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DESIGN NOTE

Birefringence monitoring of a Hi-Bi fibre under chemical etching through a fibre loop mirror

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Abstract
Birefringence monitoring of a Hi-Bi fibre under chemical etching is conducted. The Hi-Bi fibre (a bow-tie type) was inserted in a fibre loop mirror and the optical spectral response was measured while chemical etching of the Hi-Bi fibre was taking place. The birefringence of the bow-tie fibre has decreased due to the etching and the wavelength spacing of the fringe minima of the fibre loop mirror has increased.

Keywords: birefringence, Hi-Bi fibre, fibre loop mirror, etching

Introduction

A fibre loop mirror (FLM) is an interesting optical device for several applications, namely it can be used in optical communications or in optical sensing. Several configurations of FLMs were studied and demonstrated in the literature [1]. One of them is a specific fibre loop mirror containing a piece of highly birefringent (Hi-Bi) fibre. This configuration has various advantages compared with a more traditional interferometer. The wavelength spacing depends only on the Hi-Bi fibre length and the FLM is independent of the input polarization. The Hi-Bi fibre length influences the phase difference between beams that propagate with different states of polarization proportionally, resulting in constructive and destructive interference when the two beams are re-coupled in the fibre coupler. This configuration based on Hi-Bi FLM was applied in optical sensing, namely, as a temperature sensor [2] or as a displacement sensor [3]. Recently, a combination of two concatenated fibre loop mirrors has been presented as an alternative sensing head for simultaneous measurement of strain and temperature [4].

Chemical etching in optical fibres has been used in fibre Bragg gratings [5] and in long period gratings [6] for refractive index measurement. Abe *et al* [7] have studied chemical etching in Hi-Bi fibre Bragg gratings. The advantage of reducing the conventional 125 μm diameter is to have a higher dynamic range.

In this work, chemical etching of high birefringence fibre inserted in a fibre loop mirror is studied. The Hi-Bi FLM contains a length of bow-tie fibre which was chemically etched by hydrofluoric acid (HF). During chemical etching, the evolution of the birefringence of the Hi-Bi fibre was determined through the analysis of wavelength spacing changing of the fringe minima of the fibre loop mirror, while controlling the fibre diameter.

Experimental results

Figure 1 illustrates the experimental set-up that consists of an optical broadband source, a fibre loop mirror containing a section of Hi-Bi fibre and an optical spectrum analyser (OSA) with a resolution maximum of 0.1 nm. The optical source is an erbium-doped broadband source, with a central wavelength of 1550 nm and a spectral bandwidth of 100 nm, and has the purpose of characterizing the fibre loop mirror. The Hi-Bi

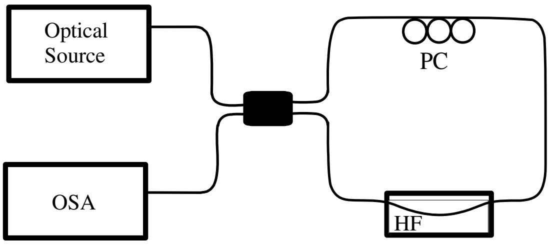

Figure 1. Experimental set-up.

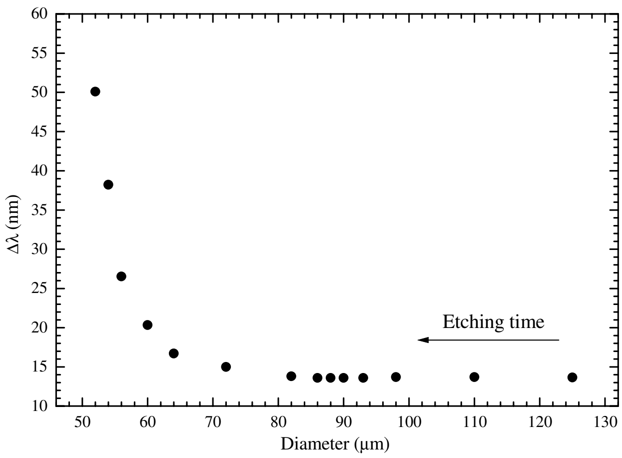

Figure 2. Relationship between the wavelength spacing and the diameter of the optical fibre.

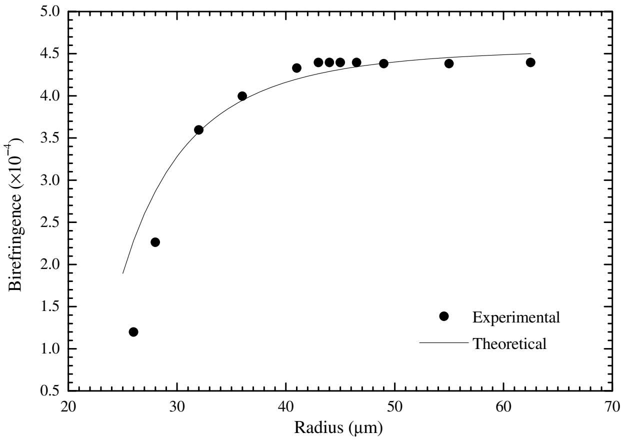

Figure 3. Experimental and theoretical comparison of the birefringence and the radius of the optical fibre.

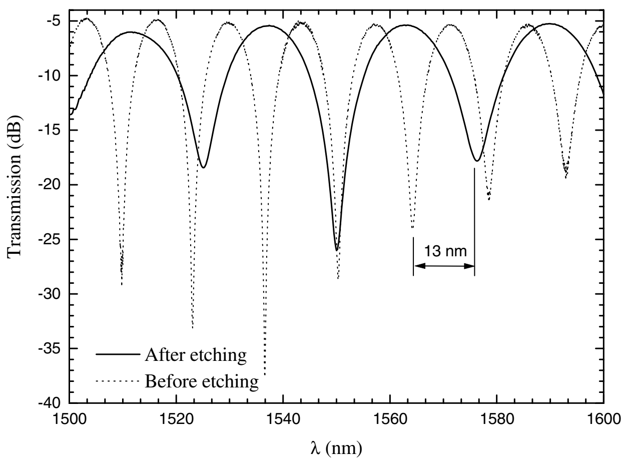

Figure 4. Spectral response of the Hi-Bi FLM before and after chemical etching.

FLM is formed by a 3 dB (2 × 2) optical coupler with low insertion loss, an optical polarization controller (PC) and a Hi-Bi fibre section. This Hi-Bi fibre section is a bow-tie fibre for a wavelength of 1550 nm with a beat length of <5 mm and an attenuation of <0.2 dB km^{-1}.

The Hi-Bi fibre was placed in a container with hydrofluoric acid, and in order to investigate the changes in the birefringence properties of the bow-tie fibre, the optical spectra of the pattern fringe were taken. On the other hand, the diameter of the bow-tie fibre during the etching was also measured by having several samples of the fibre in the acid and taking them out at predetermined time intervals. The fibre diameter versus etching time was found to be approximately 0.35 μm min^{-1} [7].

Figure 2 shows the wavelength spacing of the FLM fringe minima as a function of the bow-tie fibre diameter when etched in HF. The wavelength spacing of the FLM fringe minima change is unnoticeable for diameters higher than 90 μm. For diameter values lower than 90 μm, the wavelength spacing of the FLM fringe minima increases considerably. This is due to the change of the stress distribution of the glass caused by the chemical etching. The stress distribution was analysed by Chu *et al* [8], showing nonlinear behaviour of the radial stress between the radius region of 62.5 μm and 25 μm. This results from the asymmetrical stress distribution originated by the stress rods which are located under the 25 μm region. The geometry and different doping (boron) of the rods promote the asymmetrical stress distribution. The chemical etching process was monitored from the outer cladding to the 25 μm region and it was stopped just before reaching the stress rods. For radii less than 25 μm, the velocity of the chemical etching process was too high for the monitoring system and the pattern fringe vanished.

The modal birefringence B of the bow-tie can be expressed by [8]

$$B = \frac{EC}{\pi(1-\nu)}(\alpha_1 - \alpha_2)\Delta T \sin(2\theta) \times \left[2\ln\left(\frac{r_2}{r_1}\right) - \frac{3}{2b^4}\left(r_2^4 - r_1^4\right)\right], \quad (1)$$

where E, C and ν are respectively the Young's modulus, the stress-optic coefficient and the Poisson ratio of the optical fibre. Also, α_1, α_2 and ΔT and θ are thermal expansion of the cladding, thermal expansion of the stress rods, the difference between the ambient temperature and the melting temperature of the glass, respectively, and θ is the angle that reaches maximum perturbation between slow and fast axis ($\pi/4$), respectively. Moreover, r_1 and r_2 are the inner and outer radii of the stress rods and b corresponds to the outer radius of the fibre (62.5 μm).

Figure 3 presents the dependence of the birefringence on the radius of the optical fibre. The graph compares the experimental results and the theoretical analysis of the chemical etching in the range from 62.5 μm to 25 μm. The parameters used for the theoretical analysis were taken from [8].

Figure 4 shows the two FLM spectral responses before and after etching when the birefringence is reduced to half the initial value corresponding to the decrease of the Hi-Bi fibre diameter from 125 to 53 μm. The initial wavelength spacing of the fringe minima was approximately 13 nm and it has increased to 26 nm.

Conclusions

Chemical etching in a Hi-Bi fibre inserted in a fibre loop mirror has been studied. The Hi-Bi fibre under study was a bow-tie fibre where the birefringence is created by the internal stress effect. The chemical etching progressively altered the internal stress distribution of the glass which led to a change in the birefringence of the fibre and to an increase of the wavelength spacing of the FLM fringe minima. This behaviour is also expected in other Hi-Bi fibres, namely in PANDA fibre and internal elliptical cladding fibre. This effect created by the chemical etching can be important in optical sensing since it can tailor the birefringence of a Hi-Bi fibre, for instance the temperature sensitivity of a Hi-Bi FLM. Another advantage of the diameter reduction of a Hi-Bi fibre is to have a higher dynamic range, which was already demonstrated by Abe *et al* for Bragg gratings based on Hi-Bi fibres.

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