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Design and Fabrication of Optical Fibers by Opti-Wave Modelling Software and Simulation of Their Parameters

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Abstract— **Corning's SMF 28 fiber deployed by 47 countries world wide in 2001 has become absolute. Now a days transmission speeds has gone 100 Gbps to 1 Tbps. To cater for such high-speed advance and specialty fibers are required. This paper describes design and fabrication of such fibers by modelling software i., e., Opti-Wave software (Opti-fiber). The simulated performance of these fibers is compared with SMF 28 fiber and it is established that these fibers are far superior to SMF 28 fiber.**

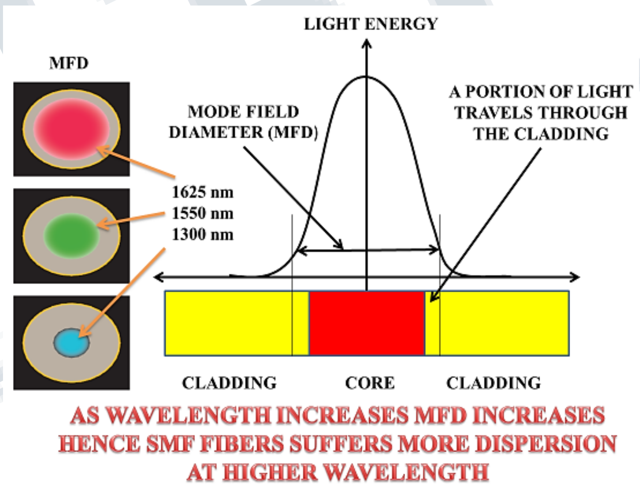
Keywords— **Optical Fibers, Opti-Wave Modelling, Software and Simulation**

I. INTRODUCTION

Use of optical fiber in Fiber Optics Communication System require selection of a specialty fiber for use in a specific application. In Telecommunications using specific fiber as a transmission medium is a very important considerations and fiber optic industry is now fully committed for use of specialty fibers in optical communications which is a major industry now a days, Optical fiber cross sectional dimensions, material composition and refractive index profile all influence the losses, dispersion, and the non -linearities of the fiber and must be chosen carefully to achieve a satisfactory trade off for a given optical fiber communications network and for it is specific applications. Now it is possible to design, fabricate and simulate specialty fibers for a specific application by modelling software like Opti -wave software. In this research we have used Opti-Wave (Opti Fiber) software to fabricate various advance refractive index profiles and then simulated various important fiber parameters to know the performance of the fiber in the field. Before going into the details, we are defining two important fiber parameters as follows:

1.1 MFD:

The mode field diameter (MFD) represents a measure of the transverse extent of the electromagnetic field intensity of a mode of light in a fiber cross section. In optical fiber, this typically is larger than the fiber core, since a portion of the light propagates through the cladding. The MFD is determine by international standard measurement of Peterman II method, a rigorous approach that calculates MFD by integrating the actual intensity distribution over the range of far field angles.



1.2 Effective Area:

Effective area is not just the geometric transform of the MFD (the old πr^2- sometimes called the mode field area [MFA]). Rather, it is a mathematical representation of the light transmitting area calculated with respect to a fibers response to nonlinear effects, primarily self-phase modulation (SPM) and four wave mixing (FWM). Thus, the effective area is different for each type of fiber, based primarily on that fibers refractive index profile and the input wavelength. The effective area has been empirically determined to be typically in the range of 95-104% of the MFA, though it has been shown to be as much as 111% of the MFA. It is possible to empirically determine a mapping relationship between MFD and the effective area, but this relation is wavelength dependent. The general relation is as

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follows:

A_{eff} = k(ʎ)[π/4] MFD^2

Where: k(ʎ) is the mapping value and MFD is determined by Peterman II method.

Following are the main fiber parameters which we are discussing and simulated for a specific fiber refractive index profile (we have simulated all fiber parameters but not all were discussed in this paper)

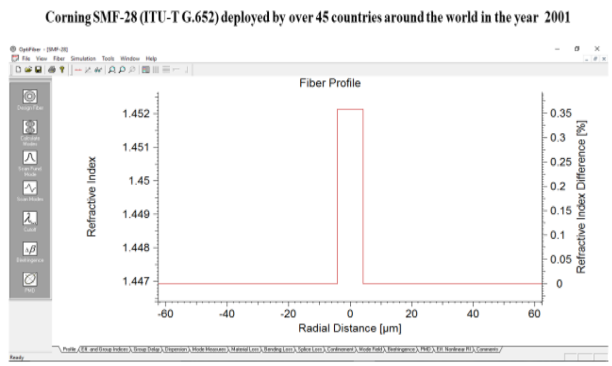
1. Refractive index of the fiber itself for a specific application
2. Dispersion (Zero dispersion wavelength)
3. Effective Mode field diameter (MFD) (At 1300 nm and at 1550 nm)
4. Effective area (Aeff) (At 1300 nm and at 1550 nm)
5. Material loss (Attenuation Vs Wavelength curve)
6. Bending loss
7. Cutoff wavelength

II. ANALYSIS OF DESIGNED AND FABRICATED FIBERS BY OPTIWAVE SOFTWARE:

As per the theory of fiber optics communications we will now critically examine the optical fibers which we have made with the help of Opti -wave software. All of the fibers made are advanced fibers for specific application in fiber optics communication systems. We will also be comparing each fiber with the standard single mode fiber (corning SMF-28 ITU-T G.652), which was deployed in 2001 by over 47 countries worldwide and this fiber till today is operational everywhere. But as on today with the speed of 100 Gbps and 500 Gbps this fiber is becoming absolute Today there is a requirement to install new advanced fibers as per the specific application of fiber optics communications Systems. Next slides consist of step index refractive index profile of SMF 28 and all standard parameters of SMF 28 fibers.

III. SALIENT FEATURES OF SMF-28 FIBERS ARE AS FOLLOWS:

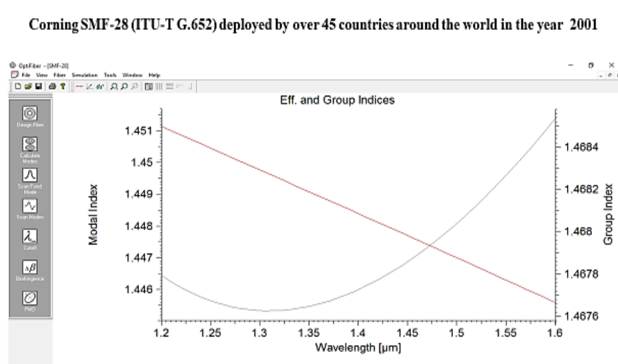
1. Zero dispersion (chromatic dispersion, CD) at 1310 nm ʎ
2. At 1550 nm total dispersion is 17 ps/nm.km
3. Effective area at 1310 nm is 65 sq µm at 1550 nm effective area is 77.5 sq µm (LEAF)
4. MFD at 1310 nm is 8.75 µm at 1550 nm it is 13 µm
5. It is a low water peak fiber. Total attenuation at 1310 nm and 1550 nm is 0.4 dB/KM and 0.25 dB/km
6. Macro bending loss is almost zero, as the wavelength increases there is a slight increase in micro bending loss.
7. Total splice loss is almost zero.
8. Differential group delay (DGD) is constant over entire wavelength range of interest.
9. Effective nonlinear refractive index decreases as the wavelength increases.
10. $ʎ_{cutoff}$ at 1.33205 µm



REFRACTIVE INDEX PROFILE OF THE FIBER SMF 28

SM Step index Fiber Refractive index profile:

Single mode step-index fibers propagate only one mode, called the fundamental mode. Single mode operation occurs when the value of the fiber's normalized frequency is between 0 and 2.405. The value of V should remain near the 2.405 level. When the value of V is less than 1, single mode fibers carry a majority of the light power in the cladding material. The portion of light transmitted by the cladding material easily radiates out of the fiber. For example, light radiates out of the cladding material at fiber bends and splices.



EFFECTIVE AND GROUP INDICES

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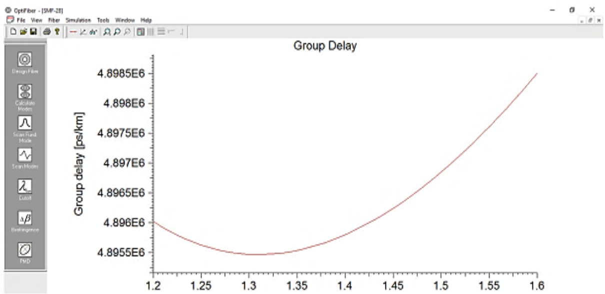
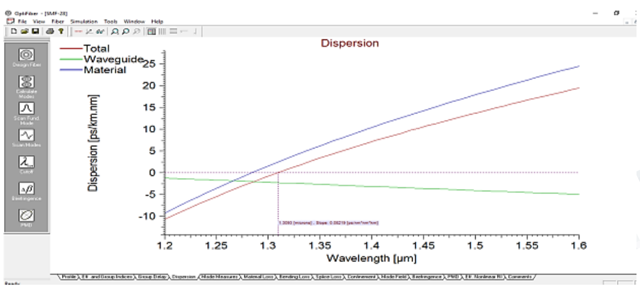
Corning SMF-28 (ITU-T G.652) deployed by over 45 countries around the world in the year 2001



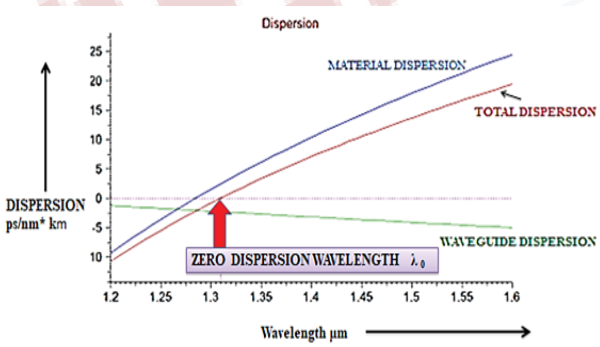
GROUP DELAY

Corning SMF-28 (ITU-T G.652) deployed by over 45 countries around the world in the year 2001



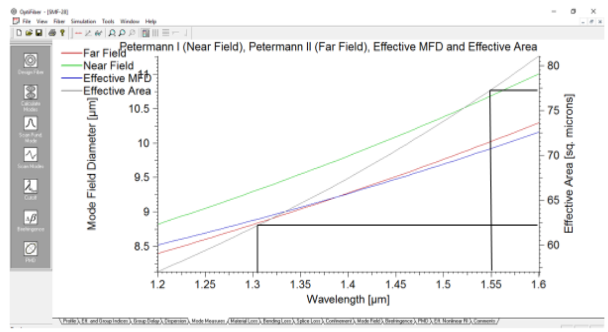
DISPERSION

Zero-dispersion Wavelength --- In a single-mode optical fiber, the wavelength at which material dispersion and waveguide dispersion cancel each other out. The wavelength of maximum bandwidth in the fiber. Also called zero-dispersion point.

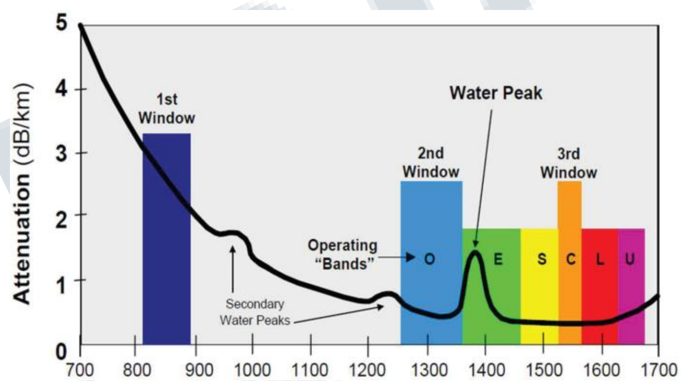


TOTAL CHROMATIC DISPERSION OF A SINGLE MODE FIBER, MATERIAL+WAVE GUIDE DISPERSION

Corning SMF-28 (ITU-T G.652) deployed by over 45 countries around the world in the year 2001

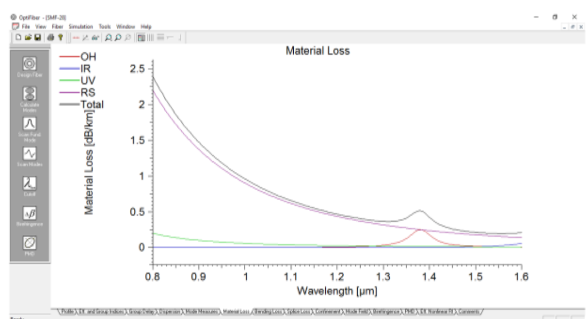


MFD AND EFFECTIVE AREA OF FIBER



ATTENUATION: MATERIAL LOSS

Corning SMF-28 (ITU-T G.652) deployed by over 45 countries around the world in the year 2001



MATERIAL LOSS

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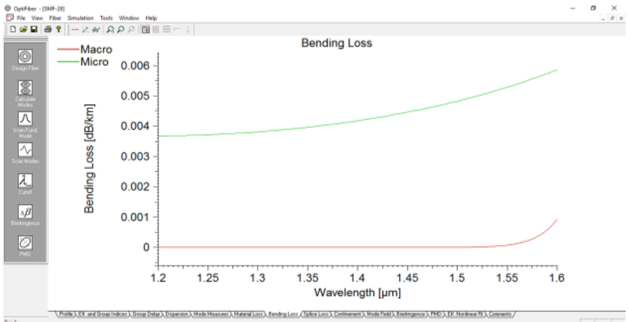
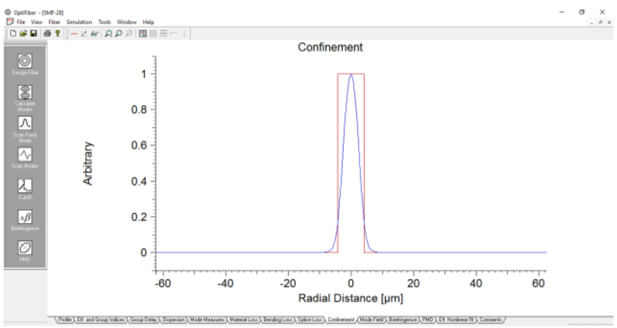


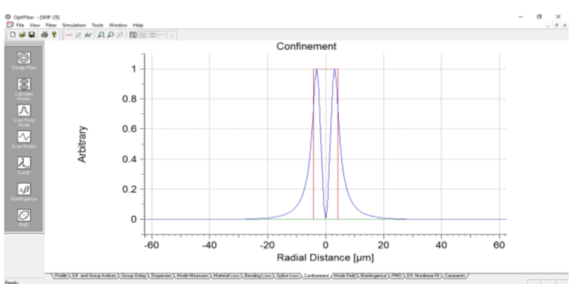
BENDING LOSS

Corning SMF-28 (ITU-T G.652) deployed by over 45 countries around the world in the year 2001



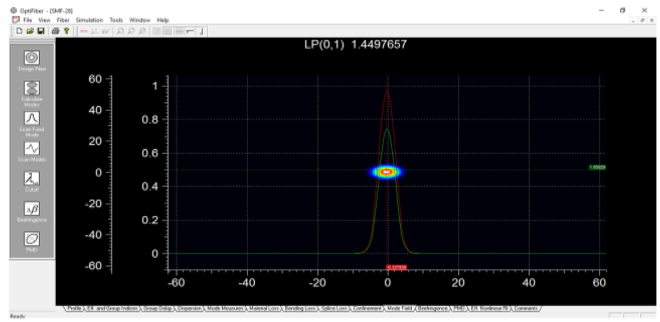
MODE CONFINMENT (FUNDAMENTAL MODE)

Corning SMF-28 (ITU-T G.652) deployed by over 45 countries around the world in the year 2001



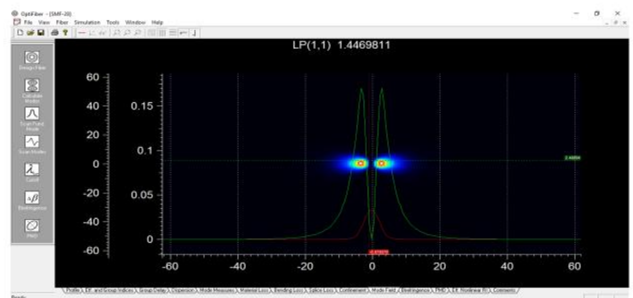
MODE CONFINMENT

Corning SMF-28 (ITU-T G.652) deployed by over 45 countries around the world in the year 2001



MODE FIELD (FUNDAMENTAL MODE)

Corning SMF-28 (ITU-T G.652) deployed by over 45 countries around the world in the year 2001



MODE FIELD

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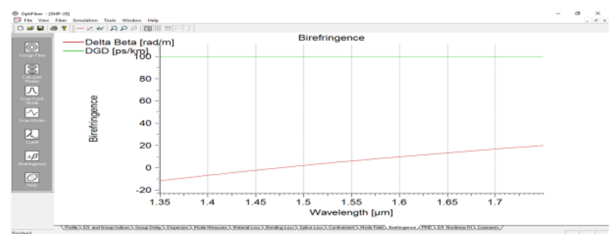
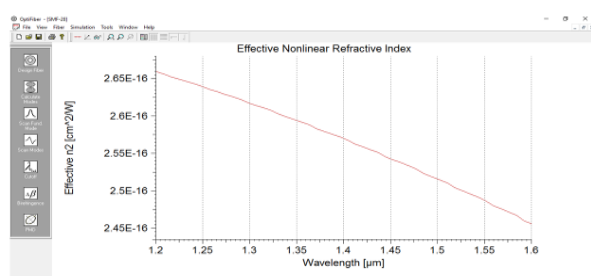


BIREFERINGENCE

Corning SMF-28 (ITU-T G.652) deployed by over 45 countries around the world in the year 2001



EFFECTIVE NONLINEAR REFERECTIVE INDEX

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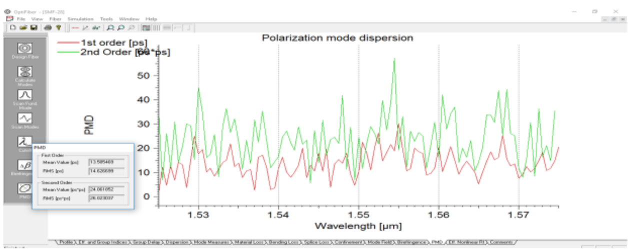
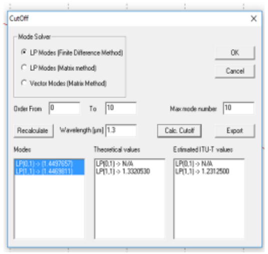


PMD (1st AND 2nd ORDER)

Corning SMF-28 (ITU-T G.652) deployed by over 45 countries around the world in the year 2001



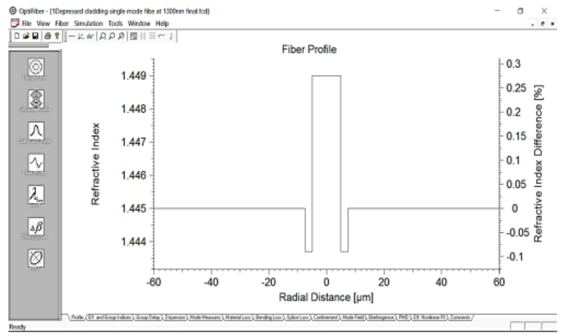
CUT OFF WAVELENGTH

SMF 28 fiber is suitable for both 1310 nm and 1550 nm λ of operation. But its optimized for 1310 nm operation. It can also be used effectively with both TDM and WDM systems.

It may be noted that we have identified all fabricated fibers based on zero dispersion wavelength of each fiber. We will only be discussing the important parameters of fabricated fibers.

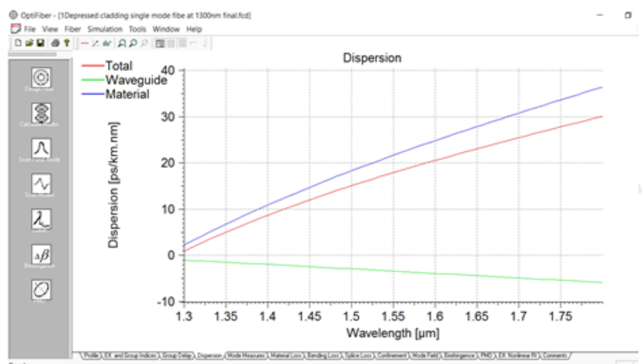
1. **1st fiber fabricated** has depressed cladding SMF zero dispersion at 1300 nm. Important simulated fiber parameter are as follows:
    1. Zero dispersion (CD) at 1300 nm at 1550 nm CD is 17 ps/nm.km
    2. Effective area at 1300 nm is 77.5 µm sq and at 1550 nm it is 94 µm sq. Effective area is largen than SMF 28 fiber and **at** 1550 nm it is LEAF.
    3. At 1300nm total material loss is o.3 dB/km and at 1550 nm it is 0.25 dB/km almost same as SMF 28 fiber.
    4. Micro and Macro bending losses are zero for entire wavelength range from 1300 nm to 1650 nm (one important difference in comparison of SMF 28 fiber)
    5. **5.** Important Note- This fiber is especially suitable for FTTH systems for last mile connectivity where fibers are frequently bent as per the requirements of house installation.

Depressed cladding SMF fiber zero dispersion at 1.3 µm



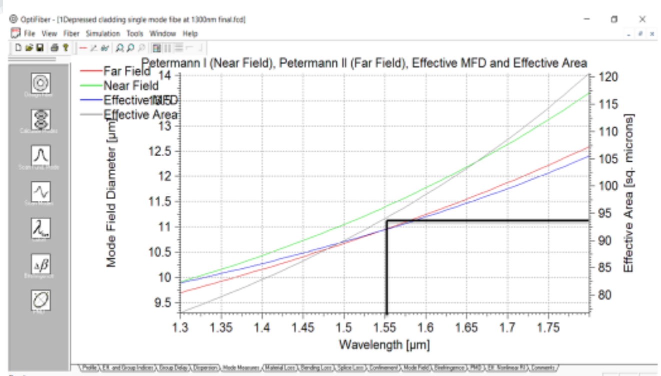
REFERACTIVE INDEX PROFILE

Depressed cladding SMF fiber zero dispersion at 1.3 µm



DISPERSION

Depressed cladding SMF fiber zero dispersion at 1.3 µm



MFD AND EFFECTIVE AREA

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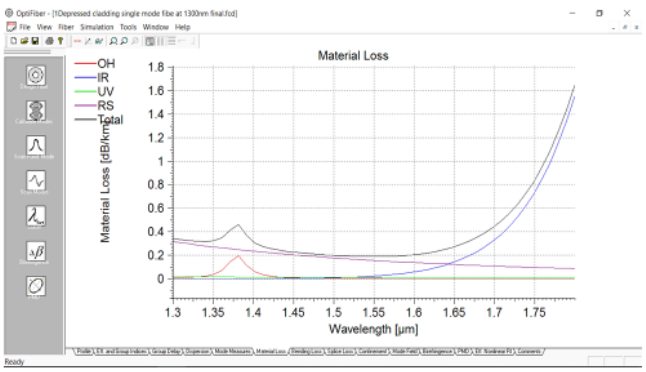
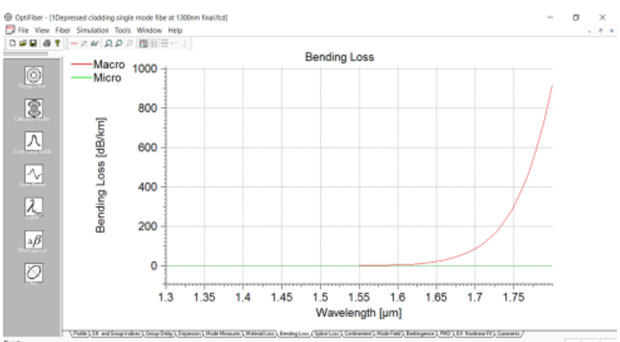
Depressed cladding SMF fiber zero dispersion at 1.3 µm



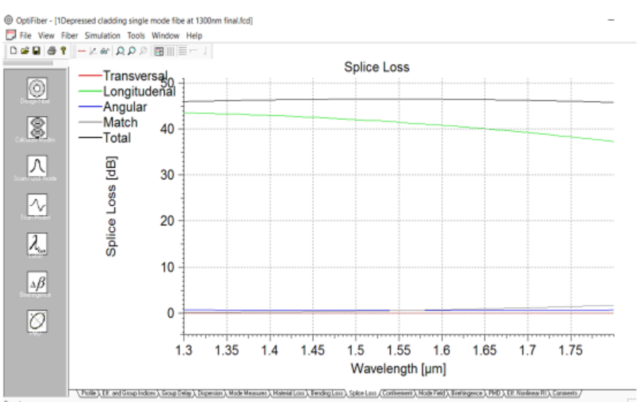
MATERIAL LOSS

Depressed cladding SMF fiber zero dispersion at 1.3 µm



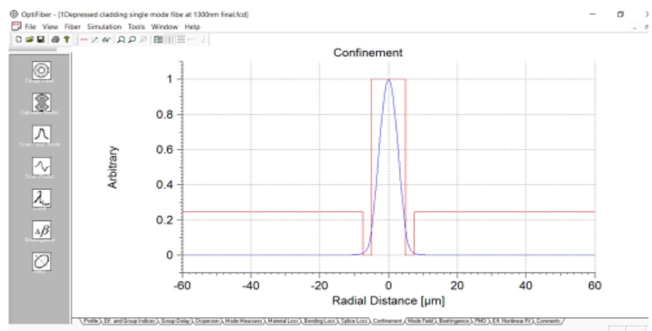
BENDING LOSS

Depressed cladding SMF fiber zero dispersion at 1.3 µm



SPLICE LOSS

Depressed cladding SMF fiber zero dispersion at 1.3 µm



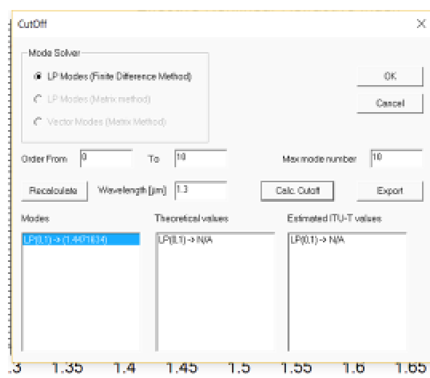
MODE CONFINMENT

Cutoff Wavelength —The wavelength below which high-order modes may propagate in a single-mode fiber in addition to the desired fundamental mode. Above the cutoff wavelength, operation in a single-mode is ensured. Cutoff wavelength (ƛc)

for single-mode fibers is given as ƛc = $2\pi a n_1(2\Delta)^{1/2}/2.405$

ƛc decides the operating wavelength for single-mode operation i.e., ƛ>ƛc

Depressed cladding SMF fiber zero dispersion at 1.3 µm



CUT OFF WAVELENGTH

2. **2nd fiber fabricated** is DFF LEAF SM fiber Quadruple Clad Zero Dispersion at 1.32 µm λ. Important simulated fiber parameters are as follows:
   1. Designed Refractive Index profile is Quadruple Clad.
   2. Average dispersion from 1.32 µm λ to 1.6 µm ƛ is 5 ps/nm-km
   3. Effective area at 1.55 µm is 129 square micron which is very large and it is a very large effective area SM Dispersion Flattened Fiber.
   4. Attenuation at 1500 nm is 0.21 dB/km

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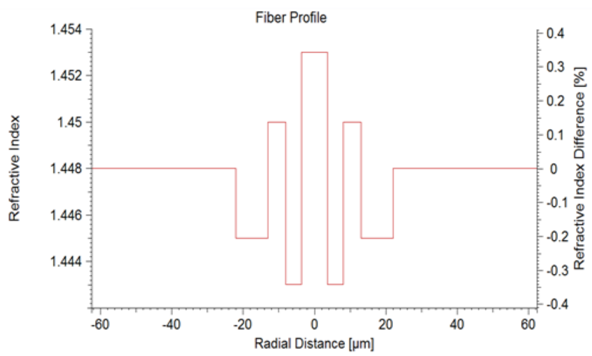
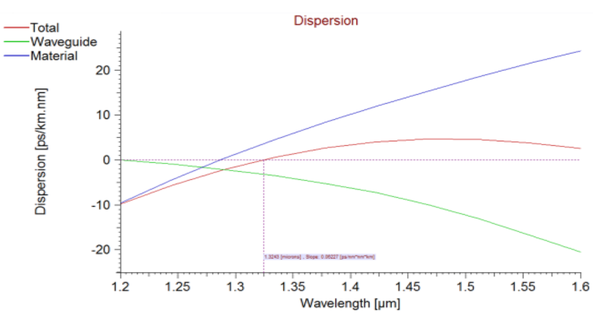
5. Macro and Micro bending losses are almost zero and macro bending los start increasing from 1500 nm onwards.
6. Mode confinement is shown in the slide.
7. Cutoff wavelength shows it is a SMF.

DFF LEAF SM FIBER QUARDRUPLE CLAD ZERO DISPERSION AT 1.32 µm λ



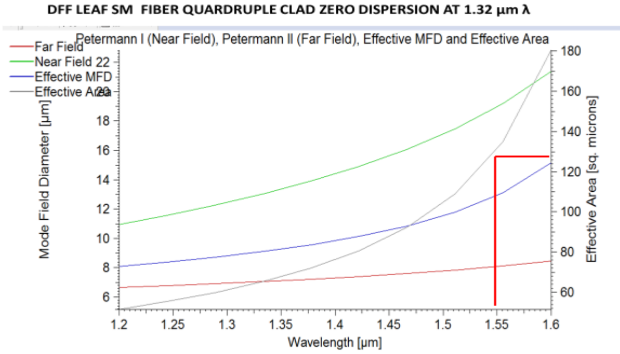
QUARDRUPLE CLAD REFRACTIVE INDEX PROFILE

DFF LEAF SM FIBER QUARDRUPLE CLAD ZERO DISPERSION AT 1.32 µm λ



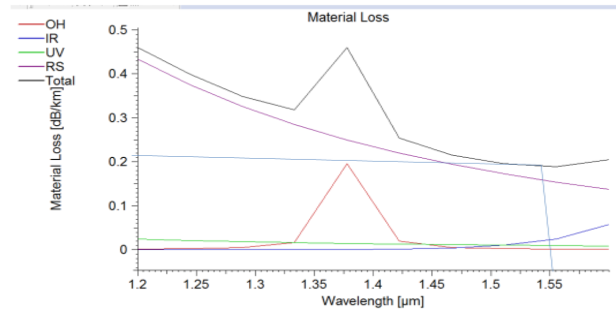
DISPERSION

DFF LEAF SM FIBER QUARDRUPLE CLAD ZERO DISPERSION AT 1.32 µm λ



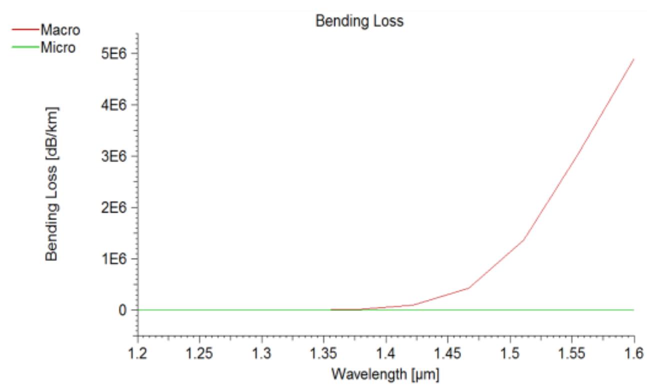
MFD AND EFFECTIVE AREA

DFF LEAF SM FIBER QUARDRUPLE CLAD ZERO DISPERSION AT 1.32 µm λ



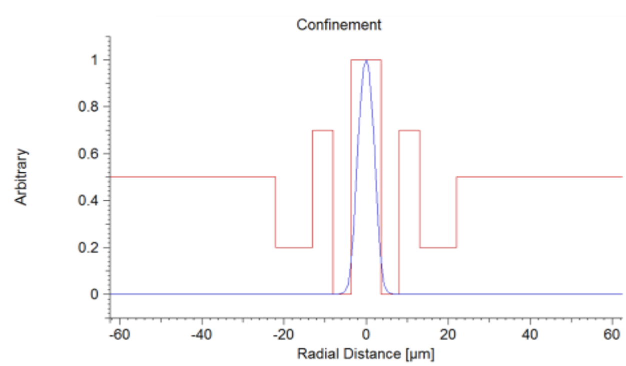
MATERIAL LOSS

DFF LEAF SM FIBER QUARDRUPLE CLAD ZERO DISPERSION AT 1.32 µm λ



BENDING LOSS

DFF LEAF SM FIBER QUARDRUPLE CLAD ZERO DISPERSION AT 1.32 µm λ



MODE CONFINEMENT

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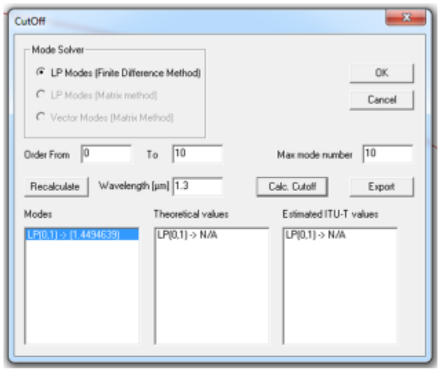
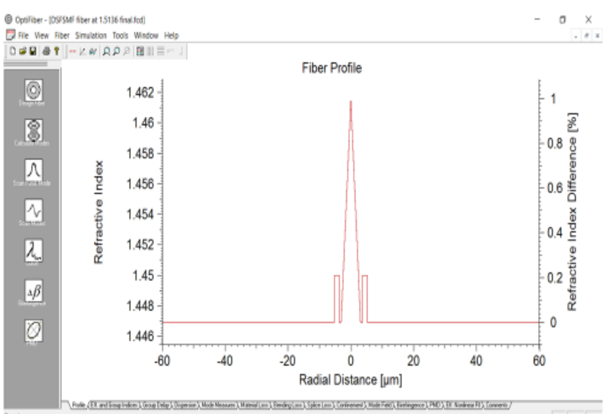
DFF LEAF SM FIBER QUARDRUPLE CLAD ZERO DISPERSION AT 1.32 µm λ



CUT OFF WAVELENGTH

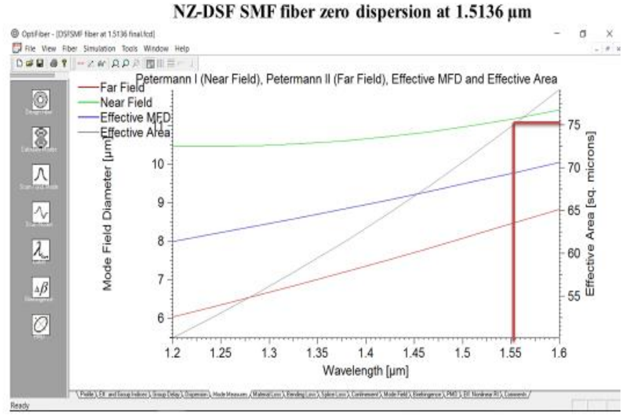
3. **3rd fiber fabricated is** NZ-DSF LEAF fiber. Zero dispersion at 1.5136 µm. Important simulated parameters are as follows:
   1. At 1550 nm dispersion is 3 ps/nm.km, perfect for NZ-DSF fibers. Fiber is good for long haul ultra-dense wavelength division multiplexing.
   2. Effective area is 75 µm sq at 1550 nm wavelength. It is a LEAF fiber.
   3. Material loss at 1550 nm is 0.2 dB/km, less than SMF 28 fiber.
   4. Macro bending loss is zero and micro bending loss is decreasing from 1.3 µm to 1.55 µm.

NZ-DSF SMF fiber zero dispersion at 1.5136 µm



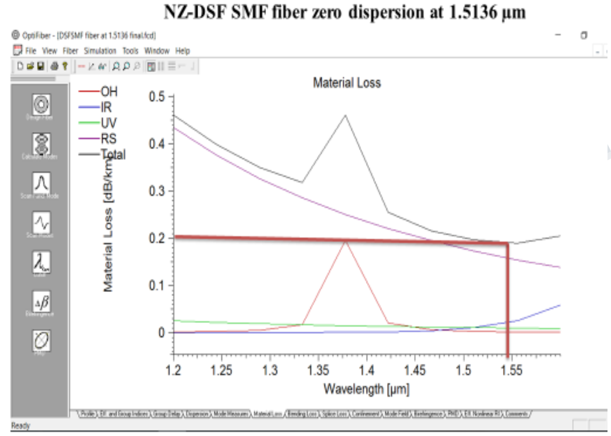
FIBER REFRACTIVE INDEX PROFILE

NZ-DSF SMF fiber zero dispersion at 1.5136 µm



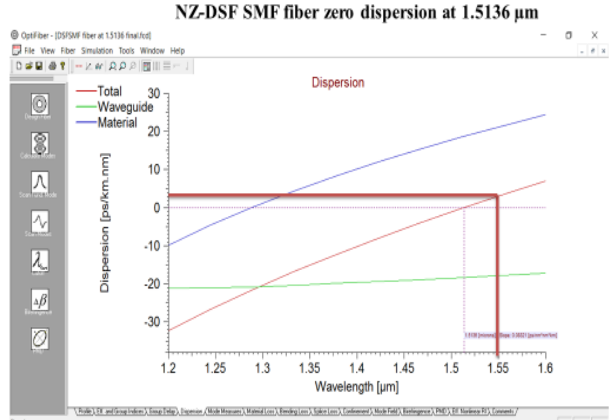
MFD AND EFFECTIVE AREA

NZ-DSF SMF fiber zero dispersion at 1.5136 µm



MATERIAL LOSS

NZ-DSF SMF fiber zero dispersion at 1.5136 µm



DISPERSION

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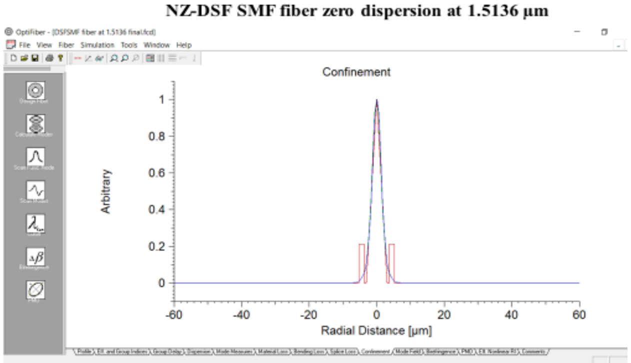
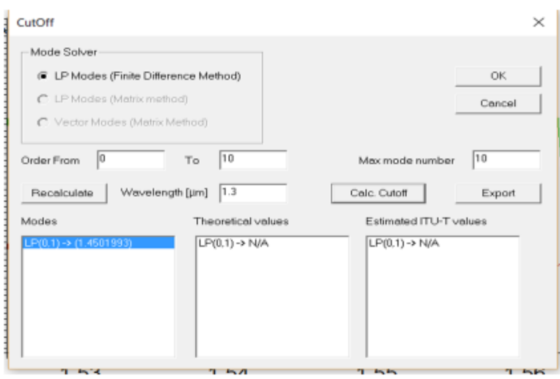
NZ-DSF SMF fiber zero dispersion at 1.5136 µm



NZ-DSF SMF fiber zero dispersion at 1.5136 µm

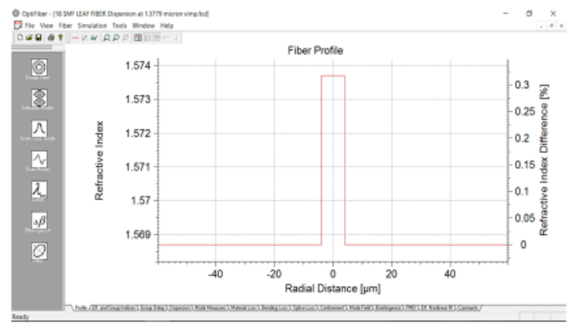


CUT OFF WAVELENGTH

4th fiber fabricated is step index NZ-DSF SMF LEAF fiber zero dispersion at 1.5779 µm λ. Important simulated fiber parameters are as follows:

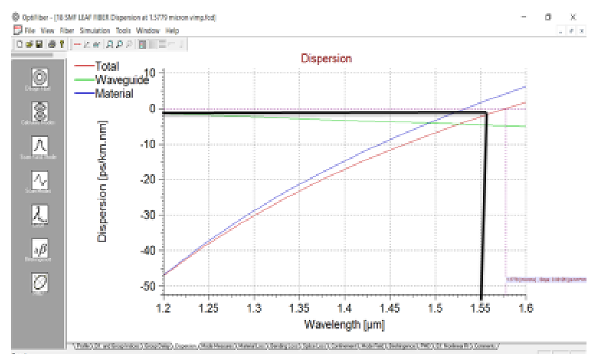
1. At 1.55 µm λ dispersion is 1 ps/nm.km.
2. Effective area at 1.55 µm λ sq 74 µm sq. {LEAF)
3. Total attenuation at 1.55 µm is only 0.19 dB/km and at 1.3 µm it is 0.35 dB/km. Less than SMF 28 fiber.
4. Macro bending loss is zero till 1.5 µm λ. Then there is slight increase up to 1.55 µm after that it is increasing sharply. Micro bending loss is very less.

NZ DSF SMF LEAF Fiber zero dispersion at 1.5779 µm



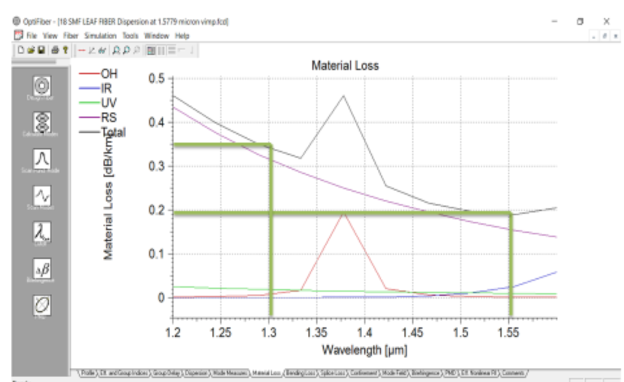
STEP INDEX REFRECTIVE INDEX PROFILE OF FIBER

NZ DSF SMF LEAF Fiber zero dispersion at 1.5779 µm



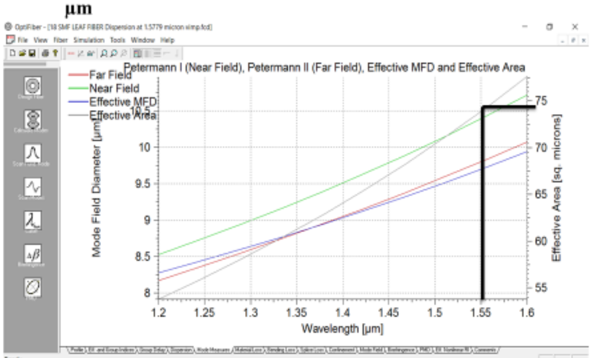
DISPERSION

NZ DSF SMF LEAF Fiber zero dispersion at 1.5779 µm



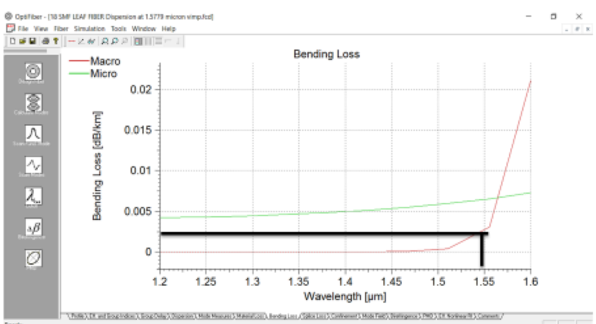
MATERIAL LOSS

NZ DSF SMF LEAF Fiber zero dispersion at 1.5779 µm



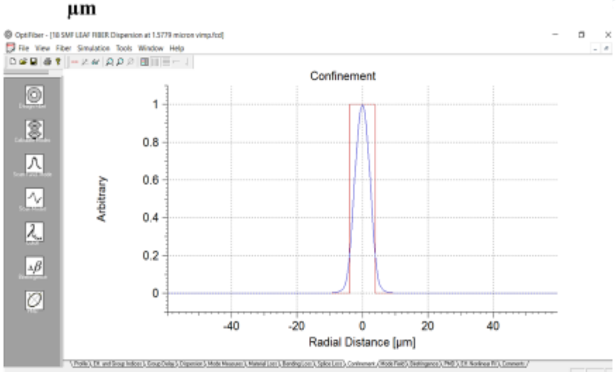
MFD AND EFFECTIVE AREA

NZ DSF SMF LEF Fiber zero dispersion at 1.5779 µm



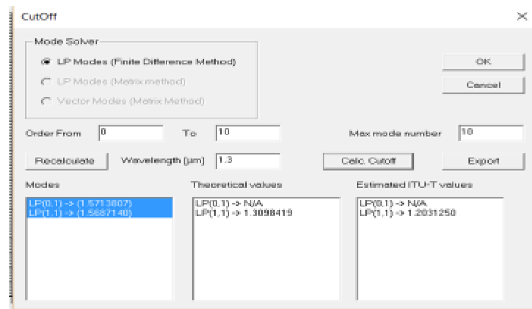
BENDING LOSS

NZ DSF SMF LEAF Fiber zero dispersion at 1.5779 µm



MODE CONFINMENT

NZ DSF SMF LEAF Fiber zero dispersion at 1.5779 µm



CUT OFF WAVELENGTH

All the above fabricated fibers are advance fibers. For new installation of optical communication systems these fibers can be used for specific applications and can replace SMF -28 fiber.

IV. CONCLUSION

It may be noted that all the fabricated fibers have one or more specialty in comparison of SMF-28 fiber. SMF-28 fiber is old but still in operation all over the world. This fiber is used for all purposes i.e., Long haul, Short haul, LAN and for first mile connectivity. As speed of communication systems is increasing e.g., 100 Gbps to 500 Gbps per channel now specialty fibers are required specific to each purpose of operation.. For example, NZ-DSF SMF fiber is required for ultra-dense wavelength division multiplexing (XDWDM) for long haul communication it avoids four wave mixing (FWM) and cross phase modulation (XPM) fiber non-linearity's. Corning LEAF fiber has effective area of 72 µm sq at 1550 nm such fiber can be used with high power laser transmitters. All of our fabricated fibers are in this category i.e., all fibers are having effective area of more than 72 µm sq at 1550 nm. We have also fabricated three DFF fiber. In fiber 2 average CD is 5 ps/nm.km They Can be used for high bandwidth applications. Such fibers can be used effectively for CWDM and DWDM applications. Depressed cladding SM LEAF fiber is also important for long haul and for last mile connectivity since micro and macro bending losses are zero. Finally, by carefully designing a fiber refractive index profile various advance specialty fiber can be fabricated for specific operational usage.

