Abstract

This work focuses on the structures of photonic and multicore photonic crystal fibers, concepts related to the propagation, production and manipulation of light, and the operation of photonic devices. Multicore photonic crystal fibers are used as routers, switches, transmitters, couplers, splitters, multiplexers and demultiplexers, all of which are devices required in optical communication systems. All of the designs of photonic and multicore photonic crystals fibers presented here were realized by using COMSOL MULTIPHYSICS software, based on the finite element method,to analyze the characteristics of the propagation of light within the structure of a photonic crystal fiber. Moreover, the work entitled "Numerical Investigation of Light Propagation in Photonic Crystal Fibers" includes all of these concepts.

In the first chapter, we present a theoretical design of a photonic crystal fiber consisting of one core, and we then examine the properties of propagation in this fiber. We alter the engineering parameters of the structure, such as the pitch, hole diameter, and the number of rings of the hexagonal lattice, and observe the extent to which these parameters affect the properties of propagation in the fiber. We note the changes that occur in both the effective refractive indices of the modes and the field distribution of the fiber due to the changes in these parameters. It is possible that changes in the fiber parameters may affect the loss of confinement, as well the properties of dispersion within the fiber, since it is easy to manipulate these parameters to control dispersion over a wide range of wavelengths or to flatten the dispersion curve. In this way, we were able to design different system based on structures that would be useful in specific applications within optical communication systems such as dispersion engineering, fiber lasers, Bragg gratings, and sensors.

In Chapter 2, we report the theoretical design of a multicore photonic crystal fiber consisting of two cores, in the same way as a directional coupler, and study the properties of the propagation and coupling in this fiber. Again, we vary the engineering parameters of the structure, such as the pitch, hole diameter, core separation, and wavelength, and observe the extent to which these parameters affect the properties of propagation and coupling between the cores of the fiber. The theoretical approach used in this work provides many advantages compared to conventional optical fibers. It is possible to design photonic crystal fibers with very small coupling lengths of micrometer, as compared with the coupling lengths of hundreds of millimeters obtained when designing optical fibers. Based on these designs, we can realize devices such as routers, couplers, multiplexers, and demultiplexers.

In Chapter 3, geometric designs are presented for photonic crystal fibers, including nonlinear light propagation in these fibers, such as the propagation of soliton pulses, self-focusing, switches in photonic crystal fibers. Investigate the propagation of soliton pulses and supercontinuum generation in the fiber, the dispersion observed, and by using higher pulse power

results as increasing in the bandwidth of the fiber spectrum, this generation has extensively applied in specialized fields such as optical coherence tomography, spectroscopy, and optical frequency metrology. The limits on the power for self-focusing in a photonic crystal fiber were also the subject of our research in order to illustrate the relationship between the changes in the refractive index of the material and the intensity of the light. The results indicate that although the refractive index is independent of the intensity at low input intensities, the introduction of high intensities to the fiber leads to a change in the refractive index, and linear behavior is seen in the intensity due to the optical Kerr effect. The self-focusing effect shows that the contrast in the induced actual refractive index is much greater than the nominal value of the induced refractive index. Self-focusing appears to be dominant in the structure of the photonic crystal fiber at a certain intensity, where it is balanced out by diffraction and the diffraction beam is limited. Switching with different levels of power indicate that the supply of low power to the coupler leads to linear switching of the power between the two cores of a coupler, while the use of high power leads to uncoupled power and nonlinear switching between the two cores. All of these results can be useful in photonic circuits in optical communication applications.

In Chapter 4, the idea of light propagation in multicore photonic crystal fibers consisting of more than two cores is examined using three and seven cores. We designed several different geometric shapes for multicore photonic crystal fibers, such as identical and non-identical coupled cores. We then manipulated the geometric parameters such as the control parameters, the diameter of the central core, and the anisotropy in all core diameters in order to gain a clear insight into these aspects. Our approach allows us to predict mode propagation in coupled multicore photonic crystal fibers designs, which offers the potential to control the properties of coupling between the cores. We can enhance the coupling of the cores and overcome the differences in the structure that cause mismatching of modes, which inhibits coupling and causes the modes to become uncoupled. Through these designs, we found that the coupling length for a structure with non-identical cores is lower than for one with identical cores, and this result may be useful in optical communication systems when coupling systems with cores that are somewhat different. We also induce a small mismatch between the modes, showing that this suppresses coupling in such a way that the modes become uncoupled via changes in the diameters of all cores, allowing the light mode to propagate independently of its neighbors. We found that by increasing the wavelength to the communication wavelength, it is possible to overcome the problem of suppression of coupling between cores, even if all of the cores are different, and these results may be useful in applications relating to communication systems, such as couplers, splitters, and multiplexer-demultiplexer photonic crystal fibers, and in particular multiple-input multiple-output processing applications.

We also designed a new model consisting of seven non-identical cores in order to achieve greater coupling between cores, with anisotropy in the diameter of the central core relative to the rest of the outer cores, and observed its behavior at different wavelengths in order to overcome the suppression of coupling between the cores and to enable the use of this design as a multiplexer and demultiplexer. We found that there was strong coupling between the central core and some of the outer cores when the propagation constants were nearly equal, especially at longer wavelengths, and the coupling was suppressed between the seven cores at shorter wavelengths. We found that the coupling length for fibers with seven non-identical cores structures took on different values, and was sometimes higher or lower than in the structure with identical cores at longer wavelengths, while the coupling length had a value of zero at shorter wavelengths in both cases (i.e. identical and non-identical cores). Despite this, we were able to achieve coupling between the seven cores, even though their diameters were non-identical, and this finding will be useful for optical communication devices when coupling systems with cores that are somewhat different.

In addition, we introduced anisotropy into all seven-core diameters of the PCF coupler by changing the diameters of all cores, to break the potential any suppression, and found from the results strong or weak coupling between the central core and some of the outer cores with propagation constants that were nearly equal. We also found that the coupling was strong/weak between some outer cores, and sometimes the outer cores did not show coupling, and this was more evident at longer wavelengths. Coupling was observed to be suppressed between the seven cores, and each core remained isolated in its place without coupling to other cores, with possibly a slight penetration of some of the adjacent cores, and this is more clearly shown at shorter wavelengths. The coupling strength was evaluated as a function of the wavelength, and the length of the device with non-identical cores was shorter than the one with identical cores. This makes it possible to design a multicore photonic crystal fiber coupler with coupling lengths on the order of micrometers, that is, much shorter than a conventional optical fiber coupler which has coupling lengths in millimeters. Such a structure would be useful in applications such as multiplexers and demultiplexers, or could be used as a power coupler in a wavelength division system.

This work on photonic crystal fibers, and especially multicore photonic crystal fibers, has many advantages that will be useful in the development of optical communication systems, and continuous research on this topic will provide an important basis for the expansion of scientific knowledge in the field of photonic circuits.