Communication

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Propagation parameters of transverse and hybrid modes in coherent optical fibres

The paper presents numerical results concerning the propagation parameters of dielectric core-cladding optical fibres with higher value of index of refraction of a core and a small core diameter. Such fibres can be produced for example from chalcogenide glasses such as As_2Se_3, As_2S_3 or As–Se–Te and As–Se–Ge, the indices of refraction of which range from 2.37 up to 2.8. These materials are of large transmission band, from 0.7 to 15 μm, and therefore are convenient for optical waveguides capable to transmit infrared light waves. Our results may be of some interest to the designers of optical fibres.

The analysis of modes in optical fibres found in the literature is frequently based on a short form of the eigenvalue equation which approximates the exact form for $n_1 \approx n_2$ (fig. 1).

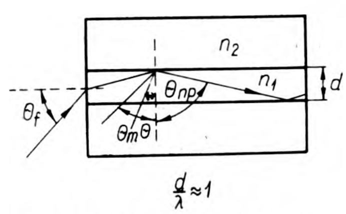

Fig. 1. Cross-section of optical fibre

In this contribution the exact form of eigenvalue equation has been used, and we show the structure of bound modes without any restriction imposed on the refractive index of the cladding.

The courses of propagation parameters have been determined as propagation constant in axial direction, h_{np}, propagation angle, Θ_{np}, and group and phase velocities, v_g and v_f, respectively, depending on the index of refraction of a cladding. As representative parameters $n_1 = 2.5$ (As-Se-Te), $\lambda = 10.6$ μm (CO_2-laser) and $d/\lambda = 3$ have been chosen. Basing on their parameters the roots, u_{np}, of the known characteristic equation, as given in [1] in the form convenient for numerical computation, have been found. These roots were used to compute other parameters, according to the relations

$$h_{np}^2 = \left(\frac{\omega n_1}{c}\right)^2 - \left(\frac{2u_{np}}{d}\right)^2,$$

$$\cos\theta_{np} = \frac{2cu_{np}}{n_1 \omega d},$$

$$v_{gnp} = \frac{c}{n_1}\sin\Theta_{np},$$

$$v_{fnp} = \frac{c}{n_1 \sin\Theta_{np}}.$$

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Fig. 2 shows the dependence of propagation constants in axial direction for transverse (electric, H_{op}, and magnetic, E_{op}), and hybrid (EH_{np}, and HE_{np}) modes on the index of refraction

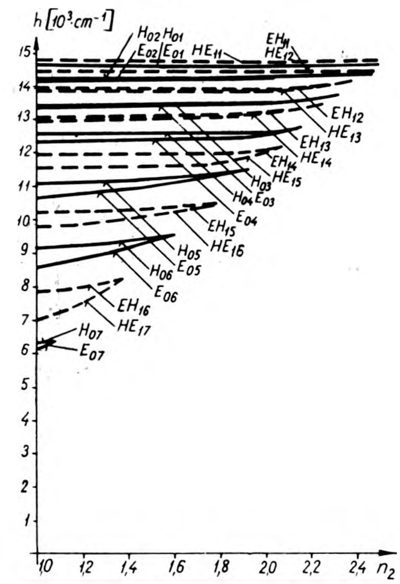

Fig. 2. The dependence of propagation constant in axial direction, h_{np}, for transverse and basic hybrid modes

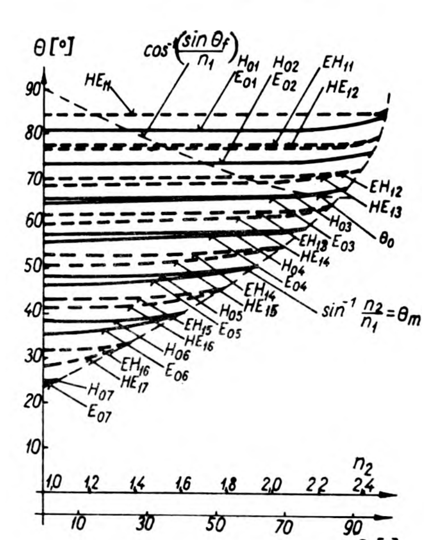

Fig. 3. The dependence of propagation angle, Θ_{np}

of the cladding. The hybrid modes are drawn only for $n = 1$. The course of the mode angles between the light rays and the normal to the fibre wall (as seen in fig. 1) are presented in fig. 3. From the course Θ_m it can be seen that the modes not obeying the condition of total reflection cannot propagate within the fibre. The curve

$$\Theta = \cos^{-1}\left(\frac{\sin\Theta_f}{n_1}\right)$$

expresses the exciting condition. (The modes with $\Theta_{np} < \Theta$ cannot be excited by an external source, even if they are allowed to propagate). Figs. 4 and 5 give the courses of group and phase velocities. The group velocity increases monotonically with increasing n_2 in the contrary to the curves of the phase velocity.

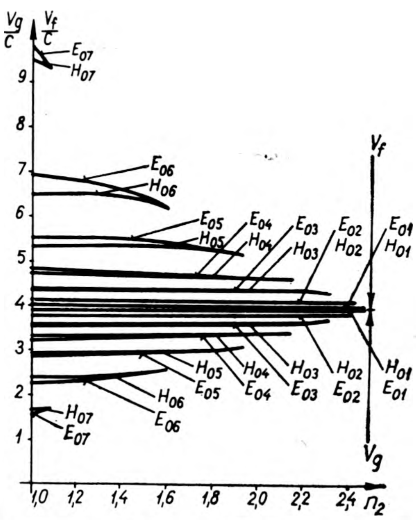

Fig. 4. The dependence of group, v_g, and phase, v_f, velocities of transverse modes

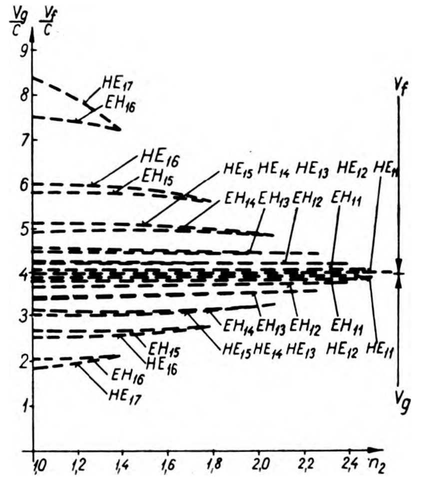

Fig. 5. The dependence of group, v_g, and phase, v_f, velocities of basic hybrid modes

The results of our analysis can be summarized in the following main conclusion. As the index of refraction of the cladding increases, the propagation constants vary very slowly. It has been found that similar curves hold also for hybrid modes of the higher order.

References

[1] Kapany N. S., Burke J. J., *Fiber Optics. IX. Waveguide Effects*, J. Opt. Soc. Am. Vol. 51, No. 10 (1961), p. 1067.

Received, 17 May, 1977
In revised form 6 March, 1978