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SPECIAL FIBRES FOR SENSOR APPLICATIONS

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Telecommunications transmission using optical fibres can now be regarded as a mature technology. As a result, optical fibres are freely available at relatively low cost and this has led to an increasing interest in their use for other applications such as sensing, signal-processing and various fibre devices. There is also much interest in fibre-based switching using non-linear optical effects.

However, whilst the great majority of experimental and commercial applications currently employ telecommunications-grade fibres, this policy frequently leads to a design compromise, and in some cases makes the performance marginal or even untenable, owing to excessive environmental sensitivity. Consequently, attention is now being given to the design of sensor fibres with enhanced (or depressed) sensitivity to suit the particular application.

There are few special fibres currently commercially available. Perhaps the best known is the highly-birefringent fibre[1] both in polarisation-maintaining[2] and polarising[3] form. Such fibres are extensively employed for polarisation control in fibre gyroscopes and other sensors, and are also under investigation for use in coherent communications systems[4] and in non-linear switching. The pace of development is increasing, however, and a large number of other fibre designs tailored to specific applications have been reported.

For example, the unusual propagation properties of circularly-birefringent fibres[5,6] make them very suitable for magnetic-field sensing. Work is also underway on metal/glass composite fibres for the production of polarisers[7] and Kerr modulators[8].

Considerable scope exists for modifying the properties of silica fibres by incorporating suitable dopants to enhance a given effect. Thus, the acousto-optic, magneto-optic, non-linear and electro-optic coefficients, which are small in pure silica, can be increased by adding various transition and rare-earth ions[9]. Several laboratories[10] are studying such effects. However, it should be noted that, in general, the greatest improvements in sensors, modulators and other devices can be obtained by abandoning silica altogether as a host material and employing compound glasses, infrared (Eg chalcogenide) glasses or even polymers. The increase in loss which may result from the use of alternative glasses is not normally a problem, since several orders of magnitude improvement in device sensitivity is attainable and only a few metres of fibre are usually required.

Perhaps the most exciting recent development has been the demonstration of lasing action at wavelengths of 0.652, 1.06, 1.08 and 1.536μm in single-mode fibres, by doping with Sm^{3+}, Pr^{3+}, Nd^{3+} and Er^{3+}, respectively[11,12,13,14]. The losses at the lasing wavelength in these fibres is so low that it has been possible to construct lasers up to 1400m in length. Apart from the obvious application of the fibres as sources and amplifiers for communication and sensor systems, the availability of a multi-pass, resonant, active device suggests a number of sensor possibilities. Both ring-resonator and Fabry-Perot laser devices have been built, with finesses of up to 300. Consequently, a sensitivity enhancement of the same order to acoustic radiation, for example, should be possible. In addition, the availability of low-loss rare-earth-doped fibres having controlled absorption and fluorescence characteristics provides further opportunities for distributed sensing by monitoring the variation of these parameters with temperature[15].

It is clear that fibre fabrication technology is now able to offer a number of attractive solutions to the unique problems presented by alternative fibre applications. A wide range of possibilities are available, including modified telecommunications fibres which are bend resistant, metal[16] and special polymer-coated[17] fibres, fibres with liquid cores[18] or claddings[19], spun low[20] and high[21] birefringence fibres and twin-core fibres[22].

As examples of the potential for special fibre designs for sensor applications, we will review here linearly and circularly-birefringent fibres, metal/glass composite fibres and rare-earth-doped fibres. In addition, recent developments in non-silica based "soft" glass fibres will be outlined.

REFERENCES

1. Dyott, R.B., Cozens, J.R., Morris, D.G.:
"Preservation of polarisation in optical fibre waveguides with elliptical cores",
Electron. Lett., Vol. 15, pp. 380-382, 1979.

2. Birch, R.D., Payne, D.N., Varnham, M.P.:
"Fabrication of polarisation-maintaining fibres using gas-phase etching",
Electron. Lett., Vol. 18, pp. 1036-1038, 1982.

3. Varnham, M.P., Payne, D.N., Birch, R.D., Tarbox, E.J.:
"Single-polarisation operation of highly-birefringent Bow-Tie optical fibres",
Electron. Lett., Vol. 19, pp. 246-247, 1983.

4. Smith, D.W., Harmon, R.A., Hodgkinson, T.G.:
"Polarisation stability requirements for coherent optical fibre transmission systems",
British Telecom Tech. J., Vol. 1, 1983.

5. Varnham, M.P., Birch, R.D., Payne D.N.:
"Helical-core circularly-birefringent fibres",
Proc. IOOC/ECOC., pp. 135-138, 1985.

6. Li, L., Qian, J.-R., Payne, D.N.:
"Current sensors using highly-birefringent Bow-Tie fibres",
Electron. Lett., Vol. 22, pp. 129-130, 1986.

7. Li. L., Wylangowski, G., Payne, D.N., Birch, R.D.:
"Broadband metal/glass single- mode fibre polarisers",
Electron. Lett., Vol. 22, pp. 1020- 1022, 1986.

8. Li. L., Birch, R.D., Payne, D.N.:
"An all fibre electro-optic Kerr modulator",
Proc. IEE Colloquium on "Advanced Fibre Waveguide Devices, London, May 1986.

9. Poole, S.B., Payne, D.N., Fermann, M.E.:
"Fabrication of low-loss optical fibres containing rare-earth ions",
Electron. Lett., Vol. 21, pp. 737-738, 1985.

10. Millar, C.A., Ainslie, B.J., Miller, I.D., Craig, S.P.:
"Concentration and co-doping dependence of the $^4F_{3/2}$ to $^4I_{11/2}$ lasing behaviour of Nd^{3+} silica fibres",
Proc. IOOC/OFC., Reno, Nevada, 1987, Paper WI4.

11. Farries, M.C., Morkel, P.R., Townsend, J.E.:
"A samarium doped visible glass laser operating at 651nm",
Proc. CLEO, Anaheim, California, Paper PD5, April 1988.

12. Reekie, L., Mears, R.J., Poole, S.B., Payne, D.N.:
"A Pr^{3+}-doped single-mode fibre laser",
IOP/IEE Symposium on "Advances in Solid State Lasers",
London, 1986.

13. Mears, R.J., Reekie, L., Poole, S., Payne, D.N.:
"Neodymium-doped silica single-mode fibre lasers",
Electron. Lett., Vol. 21, pp. 738-740, 1985.

14. Mears, R.J., Reekie, L., Poole, S.B., Payne, D.N.:
"Low threshold tunable CW and Q-switched fibre lasers operating at 1.55μm",
Electron. Lett., Vol. 22, pp. 159-160, 1986.

15. Farries, M.C., Fermann, M.E., Laming, R.I., Poole, S.B., Payne, D.N., Leach, A.P.:
"Distributed temperature sensor using Nd^{3+}-doped fibre",
Electron. Lett., Vol. 22, pp. 418-419, 1986.

16. Dandridge, A., Tveten, A.B., Sigel, G.H., West, E.J., Giallorenzi, T.G.:
"Optical fibre magnetic field sensors",
Electron. Lett., Vol. 16, pp. 408-409, 1980.

17. Koo, K.P., Sigel, G.H.:
"An electric field sensor utilising a piezo electric polyvinylidene fluoride (PVF2) film in a single-mode interferometer",
IEEE J. Quantum Electron., Vol. QE-18, p. 670, 1982.

18. Hartog, A.H.:
"A distributed temperature sensor based on liquid-core optical fibres",
J. Lightwave Tech., Vol. LT-1, pp. 498-509, 1983.

19. Scheggi, A.M., Brenchi, M., Conforti, C., Falciai, R., Preti, G.P.:
"Optical fiber thermometer for medical use",
First Int. Conf. on Optical Fibre Sensors, London, 1983.

20. Barlow, A.J., Payne, D.N., Hadley, M.R., Mansfield, R.J.:
"Production of single- mode fibres with negligible intrinsic birefringence and polarisation mode dispersion",
Electron. Lett., Vol. 17, pp. 725-726, 1981.

21. Qian, J.-R., Li, L.:
"Current sensors using highly birefringent Bow-Tie fibres",
Proc. OFS, Tokyo, pp. 85-88, 1986.

22. Snitzer, E., et al.:
In "Fibre optic rotation sensors",
Springer Verlag, p. 406, 1982.