Research Article

Waves in Microstructured Conducting Sheath Helix Embedded Optical Guides with Chiral Nihility and Chiral Materials

N. Iqbal, M. A. Baqir, and P. K. Choudhury

Institute of Microengineering and Nanoelectronics, Universiti Kebangsaan Malaysia (UKM), 43600 Bangi, Selangor, Malaysia

Correspondence should be addressed to P. K. Choudhury; pankaj@ukm.edu.my

Received 10 April 2014; Revised 28 May 2014; Accepted 28 May 2014; Published 17 June 2014

Academic Editor: Christian Brosseau

Copyright © 2014 N. Iqbal et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

The paper deals with the sustainment of electromagnetic waves in circularly cylindrical optical guide with chiral nihility and chiral materials in the core and the clad sections, respectively. A perfectly conducting tightly wound helix is introduced at the core-clad interface. The eigenvalue relation for such a complex optical microstructured guide is deduced by applying suitable boundary conditions at the core-clad interface, and the dispersion behavior is analyzed by varying the pitch angle of helix. The sustainment of energy flux density in such optical guides is estimated under various structural conditions, and the density patterns in core-clad sections are anatomized analytically.

1. Introduction

Due to many exotic electromagnetic characteristics, chiral materials attracted the attention of investigators. The interesting property of chiral medium is the deficiency in uniformity of its inner structure, which consequently results in cross-coupling of electric and magnetic fields [1, 2], making thereby the analytical treatments rather formidable. One of the interesting properties of chiral metamaterials is having the phenomenon of negative refraction/reflection that can be achieved by increasing the chirality [3, 4], and the applications of such phenomenon are described in [5, 6] as well.

Investigations pivoted to wave propagation in various forms of chirowaveguides have appeared in the literature [7–10]. Within the context, chiral nihility metamaterials can be realized through chiral materials which, by definition, have approximately vanishing dielectric permittivity $\varepsilon$ and magnetic permeability $\mu$, but nonzero chirality parameter $\eta$ [11]. References [12, 13] discuss the concept of nihility with the medium having the permittivity and permeability simultaneously zero. Although the propagation of electromagnetic waves through nihility medium is not possible, in chiral nihility medium, similar to chiral mediums, two oppositely (left- and right-circularly) polarized waves propagate. One of the interesting features of chiral nihility medium remains as the propagation of backward waves [11].

Apart from the electromagnetic analyses of varieties of conventional chirowaveguides, investigations have been reported focusing on the dispersion characteristics and/or the power transmission patterns of various other new forms of waveguide structures embedded with chiral materials [14, 15]. These constitute complex mediums, and the wave propagation through such structures would further be governed on demand by the use of twisted clad chiral guides [16]. These twists are in the form of a mounting of conducting sheath helix structure at the core-clad interface—the pitch angle of helix plays the determining role in tuning the dispersion features of the guide [17–20]. This concept is similar to the implementation of conducting helical structures in low- and medium-power travelling wave tubes [21] for the generation/amplification of microwaves.

Keeping in mind the concept of chiral nihility medium and the possible alternations of the dispersion characteristics of a fiber guiding structure, the present communication aims at the investigation of electromagnetic wave propagation in
complex structured guide with chiral nihility core, which is clad with chiral medium, and having introduced a conducting sheath helix structure at the core-clad interface. Considering the case of sheath helix with each turn being isolated from the neighboring one, but still the helical winding being continuous, the dispersion behavior of fiber is analyzed under the variation of the angle of pitch of conducting helical twists, which is followed with the determination of energy flux density patterns in the waveguide structure.

2. Theory

We consider an optical fiber guide with circular cross-section, the core of which is made of chiral nihility material, whereas the clad section is composed of chiral material. Also, the core-clad interface is loaded with a perfectly conducting sheath, the clad section is composed of chiral material. Also, the core of which is made of chiral nihility material, whereas the clad section is composed of chiral material. According to this case, the core-clad interface is loaded with a perfectly conducting sheath helix structure at the core-clad interface.

The constitutive relations for isotropic chiral medium for a time harmonic field are given as [11]

$$D_1 = \varepsilon_1 E_1 - j\kappa \sqrt{\mu_0 \varepsilon_0} H_1, \quad (1a)$$

$$B_1 = \mu_1 H_1 + j\kappa \sqrt{\mu_0 \varepsilon_0} E_1, \quad (1b)$$

where $\varepsilon_1$, $\mu_1$, and $\kappa$ are, respectively, permittivity, permeability, and chirality parameter of chiral medium. For a chiral nihility medium, we assume the permeability and the permeability both to be zero at certain frequency, but the chirality remains nonzero. As such, (1a) and (1b) can be written for chiral nihility medium as [11]

$$D_1 = -j\kappa \sqrt{\mu_0 \varepsilon_0} H_1, \quad (2a)$$

$$B_1 = j\kappa \sqrt{\mu_0 \varepsilon_0} E_1. \quad (2b)$$

Implementing Maxwell’s equations and using the above mentioned constitutive relations, we ultimately obtain the components of electric/magnetic fields in the core section as [22]

$$E_{r1} = (A + B) \left[ \frac{j m \kappa k_0}{k_0^2 \rho} J_m (k_0 \rho) - \frac{j \beta}{k_0} J_m' (k_0 \rho) \right] e^{j \rho}, \quad (3a)$$

$$H_{r1} = \frac{j}{\eta_1} (A - B) \left[ \frac{j m \kappa k_0}{k_0^2 \rho} J_m (k_0 \rho) - \frac{j \beta}{k_0} J_m' (k_0 \rho) \right] e^{j \rho}, \quad (3b)$$

$$E_{\phi1} = (A + B) \left[ \frac{m \beta}{k_0^2 \rho} J_m (k_0 \rho) - \frac{k \kappa}{k_0} J_m' (k_0 \rho) \right] e^{j \rho}, \quad (3c)$$

$$H_{\phi1} = \frac{j}{\eta_1} (A - B) \left[ \frac{m \beta}{k_0^2 \rho} J_m (k_0 \rho) - \frac{k \kappa}{k_0} J_m' (k_0 \rho) \right] e^{j \rho}, \quad (3d)$$

$$E_{z1} = (A + B) J_1 (k_0 \rho) e^{j \rho}, \quad (3e)$$

$$H_{z1} = \frac{j}{\eta_1} (A - B) J_1 (k_0 \rho) e^{j \rho}. \quad (3f)$$

In all the equations above, the subscript 1 corresponds to the situations in fiber guide core. In (3a), (3b), (3c), (3d), (3e), and (3f), A and B are unknown constants, $\eta_1 = \lim_{k_0 \rho \rightarrow 0} \sqrt{(\mu/\varepsilon)}$. The chiral clad is assumed to have the admittance $\chi_0$ and is nonmagnetic in nature; that is, the magnetic permeability for this region can be written as $\mu_2 = \mu_0$, $\mu_0$ being the free-space permeability.

Taking into account the wave propagation to be harmonic in time $t$ and the z-axis (the optical axis of guide), we may write the constitutive relations for the mediums, which the guide is composed of. Within the context, the constitutive relations for isotropic chiral medium for a time harmonic field are given as [2]

$$D_2 = \varepsilon_2 E_2 - j \eta_2 B_2, \quad (4a)$$

$$H_2 = -j \eta_2 E_2 + \frac{B_2}{\mu_2}, \quad (4b)$$

with $\varepsilon_2$ as the electric permittivity of chiral medium, and the other parameters are defined before. As the region is being composed of isotropic material, the electric permittivity $\varepsilon_2$ is taken to be a constant.

The use of Maxwell’s equations and the constitutive relations in (4a) and (4b) provides the following expressions for electric/magnetic fields in the clad section of guide [2]:

$$E_{r2} = j \eta_2 C \left[ \tau_2 \beta K_m' (\tau_2 \rho) - \frac{m \Omega_2}{\rho \eta_2} K_m (\tau_2 \rho) \right] e^{j \rho}, \quad (5a)$$

where $\tau = \kappa \sqrt{\mu_2/\varepsilon_2}$ and $C = \sqrt{(\mu_2/\varepsilon_2)}$. The chiral clad is assumed to have the admittance $\chi_0$ and is nonmagnetic in nature; that is, the magnetic permeability for this region can be written as $\mu_2 = \mu_0$, $\mu_0$ being the free-space permeability. The impedance of chiral nihility medium $\chi_1$ is assumed to have the admittance $\chi_0$ and is nonmagnetic in nature; that is, the magnetic permeability for this region can be written as $\mu_2 = \mu_0$, $\mu_0$ being the free-space permeability. The chiral clad is assumed to have the admittance $\chi_0$ and is nonmagnetic in nature; that is, the magnetic permeability for this region can be written as $\mu_2 = \mu_0$, $\mu_0$ being the free-space permeability. The chiral clad is assumed to have the admittance $\chi_0$ and is nonmagnetic in nature; that is, the magnetic permeability for this region can be written as $\mu_2 = \mu_0$, $\mu_0$ being the free-space permeability.

The use of Maxwell’s equations and the constitutive relations in (4a) and (4b) provides the following expressions for electric/magnetic fields in the clad section of guide [2]:

$$E_{r2} = j \eta_2 C \left[ \tau_2 \beta K_m' (\tau_2 \rho) - \frac{m \Omega_2}{\rho \eta_2} K_m (\tau_2 \rho) \right] e^{j \rho}, \quad (5a)$$

where $\tau = \kappa \sqrt{\mu_2/\varepsilon_2}$ and $C = \sqrt{(\mu_2/\varepsilon_2)}$. The impedance of chiral nihility medium $\chi_1$ is assumed to have the admittance $\chi_0$ and is nonmagnetic in nature; that is, the magnetic permeability for this region can be written as $\mu_2 = \mu_0$, $\mu_0$ being the free-space permeability. The chiral clad is assumed to have the admittance $\chi_0$ and is nonmagnetic in nature; that is, the magnetic permeability for this region can be written as $\mu_2 = \mu_0$, $\mu_0$ being the free-space permeability. The chiral clad is assumed to have the admittance $\chi_0$ and is nonmagnetic in nature; that is, the magnetic permeability for this region can be written as $\mu_2 = \mu_0$, $\mu_0$ being the free-space permeability.
\[ H_{ψ2} = jC \left[ \tau_2 βK'_m (τ_2, ρ) - \frac{mΩ_m}{ρn_2 τ_2} K_m (τ_2, ρ) \right] e^{imp} \]

\[-D \left[ \tau_2 βK'_m (τ_2, ρ) - \frac{mΩ_m}{ρn_2 τ_2} K_m (τ_2, ρ) \right] e^{imp}, \quad (5b)\]

\[ E_{ψ2} = -jη_2 C \left[ \frac{mβ}{ρ} K_m (τ_2, ρ) - \frac{Ω_{2+} τ_2}{η_2 τ_2^*} K_m (τ_2, ρ) \right] e^{imp} \]

\[ + jη_2 D \left[ \frac{mβ}{ρ} K_m (τ_2, ρ) - \frac{Ω_{2+} τ_2}{η_2 τ_2^*} K'_m (τ_2, ρ) \right] e^{imp}, \quad (5c)\]

\[ H_{ψ2} = C \left[ \frac{mβ}{ρ} K_m (τ_2, ρ) - \frac{Ω_{2+} τ_2}{η_2 τ_2^*} K'_m (τ_2, ρ) \right] e^{imp} \]

\[ + D \left[ \frac{mβ}{ρ} K_m (τ_2, ρ) - \frac{Ω_{2+} τ_2}{η_2 τ_2^*} K'_m (τ_2, ρ) \right] e^{imp}, \quad (5d)\]

\[ E_{ψ2} = -jη_2 \left[ t_2^* CK_m (τ_2, ρ) - t_2^* D K_m (τ_2, ρ) \right] e^{imp}, \quad (5e)\]

\[ H_{ψ2} = \left[ t_2^* CK_m (τ_2, ρ) + t_2^* D K_m (τ_2, ρ) \right] e^{imp}. \quad (5f)\]

In (4a), (4b), (5a), (5b), (5c), (5d), (5e), and (5f), the subscript 2 represents the situations in clad section. Further, in (5a), (5b), (5c), (5d), (5e), and (5f), C and D are unknown constants, and \( K_m(τ) \) is the modified Bessel function (with prime representing the differentiation with respect to the argument). Also, the other terms used in these equations have meanings as follows [15]:

\[ \tau_{2±} = \left[ \beta^2 - \gamma^2_2 - \left( 2ω^2 μ_0^2 χ_2^2 \pm 2ω^2 μ_0^2 χ_2 \frac{2ω^2 μ_0^2 χ_2}{η_2} \right) \right]^{1/2}, \quad (6a)\]

\[ Ω_{2±} = ωμ_0 \left[ χ_2 τ_2 \left( \gamma^2 + β^2 \right) \pm \left( β^2 - γ^2 \right) \right], \quad (6b)\]

\[ γ_2 = \left( ω^2 ε_2 μ_0 \right)^{1/2}, \quad (6c)\]

\[ η_2 = \left( \frac{η_0^2}{1 + \eta_0^2 χ_2^2} \right)^{1/2}, \quad (6d)\]

Now, by using the above derived field equations, and applying the boundary conditions [18] at the layer interface of microstructured guide of Figure 1, after some mathematical steps, we obtain the characteristic eigenvalue equation for the guiding structure, as follows:

\[ \frac{2jη_2}{k^4} - \left[ \left\{ \frac{βm}{a} \Gamma_m(k_ρ a) \cos ψ - \kappa k_ρ k'_m(k_ρ a) \cos ψ + k_ρ^2 k'_m(k_ρ a) \sin ψ \right\}^2 \times \left\{ \frac{Ω_{2±} τ_2}{η_2} K_m(τ_2, a) K_m(τ_2, a) (\cos^2 ψ - \sin^2 ψ) \right\} + \frac{βmτ_2^2}{a} K_m(τ_2, a) K_m(τ_2, a) (\sin^2 ψ - \cos^2 ψ) \right\} \]

\[ - \frac{Ω_{2±} τ_2}{η_2} K_m(τ_2, a) K'_m(τ_2, a) \right\} \]

\[ + \frac{βmτ_2^2}{a} K_m(τ_2, a) K_m(τ_2, a) \right\} \]

\[ - 2τ_2^2 K_m(τ_2, a) K_m(τ_2, a) \sin ψ \cos ψ \right\} \]

\[ = f(β) \text{ (say)} = 0. \quad (7)\]

The use of field expressions corresponding to the core and clad sections of microstructured guide, as represented in (3a), (3b), (3c), (3d), (3e), and (3f) and (5a), (5b), (5c), (5d), (5e), and (5f), respectively, would provide the energy flux densities [23] in the two sections of guide. After some mathematical steps, it can be shown that the flux densities in the core (\( S_{z1} \)) and the clad (\( S_{z2} \)) sections will assume the expressions, as follows:

\[ S_{z1} = \frac{|A|^2 - |B|^2}{4η_2 k^2} \left[ \left( (k k_0 + β f) \frac{J_{m+1}(k_ρ a)}{J_m(k_ρ a)} \right)^2 \right. \]

\[ - \left. \left( (k k_0 - β f) \frac{J_{m+1}(k_ρ a)}{J_m(k_ρ a)} \right)^2 \right], \quad (8a)\]

\[ S_{z2} = \frac{D^2}{2} \left( τ_2 β K'_m(τ_2, ρ) - \frac{mΩ_m}{ρn_2 τ_2} K_m(τ_2, ρ) \right) \]

\[ \times \left\{ \frac{βm}{ρ} K_m(τ_2, ρ) - \frac{Ω_{2±} τ_2}{η_2 τ_2^*} K'_m(τ_2, ρ) \right\} \]

\[ + \frac{CD}{2} \left( τ_2 β K'_m(τ_2, ρ) - \frac{mΩ_m}{ρn_2 τ_2} K_m(τ_2, ρ) \right) \]

\[ \times \left\{ \frac{βm}{ρ} K_m(τ_2, ρ) - \frac{Ω_{2±} τ_2}{η_2 τ_2^*} K'_m(τ_2, ρ) \right\} \]

\[ + \frac{C^2η_2}{2} \left\{ \frac{βm}{ρ} K_m(τ_2, ρ) - \frac{Ω_{2±} τ_2}{η_2 τ_2^*} K'_m(τ_2, ρ) \right\} \]

\[ \times \left\{ Ω_{2±} τ_2 K_m(τ_2, ρ) - \frac{mΩ_m}{ρn_2 τ_2} K_m(τ_2, ρ) \right\} \]

\[ \times \left\{ τ_2 β K'_m(τ_2, ρ) - \frac{mΩ_m}{ρn_2 τ_2} K_m(τ_2, ρ) \right\} \]. \quad (8b)\]
be determined in terms of only one constant so that the flux densities can be normalized. This essentially needs the use of boundary conditions. After implementing those, we finally obtain the values of constants $B$, $C$, and $D$ in terms of the constant $A$, as follows:

$$\begin{align*}
B &= \frac{\alpha_1 (\alpha_3 \alpha_5 + \alpha_4 \alpha_6) - 2 \alpha_3 \alpha_5 \alpha_6}{\alpha_1 (\alpha_3 \alpha_5 + \alpha_4 \alpha_6) + 2 \alpha_3 \alpha_5 \alpha_6} A, \\
C &= \frac{-\alpha_6 \alpha_3}{\alpha_2 \alpha_3 + \alpha_4 \alpha_5} \left\{ \frac{2 \alpha_1 (\alpha_3 \alpha_5 + \alpha_4 \alpha_6)}{\alpha_1 (\alpha_3 \alpha_5 + \alpha_4 \alpha_6) + 2 \alpha_3 \alpha_5 \alpha_6} \right\} A, \\
D &= \frac{-\alpha_6 \alpha_5}{\alpha_2 \alpha_3 + \alpha_4 \alpha_5} \left\{ \frac{2 \alpha_1 (\alpha_3 \alpha_5 + \alpha_4 \alpha_6)}{\alpha_1 (\alpha_3 \alpha_5 + \alpha_4 \alpha_6) + 2 \alpha_3 \alpha_5 \alpha_6} \right\} A.
\end{align*}$$

In (9a), (9b), and (9c) the used symbols have meanings, as follows:

$$\begin{align*}
a_1 &= \frac{j}{\eta_1} J_m(k_p a) \sin \psi \\
&\quad + \frac{j}{\eta_1} \left\{ \frac{\beta m}{a k_p^2} J_m(k_p a) - \frac{k_0}{k_p} J'_m(k_p a) \right\} \cos \psi, \\
&\quad + \left\{ \frac{\beta m}{a} K_m(r_{2-}a) - \frac{\Omega_2 r_{2+}}{\eta_2 r_{2-}} K'_m(r_{2-}a) \right\} \cos \psi, \\
&\quad + \left\{ \frac{\beta m}{a} K_m(r_{2-}a) - \frac{\Omega_2 r_{2+}}{\eta_2 r_{2-}} K'_m(r_{2-}a) \right\} \sin \psi, \\
&\quad + \left\{ \frac{\beta m}{a} K_m(r_{2-}a) - \frac{\Omega_2 r_{2+}}{\eta_2 r_{2-}} K'_m(r_{2-}a) \right\} \cos \psi, \\
&\quad + \left\{ \frac{\beta m}{a} K_m(r_{2+}a) - \frac{\Omega_2 r_{2-}}{\eta_2 r_{2+}} K'_m(r_{2+}a) \right\} \cos \psi, \\
&\quad + \left\{ \frac{\beta m}{a} K_m(r_{2+}a) - \frac{\Omega_2 r_{2-}}{\eta_2 r_{2+}} K'_m(r_{2+}a) \right\} \cos \psi.
\end{align*}$$

The above derived equation (7) can be used to determine the modal behavior in the guide, and (8a) and (8b) will determine the flux density patterns therein.

### 3. Results and Discussion

In order to obtain the dispersion behavior of fiber guide, we consider the regions (of guide) as nonmagnetic in nature and the operating wavelength to be $1.55\mu m$. Further, the chirality of nihility core is assumed to be $\pi = 1.55$, and the refractive index and the chirality impedance of clad region are taken to be $n_2 = 1.54$ and $\chi_2 = 1.7 \times 10^{-3}$ $\Omega^{-1}$, respectively, and the impedance of nihility core is taken to be as that of the free-space. As such, it remains explicit that we take into account the dielectric permittivity of the clad region to be a constant. Furthermore, we assume two different values of guide core radius, namely, $10\mu m$ and $30\mu m$, and the clad section is assumed to be infinitely extended. We first focus on the evaluation of the propagation constants corresponding to the low-order hybrid modes in the guide using two extreme values of the angle of pitch, that is, $0^\circ$ and $90^\circ$. Thereafter, the investigations are made of the flux density patterns corresponding to those modes as sustained in the guiding structure.

In order to obtain the propagation constants for the $EH_{01}$, $EH_{11}$, and $EH_{-11}$ modes, we solve the dispersion relation as stated in (7) for the range of $\beta$. The corresponding plots are, however, not incorporated into the text. Table 1 provides the finally evaluated values of the propagation constants corresponding to the low-order hybrid modes when the fiber core radius values are taken as $10\mu m$ and $30\mu m$ under the two extreme values of helix pitch angle twists (i.e., $0^\circ$ and $90^\circ$).

![Table 1: Propagation constants corresponding to particular modes.](image)

Further, for $m = 1$ and $m = -1$, $n_{eff}$ remains almost similar throughout increasing $V$, which exhibits a kind of mode degeneracy in this case.
Figure 2: (a) Dispersion behavior of guiding structure corresponding to the helix pitch $\psi = 0^\circ$. (b) Dispersion behavior of guiding structure corresponding to the helix pitch $\psi = 90^\circ$.

In order to plot these, the modal propagation constants are used, as enlisted in Table 1. We notice that these patterns have, in general, fluctuating kind of characteristics and exhibit dissipating trend as the peripheral region of core section is reached.

Figure 3(a) corresponds to the situation when the core radius of fiber guide is 10 $\mu$m and the pitch angle of helical turns attains a $0^\circ$ value; that is, the orientation of conducting wraps is just perpendicular to the direction of wave propagation. We observe that, in this case, the EH$_{01}$ mode occupies the highest flux density through the core region; it remains the maximum near the central section of guide and goes on decreasing as the core boundary is reached. Corresponding to the EH$_{11}$ mode, flux is reduced as compared to that occupied by the EH$_{01}$ mode, and also, the density maxima for the EH$_{11}$ mode are slightly radially shifted outward in comparison with that of the EH$_{01}$ mode. At the central region of guide, the flux maxima remains corresponding to the EH$_{-11}$ mode, though it bears the least intensity as compared to the EH$_{01}$ and EH$_{11}$ modes. For all the modes, flux density gets damped as the boundary of the core section is reached.

Under similar dimensional and operating features of guide, a change in helix pitch angle to $90^\circ$ brings in substantial change in the intensities of flux density corresponding to all the sustained modes under consideration, which is very much evident from Figure 3(b). We find that the intensities are much increased in this case as compared to the situation of a $0^\circ$ helix pitch angle (Figure 3(a)), and the EH$_{01}$ mode still occupies the maximum amount of energy density. The field maxima corresponding to the EH$_{-11}$ mode remain in the central region of core section—the feature as observed in Figure 3(b). For all the modes, similar to as seen in Figure 3(a), the energy density goes on dissipating as the peripheral region of core section is reached.

Flux density pattern results corresponding to an increased dimension of guide are shown in Figure 4, wherein the core section of the guide is assumed to have a radius as 30 $\mu$m. Keeping the other operating conditions unchanged, we consider the values of helix pitch angle as $0^\circ$ and $90^\circ$, and the plots of the flux density patterns are illustrated in Figures 4(a) and 4(b), respectively. We observe in Figure 4(a) that, for a $0^\circ$ helix pitch, the flux density patterns corresponding to all the modes taken into account exhibit dissipating ripples, but the overall intensities are much higher than that observed in Figure 3(a). This is essentially due to the increased dimension of the core region in this case. However, the maximum density of flux is occupied by the EH$_{01}$ mode, similar to what is noticed before for the guiding structure with lower dimension (Figure 3(a)). Also, the density maxima at the central section of guide correspond to the EH$_{-11}$ mode.

For a $90^\circ$ helix pitch angle, we observe from Figure 4(b) that the patterns of flux densities are very much similar to the case of $0^\circ$ pitch (Figure 4(a)), except the fact that...
the magnitudes are slightly increased in this case, and the density characteristic exhibits more dissipating ripples. As such, the increase of fiber dimension makes the effect due to the alteration of pitch angle lesser; guides with smaller dimension will be more effective to the variation of embedded helix pitch; this becomes quite evident when Figures 3(a) and 4(a) are observed together (a closer comparative look at Figures 3(b) and 4(b) too reveals similar aspect).

4. Conclusion

The aforementioned investigation reveals that the helix pitch angle greatly governs the wave propagation features of guides composed of the mixture of chiral nihility and chiral materials. Considering the low-order hybrid modes, the respective propagation constants are evaluated followed with the investigations in respect of dispersion properties and flux density patterns taking into account the variations in guide dimension as well as helix pitch angle. It has been found that the dispersion features of the guide are very much altered upon a change in helix pitch. The flux density patterns reveal that energy in the core section remains the maximum corresponding to the EH\textsubscript{01} mode. Also, the density patterns have ripples, and these go on decreasing as the core boundary of the guide is reached. Furthermore, the flux density gets amplified upon changing the pitch angle from 0° to 90°. This feature of such guides made of chiral nihility and/or chiral materials may find varieties of applications in optics industries.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgments

The authors are thankful to the Ministry of Higher Education (Malaysia) for financially supporting the work. Also, the
authors gratefully acknowledge the constructive criticisms made by the two anonymous reviewers, which greatly helped to improve the content of paper.

References


Submit your manuscripts at http://www.hindawi.com