CHARACTERISATION OF SPECIALITY FIBRES AND COMPONENTS

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Optical fibres are making ever increasing inroads into areas traditionally satisfied by older, more established technologies. One of the prime vehicles for this trend is the proliferation of specially-tailored fibres designed for specific applications[1]. Since these applications are diverse (especially in the sensor field[1]) and the required fibre characteristics often subtle, measurement of the fibre response frequently presents a challenge. On occasions it is even necessary to resort to indirect measurements by observing the performance of the fibre in the intended application, from which its characteristics can be implied. A particular example here is the fibre gyroscope, where signal processing techniques have progressed to such an extent that the gyro itself provides the ideal environment for high-accuracy measurements of fibre polarisation performance.
It is the intention of this paper to review some of the many speciality fibres currently available or being developed, the selection being made to emphasise topical measurement issues. A summary of different fibre types, their applications and associated measurement problems is given in Table 1.

Dispersion-Tailored Fibres were among the first speciality fibres to be investigated and a number of techniques have been developed to measure the chromatic dispersion. Despite this, questions remain concerning which curve-fitting routines should be used to reduce measurement noise. This is particularly true for dispersion flattened fibres, since no a priori knowledge of the shape of the dispersion curve can be assumed.

Polarisation-Maintaining Fibres:[2,3] Controversy exists as to whether these should be characterised by the polarisation holding h-parameter[4] (which is the polarisation cross-talk per unit length), or by the intrinsic modal-birefringence B. The h-parameter measures the actual cross-talk present when the fibre is subject to uncontrolled random external perturbations, for example by winding on a drum. It therefore reveals more about the quality of the winding or fibre coating than it does about the fibre. The modal birefringence, on the other hand, describes the resistance of the fibre polarisation state to cross coupling (externally induced in all but the worst fibres) and is therefore an intrinsic fibre property. The problem is complicated by the fact that the modal fields are not plane polarised[5], but are actually curved, with the orthogonally-polarised minor-field components present at levels ranging from -32 to -45 dB. Thus with state-of-the-art fibres providing h-parameters ranging from 10^{-5} to $10^{-6} m^{-1}$ (cross-talk of -20 to -30dB after 1 km), it is necessary to use long lengths of fibre in order to obtain a reliable measurement of h. In this case, the measurement is usually dominated by external perturbations.

Since the modal birefringence is an intrinsic fibre property, it would appear to be a better measure of fibre characteristics than the h-parameter[6]. Perhaps the best solution, however, would be a measurement of h-parameter with the fibre subject to controlled perturbations, such as mandrel bends and twists. In this way the fibre resistance to cross-talk could be directly specified, since the measurement would automatically include the resistance of the fibre and buffer coating to cross-talk caused by microbends and pressure.

Single Polarisation Fibres[7,8] rely on the differential-mode attenuation which occurs in depressed-cladding, stress-birefringent fibres when operated at low V-values (V~1.8). Figure 1 shows the spectral differential attenuation for the two orthogonally-polarised modes in a conventional Bow-Tie fibre and a polarising Bow-Tie fibre having the same beat length. It is clear that the polarising fibre has sharper microbending edges and a wider polarising bandwidth. To obtain reliable measurements, care must be taken to reduce the effects of stray light and polarisation dependence within the monochromator.

The performance of a polariser can only be fully specified by including cross-talk terms in the form of an intensity transfer matrix, I, between the input and output polarised modes[9]. This matrix has been measured for a coil polariser with broadband light from a laser diode, and the results are as follows:

$$I = \begin{pmatrix} T_{xx} & T_{xy} \\ T_{yx} & T_{yy} \end{pmatrix} = T_{xx} \cdot \begin{pmatrix} 1 & R_2 \\ R_1 & R_2 R_3 \end{pmatrix} = \begin{pmatrix} -2 & -44 \\ -44 & -64 \end{pmatrix} \text{ dB}$$

where T_{xx}, T_{yy} are the transmission ratios of the x and y polarised modes and T_{xy}, T_{yx} are the cross-coupled power between the modes. First T_{xx} = -2 dB is measured using a cut-back technique. X-polarised light is then launched and the output extinction ratio $R_1 = T_{yx}/T_{xx}$ = -42 dB measured with a prism polariser. Similarly, the output extinction ratio $R_2 = T_{yy}/T_{xy}$ transmission ratio $R_3 = (T_{xy} + T_{yy})/(T_{xx} + T_{yx})$ = -42 dB is measured using the prism polariser at the input.
The measurement of T_{yx} in the above may have been limited by the minor-field components[5]. This is not a limitation for the other terms because the source has the wrong spatial symmetry to launch a mode via its minor-field components. A similar principle can be used to advantage in mode extinction-ratio measurements, since a conventional monomode fibre will spatially filter (to 50 - 60 dB) the minor-field components which pass through a prism analyser. Following the analyser with a short length of monomode fibre reduces the minor field components to -80 to -100dB. Thus the measurement is now limited by the prism polariser (typically 50-60dB), not the minor field components.

Circularly Birefringent Fibres[10] (Fig.2) are fabricated by rapidly spinning a preform containing an offset core. A nondestructive method to measure the polarisation beat length L_p of such a helical-core fibre is to launch linearly-polarised light and to cross an analyser with respect to the emerging linear polarisation. The birefringence of the fibre is then perturbed by moving a pressure-point along its length and counting the nulls in the cross-coupled power. These occur when the polarisation vector is parallel or perpendicular to the direction of the force. Thus if N nulls are counted in length L, then L_p=2L/N. A similar method has been used to measure Lp in a linearly-birefringent fibre[11].
A novel feature of the helical-core fibre, is that the fibre is effectively monomode at high V-values. This is because the higher-order modes cannot survive the fibre curvature. A simple demonstration of the effect can be seen in a fibre where the spin pitch has been gradually reduced along its length. When light is launched into the fibre, bright bands appear along its length showing where successively lower-order modes are reaching their effective cut-offs.

Metal/Glass Composite Structures are formed by introducing metal into longitudinal holes close to the core of a silica optical fibre (Table 1). The fibres make ideal low-loss polarisers utilising the absorption of one of the polarisation states in the metal layer[12]. The measurement requirements are similar to those for coiled fibre polarisers, but with reduced errors from minor-field components. However, owing to their very high extinction ratio (>52dB), the optical quality of the crystal analyser and dynamic range of the spectral loss measurement system become the limiting factors. Further improvements in measurement dynamic range may be achieved using a gyroscope configuration[13].

By incorporating two metal electrodes on either side of the fibre core a fibre modulator can be constructed based on the Kerr effect[14]. Here care must be taken in separating the phase modulation produced by the Kerr effect from that caused by electrostriction.

Rare-Earth Doped-Fibres containing small (<0.25%) quantities of rare-earth impurity ions (e.g. Nd^{3+}) in the fibre core[15] are of great interest as fibre lasers and amplifiers[16]. To this end, a knowledge of their absorption and fluorescence characteristics is required. Measurement of the absorption spectra of these fibres poses a number of problems owing to the difficulty of measuring losses which vary by several orders of magnitude across the spectrum (Fig.3). However, a multiple cut-back technique in combination with attenuation equipment optimised for dynamic range (>48dB in single-mode fibres with 2nm spectral resolution c.f. 35dB in most systems) may be used to overcome these difficulties. Various fibre lengths must be measured, depending upon the regions of the spectrum under test and the results may then be re-scaled and combined to give absorption spectra with extremely high dynamic ranges. Care must also be taken to avoid fluorescence effects.

The fluorescence spectra of the fibres may itself be measured using similar equipment, but with the fluorescence excited by pumping the fibre with a laser matched to one of the impurity absorption bands. Examples of fluorescence spectra for a fibre containing 450ppm Tb^{3+}, 30ppm Nd^{3+} and 10ppm Er^{3+} ions are shown in Fig.4.

Fibre lasers present a number of measurement problems in their own right. Apart from threshold, gain and output power, the spectral output characteristics are of particular interest for potential applications such as a broad-band source for the fibre gyro, or as a narrowband optical communications source. Measurements are complicated by the fact that the axial mode spacing may be only a few MHz, owing to the length of the laser cavity (up to 300m). Results on Nd^{3+} (0.9 and 1.08 μm), Pr^{3+} (1.07 μm) and Er^{3+} (1.55 μm) will be presented.

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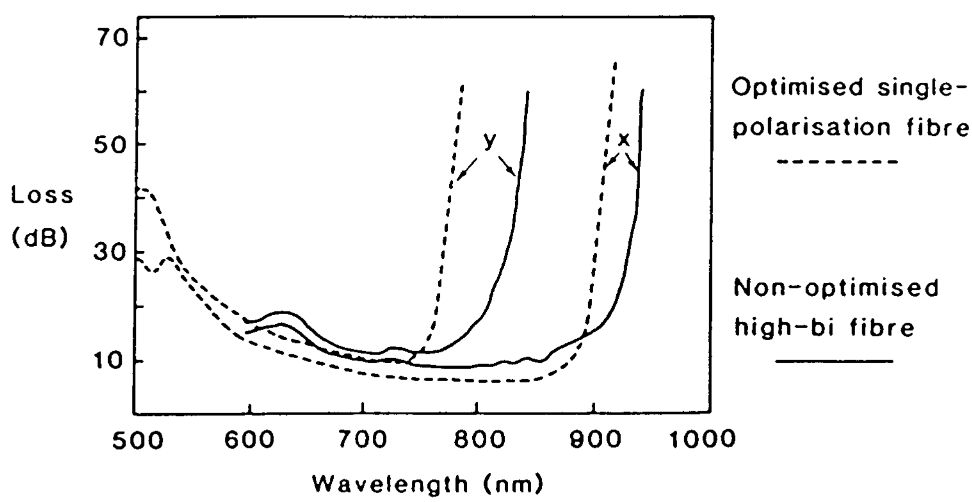


Fig.1. Spectral Attenuation of Bow-Tie fibres showing differential loss between X- and Y-polarised modes. Note wider polarising window for fibre with optimised design.

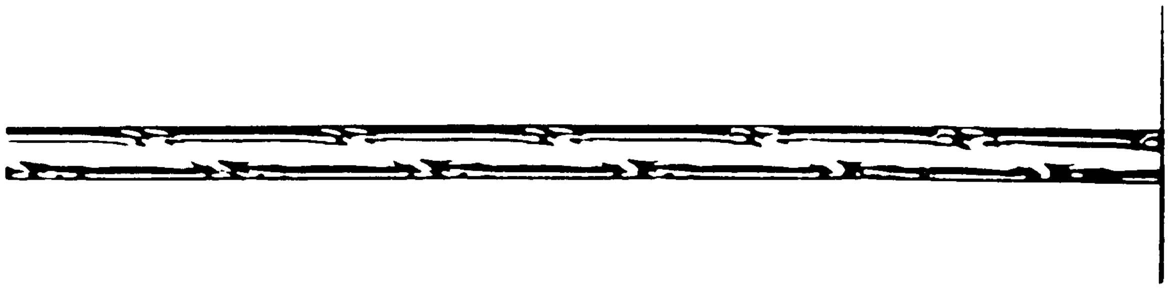


Fig.2. Transverse view of helical-core circularly-birefringent fibre.

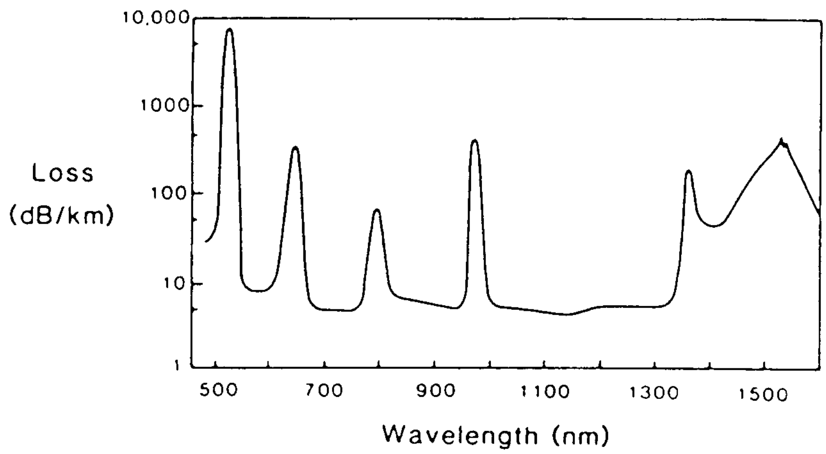


Fig.3. Spectral attenuation of a single-mode fibre doped with 10ppm Er^{3+}. Note very large measurement dynamic range required.

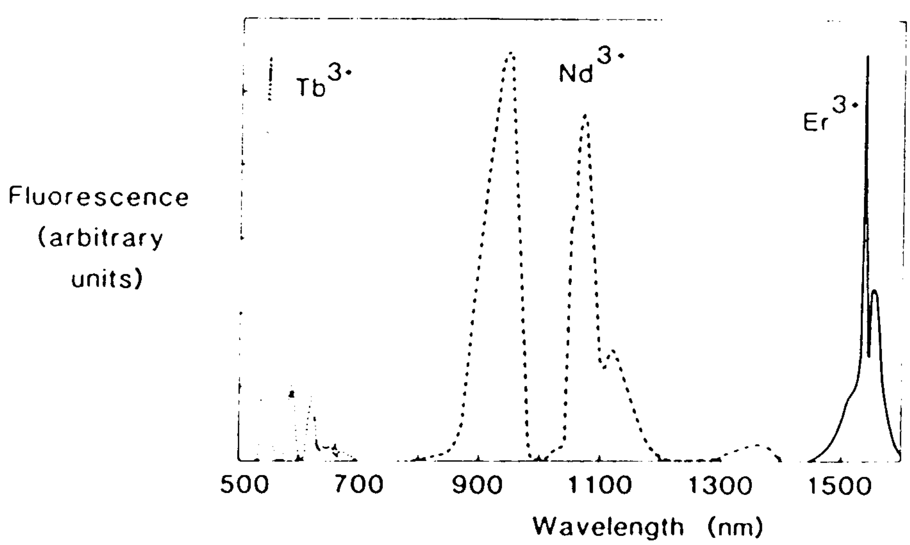


Fig.4. Fluorescence spectra of fibres containing Tb^{3+}, Nd^{3+} and Er^{3+} ions.

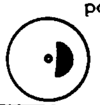
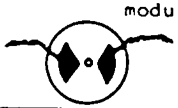
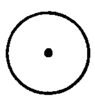
FIBRE TYPE	APPLICATIONS	MEASUREMENTS REQUIRED	POSSIBLE MEASUREMENT PROBLEMS
Dispersion-tailored	Telecommunications Non-linear effects	Dispersion, λ_0	Wide Spectral range for measurement Appropriate Fitting routines Dynamic range
Ultra-low Birefringence	Sensors Isolators Non-linear effects	Birefringence	External Effects - e.g. Temp., Banding, Stress
Highly-Birefringent e.g. Bow Tie 	Sensors (e.g.Gyros) Interferometers Coherent Communications	Birefringence Beat Length Polarisation mode-dispersion Polarisation Holding Temperature Variation of Parameters	Minor Field Component h - parameter Vs Birefringence
Single Polarisation 	Fibre Polarisers	Extinction Ratio including Spectral Dependence Matrix Measurements Temperature Variation of Parameters	Minor-Field Component Monochromator Performance
Circular Birefringent 	Current sensors Coherent communications	Mode Cut-off Birefringence Temperature Variation	Mode Coupling Circular Birefringence Vs Rotating Linear Birefringence.
Metal/glass fibre polarisers 	Fibre Polarisers	Extinction Ratio including Spectral Dependence	Monochromator Performance, Minor Field Components
Metal/glass fibre modulators 	Electro-Optic Modulators	Modulation Transfer Function	Separation of Kerr and Electro- strictive effects
Rare-Earth Doped 	Fibre Lasers Fibre Amplifiers Sensors Non-linear Optics	Absorption Spectra Fluorescence Spectra and Temporal Characteristics } Verdet Constant Non-linear Coefficients Saturation/Bistability Effects Temperature dependence of above	Measurement system performance Saturation/Multiphoton Absorption/ Excited State Absorptions Low fluorescence intensities

Table 1. Measurement requirements for specialty fibres.