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Characteristics of Mismatched Twin-core Fibre Spectral Filters

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Abstract:

Both bandstop and bandpass filters can be easily implemented with mismatched twin-core fibres designed to phase-match at certain wavelength. These filters are highly stable with very low temperature and strain sensitivity. We studied the spectral quality of these filters and that of cascaded filters designed to achieve improved bandpass response. We have also demonstrated the feasibility of achieving designed loss profile from these filters. This is very useful in gain spectrum flattening in Er-doped fibre amplifiers.

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Spectral filters are very important devices in optical fibre systems. Bandpass filters are required for rejection of out-of-band noise and loss filters for rejection of unwanted signals and gain-flattening in fibre amplifiers. In a twin-core (TC) fibre with two different cores, propagation constants of the two cores can be designed to be equal at certain wavelength. At this phase-match wavelength, strong coupling happens between the two cores and there is no coupling elsewhere. A number of papers on mismatched TC fibre spectral filters have been published[1,2,3]. Recently we have demonstrated a technique which allows the coupling wavelength to be placed anywhere with high accuracy over a range of a few hundred nanometres from the same fibre by reducing the fibre diameter on a fused coupler rig [4]. This allows bandpass and bandstop filters to be implemented with high accuracy at any wavelength over a few hundred nanometres from the same TC fibre. An important advantages of this type of filters, especially over long period grating filters [5], is its very high stability against a change in temperature and strain. The temperature sensitivity is ~0.26 nm/100°C at 1.55 μm and strain sensitivity 7.8×10^{-3} nm/mStrain at 1.55 μm [4]. They are more stable than fibre Bragg gratings. This allows easy packaging. In addition, there is virtually no decay in the filter strength even at 700 °C, unlike photosensitive gratings which would be annealed out at this temperature.

In this paper, we studied the spectral characteristics of mismatched TC filters and demonstrated improvement of spectral filtering response by cascading identical filters. We have also demonstrated the possibilities of achieving designed spectral loss profiles by cascading filters with different response. Wavelength-tuning is achieved by diameter reduction demonstrated in ref[4] and strength-tuning by adjusting length of the TC fibre.

When light is launched into one core of the TC fibre, total coupling from one core to another happens at the phase-matching wavelength λ_C after a coupling length L_C, characteristics of the fibre. Bandpass and bandstop filters can be implemented by taking light out of the respective cores. Normally one core is made to be in the centre of the fibre to facilitate splicing with a standard telecommunication (ST) fibre. At one end, the core of a ST fibre is spliced to the centre core to launch light into that core and at the other end, one of the two cores is spliced to the core of another ST fibre to achieve either bandpass or bandstop filters (see inset in fig.1). If an initial power $P_0=1$ is launched into the central core (core 1), the power in the two cores P_1 and P_2 are:

$$P_1=1-F^2\sin^2\left(\frac{C}{F}z\right),\ P_2=F^2\sin^2\left(\frac{C}{F}z\right)$$

where C is the coupling coefficient and $L_C=\pi F/2C$. If the propagation constants of the cores are denoted as β_1 and β_2, F is represented by:

$$F=\frac{1}{\sqrt{1+\frac{(\beta_1-\beta_2)^2}{4C^2}}}$$

If we can assume that the dependence of $\beta_1 - \beta_2$ on wavelength λ is linear around the coupling wavelength λ_0, i.e. $\beta_1 - \beta_2 = 2\pi K(\lambda-\lambda_C)/\lambda_C = 2\pi K\ \Delta\lambda/\lambda_C$, the spectral response of the $P_2(\lambda)$ can be easily deduced:

$$P_2(\lambda)=\frac{\sin^2\left(Cz\sqrt{1+\left(\frac{\pi K}{C}\frac{\Delta\lambda}{\lambda_C}\right)^2}\right)}{1+\left(\frac{\pi K}{C}\frac{\Delta\lambda}{\lambda_C}\right)^2}$$

For a 100% coupled filter with $Cz=\pi/2$ and the FWHM bandwidth $\Delta\lambda_{FWHM}$ is:

$$\Delta\lambda_{FWHM}=\frac{1.6C}{\pi K}\lambda_C$$

It is apparent that the bandwidth of the device can be reduced by having larger *K*, i.e. large crossing angle between the propagation constants of the two cores in a propagation constant verse wavelength plot.

A measured spectral response of a bandpass filter centred at 1259.6 nm together with the theoretical fit is plotted in fig.1. The TC fibre length is ~1.8 cm long. The FWHM bandwidth in this case is 17.7 nm. The good fit demonstrates the high spectral quality achievable with the mismatched TC fibres. The strong side bands in the spectrum is characteristics of this type of filters. A narrower bandwidth can be achieved by designing a fibre with larger *K*. Narrower bandwidth and strong side band suppression can also be achieved by cascading identical bandpass filters. A demonstration of this with two nearly identical filters is shown in fig.2. The original filters both centred at ~1239.3 nm with respective bandwidth of 19.5 nm and 18.0 nm (see fig.2a). The measured cascaded filter performance together with predicted response from that of the original filters are shown in fig.2b. A much better side band suppression (~25 dB) is achieved with the FWHM bandwidth narrowed down to 13.5 nm. We have managed to get the bandwidth down to 8.5 nm in another implementation.

To demonstrate tuning of the filter strength by choosing appropriate length of the TC fibre. Response of filters with different TC fibre lengths is shown in fig.3. Light was launched into core 1 and outputs from both core 1 and core 2 were measured separately (see inset in fig.1). The bandwidth of the filter becomes narrower as the TC fibre length increases as expected. With a length of 19 mm, a bandstop filter with more than 22 dB rejection was measured. We have also achieved more than 30 dB bandstop filter in another device.

With accurate strength tuning by adjusting TC fibre length and wavelength tuning by diameter reduction, we are able to demonstrate loss filters with a designed profiles. An example of this is shown in fig.4. We are limited to implement filters centred below 1394 nm by the fibre we used, which has a coupling wavelength of ~1394 nm without any diameter reduction. Tuning by diameter reduction only allows to achieve a shorter coupling wavelength. To assess wavelength region ~1550 nm, a TC fibre with an original coupling wavelength around 1600 nm has to be used.

In summary, we have studied spectral characteristics of filters made from mismatched TC fibres. Reduction of bandwidth and improvement of side band suppression have been demonstrated by cascading filters. In combination with a fibre with larger propagation constant crossing angle, bandwidth of few nanometres are easily achievable. Loss filters with designed spectral profiles have also been demonstrated with strength tuning achieved by adjusting TC fibre length and wavelength tuning achieved by diameter reduction. Such easily fabricated filters with their very low sensitivity to temperature and strain should find many applications in optical fibre systems.

Acknowledgements:

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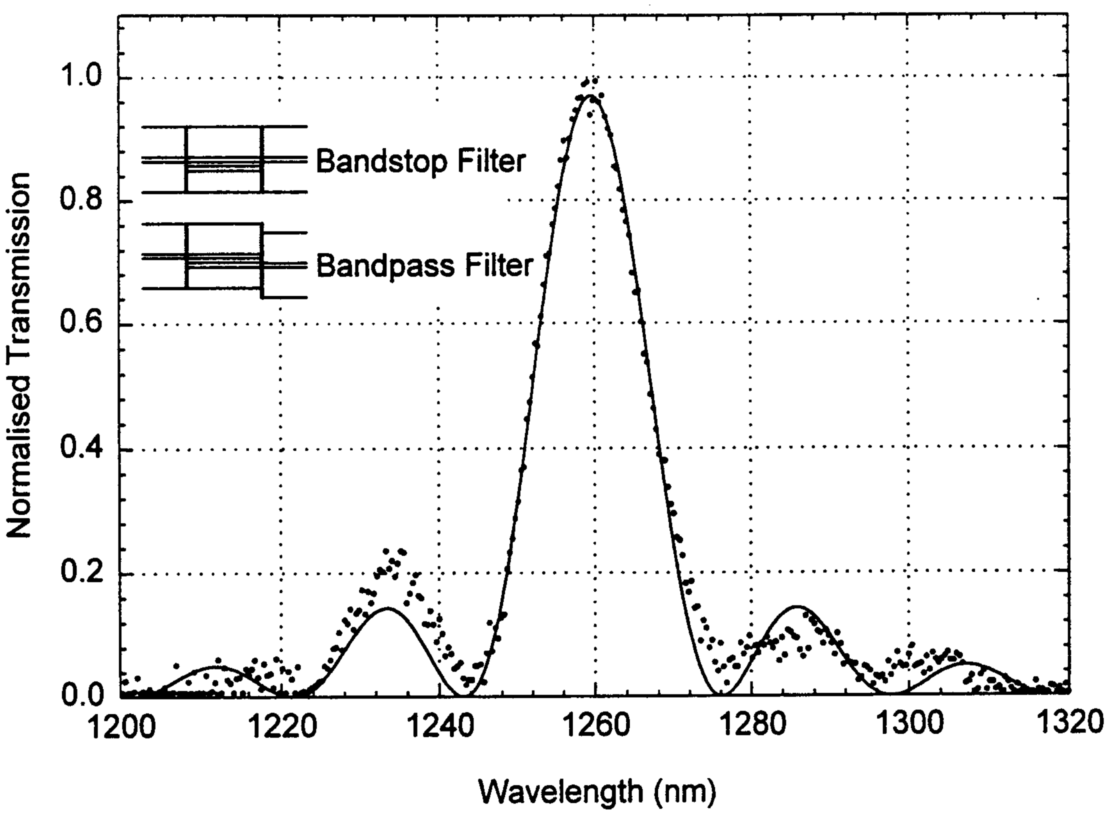
Figure Captions:

Figure 1 Measured bandpass filter response (dots) with the theoretical prediction (solid line). The filter used a TC fibre 1.8 cm long. The FWHM bandwidth is 17.7 nm.

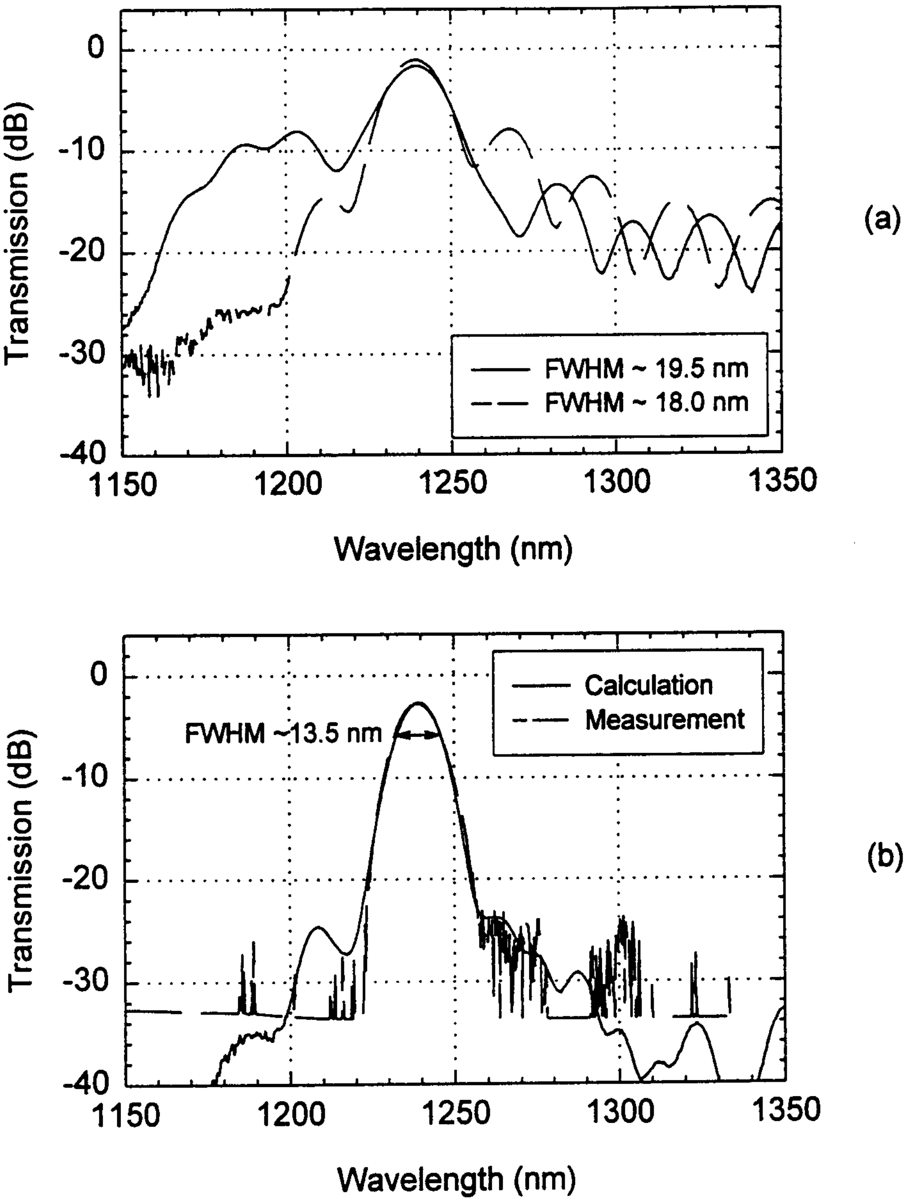
Figure 2 Performance of a cascaded TC fibre filter consisting two stages, (a) original responses of each stage. (b) measured response of the cascaded filter (dashed line) together with the prediction from the original responses of each stage (solid line).

Figure 3 Responses of filters with different TC fibre lengths. Light is launched into core 1. Solid line is output from core 1 and dashed line is output from core 2.

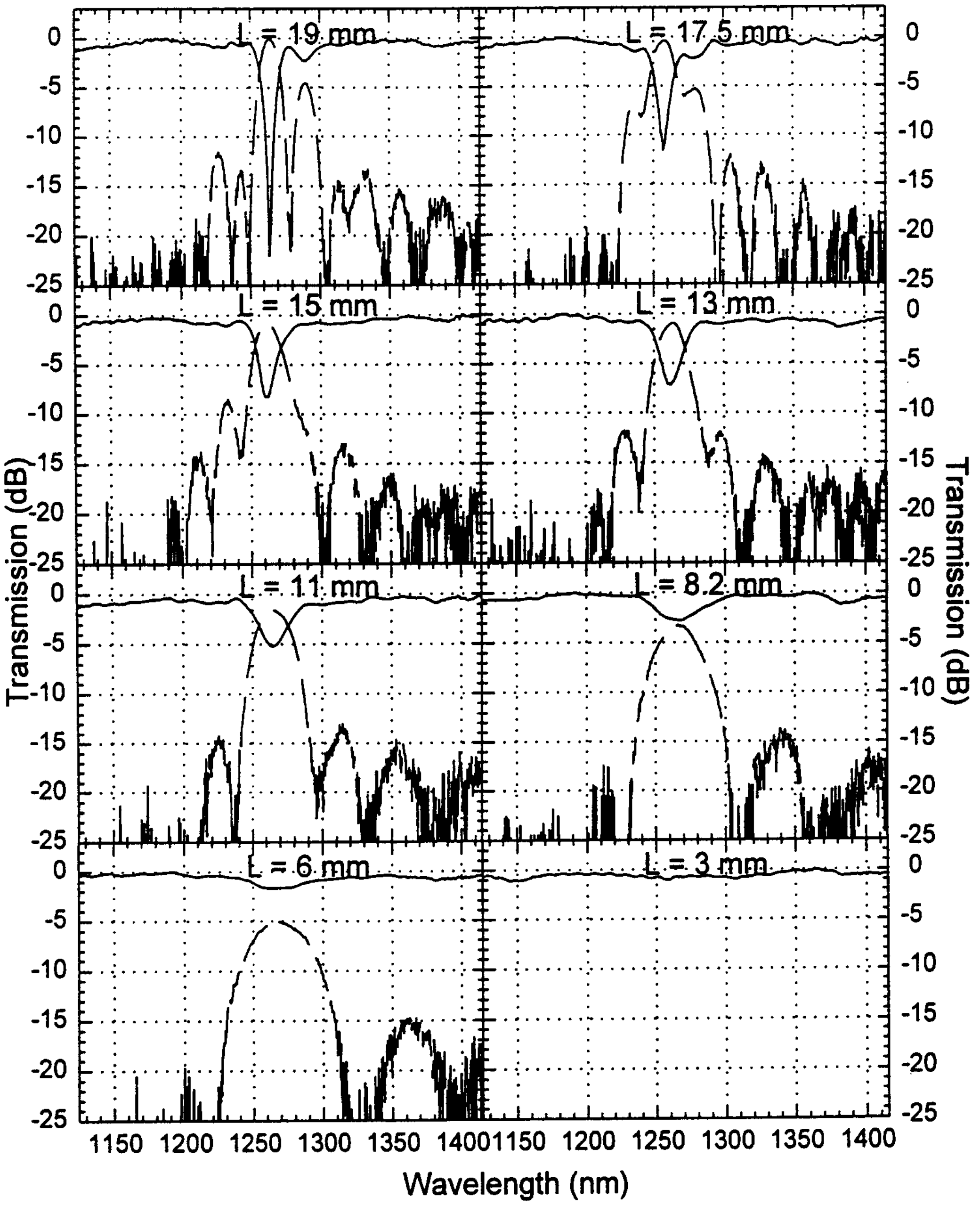
Figure 4 A loss filter consisting of three separate filters. The solid line represents the response of the combined device. Dashed lines are the original filter responses.



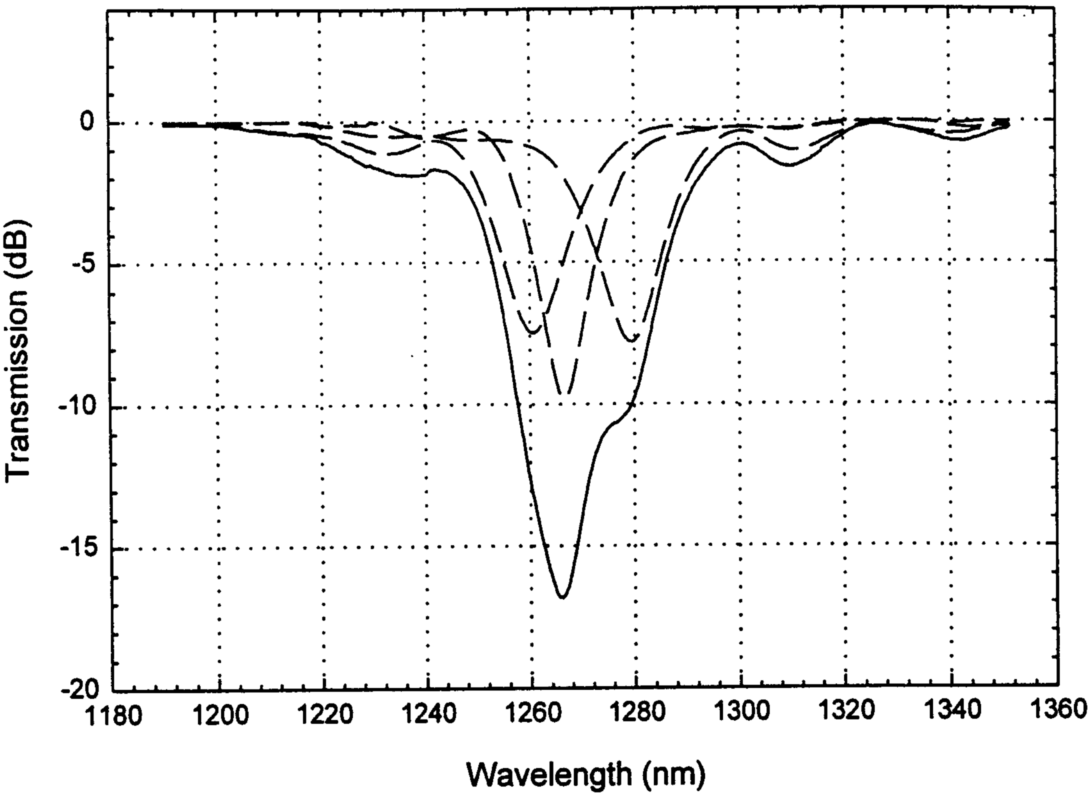
Ortega et al., Fig. 1



Ortega et al., Fig. 2



Ortega et al., Fig. 3



Ortega et al., Fig. 4