Analysis of Dispersion and Confinement Loss in Large Mode Area Photonic Crystal Fiber

Purvi Mishra[1]
[1]M.Tech Scholar (DWCE),
Suresh Gyan Vihar University, Jaipur
mishra2701purvi@gmail.com

Mrs. Sandhya Sharma[2]
[2]Associate Professor E.C.E.
Suresh Gyan Vihar University, Jaipur
sandhyasharma.mbm@gmail.com

Mrs. Dimple Bansal[3]
[3]M.Tech Scholar (DC)
RCEW, Jaipur
dimple.bansal2009@gmail.com

Abstract: 7-rod core fibers are obtained by removing the air-holes belonging to the first ring and the central one in the fiber cross-section. Dispersion for triangular photonic crystal fibers with different core dimensions has been observed. Triangular photonic crystal fibers are single mode for a fixed air filling fraction for a small wavelength range and thus, the endlessly single mode region of 7-rod core triangular fibers is smaller than that of the 1-rod core. Though, the 7-rod core photonic crystal fibers can provide high effective area values and single mode operation by properly choosing low air filling fraction and relatively small hole to hole distance. In this paper we compare the dispersion and confinement loss of two types of 7-rod core photonic crystal fibers with that of 1-rod core.

Key Words: dispersion, 1-rod core, 7-rod core

1. INTRODUCTION

Generation and delivery of high power beams have always been a priority and in the recent years their application has also increased. For example: optical lasers, amplifiers, laser welding machines have seeb increased use of this technology. For such applications, fibers with large mode size are required. These fibers are known as Large Mode Area (LMA) fibers. These fibers support high optical intensities and help in limiting the non-linear effect.

A large mode area can be achieved either by reducing the numerical aperture, that is by lowering the percentage of doping material in the core region, or by increasing the core dimension. The endlessly single mode property can provide the single mode operation. But an upper limit on the guided mode area exists because of the value of losses. In fact, the air filling fraction decrease can cause an increase of the leakage losses.

Another method of fabricating LMA fibers is offered by photonic crystal fibers (PCFs). These consist of an array of air-holes running along their entire length, which provides the confinement and guidance of light. Previous works have been done in the field of LMA by removing 3 air-holes in the center of the fiber. These fibers provided an enhancement of the guided mode area of about 30% and a higher value of robustness when scaled to a larger pitch. But the drawback provided by this kind of fiber was that their ESM region of these is smaller than that of the traditional triangular fibers, being limited by d/pitch < 0.25.

It has been demonstrated in previous works that triangular PCFs with single rod core can be made Endlessly Singe Mode (ESM). In this mode the fiber support the propagation of just the fundamental mode whatever the wavelength or the pitch value might be. Previous research works on the cutoff properties of the 1-rod core triangular PCFs have shown that their ESM region is defined by d/pitch < 0.406 [1].

Figure1: 1-rod core layout

By narrowing the air-holes for a fixed pitch or by enlarging the pitch for a fixed d/pitch value, it is possible to increase the PCF effective area. But because of the losses an upper limit on the guided mode area exists. That is because the decrease in the air-filling fraction causes an increase of the leakage losses and as the pitch increases losses induced by microbending and macrobending increases. To overcome these problems another LMA PCF with 3-rod core was introduced. But as described earlier it suffered from the drawback of the larger silica core dimension.

To overcome all these problems, recent works are being done on another LMA with 7-rod core. Simulation results have shown that for a fixed d/pitch value the single mode region for 7-rod core PCFs is smaller than that of the traditional triangular fibers. The endlessly single mode regime for the 1-rod core PFC is defined by d/pitch < 0.406 while for large core triangular PCFs d/pitch is < 0.035.

2. DISPERSION

Phase or group velocities of waves are frequency dependent. In simple terms, dispersion refers to the entire phenomenon that cause light pulses to spread while they are propagating.

Some of the main reasons of dispersion are:

Material dispersion: the signal that travels through the fiber is superposition of a range of frequencies that are centered on the frequency of the modulated light source. This dispersion leads to pulse spreading and deformation since the spectral components of the pulse propagate at different speeds.

Inter-modal dispersion: the quantity β is known as the propagation constant. In a multimode fiber, different modes are associated with different values of β for a given wavelength. This difference leads to pulse spreading or echoing.

Waveguide dispersion: since different modes have different propagation constants, they depend on different wavelengths. This results into each mode of waveguide having different waveguide dispersion. When single mode fibers are being considered, waveguide dispersion of the fundamental mode is of importance.

Polarization mode dispersion: the single mode symmetric fibers carry two degenerate modes. This type of dispersion occurs between modes that are originally degenerate. Thus, this is a phenomenon that is almost similar to that of intermodal dispersion. Because of stress, tension or bends, the degeneracy between the modes is disturbed and leads to inter-modal dispersion.

Chromatic dispersion: this is the dispersion that results from the combined effects of material and waveguide dispersions.

Dispersion is thus harmful for the signals traveling in the fiber. So, research works are in progress to design such fibers in which the light signal do not suffer much because of the dispersion. Thus, work is concentrated on obtaining fibers that have flat near zero dispersion.

3. DESIGNS FOR DISPERSION COMPENSATION

Here, in this paper, we have compared the dispersions obtained for 1-rod core fibers and 7-rod core fibers. As the number of air-hole rings is increased in the fiber dispersion reduces. Furthermore, when the dimensions of the core are increased almost flat graphs for dispersion are obtained.

We have worked on two designs with different values of d/Λ.

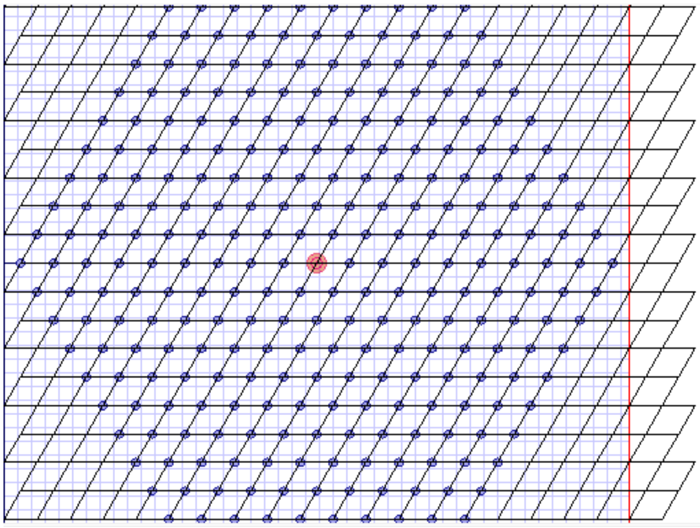

Figure2: d/Λ=0.25, λ=1.55, d=0.60, Λ=2.4. 1-rod core with 9 rings

The figure above shoes the layout for the 1-rod core with 9 rings. Similar layouts have been made for 7-rod core with 9 rings.

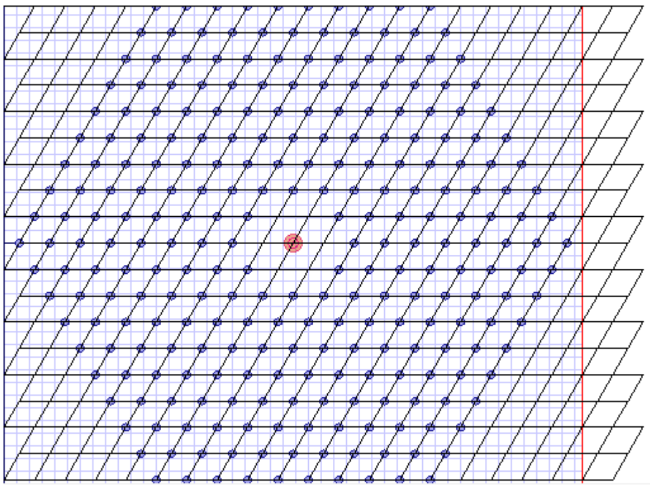

Figure3: d/Λ=0.25, λ=1.55, d=0.60, Λ=2.4. 7-rod core with 9 rings

In the next layout, the shape of the air holes has been changed and is square instead of circular. It has been found that the dispersion curve obtained from this layout has a reduced slope than its counterpart with circular air-holes [2][3].

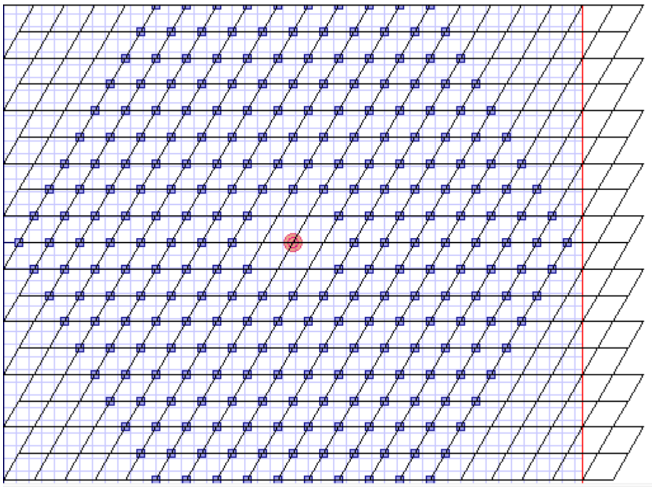

Figure4: d/Λ=0.25, λ=1.55, d1,d2=0.60, Λ=2.4. 7-rod core with 9 rings

The resulting dispersion curves are as follows:

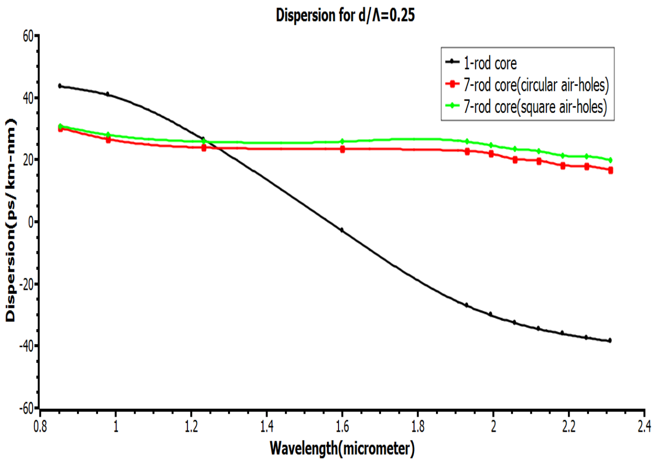

Figure5: Dispersion when d/Λ=0.25

Thus, the result obtained for the 1-rod core has more slope than those obtained for 7-rod cores.

Different results have been obtained for different values of d/Λ. The next figure shows the result for dispersion values obtained when d/Λ=0.33.

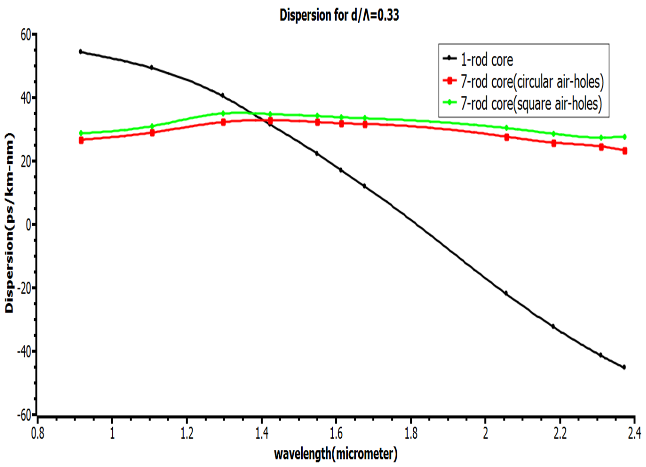

Figure6: Dispersion for d/Λ=0.33

To see how the dispersion values changes with the different values of d/Λ a comparison between dispersion curves for 1-rod core has been showed below:

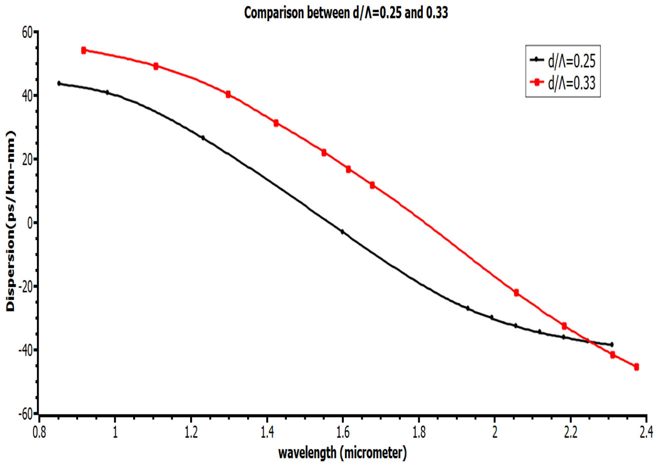

Figure7: Dispersion comparison for d/Λ=0.25 and 0.33

Thus, it is clearly visible from the figure above that the dispersion slope as well as dispersion at our working value λ=1.55 is high for d/Λ=0.33 as is shown in previous works [4] [5].
Similarly, the curves for confinement loss are shown below:

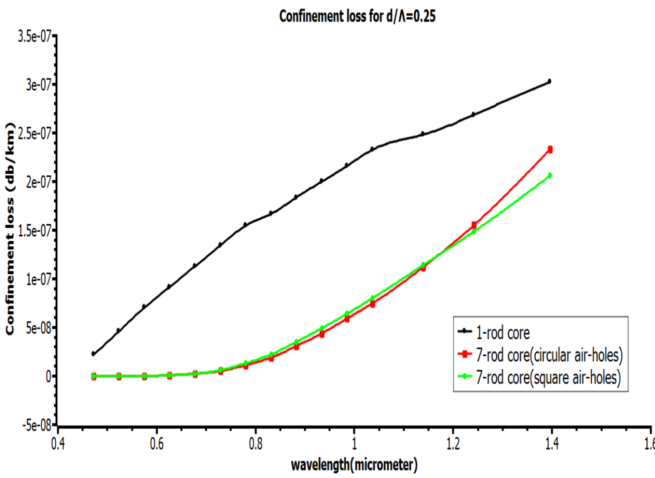

Figure8: Confinement loss for d/Λ =0.25

As we can see from the figure above that the value of confinement loss decreases for large mode area fibers. Same type of comparisons have been done for d/Λ=0.33.

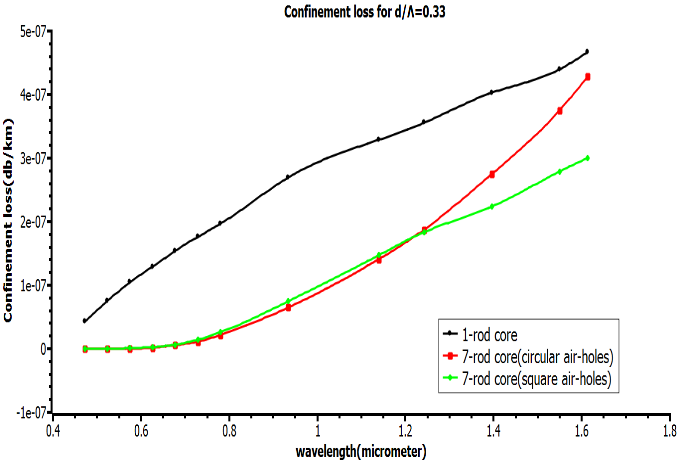

Figure9: Confinement loss for d/Λ =0.33

The figure above shows the values of confinement loss for d/Λ=0.33. To see the change that occurs in the values of confinement loss with the change in value of d/Λ, we compare its value for different d/Λ.

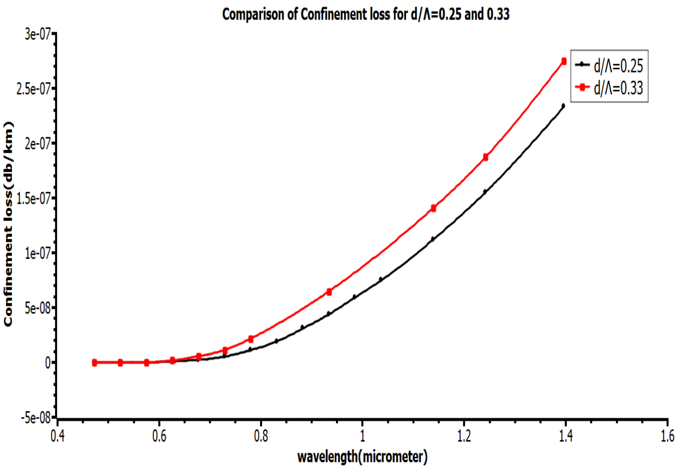

Figure10: Confinement loss comparison for d/Λ =0.25 and 0.33

The figure above shows that when the value of d/Λ increases the confinement loss also increases.

4. CONCLUSION

In this paper we have shown dispersion and confinement loss as a function of wavelength. It is found that dispersion increases as the area of the core increases, though the graph is flattened for a large range of wavelength. Thus, we can say that the large mode area fibers are better for dispersion compensation. From figure 7, it can be seen clearly that as the value of d/Λ increases, dispersion increases. In the case of confinement loss, it can be seen from the graphs clearly that its value is lower for large mode area. Similarly, as d/Λ increases, confinement loss also increases.

5. REFERENCES

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