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Dispersion Studies Of A Single-Mode Triangular-Core Fiber with a Trench By The Vector Mode Analysis

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Abstract

A Runge-Kutta procedure is used for investigating the dispersion characteristics of triangular-core fibers with a trench in the cladding. Numerical results on the total dispersion are presented, revealing some special features due to the trench. The presence of a trench has not been investigated previously.

Summary

Graded-index optical fibers have been the subject of very intensive research because many practical fibers have an inhomogeneous core. Many analytical studies have been carried out on the dispersion characteristics of such fibers, but solutions are available only for a few limited cases. For arbitrary index profiles, analytical solutions are few, and numerical solutions must be sought. In this paper we will use a reliable and accurate numerical vector mode method based on the Runge-Kutta fourth-order procedure [1,2] to study the dispersion characteristics of a single-mode triangular-core fiber with a trench in the cladding. The effects of a trench have not been investigated previously.

The index profile of the fiber considered is shown in Fig. 1 with the indices n_1, n_2, n_3, n_4 and index differences Δ_1 and Δ_2 for the various regions as given, where $n_2 = n_4$ and $\Delta_1 = (n_1 - n_2)/n_1$ and $\Delta_2 = (n_2 - n_3)/n_2$. The core radius a and trench radii b and c are also indicated.

Let F(x) represent the following functions:

$$F(x) = \begin{bmatrix} f_1(x) \\ f_2(x) \\ f_3(x) \\ f_4(x) \end{bmatrix} \tag{1}$$

Then, the field components in an inhomogeneous core can be expressed as

$$F_1(r,z,\theta,t) = \begin{bmatrix} E_z \\ E_\phi \\ H_z \\ H_\phi \end{bmatrix} = \begin{bmatrix} x^n f_1(x) \\ x^{n-1} f_2(x) \\ i\eta_0^{-1} x^n f_3(x) \\ i\eta_0^{-1} x^{r-1} f_4(x) \end{bmatrix} \tag{2}$$

$$.expi(\omega t - \beta z - n\phi)$$

where (r, z, θ) represent the cylindrical system, ω is the angular frequency, β the axial propagation constant, and n an integer. Also, $x = k_0 r$, $k_0^2 = \omega^2 \mu_0 \varepsilon_0$ and $\eta_0 = (\frac{\mu_0}{\varepsilon_0})^{\frac{1}{2}}$.

$$\frac{dF(x)}{dx} = A(x)F(x) \tag{3}$$

The solution is given by

$$F(x) = B(x,\ x_o)F(x_o) \tag{4}$$

where $A(x)$ is a 4×4 coefficient matrix and $B(x,\ x_o)$ is called the fundamental matrix. The fields at the core-cladding interface are given by

$$F(k_0\ a^-) = B(k_0\ a^-,\ 0)F(0) \tag{5}$$

The fields in the outer cladding are expressed in terms of the modified Hankel function. The imposition of the boundary conditions at $r = a$, b and c leads to a dispersion equation $det\Gamma = 0$. The fundamental matrix in Eqn. (4) is computed using a Runge-Kutta fourth order procedure, and a root-search technique is used to determine the normalized propagation constant $U = \beta/k_o$ with all the fiber parameters specified. The numerical results have been directed towards determining the variation of the total dispersion D_t with the trench parameter c/a for a given $b/a = 2$. Table 1 lists the parameters of six fibers, whose dispersion characteristics have been studied. The core radii there are obtained numerically under the condition of zero-dispersion, the wavelength λ_0 being shifted to $1.55\mu m$.

In Fig. 2, the total dispersion D_t is presented over a wavelength range $1.45 - 1.65\mu m$. All the six fibers yield zero total dispersion at $1.55\mu m$. Above $\lambda_o = 1.55\mu m$, some dramatic change in D_t occurs as c/a increases beyond 2.6. For example, D_t for fiber No. 6 continues to increase beyond $1.55\mu m$, reaches a peak and then decreases below zero, hence becoming zero at two wavelengths. With larger values of c/a, fiber Nos. 5 and 6 display a dispersion-flattened tendency in their total dispersion. These dispersion-flattened fibers have a lower total dispersion over a certain wavelength range. It is interesting to note that with a proper choice of c/a, a triangular-core fiber with a trench has the combined advantages of a dispersion-shifted and a dispersion-flattened fiber. In Fig. 3, the sensitivity $dD_t/d\lambda$ decreases with an increasing c/a at $\lambda_o \approx 1.55\mu m$. Hence, a fiber with a wider trench provides an attractive feature for wavelength multiplexing and less sensitivity to wavelength fluctuations in the laser source.

It was reported previously [3] that there are two values of a, which yield $D_t = 0$ at $1.55\mu m$ for $\Delta_1 > 0.74\%$ in a triangular-core fiber without a trench. If a trench is introduced, there are still two values of a for zero dispersion in the fiber with a set of given normalized parameters, e.g. $\Delta_1 = 1\%$, $\Delta_2 = 0.4\%$ and a fixed trench width $(c - b)/a = 0.2$ for b/a less than about 6.8. However, with this same set of parameters but for $b/a > 6.8$, as many as four values of a for zero dispersion have been observed although the two smaller values of a may not have much practical significance. Fig. 4 shows the variation of the lareger a for zero D_t with the trench parameter b/a for fibers as indicated. Curve A reveals, over a limited range of core radius, the existence of two trench positions b/a, a feature unique with the presence of a trench. Our further calculations have shown that the higher value of b/a is associated with a higher sensitivity of total dispersion to the wavelength fluctuations, but a lower sensitivity to core radius variations. The reverse is true with the lower b/a. By comparison to the step-index fibers with the same parameters, the core radii for the triangular-core fibers are, in general, about 1.5 times larger. Hence, a triangular-core fiber appears to be a better candidate for more efficient power coupling.

We have also computed the sensitivity of the total dispersion to the changes in core radius a, index differences Δ_1, Δ_2 as well as the bandwidth-length product. These details will also be reported at the meeting.

Acknowledgements

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Table 1 Parameters of Six Fibers Under Study
N.T. stands for no trench

Fiber No.	b/a	c/a	$a(\mu m)$	Δ_1	Δ_2	λ_0 (μm)	Note
1	2	2	3.29	0.01	-	1.55	N. T.
2	2	2.2	3.06	0.01	0.004	1.55	
3	2	2.4	2.88	0.01	0.004	1.55	
4	2	2.6	2.75	0.01	0.004	1.55	
5	2	2.8	2.65	0.01	0.004	1.55	
6	2	3.0	2.58	0.01	0.004	1.55	

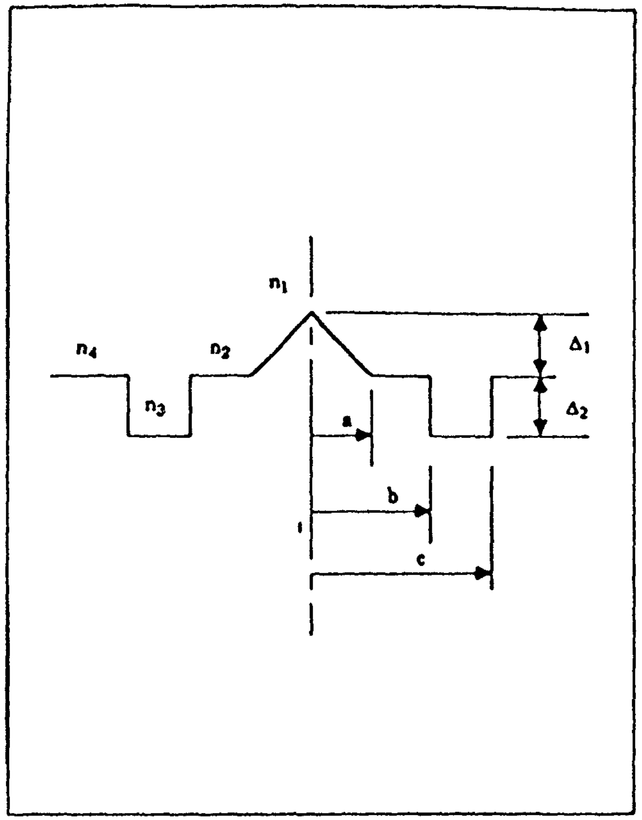

Fig.1 Refractive index profile of the fibers under study

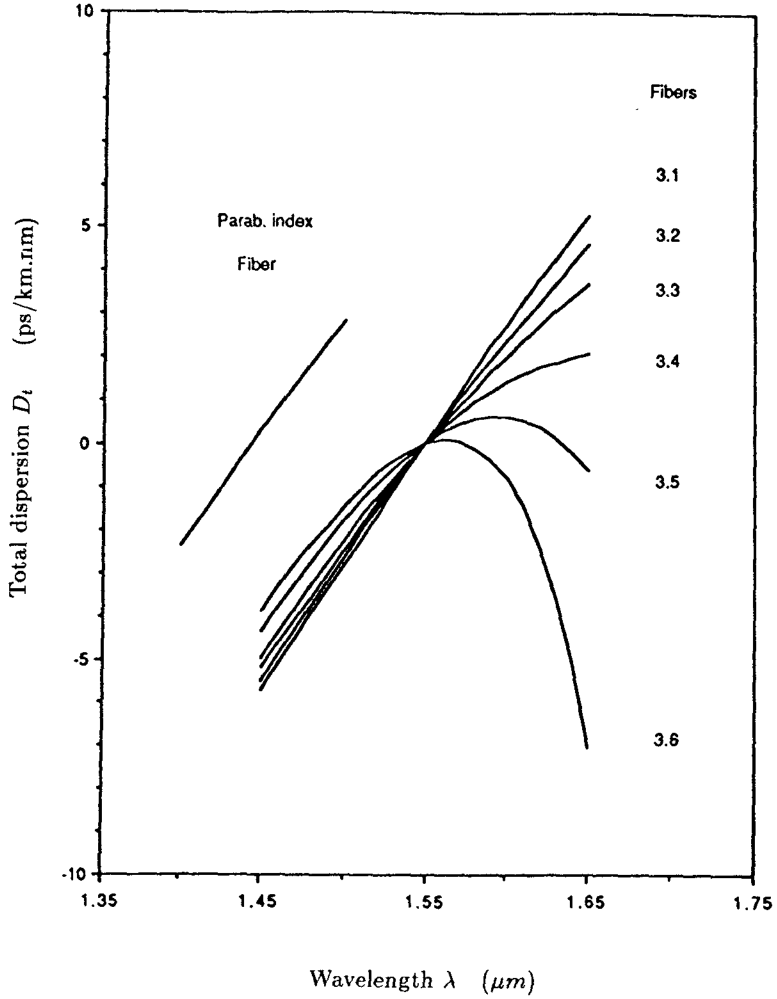

Fig.2 Total dispersion for Fibers 1 to 6 as a function of wavelength

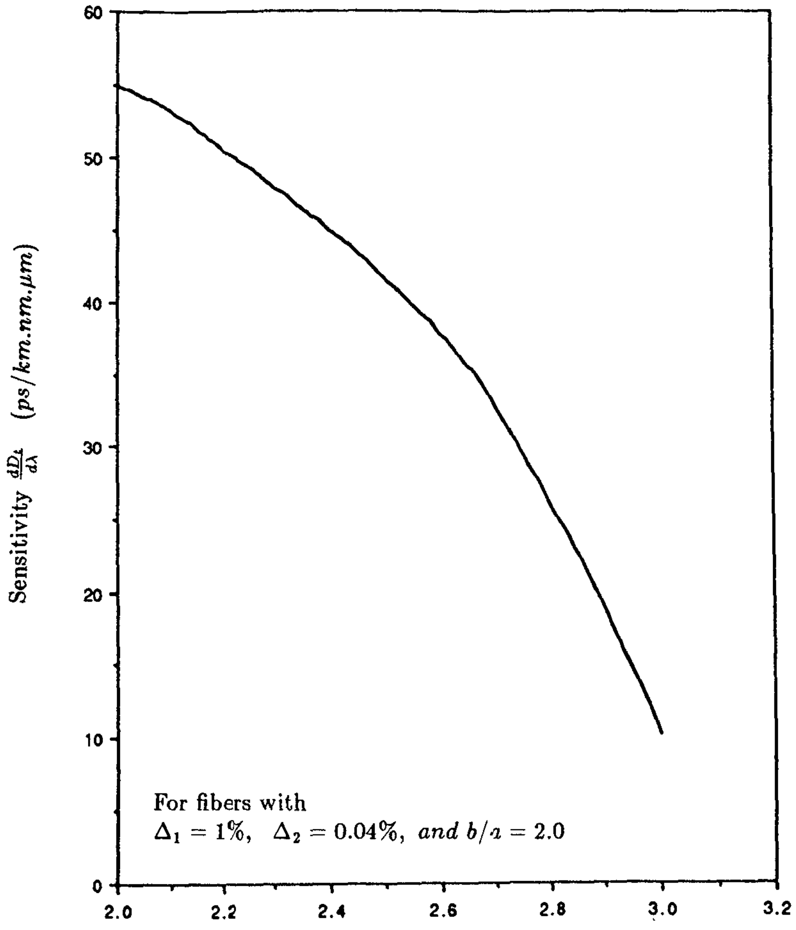

Fig.3 Calculated sensitivity $dD_t/d\lambda$ versus the normalized trench parameter c/a

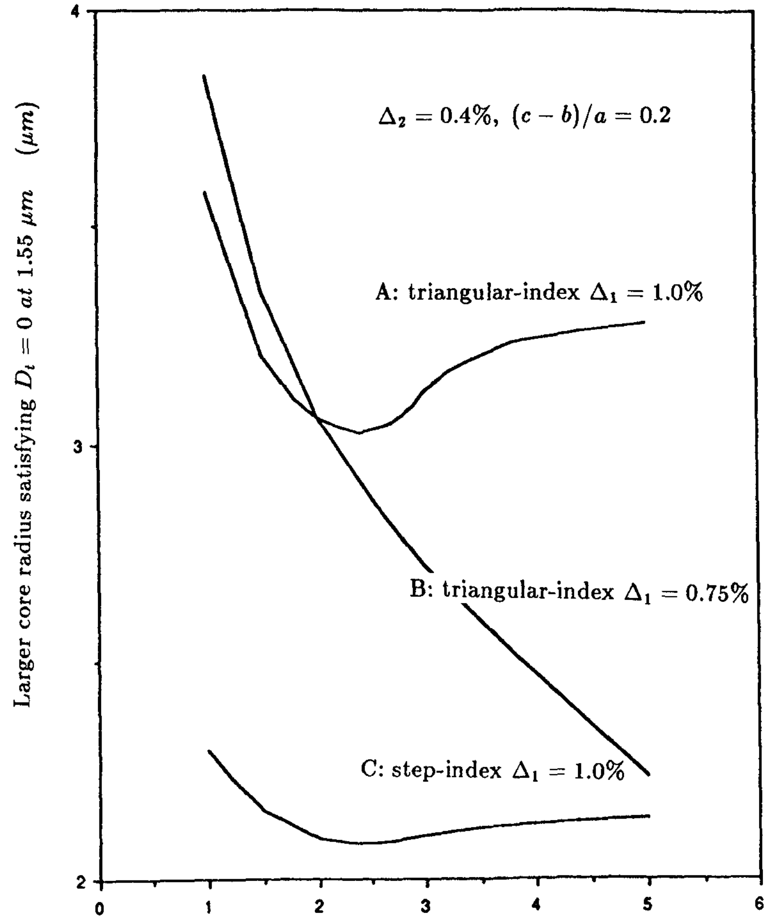

Fig.4 The larger core radius satisfying $D_t = 0$ *at* 1.55 μm versus trench parameter b/a