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Tuneable Sagnac comb filter including two wave retarders

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ABSTRACT

In this paper we study theoretically and experimentally a wavelength-tuneable Sagnac birefringence filter. The device is a Sagnac interferometer including a symmetric fibre coupler and a length of high-birefringence fibre in the loop. A wave retarder is inserted at each end of the birefringent fibre for absolute wavelength tuning. We show theoretically that wavelength tuning through wave plate orientation ensuring constant amplitude of the filtering function is possible only if a minimum of two wave retarders are included in the setup. The position of the transmission peaks then varies linearly with the angle of one of the retarders and can be adjusted over one entire channel spacing. This happens only when a quarter-wave retarder and a half-wave retarder are used, if the former is oriented at 45° with respect to the fibre birefringence axes, while the orientation of the latter serves as the adjustment parameter. The theoretical predictions are confirmed by the experimental results.

1. Introduction

Several emerging applications like wavelength division multiplexing (WDM), optical fibre sensors and spectroscopy rely on the generation and processing of multiwavelength signals. The development of all-fibre multiwavelength sources, able to generate a comb of closely spaced wavelengths extending over a wide bandwidth is crucial for these applications. Such novel devices in turn require the development of periodic all-fibre filters. The main categories of comb filters include Fabry–Perot cavities [1–4], Mach–Zehnder interferometers [5], fibre Bragg gratings [1,6–8] and filters based on fibre birefringence [9,10], in particular the Sagnac birefringence filter [11–20].

The Sagnac birefringence filter is fabricated simply by inserting a high-birefringence fibre (HiBiF) in a Sagnac loop, producing a nearly periodic, sinusoidal filtering function [21]. Compared with other all-fibre schemes, the Sagnac filter offers several advantages. Besides its simple design, the Sagnac structure, in which the two beams propagate along the same path, is more robust to environmental changes than other interferometric schemes. Another key advantage of the device is its polarisation independence [21], which makes it compatible with randomly polarised light from ordinary fibre transmission systems. Finally, the spectral comb function intrinsically extends over a wide bandwidth, whereas the bandwidth of one individual channel transmission window only depends on the loop birefringence, and can thus be made arbitrarily narrow. It was also shown that, by including several birefringent fibre segments in the loop, a high-order filtering function can be obtained [22–24], as well as a discretely tuneable channel spacing [11,12,17].

Another crucial aspect of comb filters is wavelength tunability. Indeed, for WDM applications in particular, it is important to control the absolute wavelength positions of the maxima of the periodic filtering function, while the channel spacing is maintained constant. Such wavelength tuning can be achieved by adjusting the fibre birefringence, either by applying a tension or pressure to the fibre [25], or by controlling its temperature [26–28]. While the first method can increase losses and eventually lead to fibre breaking, temperature control yields slow response. Other methods allow electrical wavelength control through the use of an electrooptic birefringence modulator [12,29] or optical control by using a semiconductor optical amplifier [30]. In spite of their cost, such methods allow convenient remote wavelength control and ensure short response times. Finally, a cheap and convenient wavelength tuning method consists in adjusting the orientation of several wave retarders (WRs) inserted in the loop [11,14,16–18].

It was soon realized that the use of WRs in conjunction with polarisers allows tuneable filtering action [9,31,32], however polarisers are responsible for large signal amplitude fluctuations when used in conventional randomly polarised transmission systems. In contrast, polarisation-independent tuneable filtering can be obtained without polarisers if the WRs are inserted in a birefringent Sagnac scheme. In [11], wavelength tuning is demonstrated using a scheme including two quarter-WRs in the loop, however the simultaneous adjustment of the two retarders

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is required, and large variations of the amplitude of the transmission peaks were observed during the adjustment. It was also demonstrated recently that wavelength tuning is even possible with only one WR in the birefringent loop, although the adjustment of the retarder angle still induces wide amplitude variations [16]. These amplitude variations (or variations of the filter insertion loss) are detrimental for several applications. In tuneable lasers for example, they induce changes of the cavity loss, thus of the laser output power. In the case of multi-wavelength sources, cavity loss variations can even modify indirectly the relative power between channels, by altering the gain spectrum [16]. Hence some effort should be made to design a filter ensuring wavelength tuning without amplitude variations. In [33], a scheme was proposed for constant-amplitude wavelength tuning. For this scheme, three WRs were used, and a polarisation beam splitter replaced the conventional coupler. In spite of the increased complexity and cost, the device is attractive because it allows wavelength tuning with maximal (= 1) amplitude of transmission peaks and minimal transmission = 0 (infinite extinction ratio). This only occurs however for particular orientations of two of the WRs included in the setup [14]. For different WRs settings, peak power is no longer maximal and channel isolation is finite (in contrast, extinction ratio is theoretically infinite for a Sagnac filter including a conventional 50/50 coupler [21]).

Although it has been demonstrated that the adjustment of the orientation of one or several WRs inserted in the loop allows absolute wavelength tuning of a Sagnac birefringence filter, it is not clear in what conditions this operation is possible without affecting the amplitude of the peaks. Besides, although half- and quarter-WRs have been used, no clear justification has been provided for the choice of the phase shift and orientation of the retarders, or for determining which WR(s) orientation would serve as adjustment parameter(s). In this paper we determine the minimal number of WRs that have to be inserted in the loop for wavelength tuning without variation of the amplitude of the filtering function, as well as the values of phase shift and orientation of the WRs together with the adjustment procedure that ensure proper wavelength tuning operation.

2. Numerical analysis

The proposed setup is shown in Fig. 1. The filter includes a 50/50 coupler, a section of HiBiF and two WRs (WR1 and WR2) inserted between the ends of the HiBiF and the coupler output ports. The reference system is chosen so that the x-axis is included in the plane of the loop, and the y-axis is perpendicular to it. The birefringence axes of the HiBiF make an angle α_F with respect to the axes of the reference system, whereas the WR1 and WR2 are oriented at angles α_1 and α_2, respectively.

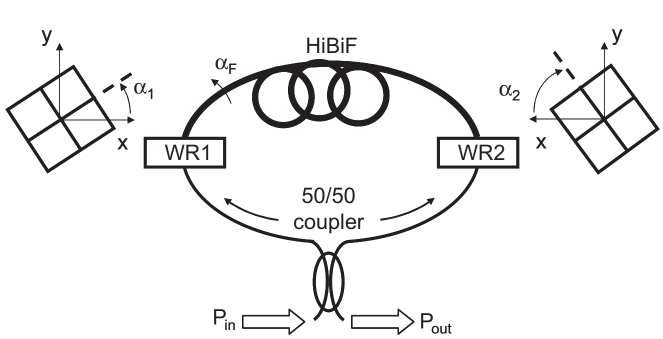

Fig. 1. Configuration under study.

In the linear $[u_x,u_y]$ polarisation basis, if their birefringence axes are parallel to the reference axes ($\alpha_1=\alpha_2=0$), the Jones matrixes of the WR1 and WR2 are given by

$$WRi(\phi_i,0)=\begin{bmatrix} e^{j\phi_i/2} & 0 \\ 0 & e^{-j\phi_i/2}\end{bmatrix}, \tag{1}$$

where ϕ_i, $i=1,2$ are the wave plates phase shifts. We assume that the ϕ_i do not depend on wavelength, a valid approximation for zero-order retarders as far as the considered bandwidth is not too large. If now $\alpha_i \neq 0$, the Jones matrixes can be obtained using Eq. (1) and the rotation matrixes

$$R(\alpha_i)=\begin{bmatrix} \cos(\alpha_i) & -\sin(\alpha_i) \\ \sin(\alpha_i) & \cos(\alpha_i)\end{bmatrix}, \tag{2}$$

yielding

$$\begin{aligned} WRi(\phi_i,\alpha_i) &= R(\alpha_i)\times WRi(\phi_i,0) \\ &\quad \times R(\alpha_i)^{-1} \\ &= \begin{bmatrix} \cos(\phi_i/2)+j\cos(2\alpha_i)\sin(\phi_i/2) & 2j\sin(\alpha_i)\cos(\alpha_i)\sin(\phi_i/2) \\ 2j\sin(\alpha_i)\cos(\alpha_i)\sin(\phi_i/2) & \cos(\phi_i/2)-j\cos(2\alpha_i)\sin(\phi_i/2)) \end{bmatrix}. \end{aligned} \tag{3}$$

If $\alpha_F=0$, the Jones matrix of the HiBiF is given by

$$F(0)=\begin{bmatrix} e^{j\Gamma/2} & 0 \\ 0 & e^{-j\Gamma/2}\end{bmatrix}, \tag{4}$$

where $\Gamma=2\pi BL/\lambda_0=2\pi L/L_B$, B is the birefringence parameter (refractive index difference between slow and fast axes), L the fibre length, λ_0 the wavelength in vacuum and $L_B=\lambda_0/B$ the beat length. Hence it appears that Γ, and thus F depend on the wavelength. The matrix $F(\alpha_F)$ of the HiBiF oriented at an angle α_F is readily obtained using Eq. (3), replacing α_i by α_F and ϕ_i by Γ. Using Eqs. (3) and (4), the Jones matrix M of the loop in the clockwise direction can be calculated as

$$M=WR2(\phi_2,\alpha_2)\times F(\alpha_F)\times WR1(\phi_1,\alpha_1). \tag{5}$$

It has been shown that, if M_{12} is the coupling term (off-diagonal) of the M matrix, then the power transfer function of the Sagnac filter is given by $T=\mathrm{Im}(M_{12})^2$ [21]. After calculating M_{12} according to Eq. (5) and after some algebraic manipulations using trigonometric identities, we find

$$\begin{aligned} \mathrm{Im}(M_{12}) &= U\cos(\Gamma/2)+V\sin(\Gamma/2), \\ U &= \sin(2\alpha_1)\sin(\phi_1/2)\cos(\phi_2/2) \\ &\quad +\sin(2\alpha_2)\cos(\phi_1/2)\sin(\phi_2/2), \\ V &= \sin(2\alpha_F)\cos(\phi_1/2)\cos(\phi_2/2) \\ &\quad -\sin(2\alpha_1+2\alpha_2-2\alpha_F)\sin(\phi_1/2)\sin(\phi_2/2). \end{aligned} \tag{6}$$

Eq. (6) can also be written as

$$\mathrm{Im}(M_{12})=A\cos(\Gamma/2-\chi), \tag{7}$$

where the amplitude $A=\sqrt{(U^2+V^2)}$ and the phase parameter χ is given by $\cos(\chi)=U/A$ and $\sin(\chi)=V/A$. By use of Eq. (6), the amplitude can be calculated as

$$\begin{aligned}A^2 = &\frac{1}{2}\cos^2(\phi_1/2)\sin^2(\phi_2/2) + \frac{1}{2}\sin^2(\phi_1/2)\cos^2(\phi_2/2)\\ &+\frac{1}{2}\sin^2(\phi_1/2)\sin^2(\phi_2/2)\\ &-\frac{1}{2}\cos(4\alpha_2)\cos^2(\phi_1/2)\sin^2(\phi_2/2)\\ &-\frac{1}{2}\cos(4\alpha_1)\sin^2(\phi_1/2)\cos^2(\phi_2/2)\\ &-\frac{1}{2}\cos(4\alpha_1+4\alpha_2-4\alpha_F)\sin^2(\phi_1/2)\sin^2(\phi_2/2)\\ &+\frac{1}{2}\sin(2\alpha_1)\sin(2\alpha_2)\sin(\phi_1)\sin(\phi_2)\\ &-\frac{1}{2}\sin(2\alpha_1+2\alpha_2-2\alpha_F)\sin(2\alpha_F)\sin(\phi_1)\sin(\phi_2)\\ &+\sin^2(2\alpha_F)\cos^2(\phi_1/2)\cos^2(\phi_2/2). \end{aligned} \quad (8)$$

Finally, the power transfer function of the Sagnac filter is given by

$$T = \mathrm{Im}(M_{12})^2 = \frac{A^2}{2} + \frac{A^2}{2}\cos(\Gamma - 2\chi). \quad (9)$$

Eq. (9) shows that the transmission spectrum of the Sagnac filter is a sinusoidal function of $\Gamma = 2\pi BL/\lambda_0$. If the wavelengths of interest extend over a narrow range about a particular value λ_{0c}, i.e. $\lambda_0 = \lambda_{0c}+\Delta\lambda$ with $\Delta\lambda \ll \lambda_{0c}$, then we have that $\Gamma \approx -2\pi BL/\lambda_{0c}^2 \times \Delta\lambda = -2\pi L/L_B/\lambda_{0c} \times \Delta\lambda$, so that Eq. (9) is a nearly sinusoidal function of wavelength, whose period (or channel spacing) $\Delta\lambda(\Gamma = 2\pi) = \lambda_{0c}L_B/L$ is inversely proportional to the fibre birefringence and length. Eqs. (6)–(9) also show that the amplitude and phase of the filtering function are both determined by the wave plate parameters ϕ_1, ϕ_2, α_1, α_2 and α_F. If we assume that ϕ_1, ϕ_2 and α_F are fixed, the adjustment of either α_1 or α_2 modifies simultaneously both A and χ in general. Finally, it has to be stressed that, according to Eq. (9), minimal transmission is $=0$, which ensures that the extinction ratio (or channel isolation) is infinite, whatever the values of the wave plate parameters.

2.1. Case of one retarder

Let us first assume that one of the retarders shown in Fig. 1, say WR2, is absent from the setup ($\phi_2 = 0$). In this case, using Eqs. (6) and (8), it comes that $U = \sin(2\alpha_1)\sin(\phi_1/2)$, $V = \sin(2\alpha_F)\cos(\phi_1/2)$ and $A^2 = \sin^2(2\alpha_1)\sin^2(\phi_1/2)+\sin^2(2\alpha_F)\cos^2(\phi_1/2)$. As $\mathrm{tg}(\chi) = V/U = \sin(2\alpha_F)\mathrm{atan}(\phi_1/2)/\sin(2\alpha_1)$ varies continuously with α_1, the WR orientation offers a possibility of wavelength tuning for various values of the phase shift ϕ_1, as it was noted in [16]. The adjustment possibilities also depend on α_F. In the particular case $\alpha_F = 0$, we find that $\cos(\chi) = U/A = \pm 1$ and thus $\chi = 0$ or π, which removes all possibility of continuous adjustment of χ through α_1 whatever the value of ϕ_1 (in this case, only the amplitude of the transmission curve can be adjusted through α_1). For other values of α_F, wavelength tuning is possible, however the amplitude A^2 of the filtering function also varies with α_1 [16], except in the trivial case where $\phi_1 = 0$ (no WR in the loop, thus no adjustment possibility). As a consequence, for constant-amplitude absolute wavelength tuning of the filtering function through the orientation of a wave retarder, a second retarder must be introduced in the setup.

2.2. Case of two retarders

If both ϕ_1 and $\phi_2 \neq 0$, a numerical analysis of Eqs. (6)–(9) shows that there exists the possibility to adjust χ by way of one of the plates orientation. However in most cases this adjustment will also affect the amplitude of the filtering curve. There is one particular configuration however for which the adjustment of one plate orientation allows wavelength tuning without affecting the curve amplitude.

Let us consider α_2 as fixed and take α_1 as the adjustment parameter. First, we look for a condition on parameters ϕ_1, ϕ_2, α_2 and α_F ensuring that the amplitude A^2 is not a function of α_1. In Eq. (8), the first four terms and the last term are constant in α_1, the fifth and sixth terms oscillate as the cosine of $4\alpha_1$, and the seventh and eighth terms as the sine of $2\alpha_1$. Parameter A^2 will be independent of α_1 if the coefficients of both oscillations in $4\alpha_1$ and in $2\alpha_1$ cancel out. From Eq. (8), the first condition is fulfilled if

$$\begin{cases}\alpha_2 - \alpha_F = 0 + k\pi/2\\ \sin^2(\phi_1/2) = 0\end{cases} \text{or} \begin{cases}\alpha_2 - \alpha_F = \pi/4 + k\pi/2\\ \sin^2(\phi_1/2)\cos(\phi_2) = 0\end{cases}, \quad (10)$$

where k is an integer. Note that Eq. (10) includes two possibilities. The left-hand relations yield $\phi_1 = 0+2k\pi$, which has to be rejected as it amounts to removing one wave plate from the system (see Section 2.1). The right-hand relations yield either $\phi_1 = 0$ (again to be rejected) or $\phi_2 = \pi/2+k\pi$. The WR2 orientation is also imposed with respect to the HiBiF by $\alpha_2-\alpha_F = \pi/4+k\pi/2$. Finally, taking into account these values of $\alpha_2-\alpha_F$ and ϕ_2, the cancellation of the $\sin(2\alpha_1)$ terms in Eq. (8) imposes the condition $\phi_1 = 0+k\pi$. After rejecting again the solutions $\phi_1 = 0+2k\pi$, it remains that $\phi_1 = \pi+2k\pi$. In summary, a necessary condition for constant-amplitude wavelength adjustment through the WR1 angle is that the WR1 be a half-WR, whereas the WR2 is a quarter-WR (or alternatively a three-quarters WR) oriented at a fixed $\pi/4$ angle with respect to the HiBiF birefringence axes. Finally, owing to the symmetry presented by Eqs. (6) and (8), a similar solution can be found if we take α_2 as adjustment parameter (in this case, WR2 is the half-WR and WR1 the quarter-WR oriented at $\pi/4$).

The parameters derived in the above guarantee that adjusting the WR1 angle α_1 will not modify the amplitude of the filter transmission, however it should now be verified that the phase of the sinusoidal filtering function χ varies effectively with α_1. Using Eqs. (6) and (8), assuming zero-order retarders with $\phi_2 = \pi/2$, $\alpha_2-\alpha_F = \pi/4$ and $\phi_1 = \pi$, it comes that $A = \sqrt{2}/2$, $\cos(\chi) = U/A = \sin(2\alpha_1)$ and $\sin(\chi) = V/A = -\cos(2\alpha_1)$, so that $\chi = 2\alpha_1-\pi/2$. Hence the phase χ of the transmission characteristic varies linearly with α_1. Using Eq. (9), the filter transmission is given by

$$T = \frac{1}{4} - \frac{1}{4}\cos(\Gamma - 4\alpha_1). \quad (11)$$

Eq. (11) shows that adjusting the WR1 angle α_1 over a quarter of a turn allows tuning the maxima of the sinusoidal filtering characteristic of the filter over an entire spectral period, without modifying the curve amplitude, which is $T_{\max} = 0.5$ in all cases. Also, for each adjustment, the minimal transmission $T_{\min} = 0$ for wavelengths at which $\Gamma-4\alpha_1$ is an integer multiple of 2π, yielding infinite extinction ratio. It is also interesting to note that this mode of operation can be obtained for any value α_F of the HiBiF orientation, provided that the WR2 is oriented in each case at $\pi/4$ with respect to the HiBiF axes. This result is of practical importance, as it is difficult to set with precision the value of this parameter experimentally [16]. Fig. 2 shows the spectrum calculated in this case for several adjustments of α_1.

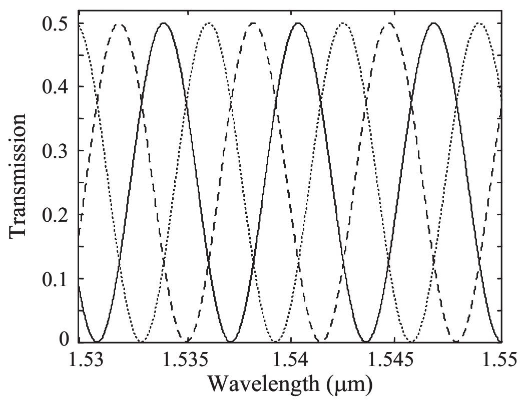

Fig. 2. Calculated Sagnac filter transmission spectra in the 1540 nm region, for $L_B = 4.15$ mm and $L = 1$ m, $\phi_1 = \pi$, $\phi_2 = \pi/2$, $\alpha_2 - \alpha_F = \pi/4$ and $\alpha_1 = 0$ (solid), $\pi/6$ (dashed) and $\pi/3$ (dotted).

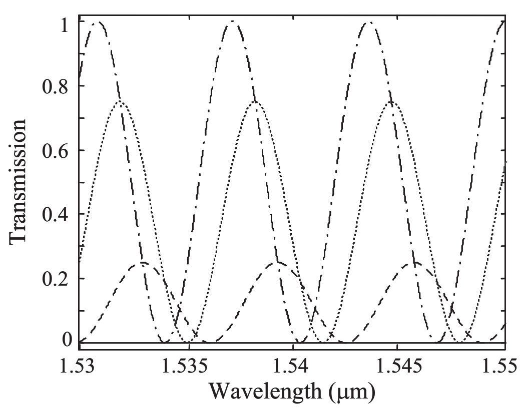

Fig. 3. Calculated Sagnac filter transmission spectra in the 1540 nm region, for $L_B = 4.15$ mm and $L = 1$ m, $\phi_1 = \phi_2 = \pi/2$, $\alpha_2 = \pi/4$, $\alpha_F = 0$ and $\alpha_1 = -\pi/4$ (solid), $-\pi/12$ (dashed), $\pi/12$ (dotted) and $\pi/4$ (dashed-dotted).

As a counter-example, let us consider the case where two quarter-wave plates are used. Taking $\phi_1 = \phi_2 = \pi/2$, $\alpha_2 = \pi/4$ and $\alpha_F = 0$, Eqs. (6) and (8) yield $A = |\cos(\alpha_1 - \pi/4)|$, $U = \cos^2(\alpha_1 - \pi/4)$ and $V = \sin(\alpha_1 - \pi/4)\cos(\alpha_1 - \pi/4)$, and the transmission is given by

$$T = \frac{1}{2}\cos^2(\alpha_1 - \pi/4) \times \{1 + \cos[\Gamma - 2(\alpha_1 - \pi/4)]\}. \quad (12)$$

The transmission spectra calculated for several values of α_1 are presented in Fig. 3. Eq. (12) shows that α_1 still allows adjusting linearly the position of the transmission maxima over an entire period, however this tuning also strongly affects the amplitude of the filtering curve, which varies between 1 and 0. Hence in practice the wavelength tunability range is effectively reduced to the values of the WR angle for which the insertion loss of the filter presents acceptable values.

For values of the WR parameters different from those discussed above, the adjustment of one of the WRs orientation over half a turn leads to a rather complex evolution of the sinusoidal transmission spectrum. As already mentioned, this adjustment allows wavelength tuning of the transmission peaks, although the range of variation may be limited to less than one period. This adjustment is also accompanied by large variations of the amplitude of the transmission curve, although we found that the minimal amplitude is not as small as zero in all cases. Limited wavelength tuning range and amplitude variations are obtained for example for the Sagnac filter including a half-WR and a quarter-WR, if the former is fixed and the latter is used for adjustment (contrary to the case of Fig. 2).

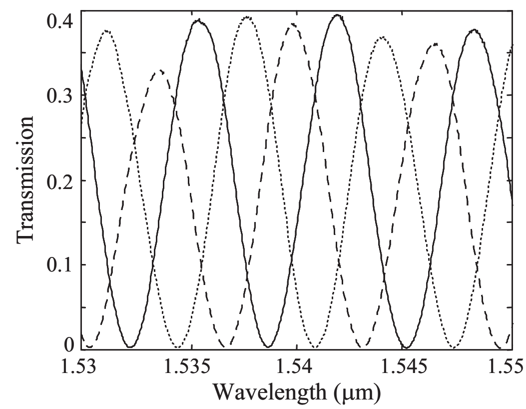

Fig. 4. Experimental transmission spectra of the Sagnac filter including a quarter-WR and a half-WR, for various orientations of the half-WR, when the quarter-WR is set at a fixed angle ensuring nearly constant filtering amplitude.

3. Experiment

In order to verify experimentally the analytical predictions, a fibre Sagnac filter was constructed. The Sagnac interferometer included a 50/50 standard fibre coupler, $L = 1$ m of HiBiF (beat length $L_B < 5$ mm at 1550 nm) and 2 fibre WRs inserted at the fibre ends. For the measurements, we used the spontaneous emission of an erbium-doped fibre pumped at 980 nm as a broadband source in the 1550 nm region. Using an optical spectrum analyser, we measured the signal spectrum at the filter input (with a 90/10 coupler) and output. The filtering curve was obtained for each adjustment by making the ratio between output and input spectra. As expected, a nearly sinusoidal transmission spectrum was observed, with a period of ~6.4 nm, a value consistent with the value calculated from $L = 1$ m and $L_B = 5$ mm at the signal wavelength $\lambda_{0c} = 1550$ nm: $\Delta\lambda(\Gamma = 2\pi) = \lambda_{0c}L_B/L = 7.7$ nm. Small differences in the amplitude of successive peaks were observed, which can be attributed to some dependence of the WRs phase shifts on wavelength over the 20 nm range.

In a first experiment, we used a quarter-WR and a half-WR. For a particular orientation of the quarter-WR, adjusting the orientation of the half-WR over ~90° allowed linear tuning of the position of the maxima over one period while their amplitude was kept nearly constant (Fig. 4, compare with Fig. 2). The amplitude of the transmission curve in all cases is ~0.4 (~4 dB insertion loss), which is smaller than the theoretical value of 0.5. This difference can be attributed to excess losses, in particular resulting from the two fusion splices between the HiBiF and the standard fibre of the coupler pigtails. Hence, the theoretical 3 dB loss that appears in this mode of operation, increased by additional excess losses, yields a rather high value for the insertion loss of the filter. This value however is not higher than the values obtained with other, more complex schemes, for which excess loss is high [33]. As the half-WR is rotated, the transmission peaks are shifted and also undergo a small and slow amplitude variation, which is visible in Fig. 4 over the 20 nm span. This can be attributed to wavelength dependence of the WRs phase shifts, as it was confirmed by numerical simulations in which this dependence was taken into account. In addition to this, some amplitude variation between successive peaks is also observed in Fig. 4, which we attribute to small variations of the source spectrum with time, as the spectra at the filter input and output were not measured exactly at the same time. The channel

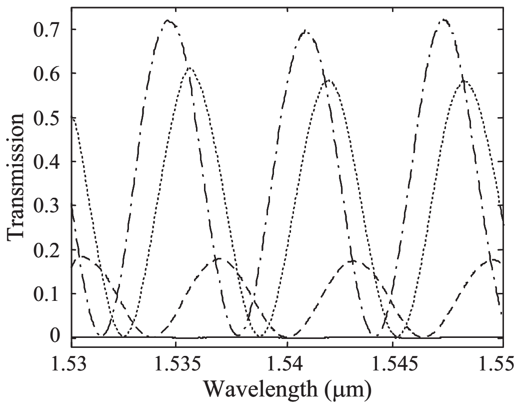

Fig. 5. Experimental transmission spectra of the Sagnac filter including two quarter-WRs, for various orientations of one of the plates, when the other is fixed.

isolation (ratio between crests and valleys) was ~25 dB, a value limited mainly by the imperfect symmetry of the coupler.

In a second experiment, we conserved the same adjustment of the fixed quarter-WR, and we replaced the half-WR by a second quarter-WR. Adjusting the orientation of this retarder over a range of ~180° yielded a linear variation of the position of the spectrum maxima over one period, while their amplitude varied between a maximum value and nearly zero (see Fig. 5, compare with Fig. 3). The maximal amplitude of the peaks is ~0.7, smaller than the theoretical value of 1. The difference again can be attributed mainly to splice losses.

It has to be noted that, although the filter period in the numerical analysis is matched to the experimentally measured period, the corresponding transmission peaks are shifted (compare Figs. 2 and 4, and Figs. 3 and 5). The values of fibre length and birefringence used in the numerical analysis were chosen in order to fit the experimentally measured filter period of 6.4 nm, however they did not ensure absolute wavelength matching, which requires very precise adjustment of these parameters. Indeed, for a given deviation of the ratio L/L_B with respect to the exact experimental value, the absolute wavelength shift is L/L_B (~240 in this case) times larger than the period variation. Absolute wavelength matching of the transmission peaks can be easily performed by a fine adjustment of L and L_B, however it has poor practical interest, considering that it would not alter our conclusions and that the magnitude of such changes is comparable with the variations of fibre length and birefringence that may occur in practice due to temperature changes.

The temperature dependence of the fibre length and birefringence, and the resulting wavelength shift of the transmission peaks is an issue for some applications of Sagnac comb filters, in which case a temperature control of the birefringent fibre is required [26–28]. Another solution consists in using a polarisation-maintaining photonic crystal fibre in the loop, for which the temperature dependence of birefringence is strongly reduced compared to conventional HiBiF [34]. In our experiment, no substantial temperature-related shift of the filter spectrum was observed, however the laboratory temperature was quite stable for the duration of the experiment, and such wavelength shifts would be expected under temperature changes.

4. Conclusion

We performed a theoretical and experimental study of a wavelength-tuneable Sagnac birefringence filter including a 50/50 coupler, a HiBiF loop and two WRs inserted at the coupler output ports. Wavelength tuning is achieved by WR rotation. First, we showed that the use of only one wave plate in the setup allows wavelength tuning at the price of large variations in the amplitude of the peaks of the filtering curve. If now two WRs are included in the loop, in general adjusting the orientation of one of the WRs allows wavelength tuning, but large amplitude variations of the transmission peaks still appear in most cases. We showed however that, if a quarter-WR and a half-WR are used, and if the quarter-WR is set at an angle of 45° with the fibre axes, then adjusting the orientation of the half-WR allows linear wavelength tuning over an entire channel spacing without variation of the amplitude of the filtering function. Such ideal adjustment procedure is possible however at the price of an intrinsic 3 dB insertion loss. The experimentally measured insertion loss was 4.1 dB, a value which also includes excess losses. In spite of this, this scheme constitutes the minimal configuration for constant-amplitude wavelength tuning through WR rotation, and we believe that it will be useful for the design of tuneable multi-wavelength sources in particular in the frame of WDM systems and fibre sensors.

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