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A comparative study of OmniGuide and a hollow metallic waveguide fiber in optical fiber communication system

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Abstract:- *The modes in an OmniGuide fiber are similar to those in a hollow metallic waveguide in their symmetries, cutoff frequencies, and dispersion relations. The differences can be predicted by a model waveguide extends to the transmission properties, resulting in the identification of the TE_{01} mode as the lowest-loss mode of the OmniGuide fiber. So information carrying capacity of the optical fiber communication link in this mode is greater compared to the other modes.*

***Keyword : -** OmniGuide fiber ,hollow metallic waveguide fiber, frequency, dispersion relation, TE_{01} mode .*

Introduction

A waveguide is a device used to carry electromagnetic waves from one place to another without significant loss in intensity while confining them near the propagation axis. The most common type of waveguides for radio waves and microwaves is a hollow metallic pipe. Waves propogate through the waveguide being confined to the interior of the pipe. A representative weaveguide in the optical region is an optical fiber. The advent of high-purity ultra-low-loss silica fiber as a transmission medium in the late 1970s provided a basis for the modern optical communication infrastructure. Although highly successful, silica waveguides have fundamental limitations in their attenuation and nonlinearities that result from the interaction of optical wave with a dense, material-filled core. A different approach to waveguiding circumvents these problems by confining light in a hollow core using highly reflective walls. This approach is exemplified by hollow metallic waveguides that are very efficient in the millimeter wavelength range. Prior to the emergence of silica fiber, these waveguides were seriously considered as candidate media for long-distance telecommunications.[1] An impairment of metallic waveguides is that they become lossy at high frequencies due to the finite conductivity of metals. Thus, their use is restricted to low frequencies. This severely limits the ultimate bandwidth that they can transmit. By adding a dielectric coating on the inside of the metallic waveguide we can improve its properties. Such metallodielectric waveguides have been developed for infrared wavelengths, in particular, for laser power delivery. [2,3] In this chapter, we have studied the properties of a hollow dielectric waveguide in which light is confined by a large index-contrast omnidirectional dielectric mirror. The large index contrast produces a high degree of optical confinement in the core and results in a waveguide mode structure that is very similar to the mode configuration of a hollow metallic waveguide. We have presented the similarities and differences between the hollow dielectric and metallic waveguides, and we have explained these results using a single-parameter model based on the phase shift upon reflection from the dielectric mirror. In addition, we have showed that the similarities between these two types of waveguides extend to their transmission properties, in which they have the same lowest-loss mode, the TE_{01} mode of the omniguide fiber. Thus we have analyzed the optical wave mode configuration of an omniguide fiber and comparative result is obtained.

Body text :-

In Fig. 1, we have showed the lowest-frequency resonant modes of the Omni Guide fiber for a radius R=2.0a. TE modes and TE-like (HE) modes, TM and TM-like (EH) modes are shown. The modes of a hollow metallic waveguide with the same radius are shown as dots. The figure shows that, indeed, the dispersion relations of the OmniGuide fiber are very similar to those of the metallic waveguide, but the modes can now only exist in the TE or TM band gaps of the multilayer mirror. For example, the TM_{01} mode in the metallic waveguide is now split into two submodes, TM_{01} and TM'_{01}. Thus, it is useful, in a zeroth-order approximation, to think that the dispersion relations for the different modes of the Omni Guide fibers can be obtained by overlapping the band structure of the dielectric mirror on top of the dispersion relations for the metallic waveguide. Finally, we note that it is possible for resonant modes to exist outside the omni directional frequency range [such as the HE_{11} mode for $\beta<0.05(2\pi/a)$ in Fig. 1] as long as the modes fall within the band gap.

In Fig. 2 we have showed the dispersion relations for a larger radius of the fiber, R=3.8a. More resonant modes can be found now in the first band gap as the cutoff frequencies vary inversely with the radius R. We focus on the first band gap of the dielectric mirror, and we consider only the lowest five resonant modes of the waveguide.

We have compared the resonant modes shown in Figs. 1 and 2 with the modes in metal waveguides of corresponding radii (R=2.0a and R=3.8a). In particular, we have compared the resonant modes to the metal waveguide modes in terms of their cutoff frequencies, group velocities, group velocity dispersions, degeneracies, and mode symmetries. The lowest resonant mode in Fig. 1 is HE_{11} with a cutoff frequency ω =0.155($2\pi/a$). This corresponds to TE_{11}, the fundamental mode in a hollow metal waveguide, which has a cutoff at ω=0.146($2\pi/a$). Here we note that second mode in Fig. 2.3 is TM_{01} with ω=0.189($2\pi/a$), corresponding to TM_{01} in the metal waveguide with ω=0.191($2\pi/a$).Thus here we note that for m=0 modes, the OmniGuide fiber modes are exactly TE or TM polarized, as is the case with all-metal waveguide modes. For nonzero m, TE modes become HE modes, and TM modes become EH modes and also, in both waveguides, the nonzero m modes are doubly degenerate, while the m=0 are nondegenerate.

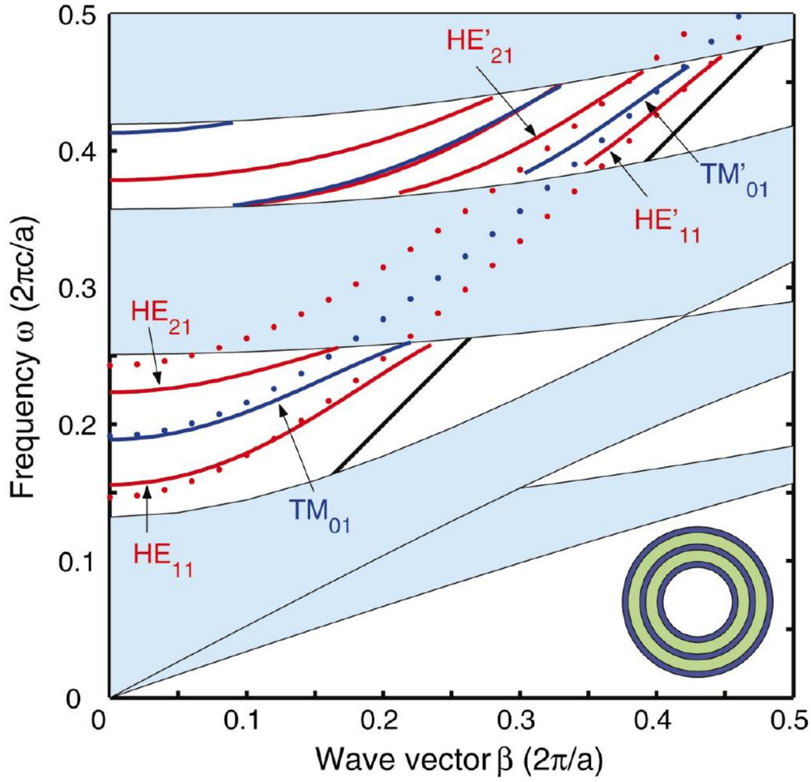

Fig. 1 : Frequency (ω) Vs wave vector β plot supported by an omni Guide fiber with radius R = 2.0a.

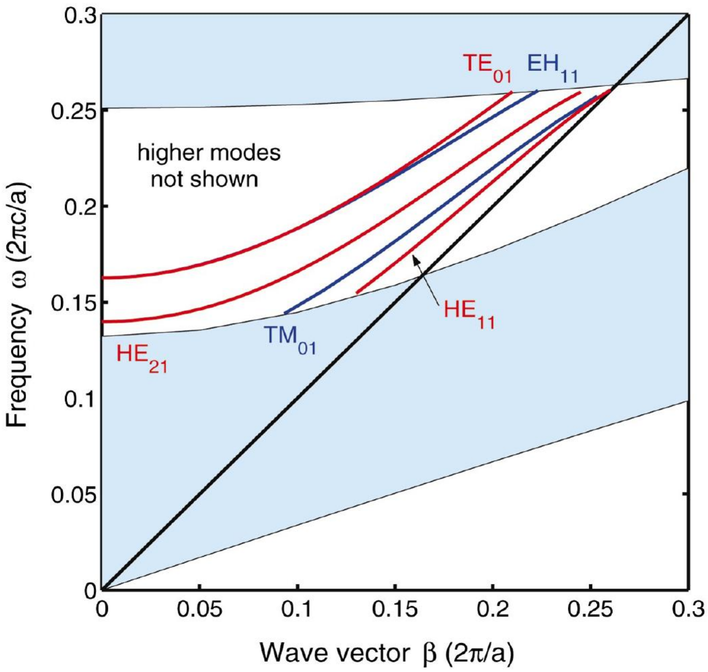

Fig. 2. : The lowest five modes supported by an omni Guide fiber with radius R = 3.8a (ω Vs β plot)

Result and discussion:-

In Table 1, we have summarized the similarities between the equivalent modes in the OmniGuide fiber and the hollow metallic waveguide. The first three modes are taken from Fig. 1 for a radius R=2.0a, and the next two are from Fig. 2, corresponding to R=3.8a. The cutoff frequencies for the two types of waveguides are quite similar for all the five modes. The differences vary from 28% for the HE_{21} mode to 16% for the TM_{01} mode. Also we have noted that the modes in the metal waveguide having low cutoff frequencies [below 0.18(2π/a)] are shifted up in the OmniGuide fiber, while metallic modes with higher cutoff frequencies are shifted down..

Table 1

Summary of comparison between OmniGuide fiber (OGF) modes and their hollow metallic waveguide (HMW) counterparts. The first three modes are taken from Fig. 2.3 for a radius R=2.0a, and the next two are from Fig. 2.4, corresponding to R = 3.8a.

Mode label		Cutoff frequency			Degeneracy	
OGF	HMW	OGF	HMW	Difference	OGF	HMW
HE_{11}	TE_{11}	0.155	0.146	16%	2	2
TM_{01}	TM_{01}	0.189	0.191	21%	1	1
HE_{21}	TE_{21}	0.223	0.243	28%	2	2
EH_{11}	TM_{11}	0.163	0.160	12%	2	2
TE_{01}	TE_{01}	0.163	0.160	12%	1	1

The group velocity of a resonant mode is zero at β=0 and approaches c as the frequency is increased, as is the case in a metal waveguide. However, as the mode nears the upper band edge, the group velocity starts decreasing as a result of the gradual loss of confinement in the core.The group velocity dispersion of a resonant mode is positive for low frequencies (closer to the lower edge of the band gap), negative for high frequencies and transitions through zero. This is in contrast to the group velocity dispersion of modes in a metal waveguide, which is always positive.

To provide a better understanding of the field patterns of Omni Guide fiber modes, in Fig. 3 the electric-field time average energy density $\frac{1}{2}\varepsilon\left|\vec{E}\right|^2$ is plotted for the five modes shown in Fig. 2 at a frequency ω=0.230(2π/a). All modes are normalized such that the power flowing in the z direction is the same. Also, in order to capture the angular dependence of a mode, we no longer use the $e^{im\phi}$ complex form of the field. Instead, we use linear combinations of the degenerate m and $-m$ modes to obtain real fields.

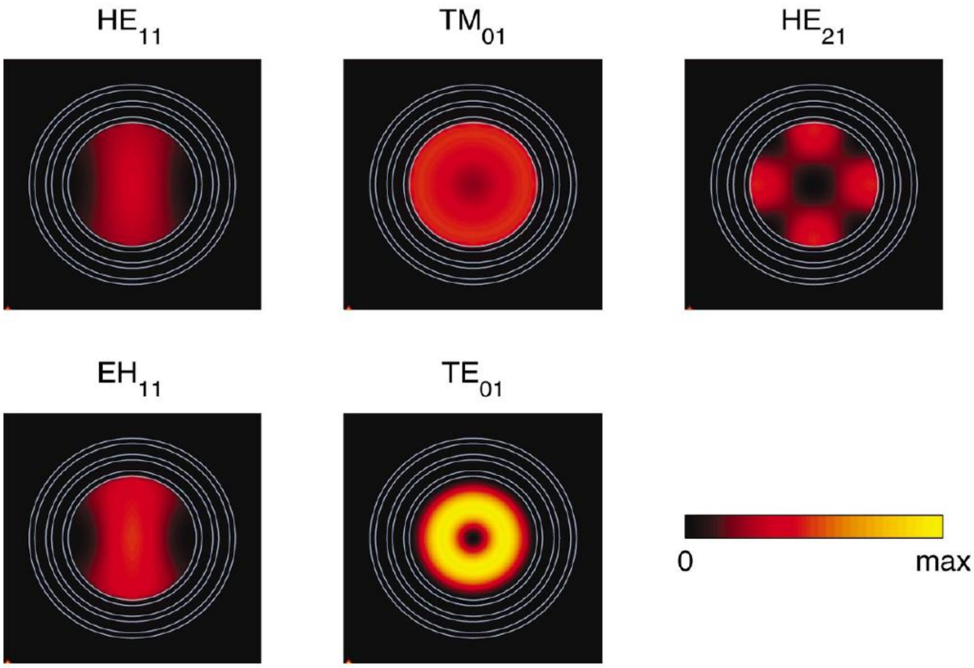

Fig. 2.5 : The electric field time - average energy density of the lowest five modes, ω = 0.230 (2π/a)

All modes appear to be very well confined to the hollow core. The energy density in the cladding layers is much smaller than the energy density in the core. The TE_{01} mode is different from the other four modes, in which its electric field energy density has a node near the core-mirror interface. This is true, in general, for all modes of the same symmetry, i.e., $TE_{0\ell}$, with ℓ=1,2, ... Here we have observed that the number of angular oscillations of the energy density is twice the angular momentum of a mode.

In order to quantify the comparison between the field distribution of modes in the OmniGuide fiber and in the metal waveguide, we use a correlation function Γ defined by

$$\Gamma = \frac{\left|\int rdrd\phi \vec{E}_1(r,\phi).\vec{E}_2(r,\phi)\right|}{\left[\int rdrd\phi\,|\vec{E}_1(r,\phi)|^2 \int rdrd\phi\,|\vec{E}_2(r,\phi)|^2\right]^{1/2}} \qquad \text{..........(1)}$$

Γ can take values in the interval [0,1], a value of 1 corresponding to maximum correlation (Γ=1 can only happen if the two modes are the same up to a constant amplitude scaling factor). For all modes, the correlation is largest, close to the middle of the band gap and decreases as the mode approaches the band edges. The maximum value of the correlation as a function of frequency is above 95% for all modes, and the largest correlation is found for the TE_{01} mode, i.e., 99.1%.

Conclusion:

we have shown that the mode configuration of an OmniGuide fiber has many similarities with that of a hollow metallic waveguide. We explained why these similarities exist, and we presented a simple model that accounts for the differences. We identified the TE_{01} mode as the lowest-loss mode in the dielectric waveguide, as it was the case for the metal waveguide fiber. It is hoped that the analogy developed in this paper has provided a better understanding of the modal configuration of the Omni Guide fiber and could be applied to the design of transmission lines or optical devices based on this type of fiber.

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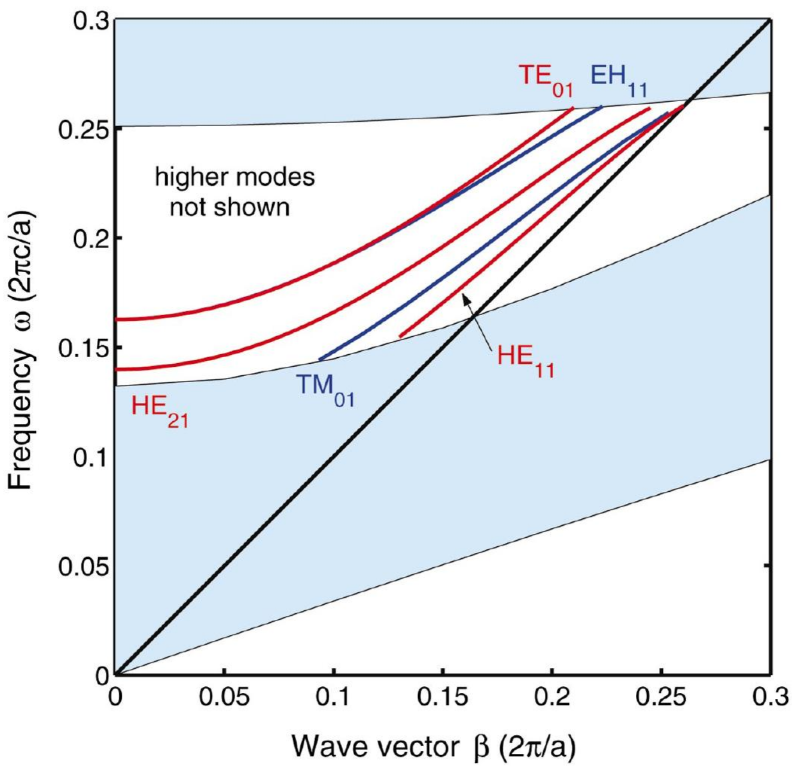

Fig. 2.4 : The lowest five modes supported by an omni Guide fiber with radius R = 3.8a (ω Vs β plot)

