGEN, K. and BENNION, I.: 'Multiwavelength generation in an erbium-doped fibre laser using in-fibre comb filters' *IEEE Photon. Technol. Lett.*, **8**, (1), pp. 60-62, 1996.

[4] IBSEN, M., DURKIN, M.K., COLE, M.J., LAMING, R.I.: 'Sinc-sampled fibre Bragg gratings for identical multiple wavelength operation', *IEEE Photon. Technol. Lett.*, **10**, (6), pp.842-4, 1998.

[5] IBSEN, M., DURKIN, M.K., COLE, M.J., ZERVAS, M.N. and LAMING, R.I.: 'Recent advances in long dispersion compensating fibre Bragg gratings', *IEE* publications, UK ISSN 0963-3308 - Reference no. 1999/023, 1999.

[6] ERDOGAN, T. and MIZRAHI, V.: 'Characterisation of UV-induced birefringence in photosensitive Ge-doped silica optical fibers'. *J. Opt. Soc. Am.*, **11**, (10), pp. 2100-2105, 1994.

[7] DONG, L., LOH, W. H., CAPLEN, J. E., MINELLI, J. D., HSU, K. and REEKIE, L.: 'Efficient single-frequency fiber lasers with novel photosensitive Er/Yb optical fibers', *Opt. Lett.*, **22**, (10), pp. 694-696, 1997.