IN-LINE OPTICAL FIBRE FILTERS USING DISPERSIVE MATERIALS

Indexing terms: Optical fibres, Optical filters

It is shown that optical fibre filters can be made by choosing core and cladding materials having appropriate dispersive characteristics. The bending loss of the dispersive optical fibres is calculated, and proves them to be useful for short- and long-wavelength-pass filters.

Introduction: In-line optical fibre filters could have important applications for optical communications and spectral measurements. Several types of structure having the desired characteristics have been proposed, including directional couplers[1-4] and a combination of an optical fibre with a grating.[5] Filters employing external dispersive elements, prisms or gratings, have also been reported.[6] However, the design of in-line filters comprising optical fibres fabricated with suitably dispersive materials has not yet been proposed.

We show here that by choosing suitable core and cladding materials, optical fibres can be made to have short- or long-wavelength-pass filter characteristics. Furthermore, bandpass filters may be constructed by the concatenation of appropriate short- and long-wavelength-pass filters. The spectral curvature loss of dispersive fibres is calculated and their potential characteristics as in-line filters are discussed.

Theory and filter design: Light guidance is produced in optical fibres by ensuring that the refractive index of the core is greater than that of the cladding. In conventional fibres the core and cladding materials have similar spectral characteristics so that guidance is obtained over a wide range of wavelengths, although the normalised frequency and mode density will vary. However, it is possible to choose core and cladding materials having different variations of refractive index with wavelength. If a single-mode fibre is designed in such a way that the refractive index in the core falls below that of the cladding at some wavelength λ_c, then guidance ceases and even the fundamental mode becomes cut off. Thus propagation occurs at wavelengths greater (or less) than λ_c but not at shorter (longer) wavelengths, i.e. the fibre becomes a wavelength filter.

Consider the specific example of optical fibres in which the core and cladding materials are of TiF6 and SK1, or of SK6 and TiF6 glasses, respectively. The variations of refractive index of these glasses with wavelength are shown in Fig. 1. It can be seen that in the TiF6/SK1 fibre the core (TiF6) index falls below that of the cladding at all wavelengths longer than 874 nm, which thus becomes the theoretical cutoff for the resulting short-wavelength-pass filter. The SK6/TiF6 fibre is a long-wavelength-pass filter, with a theoretical cutoff wavelength of 669 nm, at which the core index is lower than the cladding index.

However, the theoretical cutoff wavelength, as defined above, is not of great practical importance because the propagating mode suffers considerable radiation loss at nearby wavelengths in the passband. The magnitude of the loss depends strongly on the fibre curvature and microbends. Since it is easier to control curvature (or bend) loss than microbend loss, we assume that the characteristics and effective cutoff wavelength of in-line fibre filters will be controlled by winding the fibres on to coils of suitable diameter. The bend loss will then predominate and microbending effects can be ignored.

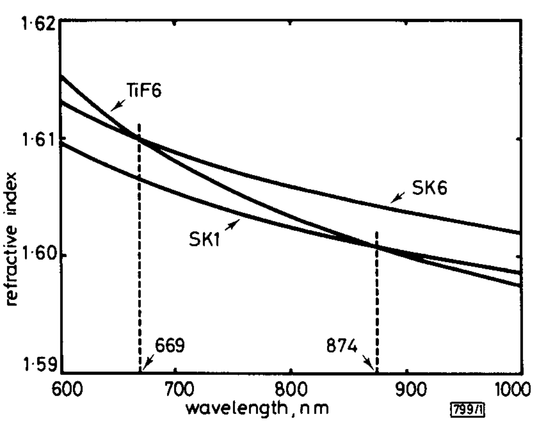

Fig. 1 *Chromatic refractive indices of TiF6, SK1 and SK6 calculated from Schott optical glass catalogue*

We therefore compute the bending loss of coiled optical fibres to estimate the filter characteristics. The following equations are used to calculate the bend loss α:[7,8]

$$\alpha = \frac{4\cdot34}{\sqrt{\pi a R W}}\left(\frac{U}{V}\right)^2 \exp\left\{-\frac{4}{3}\frac{W^3}{V^2}\Delta\frac{R}{a}\right\} \tag{1}$$

$$U = \frac{(1+\sqrt{2})V}{1+\sqrt[4]{4+V^4}} \tag{2}$$

$$W^2 = V^2 - U^2 \tag{3}$$

where V is the normalised frequency, $2a$ is the core diameter and R is the radius of fibre curvature.

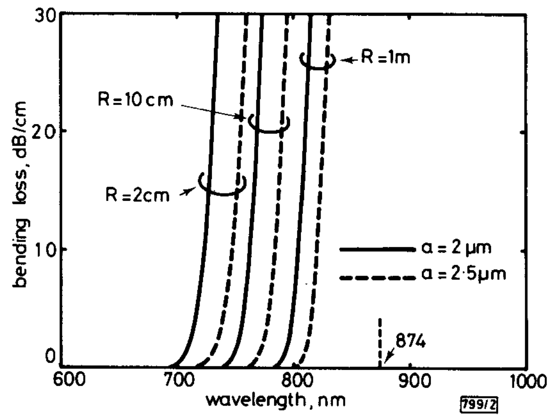

Fig. 2 *Bending loss of optical fibres in which core and cladding are of TiF6 and SK1, respectively*

The bending loss of the TiF6/SK1 step-index fibre is shown in Fig. 2 for bend radii of 2 cm, 10 cm and 1 m and core diameters of 4 and 5 μm. It can be seen that the loss increases by about 30 dB/cm for a 30–45 nm wavelength change, depending on the radius of curvature of the fibre. For a large radius of curvature with increased core size the bending loss curves become steeper and approach the theoretical cutoff point (874 nm). However, for practical coil radii the effective cutoff wavelength differs considerably from the 'theoretical' one.

Fig. 3 shows the bending loss of the SK6/TiF6 step-index fibre for the same curvatures and core diameters of 6 and 7 μm. The loss decreases by 30 dB/cm for a wavelength change of 10 nm to 66 nm, depending on R. For large curvatures the bending loss curves are much steeper and closer to the theoretical cutoff wavelength (669 nm) than those of Fig. 2.

Bandpass filters can be obtained by splicing together fibres with characteristics such as shown in Figs. 2 and 3. For the examples considered, Fig. 2 shows that the TiF6/SK1 fibre for 2 cm bend radius, 5 μm core diameter and 5 cm length produces a short-wavelength-pass filter with an excess loss exceeding 100 dB at wavelengths greater than 754 nm and below 1 dB for wavelengths under 720 nm. The SK6/TiF6 fibre for 10 cm bend radius, 6 μm core diameter and 5 cm length produces a long-wavelength-pass filter with a loss below 1 dB above 714 nm. By splicing these two bent fibres, of length 5 cm, a bandpass filter results with excess losses exceeding 100 dB for 754 nm $< \lambda$ or $\lambda <$ 695 nm and below 1 dB for 714 nm $< \lambda <$ 720 nm.

The bandwidth and centre wavelength are adjustable within two theoretical cutoff wavelengths by a suitable choice of coil radius and core diameter of the fibres. The theoretical cutoff points can be shifted to other wavelengths by selecting different dispersive materials. In a practical filter design the spot sizes in the filter fibres and the transmission fibre would be optimised to minimise the total joint losses.

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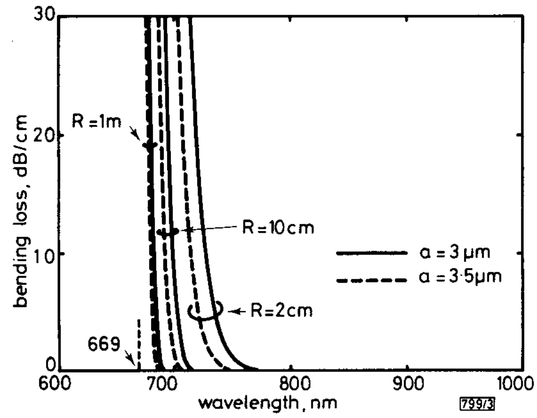

Fig. 3 *Bending loss of optical fibres in which core and cladding are of SK6 and TiF6, respectively*

Conclusions: A technique for realising in-line optical fibre filters is proposed. The dispersive characteristics of the fibre materials are such that guidance ceases at a particular wavelength. The effective cutoff of the fundamental mode can then be varied by choice of the bend radius. It should be possible to fabricate short-wavelength-pass, long-wavelength-pass and bandpass filters.

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