Interferometric measurements of birefringence in single mode fibers and devices

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ABSTRACT

A simple method for interferometric measurements of chromatic and polarization mode dispersion os single mode fibres and devices is presented. Accuracy of the method and resolution limits are discussed.

1. INTRODUCTION

In actual single mode fibres the polarization state degeneracy is usually raised by either residual or induced anisotropies and internal stresses within the fibre. In a classical transmission system, birefringence gives rise to polarization mode dispersion (PMD) which will limit the ultimate bit rate which can be transmitted in such system. On the other hand, in coherent transmission systems the polarization state of the light must be well defined. This can be achieved either by using low birefringence fibres and polarization control devices or by using high birefringence polarization maintaining fibres. Moreover, passive or active integrated optical devices are often birefringent, so that the characterization of birefringence properties becomes increasingly important in modern applications.

Many methods have been developed for birefringence measurements using frequency domain[1] or interferometric techniques[2][3]. All these methods involve linear polarizers and discrete optical elements as well as the search of birefringence axes of the fibre or device. These features rend this kind of measurement quite delicate and great care and time are needed to perform a complete characterization. In this paper we present an interferometric technique which can be used to both chromatic dispersion and birefringence characterization of single mode fibres and devices.

2. EXPERIMENTAL

The basic instrument is an all-fibre Michelson interferometer[4] whose reference arm is a non-birefringent single mode fibre, the other incorporating the fibre or device to be measured. Unpolarized white light filtered by a monochromator ($\Delta\lambda$=10 nm), is launched into the interferometer and the lenght of the fibre in the reference arm is veried by elastically pulling its extremity with a computer controlled 0.1 μm stepper motor translation unit. The cleaved end of the reference fibre is silvered so that the mobile mirror of the Michelson interferometer is directly attached to the fibre and no launching optics is needed. The single mode fibre or device to be measured is butt-coupled to the cleaved face of the single mode coupler pigtail, which act as beam-splitter. The other end of the test arm is placed directly in front of a mirrored surface.The length of the reference fibre can be varied by 1 cm by the translation unit, so that the test arm length must have the same length of the reference within approximately 5 mm.In our case, the test fibre length was 196.5 cm.In the case of small fibre samples or devices, a low birefringence fibre whose chromatic dispersion was well known was used to couple the sample to the interferometer .

Because of the limited coherence length of the light source, an interference signal can be detected only when the length of both arms of the interferometer are equal within the coherence length of the source. The length of the reference arm is swept at constant speed so that an AC signal is detected and its amplitude gives directly a measure of the fringes contrast. For a given wavelength the overall fringes contrast was obtained by direct integration of the contrast signal with the computer. A Fourier transform technique was used to locate the position of the fringes pattern. With this technique group delays can be measured with 2 femtoseconds resolution over the 1100 -1700 nm spectral range[4].

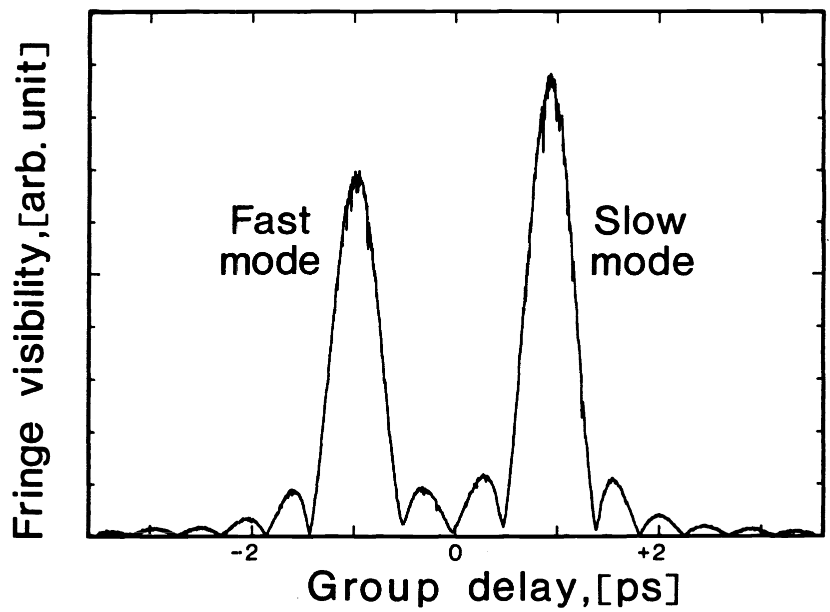

Figure 1. Polarisation modes interference fringes contrast of a high birefringence PANDA fibre

3. RESULTS AND DISCUSSION

When a high birefringence fibre is placed in the test arm, each polarization mode independently interfere, with its own phase and group delay, with the corresponding mode of the non-birefringent reference arm, giving rise to a double pattern as shown in figure 1. The polarization mode dispersion is obtained by direct subtraction of the group delays of the two polarization modes over the full spectral range covered by the interferometer(5).

In the case of standard single mode fibres, the birefringence is usually small so that the two peaks corresponding to the two polarization modes overlap and a single peak is observed. The same situation occurs when the device to be measured is a small piece of birefringent crystal or high-birefringence fibre. In this case the difference between group delays is smaller than the coherence time of the source and again a single peak is observed. This signal is actually the sum of the two AC signals generated by the interference fringes of the two orthogonal polarization modes, each one carrying its own phase. The shape of the total fringes contrast can be calculated and the polarization mode dispersion obtained from the best fit to the experimental data(6). This procedure, however, requires a complicated procedure of curve fitting, which may take quite a long computational time.

The above procedure can be greatly simplified when the polarization mode dispersion can be considered to be much smaller than the coherence time of the incoming light. In this case the relative phase delay between the two polarization modes will modulate the overall visibility of the interference fringes with a periodic function of the wavelength. If the relative phase delay is zero the interference signals add up leaving a high overall contrast. Contrary, the contrast is poor when the phase difference is . Change from in-phase to out-of-phase situation can be performed by properly changing the wavelength setting of the monochromator. The total fringes contrast can be directly obtained by numerical integration of the envelope curve of the interference signal during the measurement.

Figure 2 shows the measurement of the fringes contrast of a depressed-cladding single mode fibre with unexpected internal stresses. The theoretical wavelength dependence of the contrast is given by $[1 + \cos \Delta nkl]^{1/2}$, where Δn is the fibre birefringence, l the sample length and k is the vacuum wavenumber of the light(6). In order to fit the experimental data it would be necessary to take into account the spectral dependence of the light source as well as the coupling ratio of the single mode coupler used as beam-splitter in the Michelson interferometer. Nevertheless the theoretical dependence can be clearly recognized in figure 2. To get rid of the complicated procedure of curve fitting, we perform the Fourier transform of the experimental data taking the wavenumber k and the birefringence l Δn as conjugate coordinates. The result is a power spectrum showing a sharp peak at the fibre birefringence as can be seen in figure 3. The corresponding polarization mode dispersion, 0.026ps/m, is quite greater than chromatic dispersion in ordinary fibre link (<0.015ps/m) so that systematic birefringence check-up may be important, even for standard applications.

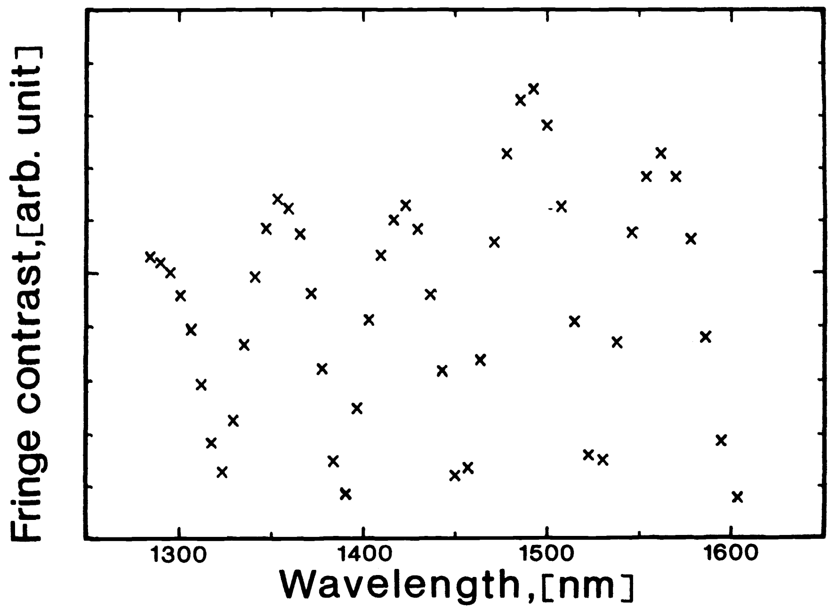

Figure 2. Contrast spectrum of the depressed cladding single mode fibre D of Table 1.

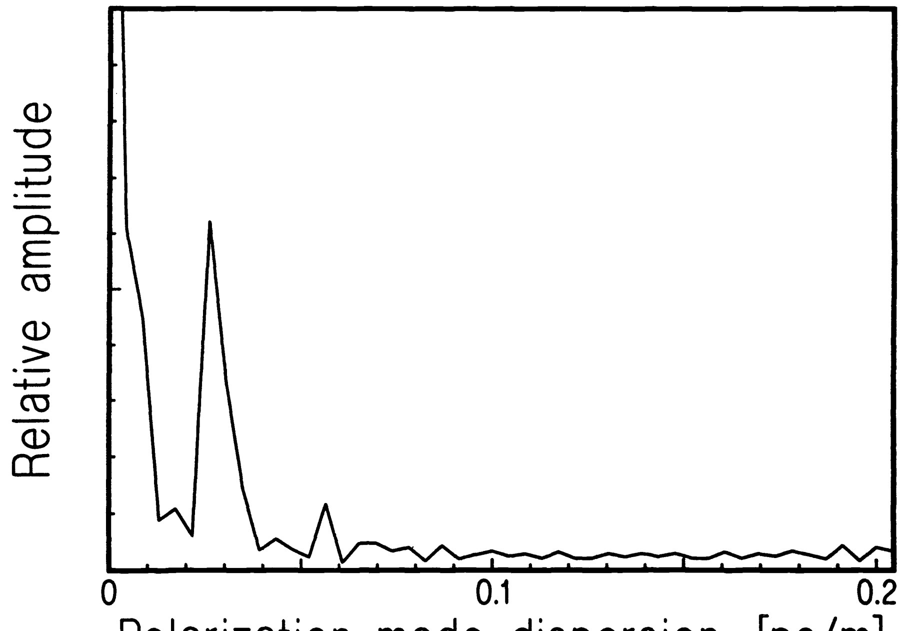

Figure 3. Power spectrum of birefringence corresponding to the contrast spectrum of Figure 2.

It should be pointed out that the extrapolation of the birefringence measured on a short sample to a long length fiber must take into account some level of mode coupling which depends on the birefringence of the fibre as well as on external perturbation. This mode coupling tends to decrease the birefringence of a long length of fibre with respect to the linear extrapolation of the PMD measured over the short length. Assuming a totally random coupling an estimation can be made with a $l^{1/2}$ dependence of the polarization mode dispersion. In this case, the 0.026ps/m value obtained with a 3.5 m length sample would result in a ~ 1,5 ps/Km polarization mode dispersion over a kilometer length fibre, which is still a quite high level of dispersion even for standard transmission applications.

Table 1 Characteristics of measured fibres. Δn^+ and Δn^- are respectively the index difference of core and inner cladding with respect to the outer silica cladding.

	FIBRES			
CHARATERISTICS	A	B	C	D
Mean core diameter (μm)	6.7	9.5	6.9	5.1
Ellipticty	0.21	0.09	0.0	0.0
$\Delta n^+ (10^{-3})$	12.0	6.5	4.5	13.0
$\Delta n^- (10^{-3})$	0.0	0.0	-2.5	-2.2
PMD (ps/m)	0.077	0.024	0.022	0.026

Results for different fibre samples are shown in table 1, together with other fibre parameters. Fibres A and B are matched cladding elliptic core single mode fibres, fibre C is a depressed-cladding single mode fibre designed for 1300 nm transmission applications and fibre D is a depressed cladding fibre designed for special applications. Fibre C and D present no ellipticity but the same level of birefringence as fibre B. This means that the birefringence is determined by random internal stress which appear due to the mismatch of the thermal expansion coefficients of the doped inner cladding and the silica. This feature was confirmed by the systematic observation of birefringence levels in depressed-cladding fibres much higher than in standard circular core matched-cladding fibres.

The results presented in table 1 are in quite good agreement with the previous interferometric method(6) except for a small difference observed in the more elliptic core fibre A. A possible explanation to this difference is that in geometric induced birefringence the peak in the birefringence spectrum obtained by the Fourier transform technique is wider than the one observed in stress induced birefringence. This fact is probably due to the wavelength dependent geometric contribution to the birefringence, which can not be assumed to be constant over the whole spectrum. Nevertheless, the agreement is still remarkable, and the Fourier transform method is much simpler than the non linear fit required by the previous method.

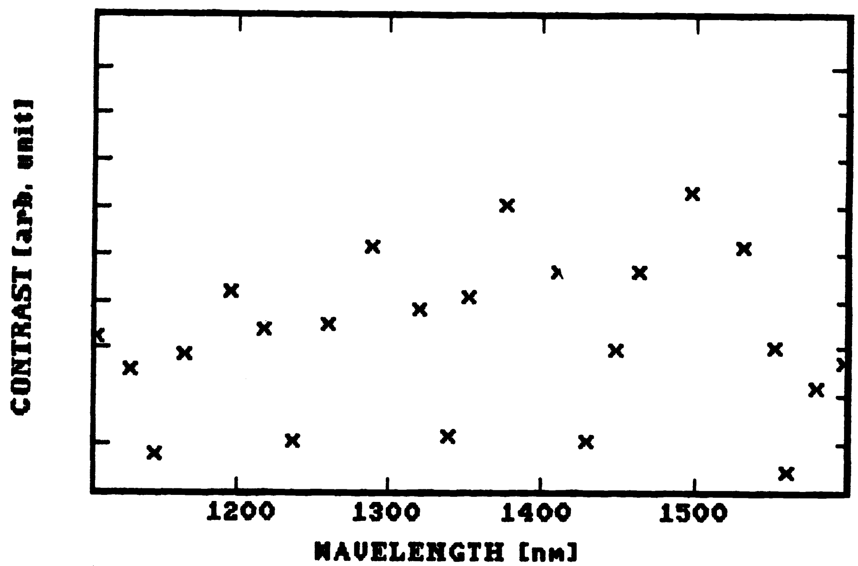

Figure 4. Contrast spectrum of a 5.5 cm Bowtie fibre

In order to test the method for birefringence characterization of small integrated optic devices we measured a small piece (5,5 cm) of high birefringence Bowtie fibre, which was also measured directly by subtraction of the polarization mode group delays. The contrast spectrum is shown in figure 4. The result obtained, 1.16 ps/m, is in quite good agreement with the one obtained by the direct measurement over a 1.98m sample, so that this experiment confirms the applicability of the Fourier transform technique to short length birefringent single mode devices.

The resolution of the method is limited by the spectral range because a full oscillation of the fringer contrast must be recorded to measure the period. Hence

$$PMD_{min} \quad \frac{\Delta n}{c} = \frac{\lambda_{min}\,\lambda_{max}}{l\ c\ (\lambda_{max} - \lambda_{min})} \qquad (1)$$

where $_{min}$ and $_{max}$ are the lower and upper bounds of the investigated spectrum, l is the sample length and c is the vacuum speed of the light. With our experimental conditions (λ_{min} = 1100 nm, λ_{max} = 1700 nm, l=3,8 m) the resolution is 0.003ps/m more than two orders of magnitude better than the direct substraction of group delays[5]. The draw-bak is the spectral dependence of PMD, which cannot be found, but it is usually approximately constant, photoelastic effects being mostly predominant. In the case of a short device, l ~ 0,05 m, the lowest limit of polarization mode dispersion will be 0.2ps/m, which corresponds to a relatively high birefringence such as can be observed in PANDA or BOW-TIE fibres as well as in electrically polarized Lithium Niobate crystals.

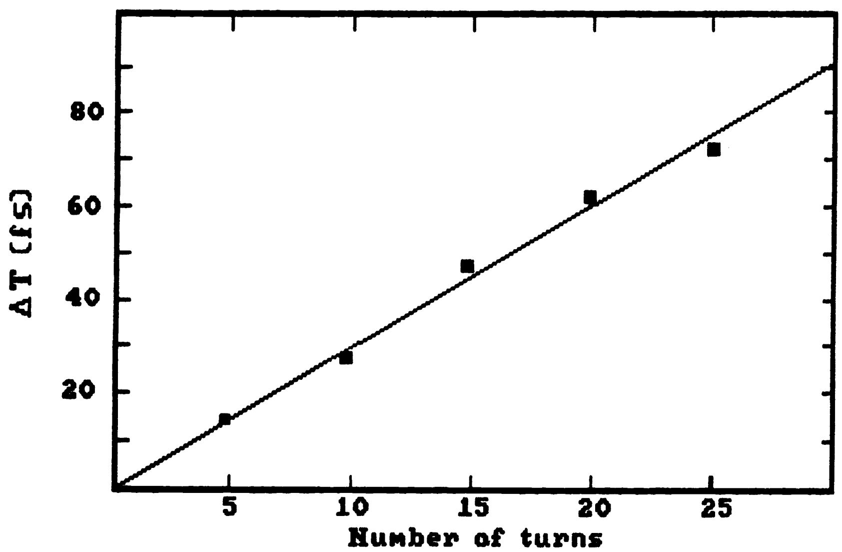

Figure 5. Polarisation mode delay of a coiled single mode fibre as a function of the number of turns

The stress induced birefringence in a coil of single mode fibre was also measured with the interferometric technique. The sample had its extremity silvered and coiled over a 15 mm diameter mandrell. The fringes contrast, as well as the chromatic dispersion, was measured as a function of the coiled length. The total polarization mode delay as a function of the number of turns is shown in figure 5, together with the teoretical calculation of bend induced birefringence[3].From the slope of the linear dependence shown in figure 5, the polarization mode dispersion of the coiled fibre is 30.5 fs/m for a 15 mm mandrell.This result correspond to a sensitivity of the method at least one order of magnitude better than other interferometric methods[3], with a much simpler and low cost equipment.

We have also observed a marked variation of the chromatic dispersion of the coiled fibre. Since the total group delay is the sum of the group delays in the coiled and in the straight section of the fibre, the chromatic dispersion of the coiled section can be deduced from the measurement. With a 15 mm mandrell, the wavelength of zero dispersion shifted from 1337 nm in the straight fibre to 1359 nm in the coiled fibre.

4. CONCLUSIONS

In conclusion, we present a simple method for birefringence evaluation of standard single mode fibres which can be performed simultaneously to chromatic dispersions measurements, without the need of linear polarizers or discrete optical elements. In addition, the light being fully unpolarized, the method apply to any kind of birefringence, linear or circular. Moreover, the method can be applied to the characterization of short length of birefringent devices. The difficulty with this last application is the poor dynamic range which may arise with the double pass over the device due to the Michelson configuration. When the insertion losses arc great, the double pass will impose severe limitations on the signal to noise ratio. In this case a Mach-Zender configuration could give better results.

5. ACKNOWLEDGMENTS

The authors wish to thank B. Costa of CSELT for kindly providing one of the fibre samples used for this experiment.

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Dr. Małgorzata Kujawińska and Professor Amar Choudry, bottom centre.