SINGLE-LONGITUDINAL-MODE OPERATION OF AN Nd^{3+}-DOPED FIBRE LASER

Indexing terms: Lasers and laser applications, Optical fibres

We report the first operation of an Nd^{3+}-doped monomode fibre laser oscillating in a single longitudinal mode. The laser incorporated an integral fibre grating used as a narrowband reflector. The lasing linewidth was measured as 1·3 MHz FWHM at a wavelength of 1082 nm.

Introduction: The inclusion of rare-earth dopant ions into monomode fibres has led to the development of a new class of laser devices. The small active core volume offers a number of advantages over conventional bulk-glass lasers, and fibre lasers have been constructed operating on a number of transitions in the near-infra-red.[1,2]

Narrow-line single-longitudinal-mode lasers are of great interest in a number of applications, such as injection-locking larger lasers and in coherent communications. However, using a conventional Fabry–Perot cavity configuration, fibre lasers exhibit a large lasing linewidth, typically 10 nm. Narrow linewidth operation of these lasers has been previously demonstrated by the incorporation of wavelength-selective elements such as a bulk diffraction grating[2] or an integral fibre grating[3] within the cavity. Although not single-longitudinal-mode, it was observed that line-narrowing of the fibre laser does not significantly reduce its efficiency.[2] Fibre gratings are particularly attractive for line-narrowing fibre lasers, since they provide a route towards compact integrated all-fibre laser devices.

Fibre gratings are narrowband reflectors which consist of polished half-couplers into which a grating has been etched close to the core.[4] They have been employed previously to achieve single-longitudinal-mode operation of diode lasers.[5] Gratings have already been incorporated into fibre lasers to produce narrow-linewidth ($\sim$1 GHz) devices operating at a wavelength of 1·08 μm[3] and 1·55 μm.[6] However, these devices oscillated in tens of longitudinal modes, and they are not therefore serious competitors to DFB injection lasers. We report here improvements in fibre and grating characteristics which have resulted in the demonstration of the first single-longitudinal-mode fibre laser. The laser linewidth of 1·3 MHz is considerably better than that of a DFB injection laser.

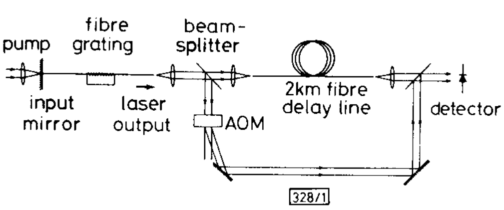

Fig. 1 *Experimental configuration of single-longitudinal-mode fibre laser including self-heterodyne interferometer*

Experiment: The experimental configuration is shown in Fig. 1. For convenience, the pump source was a CW Rh6G dye laser operating at 594 nm, and the pump light was launched through the input mirror with an efficiency of approximately 32%. The input mirror was chosen to have a high transmission at the pump wavelength ($T = 90\%$) and a high reflectivity at the lasing wavelength ($R = 99{\cdot}8\%$). The fibre was fabricated using the solution-doping technique,[7] which allowed a relatively high Nd^{3+} dopant concentration of 0·1% to be incorporated into the fibre while maintaining low loss (30 dB/km) at the lasing wavelength (Fig. 2). The fibre was characterised by a numerical aperture of 0·20 and a core diameter of 3·6 μm, giving a cutoff wavelength of 940 nm. The fibre grating was fabricated directly into the doped fibre and was overlaid with oil of refractive index 1·452 to increase the interaction of the field in the core with the grating. The peak reflectivity of the grating was centred on 1082 nm, with a bandwidth of 0·8 nm and an absolute peak reflectivity estimated to be greater than 80%. The fibre was cleaved and butted against the input mirror.

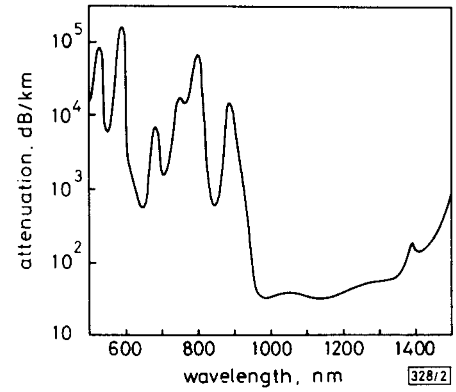

Fig. 2 *Absorption characteristic of highly Nd^{3+}-doped fibre*

Initially, the output from the fibre laser was analysed using a scanning Fabry–Perot interferometer. With an absorbed pump power of 40 mW and a fibre cavity length of approximately 50 cm (corresponding to an axial mode spacing of $\sim$200 MHz), some 10 longitudinal modes were seen to oscillate. The resultant total linewidth of $\sim$2 GHz was considerably narrower than the reflection bandwidth of the fibre grating ($\sim$200 GHz), as observed in previous work.[2] The fibre cavity was then cut back to one tenth of its original length (51 mm), at which point only a single longitudinal mode oscillated. Because the fibre was relatively highly doped, the absorption length at 594 nm was 2·7 cm. Thus, most of the pump light was absorbed in the fibre laser, despite the relatively short fibre length.

The CW single-longitudinal-mode laser characteristic is shown in Fig. 3. The threshold for laser action was 6 mW launched power, and the laser slope efficiency was 2·3%. These nonoptimal values can be considerably improved and are the result of relatively high intracavity losses and insufficient output coupling.

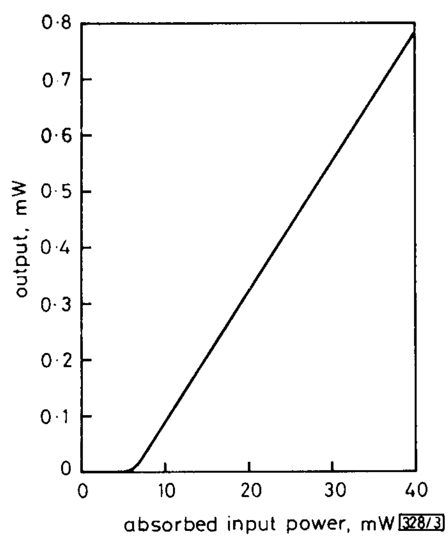

Fig. 3 *Lasing characteristic of single-longitudinal-mode fibre laser*

The output wavelength was measured to be 1082 nm, coincident with the peak reflectivity of the grating, as expected. The single longitudinal mode remained stable with no other modes visible up to the maximum available launched pump power of 40 mW, at which an output power of 0·78 mW was obtained.

A delayed self-heterodyne interferometer was used to investigate the spectral width of the fibre laser output (Fig. 1). The interferometer employed a 2 km fibre delay line and had a nominal resolution of 100 kHz. The RF spectrum analyser had a resolution of 30 kHz. The RF output from the interferometer is shown in Fig. 4 and is approximately Lorentzian in profile, indicating that the coherence length of the laser was significantly shorter than the interferometer delay line. Consequently, the optical linewidth is half the measured RF linewidth of 2·6 MHz FWHM, i.e. an optical linewidth of 1·3 MHz FWHM. This figure is about one tenth the spectral width of a

Reprinted from ELECTRONICS LETTERS 7th January 1988 Vol. 24 No. 1 pp. 24-26

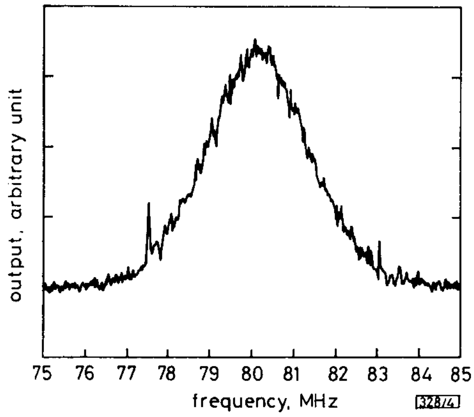

Fig. 4 *Self-heterodyne interferometer RF spectrum of single-longitudinal-mode fibre laser*

DFB injection laser, and indicates the potential use of fibre lasers in coherent transmission systems.

Conclusion: We have demonstrated for the first time single-longitudinal-mode operation of an Nd^{3+}-doped monomode fibre laser. This was achieved without the use of bulk optical components in the laser cavity, as would be required with a conventional laser. The linewidth was measured to be 1·3 MHz at a wavelength of 1082 nm. Single-longitudinal-mode fibre lasers have considerable potential as compact, narrow-linewidth sources, with numerous applications such as seed lasers for injection-locking, and coherent optical communications sources.

Acknowledgments: A CASE studentship (IMJ) was kindly provided by Plessey Research Caswell Ltd., and one of us (CJR) would like to thank the Directors of the Plessey Company plc for permission to publish this letter. The work was supported by the UK Science and Engineering Research Council and the UK Department of Trade & Industry under the JOERS programme.

I. M. JAUNCEY
L. REEKIE
J. E. TOWNSEND
D. N. PAYNE

30th October 1987

Optical Fibre Group
Department of Electronics & Computer Science
University of Southampton
Southampton SO9 5NH, United Kingdom

C. J. ROWE

Plessey Research Caswell Ltd.
Allen Clark Research Centre
Caswell, Towcester, Northants. NN12 8EQ, United Kingdom

References

1 JAUNCEY, I. M., LIN, J. T., REEKIE, L., and MEARS, R. J.: 'Efficient diode-pumped CW and Q-switched single-mode fibre laser', *Electron. Lett.*, 1986, **22**, pp. 198–199

2 REEKIE, L., MEARS, R. J., PAYNE, D. N., and POOLE, S. B.: 'Tunable single-mode fibre lasers', *J. Lightwave Technol.*, 1986, **LT-4**, pp. 956–960

3 JAUNCEY, I. M., REEKIE, L., MEARS, R. J., PAYNE, D. N., ROWE, C. J., REID, D. C. J., BENNION, I., and EDGE, C.: 'Narrow-linewidth fibre laser with integral fibre grating', *Electron. Lett.*, 1986, **22**, pp. 987–988

4 BENNION, I., REID, D. C. J., ROWE, C. J., and STEWART, W. J.: 'High-reflectivity monomode-fibre grating filters', *Electron. Lett.*, 1986, **22**, pp. 341–343

5 PARK, C. A., ROWE, C. J., BUUS, J., REID, D. C. J., CARTER, A., and BENNION, I.: 'Single-mode behaviour of a multimode 1·55 μm laser with a fibre grating external cavity', *Electron. Lett.*, 1986, **22**, pp. 1132–1133

6 JAUNCEY, I. M., REEKIE, L., MEARS, R. J., and ROWE, C. J.: 'A narrow linewidth fibre laser operating at 1·55 μm', *Opt. Lett.*, 1987, **12**, pp. 164–165

7 TOWNSEND, J. E., POOLE, S. B., and PAYNE, D. N.: 'Solution-doping technique for fabrication of rare-earth-doped optical fibres', *Electron. Lett.*, 1987, **23**, pp. 329–331