PREFACE

The advent of the laser source and its exhaustive applications have created many new fascinating fields like modern fiber optics which utilizes low-loss high-silica glass optical fibers as the best transmission media available at present for optical communication systems. The most extensive applications of such systems are found to be in the telephone network, cable television, fiber-optic sensors and channeling of laser radiation for medical and technological purposes. Due to large interaction lengths and small cross-sections available in optical fibers, the threshold for different nonlinear phenomena is sharply reduced. This has enabled to observe practically all the known nonlinear optical phenomena. Many new and unique effects such as soliton mode of propagation, production of femtosecond optical pulses etc. have also come out recently. This has led to the development of low-power tunable dye and doped crystal lasers, soliton lasers and possible nonlinear optical communication lines. A thorough understanding of the dependence of nonlinear optical phenomena on the high field intensities and large interaction lengths is required for further progress in solving relevant problems.

In this dissertation, the author has theoretically analyzed a few problems related to the propagation of HE_{11}

and HE_{21} laser modes through optical fibers having different shapes of refractive index profiles. The dissertation comprises of four chapters.

At the outset of Chapter 1 a brief description of historical developments of low-loss high-silica optical fibers is given. This is followed by a summary of structure and design of optical fibers. It includes the classification of fibers into step index, graded index, monomode and multimode types. Typical values of structure parameters for each type of fibers are also listed. A brief survey of important materials for the fabrication of optical fibers is taken and the chief preparation techniques for the same have been outlined. Optical sources form an unavoidable part of the optical fiber communication system. The characteristics of the main types of optical sources are described qualitatively. The problem of coupling these light sources to optical fibers is also discussed. Finally important applications of optical fibers in a variety of fields like optical communication, optical fiber sensors and nonlinear fiber optics are described at length.

The analysis of light wave propagation in optical fibers is carried out mainly by two types of theories. In the beginning of Chapter 2 we have given a brief account of ray theory which provides a good approximation to the

light acceptance and guiding properties of optical fibers. This account includes the concepts of meridional and skew rays, acceptance angle, numerical aperture etc. This is followed by the important features and main results of the mode theory of uniform core fibers. The scalar wave equation is given and differential equations for longitudinal propagation constants β and the function of radial distance $F(r)$ are listed. These are applied to discuss the azimuthal fields in the core and cladding regions of step index and graded index fibers. The definitions of normalized frequency and normalized propagation constant are given. The classification of different types of modes is discussed and the expressions for their cutoff frequencies are listed. The power distribution within a mode is described in short. The weakly—guiding approximation and the subsequent classification of LP modes are also presented. The signal attenuation and distortion in optical fibers are explained by giving different physical mechanisms responsible for the same. At the end the problem of minimizing the pulse broadening is mentioned.

At the start of Chapter 3 we have described the importance of parabolic or nearly parabolic optical fibers in many different long distance optical communication systems.

The necessity of incorporating the effects of nonlinear optical phenomena in the design of optical fiber system is stressed. The need for examining the propagation of HE_{11} mode beam through fibers with different refractive index profiles is also mentioned.

The first refractive index profile we have considered is the distorted parabolic profile. First the expression for refractive index distribution in a parabolic refractive index profile with flat continuation is given. This is used in the parabolic equation approach to obtain the coupled equations for intensity and eikonal of HE_{11} wave. Hence, the beam-width parameter equation is obtained and solved analytically for a typical set of experimental data of various parameters and constants involved. The solution favours for a periodic focusing and defocusing of HE_{11} beam. This is true both for low and high relative distortions in the parabolic profile.

The intensity effect is taken care of by calculating the intensity induced refractive index resulting from the radial intensity distribution of HE_{11} mode. By including this additional refractive index the above set of waveguiding equations is modified. These new equations describe the nonlinear propagation of HE_{11} mode beam. The solution for beam-width parameter is again oscillatory in nature irrespective of different relative distortions.

The true parabolic optical fiber is regarded as a special case of nearly parabolic optical fiber in the event of zero relative distortion. In this case also the solutions for beam-width parameter are found to be oscillatory with and without considering the intensity effect. A comparative study of the results calculated for both true and nearly parabolic optical fibers leads to some interesting observations as listed below :

i) HE_{11} mode beam is subjected to periodic focusing and defocusing irrespective of relative distortions and including/excluding the intensity effect.

ii) With increase in relative distortion, the f^2(minimum) values decrease both for linear and nonlinear cases.

iii) On account of intensity effect the f^2 values are found to change mostly in the third or fourth significant digits. This means the self-focusing, arising due to intensity-induced refractive index, causes negligible additional confinement of the beam in an optical fiber.

Next we have studied optical fiber with triangular refractive index profile. The necessary expressions for refractive index distribution and the waveguiding equations are given both by including and excluding the intensity effect. The solutions for beam-width parameter are obtained in the two situations. In the linear propagation (without intensity effect) of HE_{11} mode beam, the beamwidth parameter is found to remain constant equal to unity. This means the triangular shape of refractive index profile has no effect on the propagation. However in the nonlinear case (including intensity effect) the solution clearly indicates a slow self-focusing effect with a long space periodicity in the fiber. This is attributed to the smallness of intensity parameter involved.

Finally we have studied in Chapter 3, the linear and nonlinear propagation of HE_{11} mode beam through an optical fiber with symmetric exponential refractive index profile. The necessary mathematical relations are given both for linear and nonlinear cases. In each case, the beamwidth parameter equation is required to be solved by the numerical method involving Taylor's polynomial series truncated at sixth order derivative. Both solutions show that there is a slow divergence of the beam during its linear and nonlinear propagations. The intensity effect is found to lower the divergence trend to a very small extent.

In the last Chapter 4 we have studied the propagation of HE_{21} mode beam through optical fibers with true and nearly parabolic, triangular and symmetric exponential shaped refractive index profiles. Our main interest in this study is to examine the effect of non-Gaussian intensity profile of HE_{21} mode on its propagation characteristics. In the beginning we have considered the case of nearly parabolic fiber and hence that of a true parabolic fiber as a special case by excluding and including the intensity effect. Expression for intensity dependent refractive index profile is established starting from the transverse field components of HE_{21} mode under weakly-guiding approximation. In each type of fiber, waveguiding equations are established for linear and nonlinear propagations. Analytical solutions of the relevant beam-width parameter equations are obtained. The behaviour of the calculated numerical values of beam-width parameter is studied in each case. The following observations are found to be noteworthy:

i) Independent of the relative distortion present in the nearly parabolic profile, f^2 values favour for periodic focusing and defocusing of HE_{21} mode beam during its linear and nonlinear propagation.

ii) The f^2(min) values decrease with the increase in relative distortion.

iii) On account of intensity effect, the changes in f^2 values occur mostly in the third significant figures or beyond. Thus the intensity effect causes insignificant additional confinement of HE_{21} mode beam.

Next we have examined the linear and nonlinear propagation of HE_{21} mode beam through a triangular refractive index profiled optical fiber. In each case the necessary waveguiding equations are given. The differential equation for beam-width parameter in linear propagation is solved analytically, while the other equation(involving intensity) was required to be solved only by a numerical method based upon Taylor's polynomial series expansion. In linear propagation, f parameter is found to remain constant (equal to unity) whereas the intensity effect leads to a slow divergence of the HE_{21} beam. The latter observation is unlike the self-focusing of HE_{11} mode arising in its linear propagation.

At the end of Chapter 4, we have investigated the HE_{21} mode propagation through an optical fiber with symmetric exponential refractive index profile. In this case, the beam-width parameter equations, both for the linear and nonlinear propagations, could be solved only by the numerical method mentioned above. Each solution describes a slow divergence of the beam, the f values for nonlinear situation being slightly greater (from third decimal place onwards) than those for linear propagation. It is unlike the lowering of f values in HE_{11} case.

From our study presented in Chapters 3 and 4, we have noted the following findings :

a) Independent of relative distortion in parabolic optical fibers, HE_{11} and HE_{21} mode beams individually undergo periodic self-focusing whether intensity effect is included or not. The contribution of intensity effect to self-focusing phenomenon is found to be negligibly small. Relatively speaking this effect is slightly less in HE_{21} beam focusing than that for HE_{11} case. This can be attributed to the 'opposite' shapes of irradiance distributions of the two modes. As against the Gaussian intensity profile of HE_{11} mode, there is a less intensity confinement around the axis of HE_{21} mode beam.

b) Both HE_{11} and HE_{21} mode beams are subjected to a uniform linear propagation in the optical fiber with triangular refractive index profile. The intensity effect however causes HE_{11} mode beam to undergo a slow self-focusing with a long space periodicity, whereas the HE_{21} mode beam is subjected to a slow divergence. This difference in the behaviour can again be explained on the basis of 'opposite' shapes of intensity profiles of the two modes.

c) In optical fiber with symmetric exponential refractive index profile, both HE_{11} and HE_{21} mode beams experience a slow divergence during their linear and nonlinear propagations. Nevertheless, the intensity effect is found to lower the divergence trend of HE_{11} beam, while it enhances the divergence of HE_{21} beam although to a very small extent in each case.

All the calculations of f values reported in Chapters 3 and 4 have been carried out by using appropriate simple computer programs in BASIC which have been run on WIPRO PC available in the Department of Physics, Shivaji University, Kolhapur.