# CHAPTER 6. CONCLUSIONS AND SUGGESTIONS FOR FURTHER INVESTIGATIONS

## 6.1 CONCLUSIONS

In coherent optical fiber communications and polarization-sensitive fiber-optic sensing devices, single-mode fibers that maintain state of polarization along their length are required. In optically amplified lightwave systems where high output power erbium-doped fiber amplifiers and multi-channel dense wavelength division multiplexing are used, the fiber of choice is the one that offers single-mode operation with both low dispersion and low loss, and is less susceptible to nonlinear effects.

In this dissertation, the issues of maintaining polarization and polarization-mode dispersion in fibers have been discussed. Analysis and design of optical fibers that maintain polarization over long lengths, provide zero polarization-mode dispersion, and function as polarizers or mode filters have been presented. The solution to maintaining polarization in fibers is achieved by optical fiber designs that provide either high birefringence with single-mode operation or single-polarization single-mode operation. The polarization-maintaining fiber designs presented are of dispersion-shifted, dispersion-flattened, and dispersion-unshifted types. The zero polarization-mode dispersion single-mode design is a dispersion-shifted fiber that provides large effective area and hence reduces signal distortions due to nonlinearity in fibers. Also a wedge-shape waveguide structure with arbitrary wedge angles has been proposed for applications as a mode filter and polarizer. It employs mixed boundaries of metal and dielectric materials.

In the first part of the work, designs for high-birefringence and single-polarization single-mode fibers have been addressed. The designs are based on multiple-clad geometries with the core and inner cladding regions being anisotropic due to induced stress. Refractive-index profiles with double and triple-clad structures were studied and optimized. The fiber designs were optimized for the two types of polarization-maintaining fibers in order to achieve high-birefringence fibers and single-polarization single-mode fibers with zero or very small dispersion at about 1.3 μm and 1.55 μm wavelengths. For the optimum designs, the propagation constant, cutoff wavelength, and dispersion characteristics were evaluated. The smallest birefringence obtained with zero dispersion is $1.48\times10^{-4}$. Also, single-polarization single-mode fibers with nearly zero or zero dispersion at about 1.3 μm and 1.55 μm have been realized using three different index profiles. For these designs, the wavelength range for single-mode and single-polarization operation is 100 nm to 500 nm [117].

In the second part of the work, a comprehensive analysis of polarization-mode dispersion in multiple-clad fibers due to ellipticity of fiber cross-section was carried out using a perturbation technique. The design of large effective area single-mode dispersion-shifted fiber that provides zero polarization-mode dispersion at the wavelength 1.55 μm was accomplished using the analysis developed. The refractive-index profile chosen for this design is depressed core with multiple-claddings. In addition to zero polarization-mode dispersion, the design also provides small chromatic dispersion, large effective area, and low bending loss. Chromatic dispersion of 0.65 ps/nm.km with a slope of 0.055 $ps/nm^2.km$, effective area on the order of 122 $\mu m^2$, and mode-field diameter of about 10 μm have been attained at 1.55 μm. Tolerance analysis on the transmission parameters, including, polarization-mode dispersion, chromatic dispersion, effective area, and mode-field-diameter, due to ±1% and ±2% variations in the radii of the fiber layers were carried out. In general, the results of this analysis show that variations in the thickness of second inner cladding layer's radius have negligible effect on the transmission parameters considered. The effects of central core and the first inner cladding on the transmission parameters are more pronounced but are reasonable.

In the third and last part of the work, a comprehensive modal analysis of wedge-shape dielectric waveguides bounded by conducting planes was carried out. Propagation constant, single-mode frequency range, cutoff frequency, conductor and dielectric losses were evaluated for the fundamental mode in waveguides with wedge angle of $2\pi/3$, and $\pi/n$; $n \geq 1$, as example cases [118]. Wedge-shape waveguides, compared to the hollow circular waveguide, can be operated at higher frequencies or may assume larger core sizes, while maintaining single-mode regime. These waveguides generally support fewer number of modes for smaller wedge angles and the TM modes are extinct.

## 6.2 SUGGESTIONS FOR FURTHER INVESTIGATIONS

The analysis of polarization-mode dispersion presented here accounts for fiber cross-section elliptical deformations. However, in addition to core ellipticity, random residual stress also contributes to polarization-mode dispersion. Thus, the analysis of polarization-mode dispersion should be extended to random anisotropy in the fiber.

An important task to be pursued is the experimental verification of the designs presented here. This task, however, can only be performed in collaboration with fiber manufacturing industries.

The effect of finite conducting planes on propagation properties of the wedge-shape waveguide is a matter that is worth investigating and comparing the results with what have been presented in Chapter 5.